DESIGN AND SCHEDULING OF MULTIPLE MODEL PRODUCTION ON COMPLEX STATION ASSEMBLY LINES

Thesis submitted in accordance with the requirements of the University of Liverpool for the degree of Doctor of Philosophy

by

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بسم الله الرحمن الرحيم

ربنا آتنا من لدنك رحمة وهيئ لنا من أمرنا رشدا

صدق الله العظيم

إلى والديّ

TO MY PARENTS

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SUMMARY

This thesis is concerned with the problem of balancing and operating manual assembly line production. The objective was to develop firstly a new balancing procedure allowing enlarged stations and to secondly construct a simulation model for examination of balancing results under actual production conditions.

A ranking heuristic approach was identified as suitable for balancing larger balancing problems and this was combined with a practical treatment of working an enlarged station as a means of overcoming the restrictive "closed station" approach.

Three methods were available for increasing station capacity: extension through upstream and downstream working, duplication through parallel or rotating stations and enlargement through multi-manning. Extended stations were rejected at balancing on the grounds of being a temporary increase in capacity and duplicated stations were rejected as being unsuitable for encouraging a group approach to work.

The advantages of enlarged stations were identified as:

- The ability to deal with multi-operator tasks.
- The ability to deal with large element durations.
- The ability to consider a limit on the assembly line length.
- The possibility of higher balancing efficiency.
- Use of a group approach to working.

In developing the principles of balancing with enlarged multi-manned stations the concept of work compressibility was introduced. This concept acknowledges that no matter the resources available there is a natural minimum time in which any task can be completed and that

consequently the time content of elements cannot be simply divided between the number of operators present. Work compressibility therefore introduces two new element durations: minimum time representative of the shortest period in which a work task can be completed and effective time representative of the actual time taken by a particular working group.

Three balancing models and appropriate computer programs have been developed using work compressibility and enlarged stations:

- Single model balancing ASSIGN 1.
- Mixed-model multiple element assignment ASSIGN 2.
- Mixed-model single element assignment ASSIGN 3.

In addition, in order to examine the view that actual assembly lines rarely operate under the exact conditions on which they were balanced an extensive simulation model has been developed with a view to examining the versatility of balance results under changed operating conditions. The simulation model has three principle parts: methods of varying line conditions; detailed analysis of station performance and detailed analysis of line performance.

Both the assembly line balancing models and the simulation program has been used to examine a number of the key parameters involved in the balancing problem and to draw appropriate conclusions on the new models. In all 273 tests were involved in the validation of computer models and examination of parameters.

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CHAPTER 1

INTRODUCTION

1. INTRODUCTION

Examining economic and social history since the beginning of the industrial revolution, the greatest contribution to the growth in prosperity over this period can be identified as the introduction of mass-production methods into the industrial scene. This is particularly true of the twentieth century where standards of health, wealth and social expectations have all substantially increased as the methods of mass production have made available to the majority services and products previously reserved for the financially advantaged minority.

This growth in social welfare has continued to the point where the expectations and structure of many societies, particularly those of the industrialised European and American nations, are highly dependant on mass-production procedures and therefore investigations into methods capable of further improving the management of mass-production must be seen as beneficial exercises. Within this thesis one particular form of volume production, the manufacture of products on assembly lines, will be examined with a view to introducing a new practical approach to the assignment of work tasks on assembly line stations.

Economic dependence on mass production.

The dependence of society on large scale manufacturing methods, and therefore the importance of efficient production, can be demonstrated by a brief examination of how basic needs and social expectations are provided for the majority of people. Consider firstly the provision of the three essentials: food, shelter and energy. In the case of food production the transition towards larger and larger manufacturing units has been going on since before the industrial revolution and as a consequence of this development where geographic and economic conditions are suitable agricultural production has become characterised by mechanisation and specialisation. Mechanisation appears in the form of purpose built machinery for rapid planting, sowing and harvesting of large areas of a given product and can involve tractors, crop sprayers, harvesters, bailers and a host of other high volume machinery. Even where agricultural production takes place on medium and small scale lines the supply of materials (e.g. fertilizers, pest and weed control chemicals) and the distribution of products has of necessity become large scale operations in order to minimise cost and provide sufficient quantities.

Mass-production methods, embracing the principles of standardisation and mechanization, has also dramatically changed the working procedures of the building industry. In the first case the components used in construction have become standardised and in many cases (e.g. window frames, plasterboard, concrete) are prepared in factory conditions away from construction sites where large volumes and specialised equipment again leads to lower unit costs. Secondly the actual construction sites themselves have moved towards factory type principles with the introduction of highly productive mechanised building equipment (e.g. hydraulic excavators) and simplification of working practices, where pre-prepared factory components reduces the level of skill required of the construction workforce and increases the level of productivity. The appearance over the past fourty years of concrete, steel and glass as major building and construction materials is a significant case of the move towards standardised larger scale production.

The provision of energy in vast quantities is also an example of the application of mass production principles. Whilst less significant sources of energy are available (e.g. solar energy, wave and wind power) industrialised societies would fail to function without widespread availability of combinations of electricity, gas, petroleum and coal and as a consequence the manufacture (or extraction) and distribution of these energy sources has been organised on mass-production principles. The transition to very large scale output can be identified in the development of the modern gas supply industry in the United Kingdom where low cost sources of gas in the North Sea have been brought ashore and distributed nationally over the past decade,replacing far more expensive town-gas generating plants.

These illustrations of volume orientated operations serve to identify four general principles on which mass-production is based:

(a) Mass-production will only take place when there is a demand for large quantities of a given service or product. Where the product or service in question is essential and mass-production is the only reasonable method of providing sufficient quantities at the required quality then mass-production will take place even if comparatively expensive.

(b) The widespread use of mass-production principles has arisen because in the vast majority of cases a significant cost reduction is obtained when compared to lower volume more traditional procedures.

(c) Large scale production involves the standardization and rationalization of product ranges. For true high volume production very little if any product diversity can be allowed as this would detract from the high volumes required and the uniformity desired.

(d) The transition towards large scale production or distribution permits the use of highly efficient specialised equipment. In many cases it is the introduction of this specialised equipment that gives the lower unit cost.

The effect of mass-production methods on the expectations of society and indeed on the whole infrastructure of an economy can be illustrated further by considering the changes brought about in the field of transportation and communications by mass-produced products. The most dramatic change in transportation, the introduction of the automobile, owes it success directly to the use of mass-production principles. The first petrol driven automobile using an internal combustion engine was produced by Carl Benz in 1885, followed by Daimler in 1886 and by F.R. Simms in Great Britain in 1893, who had acquired the Daimler Patent Rights. The subsequent period 1900-1914 saw the introduction of many famous car manufacturers (Rolls-Royce, Austin, Morris, Ford and Vauxhall) and the beginning of mass-production in the automobile industry. The first British mass produced car was the model "T" Ford, assembled at Old Trafford, Manchester in 1911, three years after its introduction in the United States. It was the period 1920-1930 however that saw a rationalization in the British Motor Industry as assembly line manufacture of standardised light cars was introduced with resultant low prices. The effect was a dramatic change with the number of competing firms falling from 88 (1922) to 31 (1929) and with Morris, Austin and Singer accounting for seventy-five per cent of the industries output of 239,000 vehicles (13). This rationalization and increasing concentration has continued to this day with the emergence of four giant mass-production companies (British Leyland, Ford, Talbot and Vauxhall) supplying over two million vehicles. In a period of seventy years therefore the use of mass-production has made available on a large scale a cheap and effective form of transport, which in turn has reduced the cost of providing goods and services in many other industries.

If mass production methods can be credited with improving transportation and welfare then it can also be credited with improving communications and understanding as the modern printing, telecommunications and broadcasting services are all based on the provision of high volume-low cost products. The attractions of mass-production can be considered to be strong if between 1945 and 1980 the production of firstly black and white and then colour television sets increased from almost zero to quantities capable of supplying world-wide demand.

Many other illustrations of the impact of mass-production methods can be drawn to support the case with respect to the importance of developing effective production systems in large scale manufacture but the automobile and television cases have been highlighted for they are particularly relevant to the form of mass-production examined in this thesis.

Types of mass-production

Reference has been made in the opening part of the introduction to the characteristics of mass manufacture, i.e. high volume and low variety, but in practice the term mass-production is a global term used to describe a quite diverse set of manufacturing methods. Accepting that in the context of the work described in this thesis mass-production relates to the application of advanced technology then three polar types of large scale production emerge:

Flow/process production

Large scale machine line production

Assembly line manufacture.

Flow/process production is largely associated with the continuous manufacture of products that do not appear in discrete form and can therefore be said to include the refining of oil, chemical engineering and basic industrial processes like iron and steel production. In these industries the organisation of manufacture is largely dictated by the nature of the product and the technical requirements of the manufacturing process and therefore will give only limited choice with respect to designing and operating the manufacturing system.

Machine lines, or transfer lines, can be considered to be the general engineering equivalent of flow/process production, where highly automated machining centres are used for the continuous manufacture of discrete engineering components (e.g. automobile engines). Transfer machining lines can vary from single unit rotary transfer lines, similar in appearance to large conventional machine tools, to extensive transfer lines with independent machining heads or "stations" linked by automatic materials transfer and location.

When considering the design of transfer and flow/process production systems the alternatives available are generally restricted by the production technology involved and design is therefore comparatively stereotyped. In addition, as both flow/process and transfer line manufacture are highly automated with very limited or no product variation the subsequent operation of these types of manufacture is also comparatively simple.

Assembly line manufacture is the converse in both cases. A stereotype assembly line is concerned with the fabrication and assembly of a given product which is generally achieved through manual activity. As assembly line principles can be applied to a wide variety of products and no specific manufacturing limitations exist the design of assembly lines require greater levels of planning. In addition, as assembly lines are manually operated and can be required to produce a wider variety of production the operation and control of assembly lines is also more complex. It is the design and operation of assembly lines that is the subject of the models presented in later chapters of this thesis.

Overview of Assembly Line Production

The design and operation of assembly lines is a particularly challenging problem because of the many considerations that have to be taken into account in order that high levels of efficiency can be obtained. Furthermore assembly line manufacture can be considered to fall into two separate stages: firstly the design and balancing of the assembly line and secondly the subsequent operation of the assembly line during production and it is an unfortunate condition of balancing that the assembly line will rarely operate under the exact conditions estimated during balancing.

Four main factors as shown in Fig. (1.1) influence the balancing stage of assembly line design:

The product.

The assembly line.

The balancing procedure.

The balancing criteria.

The product to be made on an assembly line can have in itself six major influences which are: the precedence order of assembly,

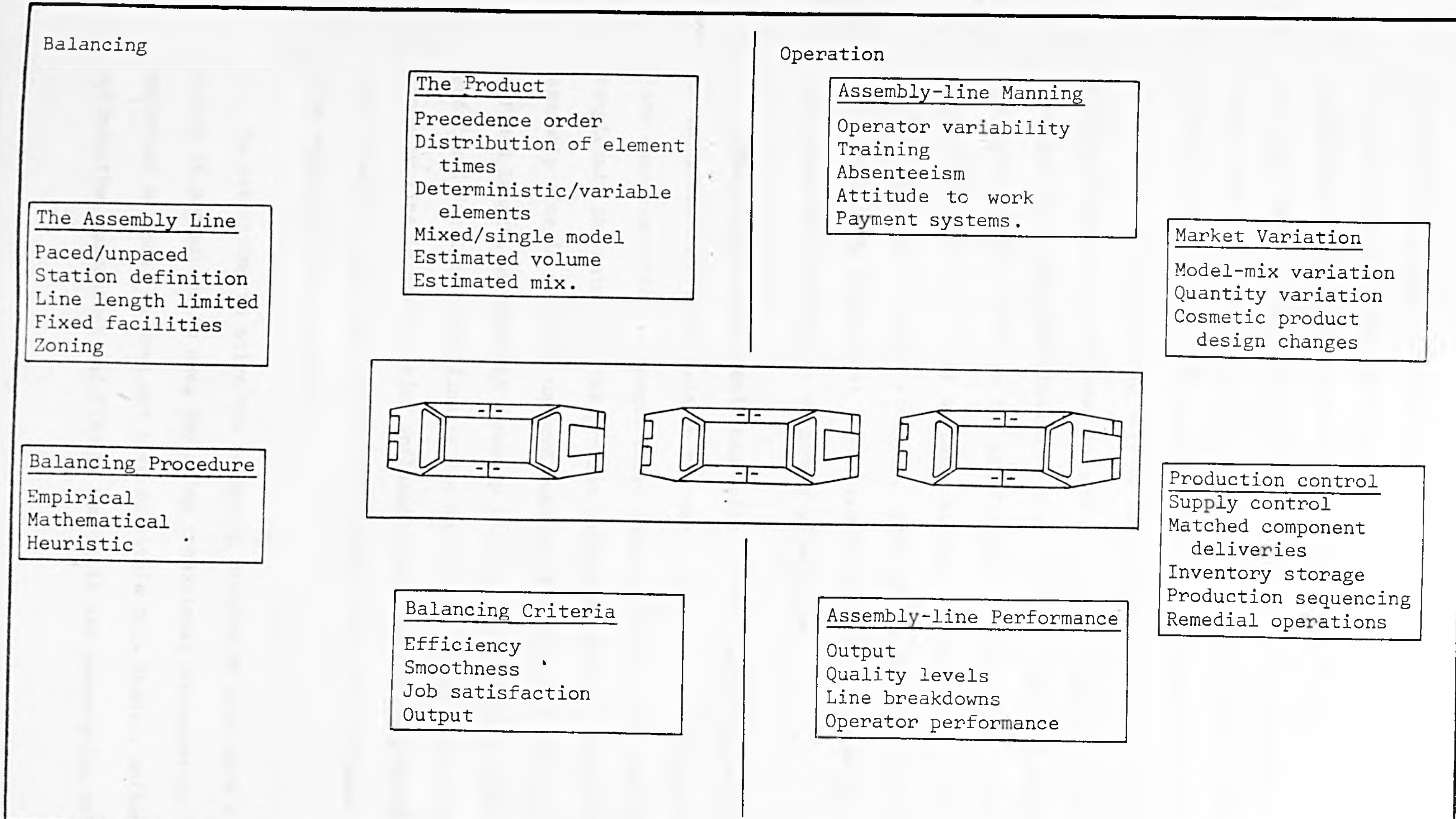


FIG. (1.1) OVERVIEW OF CONSIDERATIONS IN ASSEMBLY LINE PRODUCTION.

the distribution of element task times, whether deterministic or variable work is being undertaken, whether mixed or single model production is involved and finally the estimated volume and product mix will have a strong influence on balancing. The precedence order represents the compulsory sequence for manufacture and for certain products this order can be so strong that very little choice is available when assigning work to assembly line stations, making efficient balancing difficult to achieve. In the same way a product that has an uneven distribution of element times, where elements are the component tasks in the manufacture of the product, would also prove difficult to balance as large elements cannot be efficiently packed together into work stations. Comments on the difficulties that arise from the product itself are discussed in more detail in the review and development of models given later.

The assembly line itself can influence the balancing problem as decisions have to be made in the early stage on essential assembly line characteristics. Amongst these characteristics that can change completely the nature of the problem being examined is whether the assembly line is paced or unpaced, whether the assembly line has a fixed length, whether the assembly line has to deal with zoning and fixed facilities and finally the definition of stations on the assembly line is also a major influence, with the choice ranging from closed to open stations and from single sized to increased capacity stations being available.

In attempting to solve the balancing problem we also have a choice of procedures to use, including traditional non-numerate empirical methods, an area not covered within this thesis, mathematical optimisation approaches and finally heuristic and enumeration methods.

The balancing procedures available will be substantially reviewed in Chapter 3.

The final question that can arise in balancing an assembly line is the question of criteria. Four criteria can be put forward: efficiency, equality of work assigned, job satisfaction and output achieved. In present balancing methods efficiency is the most common criteria selected with smoothness a next significant second, but no numerate balancing procedures have yet given consideration to job satisfaction as this is very difficult to quantify. The most important balancing criteria at the end of the day is practicality, for in balancing assembly lines the main objective is that they must eventually work, for this reason practical heuristic procedures and efficiency criteria would tend to dominate.

Having balanced an assembly line the subsequent operation of the line would introduce dimensions to the problem that could not have been visualised or specified at the balancing stage. Four particular considerations will affect the subsequent operation of a balanced assembly line:

Assembly line manning.

Market variation.

Production control.

Assembly line performance.

One of the most difficult problems of assembly lines is that they largely at present involve manual work and therefore the actual operation of assembly line would have to take into account human characteristics including operator variability, training, absenteeism, attitude to work and the payments systems to be employed on the assembly line. Only operator variability has so far been considered at the balancing stage yet any of these factors could strongly affect the efficiency of the assembly line.

The particular problem details with which balancing would occur must be considered to be estimated or provisional and that once the assembly line is in operation an inevitable variation in these conditions would arise particularly with respect to such factors as model mix quantities to be produced and minor product design changes. Once these variations occur there will arise different operational conditions to those with which the assembly line was balanced and the question then arises as to whether the original balancing solution is still appropriate and whether in fact the line can still function efficiently.

One particular task that takes no part at all at present in the balancing stage is the question of product control on the assembly line where performance can be influenced by the way in which components are procured and scheduled onto the assembly line, including the way in which they are stored and sequenced to meet the actual sequence of products. Within this group of product control tasks can also be included a very important question of selecting methods for achieving remedial work on products that are found to be unsatisfactory.

Acknowledging that assembly lines in operation are a different matter to assembly lines being balanced then again there arises a question of how to assess actual assembly line performance and whilst actual criteria are available like output quality levels, line breakdowns and operator performance statistics, the question does arise as to whether there should be some mechanism for relating actual performance on an assembly line back to the balancing stage.

In examining the assembly line manufacturing problem in this thesis the view has been taken that assembly line manufacture represents a very important part of our economic welfare and that the use of assembly lines in an efficient manner can be seen as a two part problem of firstly balancing and secondly operating assembly lines. Therefore after introducing the terminology relating to the subject and reviewing the existing approaches to assembly line design a new practical approach to balancing assembly lines will be given and this will be followed by the introduction of a simulation model for examining how the balanced assembly lines would operate during subsequent production.

CHAPTER 2

GENERAL TERMINOLOGY AND DEFINITIONS

2. GENERAL TERMINOLOGY AND DEFINITIONS

The design and operation of assembly lines makes use of a number of specialised management terms which are worthy of definition before the review of existing work and the development of the new balancing and simulation models are given. At this point only a general definition of each term is given and where required later chapters will explain in full the use made of specific terms. With a substantial number of general definitions to be given the relevant terms have been grouped under the following headings:

Element definitions
Precedence definitions
Station definitions
Line definitions
Balancing definitions
Operational definitions
Evaluation definitions
General definitions.

2.1 Element definitions

1. Work element

An indivisable element of work which can not be subdivided rationally i.e. cannot be separated into smaller work units that can be completed separately.

2. Element followers

Elements that immediately follow the element under consideration with respect to precedence order.

3. Normal element duration

This is the time taken by a practiced worker working at normal pace to achieve the completion of a work element. (Equivalent 100 British Standard Rating.)

4. Minimum element duration

This is the shortest time in which a work element can be completed allowing unlimited resources.

5. Effective element duration

This is the actual time taken to complete an element of work at a given station size.

6. Element compressibility
(Work compressibility)

This is the percentage reduction between normal element duration and effective element duration. By definition the maximum element or work compressibility is the percent reduction between normal element duration and minimum element duration.

7. Deterministic duration

This occurs where elements have so little variation in completion time that they can be considered to be of constant duration.

8. Variable duration

This occurs where significant variation in completion time is detected and therefore element durations are considered not to be constant.

9. Element variance

This is a measure of the variance in element completion times assuming a normal or Gaussian type distribution.

10. Large element

A general term used to describe an element whose work content is substantially greater than the work content of average elements or whose work content is greater than the cycle time under consideration.

11. Multi-operator elements

This describes work elements that require two or more workers in order to complete work in a rational manner.

12. Fixed-location elements

This describes work elements that must be located at a given position or limited set of positions on the assembly line.

13. Element models

These are models that contain the element in question as part of their work content.

14. Element resources

These are resources required under normal circumstances to complete a given element.

15. Element resource quantity

This is the quantity of each resource required under normal circumstances to complete a given element.

2.2 Precedence

16. Precedence

This is the natural ordering of the sequence of production dictated by the nature of the product and the method of manufacture.

17. Precedence diagram

Diagrammatic representation of the precedence relationships between elements. The conventions for constructing and using precedence diagrams are discussed in Chapter 3.

18. Weakly-ordered precedence

Where the precedence relationships allow alternative selections of elements for completion the product is said to have weakly-ordered precedence. Diagrammatically this will appear as a diagram with few columns of elements and higher numbers of elements in each column and will generally assist the balancing procedure.

19. Strongly-ordered precedence

Where the precedence relationships restrict considerably the order of selection of elements for completion the product is said to have strongly ordered precedence. Diagrammatically this will appear as a diagram with few elements in each column and will present difficulties with respect to balancing the assembly line effectively.

20. Transferability

The amount by which an element can be transferred to the right on a precedence diagram without extending the number of columns.

21. Precedence difficulty

This is a simple expression of ordering of the precedence diagram and is the ratio between number of work elements and number of columns on the precedence diagram.

2.3 Station definitions

22. Operator

Worker manning an assembly line station.

23. Work station

A given section of an assembly line at which a specified set of work elements are undertaken by one or more operators.

24. Simple station

A single size closed station with no zoning, upstream or downstream excess.

25. Complex station

A station which involves either zoning, enlargement, duplication or extension.

26. Upstream excess

The allowance given to a station to allow an early start of work. Upstream excess is outside the normal working length of a station.

27. Downstream excess

The allowance given to a station to allow the late completion of work. Downstream excess is outside the normal working length of a station.

28. Closed station

Station with no upstream or downstream excess.

29. Open station

Station with either upstream or downstream excess or both.

30. Interference zone

The area of line between two consecutive stations in which there is a possibility of parallel working, i.e. operators from each station attempting to work on a model at the same time.

Open and closed stations are illustrated in Figure (2.1).

31. Duplicated station

A station of permanently increased length where the additional time gained is adjusted by additional operators working in parallel or rotating fashion, thus keeping the same overall cycle time.

32. Parallel stations

A form of duplicated station where the assembly line is branched into two or more equally equipped and manned stations where alternate products are assembled before

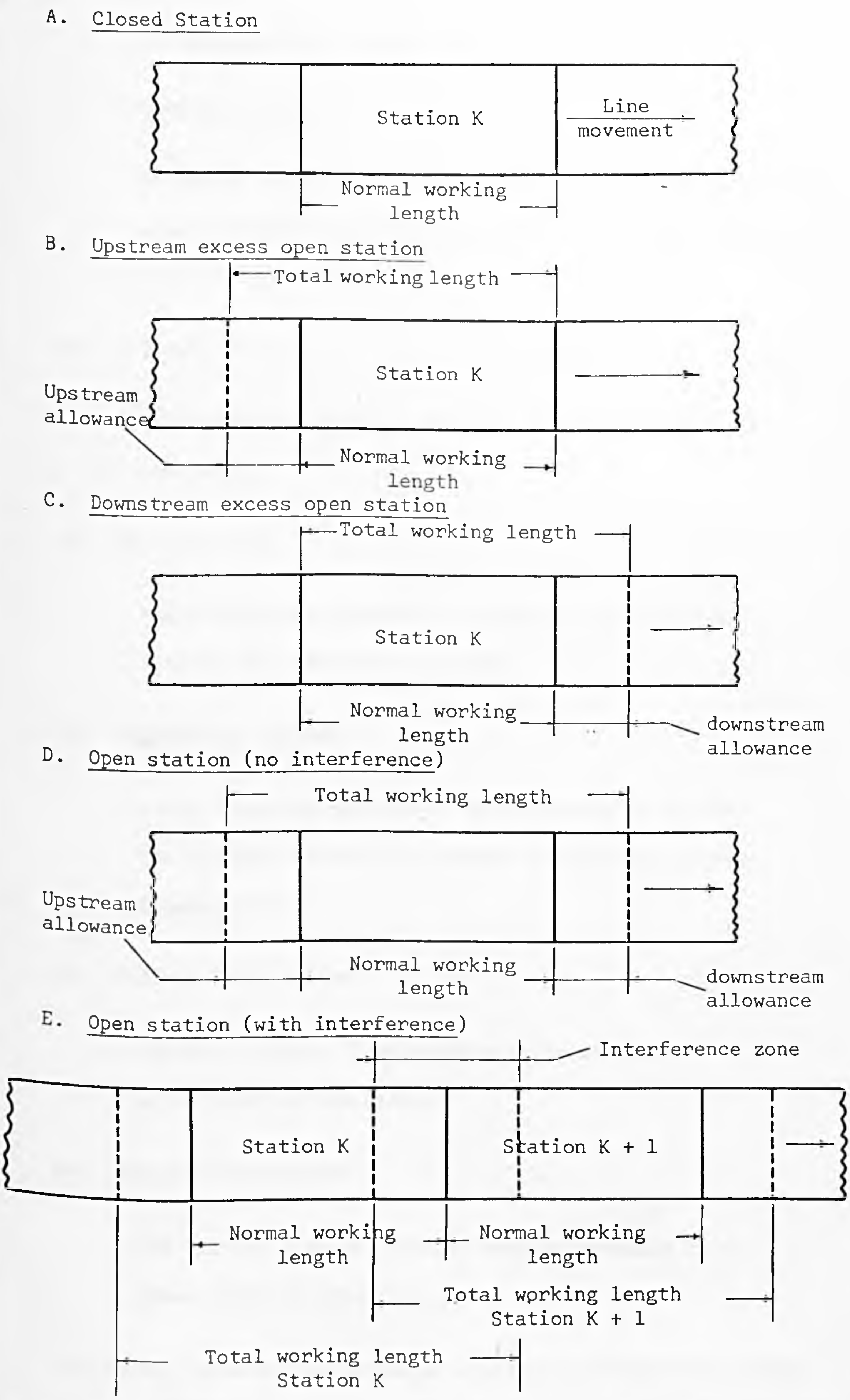


FIG. (2.1) EXTENDED WORK STATIONS.

merging again to one assembly line.

33. Rotating stations

A form of duplicated station where two or more independent operators work on alternate products in a single station with duplicated facilities.

34. Enlarged station

Station manned by more than one operator or group of operators.

35. Group working

Where operators manning an enlarged station jointly attempt the completion of work.

36. Independent working

Where operators manning an enlarged station divide the elements of work and attempt independent working arrangements.

37. Minimum station size

The minimum size of enlarged station possible at a given point of balancing.

38. Maximum station size

The maximum size of enlarged station possible at a given point of balancing.

Duplicated, extended and enlarged station all in practice extend and enlarge resources available but as a means of differentiating between the three types the given definitions will be applied.

Duplicated and enlarged stations are illustrated in Figure (2.2).

39. Zoning

The division of a station into separate working areas.

40. Physical zoning

Station zones based on physical position (e.g. top, bottom, left, right).

41. Specialised zoning

Station zones based on special requirements (e.g. clean and dirty working zones).

42. Station location

Position of a station on the assembly line.

2.4 Line definitions

43. Assembly line

A defined collection of stations through which products are passed in an ordered sequence.

44. Paced assembly line

A motorised assembly line on which products automatically move from station to station at a given speed.

45. Unpaced assembly line

An assembly line on which the movement from station to station is dictated by individual operator performance.

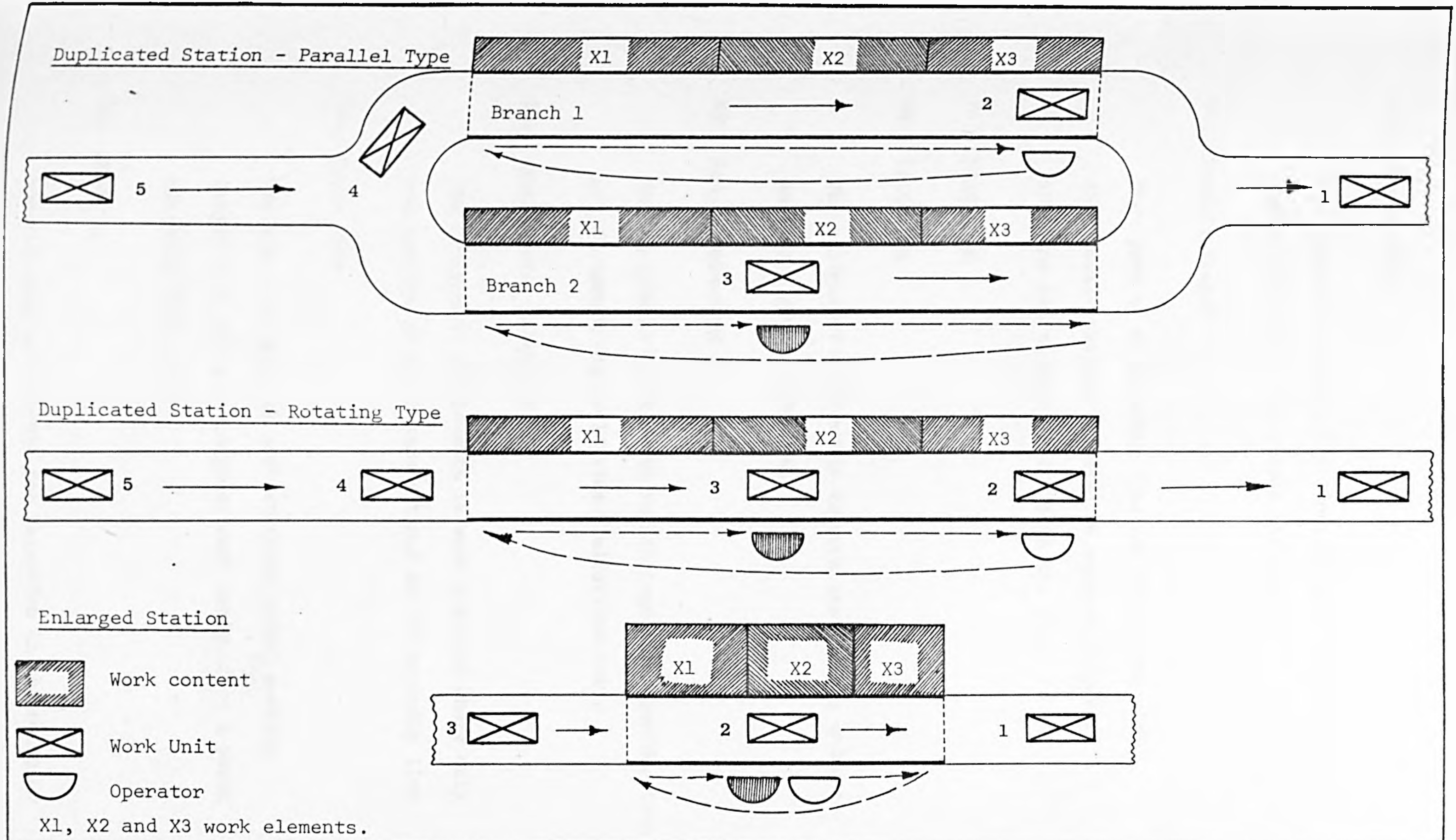


FIG. (2.2) DUPLICATED AND ENLARGED STATIONS.

46. Line length

The length of an assembly line, usually expressed in numbers of equivalent simple stations.

47. Transit length

That part of an assembly line not associated with individual stations but used to connect dispersed stations and to start and finish the line.

2.5 Balancing

48. Balancing

The assignment of elements to work stations in order to satisfy a given objective.

49. Simple balancing

The assignment of elements to stations with consideration of precedence and cycle time limitations only.

50. Single model balancing

The assignment of elements to work stations where only one product is to be manufactured on the assembly line.

51. Cycle time

The time available at each stations normal working length with which to complete work assigned on a paced assembly line.

52. Ranking

The ordering of elements for selection in ascending or descending criteria value.

53. Positional weight

A calculated measure of the relative importance of an element with respect to selection for assignment (e.g. element duration).

54. Lexicographic order

Ranking in order of appearance within the list of elements.

55. Candidate element

Element selected for assignment by the ranking or any alternative procedure.

56. Continuous ranking

The repeated ranking of subsets of elements available for assignment each time an assignment is about to be made.

57. Backtracking

The process of returning assigned elements to the unassigned element list according to a specified procedure.

58. Reverse assignment

An alternative balancing approach, which reverses the normal logic, i.e. assigns elements to the last station first and calculates positional weight on the basis of a reversed precedence diagram.

59. Mixed model balancing

The assignment of work elements to work stations where more than one product is to be manufactured on the assembly line.

60. Single element assignment

The assignment of an element to a station on a single occasion irrespective of the number of models with which the element is associated.

61. Multi-element assignment

The assignment of elements to stations on a model by model basis as each station is considered in turn. In this case each element will be assigned the same number of times as it appears in the model element lists, noting that this may involve assignment to a number of stations.

62. Schedule adjustment

The adjustment of positional weights and lost time according to the relative importance of models as dictated by the quantities shown in the estimated production programme.

63. Model dominance

An expression of the relative distribution of model quantities obtained by dividing the largest quantity required of any model by the average model requirement.

64. Confidence level

The desired probability of being able to complete work assignments where variable element durations are in existence.

2.6 Simulation

65. Continuous scheduling

The phasing in of a production schedule between two other unspecified schedules so as to avoid start up and run down station idleness.

66. Independent scheduling

The running of a production schedule totally independent of other possible schedules, a process which incurs additional start up and run down station idleness.

Continuous and independent scheduling are illustrated in Figure (2.3).

67. Production schedule

The ordered list of models to be manufactured.

68. Cycle group

Part of a production schedule showing models involved in the cycle group, the order and quantity of models to be produced and the number of times the cycle is to be repeated. A production schedule is made up of an ordered list of cycle groups.

69. Production cycles

The number of launches needed to complete a given production program including start up and run down time.

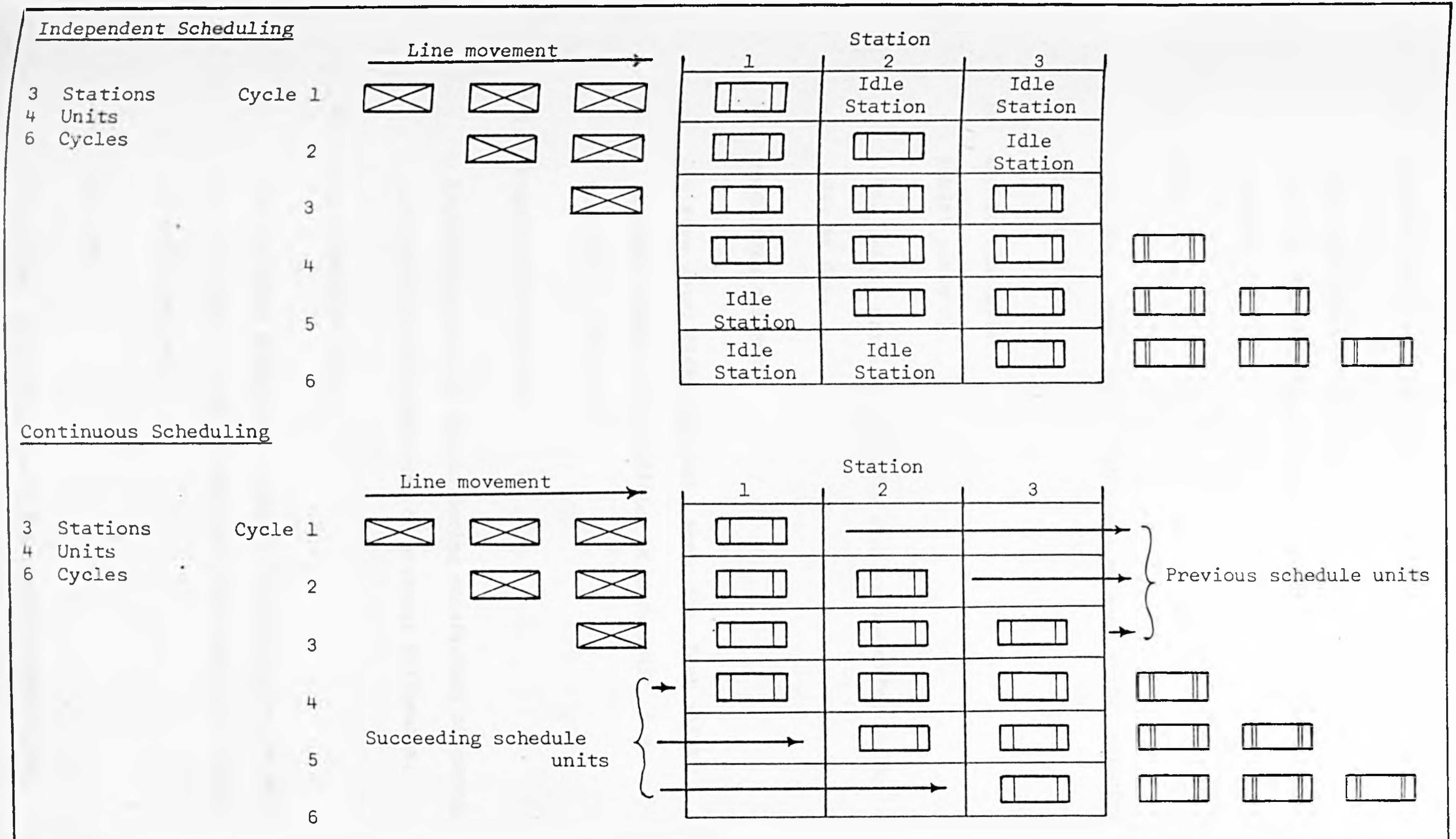


FIG. (2.3) INDEPENDENT AND CONTINUOUS SCHEDULING.

70. Schedule start and schedule finish times

The expected time in hours, shift, day, week and year of the start and finish of a particular production program.

71. Shift times

The daily start and finish times of each shift including split shifts.

72. Weekly timetable
(Shift pattern)

The weekly pattern of shifts showing operating shifts day by day.

73. Production calendar

A five year, fifty-two week, seven day, four shift calendar showing the condition of each shift, i.e. working or disrupted.

74. Programme disruptions

Expected production breaks during manufacture of current schedule caused by internal or external influences.

75. Line characteristics

The physical position of component parts of an assembly line including start, finish, location and full details of each station.

76. Line speed

The actual operating speed of a paced assembly line.

77. Equivalent cycle time

(Line cycle time)

The actual cycle time of production resulting from the line speed.

78. Deterministic simulation

A simulation run in which element durations are considered to be uniform, i.e. deterministic.

79. Station variability

A simulation situation in which the performance of work on each model at each station is considered to vary normally with respect to the total station work.

80. Element variability

A simulation situation in which the performance of each individual element of work is considered to vary normally independent of other elements.

81. Station condition

The status of a given station at any point in time i.e. working, finished, waiting.

82. Nominal station output

The number of cycles elapsed at a given station with respect to a particular point in the given production programme.

83. Actual station output

The actual number of units on which work has taken place at a given station with respect to a particular point in the given production programme.

84. Station start position

Theoretical position of operator or operators with respect to the arrival of the next unit.

85. Overlap working

Attempted working on a particular model by operators from differing stations at the same time.

86. Model run

The number of consecutive units produced which belong to the same model.

87. Sequencing

The task of ordering the launching of units onto the assembly line.

88. Fixed-rate launching

The launching of production units at a fixed constant rate.

89. Variable-rate launching

The launching of production units at differing intervals according to individual work contents.

2.7 Evaluation criteria

90. Idle time

Time not used by operators at each station.

91. Work deficiency

Time lost through unavailability of work.

92. Utility work

(Lost time)

Uncompleted work.

93. Work congestion

Downstream work.

94. Efficiency

Work content expressed as a fraction of total station time available.

95. Balance Delay

Total idle time expressed as a percentage of total station time available.

96. Smoothness Index

A measure of the unevenness of work assignments calculated as the square root of the sum of individual station idle times squared.

2.8 General

97. Heuristic

A procedure using logic and limited mathematics

CHAPTER 3

EXISTING APPROACHES TO LINE BALANCING

3. EXISTING APPROACHES TO LINE BALANCING

3.1 Introduction

The considerable variety of products and product mixes that can be assigned for manufacture by assembly line principles combined with the many permutations of assembly line manning and layout arrangements leads naturally to both differing assembly line problems and solution procedures. When reviewing this range of balancing procedures it is logical to examine their contribution in order of the type of assembly problem being investigated. Using problem type therefore as the basis for structuring this review of existing methods of assembly line balancing, five areas for examination appear:

Simple balancing approaches

1. Single model balancing approaches.
2. Mixed model balancing.

Complex approaches

3. Complex station balancing
4. Work element variation.

Balancing criteria

5. Methods of evaluation.

In carrying out the review a detailed explanation and illustration of original single balancing approaches, along with discussion of their relative advantages and disadvantages, will be used to identify the basis for a new balancing procedure capable of dealing with enlarged work stations. The later section of this review concerns approaches for dealing with mixed model, complex station, and other possible variations on line balancing along with comments on methods of evaluation and will identify problems to be encountered when using enlargeable work stations over a variety of problems: this will indicate the suitability of present methods for handling assembly line balancing problems where group working and large element duration are involved.

Simple balancing approaches

Balancing procedures mentioned under simple balancing are summarized along with a number of related complex balancing approaches in table (3.1).

3.2 Single model balancing

A high proportion of the published work in line balancing relates to the assignment of work elements associated with one single product to work stations of a simple closed nature with no consideration of zoning, station size, special equipment needs or other complicating factors.

In reviewing these single simple balancing procedures the interest lies firstly in understanding the individual methods employed for selecting and assigning work elements to stations in order that the possibilities for new approaches may be developed. Secondly where tests of comparative performance have been carried out, there is some benefit in determining whether any one group of techniques is shown to produce consistently better results. The published single model balancing procedures available can be classified within the following groups based upon their principle approach:

Precedence diagram methods

Heuristic ranking methods

Linear programming methods

Enumeration methods.

AUTHOR	SINGLE MODEL												MIXED MODEL	
	Precedence	Ranking								Enumeration	Linear Programming	Comparative Studies & Reviews	Individual balancing	Mixed model aggregate balancing
		Type			Criteria									
		Single ranking	Contin-uous ranking	Back-tracking	Positio-nal weight	Largest element	No. of followers	No. of immediate followers	Random & Miscella-neous					
Arcus			(1)		(1)	(1)	(1)	(1)	(1)	(1)				
Bowman											(2&3)			
Buxey			(4)		(4)				(4)					
Gutjahr and Nemhauser										(9)				
Helgeson and Birnie		(11)			(11)									
Heskiaoff		(12)			(12)									
Hoffman										(14)				
Held, Karp and Shareshian										(10)				
Ignal												(15)		
Jackson										(16)				
Klien										(20)				
Kilbridge and Wester	(17)											(30)		
Mukherjee and Basu		(32)			(32)		(32)							
Moodie and Young			(31)			(31)								
Mastor									(30)			(30)		
Mansoor		(26)			(26)	(26)	(5&6)	(5&6)						
Salveson										(35)	(35)			
Tonge								(43)	(42)	(41)				
White											(46)			
Kilbrdige and Wester													(45)	
Macaskill													(22)	(23 & 24)
Thomopoulos														(37 & 38)

TABLE (3.1) REFERENCES MADE IN REVIEW OF SIMPLE BALANCING PROCEDURES.

3.2.1. Balancing by precedence diagram

In any approach to assembly line balancing one of the key pieces of information, without which the balancing problem is not defined, is the precedence relationships between each of the work elements involved. These relationships represent the minimum necessary ordering of work elements dictated by the technical nature of the product and the restrictions imposed by production manufacturing technology and are most conventionally represented in a form of a precedence diagram, although a less informative precedence matrix could also be used. Precedence diagrams that have been constructed using the normal conventions outlined by Prenting and Battaglin (33) have in their own right been used as the basis of an early approach to assembly line balancing by Kilbridge and Wester (17). A significant early contribution to assembly line balancing the Kilbridge and Wester method however is unique in its use of the precedence diagram as a means of assigning elements to work stations.

Kilbridge and Wester Method

The problem examined by Kilbridge and Wester assumes an unlimited number of work stations and balances to a given cycle time by using the following principle steps:

Step 1:

Starting with the first work station and repeating for the following subsequent new stations prepare a precedence diagram using the normal conventions of Prenting and Pattaglin (33) and construct on accompanying table containing:

Column numbers

Element numbers

Transferability of elements between columns

Element durations

Column totals for unassigned elements

Cumulative column totals for unassigned elements.

The key of the Kilbridge and Wester approach is the use of the cumulative column duration list included in the table and the transferability of elements from column to column on the diagram. Figure (3.1) and Table (3.2) illustrate the precedence diagram and calculation table for a 16 element problem used throughout the thesis as an illustrating example. Transferability is calculated by fixing the number of columns on the diagram and then transferring as far right as possible for all elements, accepting that followers again cannot appear in the same column as predecessors. The transferability for example of elements "B" would be from column IV to column VII under these conditions.

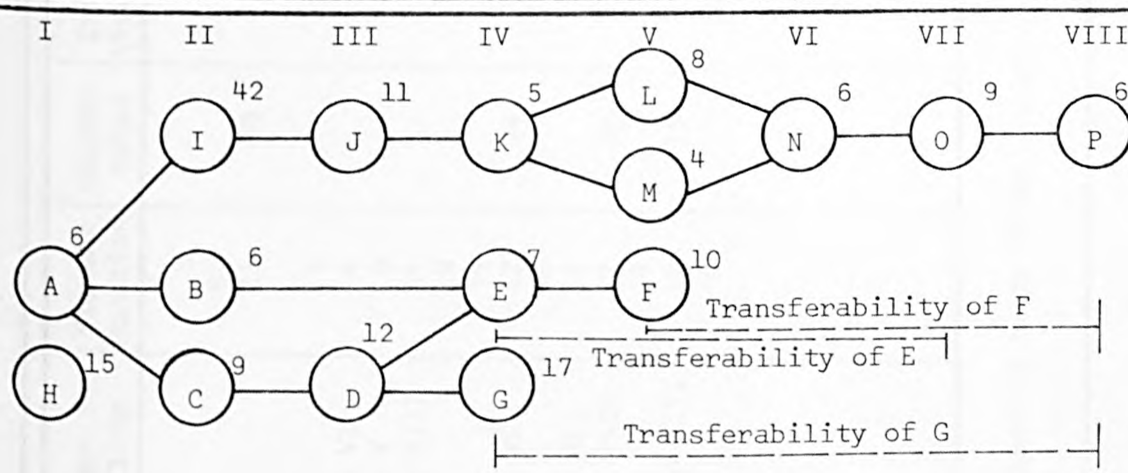
Step 2: Assignment of whole columns with no balance delay.

Where the cumulative duration is equal at some point to the cycle time, this means that a whole number of columns can be assigned to the current work station with no waste time. When this arises all the relevant elements in the columns concerned are assigned to the current station and the precedence diagram and table are updated as shown in figure (3.1) and table (3.2) before going to step 7.

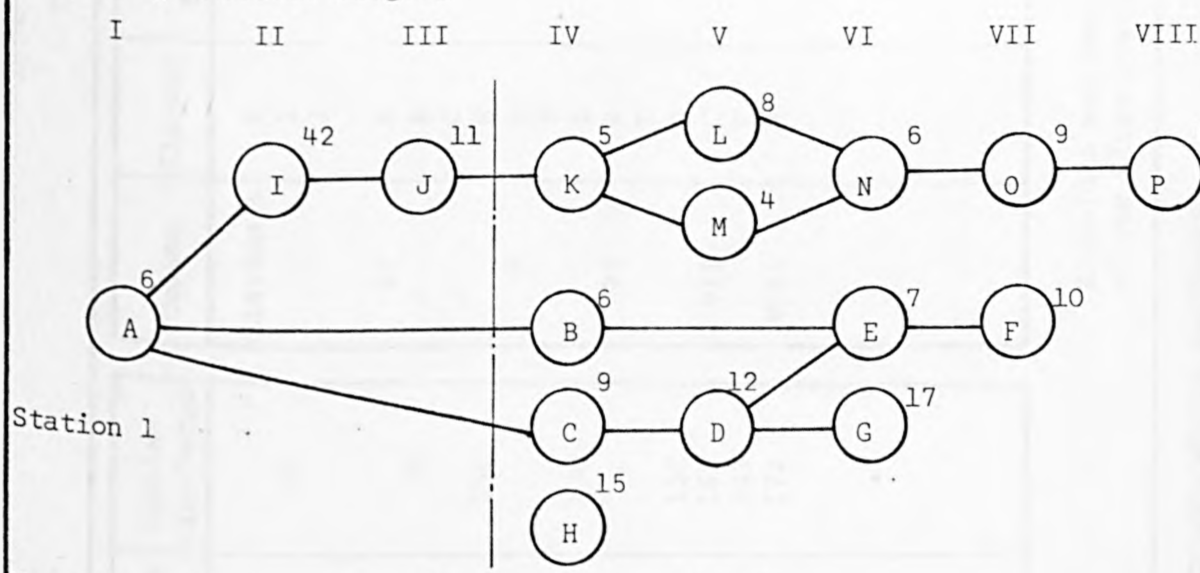
Step 3: Assignment where perfect balance may not be possible.

Where a whole number of columns cannot be assigned to the station, the procedure is as follows:

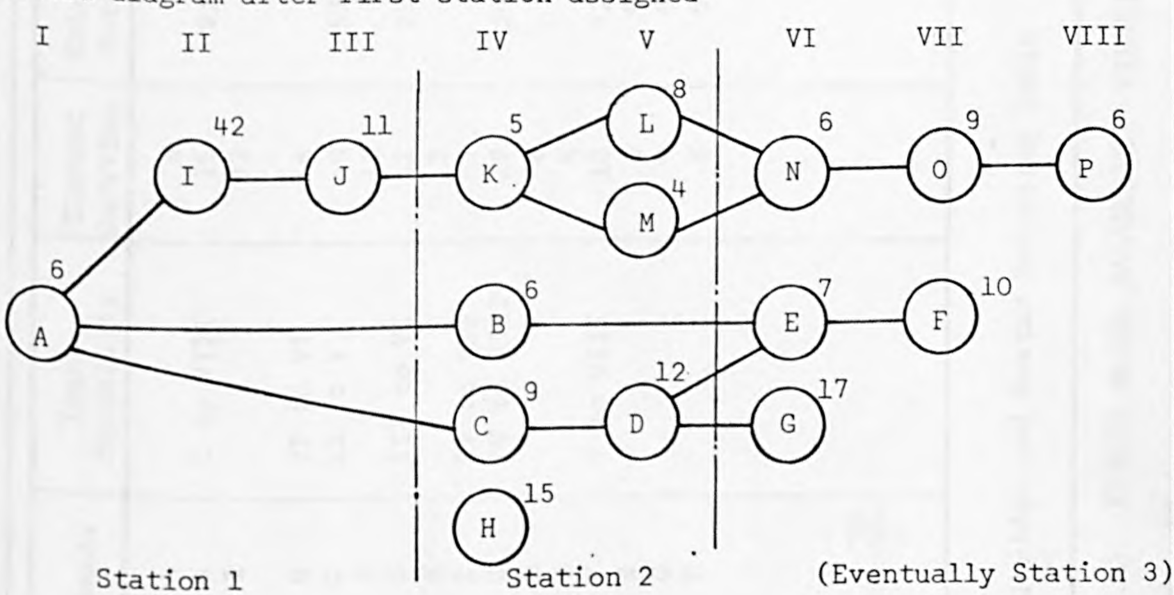
Illustration example (16 Element Problem Application)



Original precedence diagram



Precedence diagram after first station assigned



Precedence diagram after second station assigned

FIG. (3.1) KILBRIDGE AND WESTER APPROACH STEPS.

Illustrating problem - 16 element

Column	Element	Trans-ferability	Element Duration	Column Total	Cumulative Total
I	A		6		
	H	I to VIII	15	21	21
II	I		42		
	B	II to VI	6		
	C	II to V	9	57	78
III	J		11		
	D	III to VI	12	23	101
IV	K		5		
	E	IV to VII	7		
	G	IV to VIII	17	29	130
V	L		8		
	M		4		
	F.	V to VIII	10	22	152
VI	N		6	6	158
VII	O		9	9	167
VIII	P.		6	6	173

Initial Kilbridge and Wester Balancing Table

Column	Element	Trans-ferability	Element Duration	Column total	Cumulative Total
Station 1	A		6		
	I		42		
	J		11	59	
IV	K		5		
	B	IV to VI	6		
	C	IV to V	9		
	H	IV to VIII	15	35	35
V	L		8		
	M		4		
	D	IV to VI	12	24	59
VI	N		6		
	E	VI to VII	7		
	G	VI to VIII	17	30	89
VII	O		9		
	F	VII to VIII	10	19	108
VIII	P		6	6	114

Kilbridge and Wester balancing table after assignment of the first station.

TABLE (3.2.A) SINGLE MODEL BALANCING - KILBRIDGE AND WESTER PROCEDURE.

Illustrating Problem - 16 Element

Column	Element	Transferability	Element duration	Column total	Cumulative total
Station 1	A		6		
	I		42		
	J		11	59	
Station 2	K		5		
	B		6		
	C		9		
	H		15		
	L		8		
	M		4		
	D		12	59	
Station 3	N		6		
	E	VI to VII	7		
	G	VI to VIII	17	30	30
	O	VII to VIII	9		
	F		10	19	49
	P		6	6	55

Kilbridge and Wester balancing table after assignment of the second station.

Column	Element	Transferability	Element duration	Column total	Cumulative total
Station 1	A		6		
	I		42		
	J		11	59	
Station 2	K		5		
	B		6		
	C		9		
	H		15		
	L		8		
	M		4		
	D		12	59	
Station 3	N		6		
	E		7		
	G		17		
	O		9		
	F		10		
	P		6	55	

Kilbridge and Wester balancing table after balancing achieved.

TABLE (3.2.B) SINGLE MODEL BALANCING - KILBRIDGE & WESTER PROCEDURE.

3.a. Identify the column whose cumulative duration is closest but less than the cycle time and also the column whose cumulative duration is closest but greater than the cycle time.

3.b. Taking all the elements in the lesser column and adding them to each combination of elements from the greater column that is possible, determine the work time involved.

If one of these combination only is equal to the cycle time then place all elements involved in the current work station and the precedence diagrams and table are updated before going to step 7.

Where two or more solutions exist equal to the cycle time select the solution with the largest size elements, assign these elements to the current work station and the precedence diagram and table are updated before going to step 7.

Step 4:

If a perfect balance has still not been obtained, it is now necessary to consider transferring elements to later columns. Take the set of unassigned elements up to and including the larger column and identify those elements of the set that can be transferred to other columns outside those under consideration. For every permutation of transfer determine the work time of remaining elements.

Where only one set of transfers leaves work equal to the cycle time assign the elements in question to the current station, transfer the required elements to the next available column and update the precedence diagram and table before going to step 7.

Where two or more solutions are equal to the cycle time, select the solution with the largest size elements, assign these elements to the current station, transfer the unassigned elements to the next available column before going to step 7.

Step 5:

Where a perfect balance has still not been found increase the number of columns to be considered by one and return to step 4.

Step 6:

When all columns have been included in step 4 and no perfect solution has yet been found, take the solution that comes closest to the cycle time and where more than one solution exist with this time select the solution with the largest size elements. Transfer elements as required and assign remaining elements to the current work station before going to step 7.

Step 7:

Check if all elements have been assigned, if so, balancing is complete. Where all elements have not been assigned close the present station and start a new station before returning to step 1.

The procedure outlined has been written after examining the article of Kilbridge and Wester (17) and the enlightening example given by Wild (47) as the procedure has never been written in detail by Kilbridge and Wester, and table (3.3) shows the considerable calculations that were required to solve the 16 element problem using Kilbridge and Wester. It is an important point to appreciate that precedence diagram balancing works best when perfect assignments can be made to

16 Element Illustrating Problem

Step 1

Work Station 1 Cycle time = 60

Step 2

No cumulative total = 60

Step 3 (3A)

Column I (21) < Cycle time
Column II (78) > Cycle time

Step 3 (3B)

Column II, Elements I, B and C
Possible Combinations

Elements	Time
Column I + I	63 NF
+ B	27
+ C	30
+ I & B	69 NF
+ I & C	72 NF
+ B & C	36
+ I & B & C	78 NF

None equal cycle time therefore step 4.

Step 4

Columns I & II
Elements A, H, I, B and C
Transferable H, B and C

Transfer	Time
	63 NF
H	72 NF
B	69 NF
C	57
H & B	54
H & C	63 NF
B & C	48
H, B & C	

None equal cycle time therefore step 5.

Step 5

Columns I, II and III therefore step 4.

Step 4

Columns I, II and III.
Elements A, H, I, B, C, J and D.
Transferable H, B, C and D

Transfer	Time
	86 NF
H	95 NF
B	92 NF
C	
D	89 NF
H & B	PF
H & D	74 NF
B & C	83 NF
C & D	80 NF
H, B & C	PF
H, B & D	68 NF
B, C & D	74 NF
H, C & D	65 NF
H, B, C & D	59

None equal cycle time therefore step 5.

Step 5

Columns I, II, III and IV.

Step 4

Columns I, II, III and IV
Elements A, H, I, B, C, J, D, K, E & G.
Transferable H, B, C, D, E & G.
Number of possible transfer combinations = 63.
None feasible as transfer of all six still exceeds cycle time.
Best solution = 64 NF.
Transfer H, B, C, D, E & G.
Therefore step 5.

Step 5

Columns I, II, III, IV & V.

Step 4

Columns I, II, III, IV & V.
Elements A, H, I, B, C, J, D, K, E, G, L, M & F.
Transferable H, B, D, E, G & F.
Number of possible transfer combinations = 63.
None feasible as transfer of all six still exceeds cycle time.
Best solution = 85 NF.
Transfer H, B, D, E, G & F.
Therefore step 5.

Step 5

Columns I, II, III, IV, V & VI.

Step 4

Columns I, II, III, IV, V & VI.
Elements A, H, I, B, C, J, D, K, E, G, L, M, F & N.
Transferable M, E, G & F.
Number of possible transfer combinations = 15.

TABLE (3.3.A) KILBRIDGE AND WESTER CALCULATIONS.

16 Element Illustrating Problem

None feasible as transfer of all four still exceeds cycle time.
Best solution = 109 NF
Transfer H, E, G & F.
Therefore step 5.

Step 5

Columns I, II, III, IV, V, VI & VII

Step 4

Columns I, II, III, IV, V, VI & VII
Elements A, H, I, B, C, J, D, K, E, G, L, M, F, N & O.
Transferable H, G & F.
Number of possible transfer combinations = 7.
None feasible as transfer of all three still exceeds cycle time.
Best solution = 123 NF.
Transfer H, G & F.
Therefore step 5.

Step 5

Columns I, II, III, IV, V, VI, VII & VIII.

Step 4

Columns I, II, III, IV, V, VI, VII & VIII.
All elements involved.
None transferable.
Time = 173.
Therefore as no optimum solution found go to step 6.

Step 6

Accept nearest possible solution:
Assign A, I & J.
Transfer H, B, C & D.
Station time = 59.

Step 7

Check is the balance completed no therefore step 1.

Step 1

<u>Work station 2</u> <u>Cycle time = 60</u>

Step 2

No cumulative total = 60.

Step 3 (3A)

Column IV & V (59) < Cycle time
Column VI (89) > Cycle time

Step 3 (3B)

Column IV
Elements N, E & G.
Possible combinations.

Elements	Time
Columns IV & V + N	65 NF
+ E	66 NF
+ G	76 NF
+ N & E	72 NF
+ N & G	82 NF
+ N, E & G	89 NF

None equal cycle time.
Therefore step 4.

Step 4

Columns IV, V & VI
Elements K, B, C, H, L, M, D, N, E & G.
Transferable H, E & G.

Transfer	Time
H	74 NF
E	82 NF
G	72 NF
H & E	67 NF
H & G	57
E & G	65 NF
H, E, G	50

None equal cycle time.
Therefore step 5.

Step 5

Columns IV, V, VI & VII

Step 4

Columns IV, V, VI & VII.
Elements K, B, C, H, L, M, D, N, E, O & F.
Transferable H, G & F.

Transfer	Time
H	93 NF
G	91 NF
F	98 NF
H & G	76 NF
H & F	83 NF
G & F	81 NF
H, G & F	66 NF

None equal cycle time.
Therefore step 5.

Step 5

Columns IV, V, VI, VII & VII.

TABLE (3.3.B) KILBRIDGE AND WESTER CALCULATIONS.

16 Element Illustrating Problem

Step 4

Columns IV, V, VI, VII & VIII.
All elements involved.
None transferable.
Time = 114 NF.
Therefore as no optimum solution found go to step 6.

Step 6

Accept nearest possible solution.
Assign K, B, C, H, L, M & D.
Transfer none.
Station time = 59.
Therefore step 7.

Step 7

Check is the balance completed.
No therefore step 1.

Step 1

Work station 3 Cycle time = 60

Step 2

No cumulative total = 60.
Best solution columns VI, VII & VIII = 55.
As this is below cycle time and involves all remaining elements, final assignment found.
Assign N, E, G, O, F & P.
Station time = 55.

* PF = Precedence failure.
NF = Not feasible.

TABLE (3.3.C) KILBRIDGE AND WESTER CALCULATIONS.

stations i.e. no waste time is incurred. If this is not the case, as in the 16 element problem, the number of calculations involved is large for the following reasons:

(a) All possible combinations of elements to be transferred or elements to be included are taken into account. If a particular problem was to have as few as six (N) possible transfers this would require the evaluation of:

$$\sum_{m=1}^{N} \frac{N!}{(N-m)! \times m!} \qquad (3.1)$$

alternative solutions which for six possible transferable elements would result in 63 combinations being evaluated.

(b) The list of transferable elements compiled each time transferability is considered, must be carefully checked to ensure that elements can actually be transferred to a position outside the complete range of columns being considered for allocation.

(c) In evaluating all the possible combinations of transfer a precedence check has to be carried out to ensure that the precedence logic has not been disturbed, i.e. elements have been transferred whilst their followers remain.

Both the illustrating problem of Kilbrdige and Wester and the problem used by Wild were fortunate to have frequent perfect allocations. In the Kilbridge and Wester case perfect assignment were achieved to all work stations, solutions having been found after examining relatively few combinations, in the case of Wild three of the four stations achieved perfect balance and personal judgement was used to reduce the amount of calculations on the fourth station. Where computers are to be used the full set of time consuming calculations would be undertaken. In the

16 element problem used to illustrate Kilbridge and Wester method it was not possible to balance perfectly any station at a cycle time of 60 time units and as a result approximately 214 possible assignments were evaluated. Had the cyle time been 59 time units the number of possible assignments evaluations would be 44, again indicating how the Kilbridge and Wester method is biased towards perfectly balanced stations. The conclusion to be drawn from this is that the Kilbridge and Wester approach requires considerable computation time for evaluating unhelpful solutions.

One interesting conceptual problem could also arise with the Kilbridge and Wester method under adverse circumstances. Consider a weakly ordered diagram with considerable number of elements in each column and a low cycle time. This is likely to result in more stations than columns, something not seen so far in a Kilbridge and Wester example. Under these circumstances the concept of transferability could break down when trying to balance elements in the final column as transfers may be required but no columns would be available.

In conclusion therefore the Kilbridge and Wester method of balancing presents an approach which is of use for smaller problems but which requires considerable calculations for inconvenient cycle time and which has a potential fault in logic under difficult circumstances. For these reasons precedence diagram balancing has not been pursued as the basis for a new balancing procedure.

The Kilbridge and Wester approach does however highlight the importance of taking precedence relationships into account when seeking to balance assembly lines efficiently. What is required however is a more numeric representation of precedence which requires less calculation to produce a balancing solution.

3.2.2. Heuristic ranking methods

The balancing approach that comes closest to representing the restrictions on precedence in numerical form was first introduced by Helgeson and Birnie (11) in 1961 and can be referred to as the Rank Positional Weight approach. Since the first heuristic was introduced this group of balancing procedures has become the largest and most powerful group available for solving both single and mixed model balancing.

The essential procedure involved in the ranking methods is firstly rank in importance each element using a defined criteria and secondly use this rank order for selecting elements for assignment to stations. In some ranking heuristics ranking is performed once at the onset of the problem and candidates are then selected in rank order before their availability is checked in terms of their precedence freedom. In other procedures the set of the available elements for allocation is first selected and then the set of elements are ranked by an appropriate criteria, these two different approaches will be referred to as single ranking and continuous ranking respectively.

A second major variation between the different ranking methods available is the method of selecting a solution. In some cases only one ranking calculation takes place and only one solution is produced (the original Helgeson and Birnie method). In other situations several solutions using different ranking criteria are produced and the best solution is selected from this set of solutions. The result of the variation in ranking approach means that there will be an increase in the amount of calculation required as the change is made from single to continuous ranking and an additional further increase in calculation will be encountered as the move is made from single choice assignment to multiple choice assignment.

Apart from different ranking methods and different assignment approaches there are a few minor variations in procedure which will be indicated at the appropriate point, these variations have been concerned with whether elements are assigned to stations in a downstream or upstream order.

Single Ranking

Helgeson and Birnie Rank Positional Weight

The general principles of the ranking approach to assembly line balancing can again be demonstrated by firstly considering a representative heuristic in detail and then by discussing the variation introduced by other published procedures. A most suitable example of rank positional weight is the original work of Helgeson and Birnie, and the 16 element problem previously used in this chapter will be used to illustrate the steps involved in this procedure.

The Helgeson and Birnie rank positional weight procedure is concerned with assignments to an unlimited number of stations on an assembly line, in conjunction with a fixed cycle time and employes the following steps:

Step 1:

For each work element the positional weight is obtained using the formula:

$$W_i = t_i + \sum_{j=1}^{n} t_j(F) \qquad (3.2)$$

where:

W_i = Positional weight of element i

t_i = Normal element duration for element i

n = Number of all elements involved in the balancing problem.

$t_j(F)$ = Normal element duration of element j for followers of element i.

= 0 for non-followers of element i

n, t_i are as previously defined.

i.e. Positional weight equal element duration plus total durations of all followers, where followers include both immediate followers and subsequent indirect followers.

Step 2:

Rank each element in descending order of positional weight.

Step 3:

Starting a new work station, set the time available for elements equal to the given cycle time. Set the starting rank to 1.

Step 4:

Find the element with the present rank and make the following tests:

(a) Is the work element waiting to be assigned.

(b) Have all preceding elements been assigned.

(c) Does sufficient time remain at the station for the element to be allocated.

If any answer is no go to step 6.

Step 5:

Assign the element to the work station, reduce the time available by the element time and return to step 6.

16 Element Illustrating Problem

Element E_i	Element Duration t_i	Positional Weight W_i	Rank R_i	Element E_i	Element Duration t_i	Positional Weight W_i	Rank R_i
A	6	158	1	I	42	91	2
B	6	23	9	J	11	49	4
C	9	55	3	K	5	38	6
D	12	46	5	L	8	29	7
E	7	17	11	M	4	25	8
F	10	10	15	N	6	21	10
G	17	17	12	O	9	15	14
H	15	15	13	P	6	6	16

(Element durations, positional weights and ranking)

Rank	Element	Check on Precedence	Element Duration	$C - \Sigma t_i$	Comment
Work station 1 Cycle time C = 60 time units					
1	A	✓	6	54	Assign
2	I	✓	42	12	Assign
3	C	✓	9	3	Assign
All remaining element durations > 3					Close station
Work station 2 Cycle time C = 60 time units					
4	J	✓	11	49	Assign
5	D	✓	12	37	Assign
6	K	✓	5	32	Assign
7	L	✓	8	24	Assign
8	M	✓	4	20	Assign
9	B	✓	6	14	Assign
10	N	✓	6	8	Assign
11	E	✓	7	1	Assign
All remaining element durations > 1					Close station
Work station 3 Cycle time C = 60 time units					
12	G	✓	17	43	Assign
13	H	✓	15	28	Assign
14	O	✓	9	19	Assign
15	F	✓	10	9	Assign
16	P	✓	6	3	Assign
All elements are assigned, the balance complete					Close station

(Balancing procedure for rank positional weight technique)

Station 1	Elements:	A	I	C							
	Durations:	6	42	9	=	57					
Station 2	Elements:	J	D	K	L	M	B	N	E		
	Durations:	11	12	5	8	4	6	6	7	=	59
Station 3	Elements:	G	H	O	F	P					
	Durations:	17	15	9	10	6	=	57			

(Balancing results for the 16 element illustrating problem)

TABLE (3.4) RANK POSITIONAL WEIGHT BALANCING CALCULATIONS.

Step 6:

Move to the next rank and return to step 4. If the highest rank has been exceeded go to step 7.

Step 7:

If elements still remain to be assigned close the present work station and return to step 3. If no elements remain to be assigned, end the balancing process.

Consider firstly the method used by Helgeson and Birnie for calculating the positional weights of elements and for ranking these elements in order. The positional weights are calculated quite rapidly and once having been calculated the process is not repeated again, making the process computationally efficient.

A more significant advantage of this R.P.W. approach is the ranking formula itself, which proves to be a good numerical representation of both the precedence position of an element and the amount of work dependent on that given element. This means that if the descending order of ranking is strictly followed in the assignment of elements, the number of candidate elements rejected on precedence grounds will be reduced considerably, again making for computational efficiency. In the illustrating example no elements were rejected on precedence grounds, whilst the 11 element problem used by Helgeson and Birnie produced only 3 precedence rejections in the entire solution.

The equation used for the calculating of positional weight also reflects a measure of the importance of each element in so far as the larger element or elements with the greater amount of dependent element times will come first in the ranking order. Unlike the precedence diagram approach which does not distinguish between elements, the rank positional weight approach will therefore identify the more important or the more difficult elements.

The whole heuristic procedure adopted by Helgeson and Birnie is in itself very computationally efficient for it both ranks only once and assigns elements to stations only once, later techniques which involve repeated ranking and multiple assignments are not so efficient in computational terms.

It is important to appreciate however that computational efficiency itself is not the objective of balancing, and if greater amounts of calculations are likely to produce better balanced lines then greater amounts of calculations should be undertaken. However a computationally efficient heuristic procedure will be able to balance more realistic larger size problems than would less efficient procedures.

The rank positional weight procedure originated by Helgeson and Birnie has been used unaltered by Buxey (4), Heskiaoff (12), and Mukherjee and Basu (32) in alternative formulations of the line balancing problem.

Four line balancing procedures, those of Moodie and Young (31), Arcus (1), Mastor (30), and Mansoor (26), used an alternative ranking criteria by ranking elements in order of the largest element duration first. The concept of largest element first has some merits in that the solution of the general set of "packing" problem of which assembly line balancing is an example, benefits from placing the largest elements first and subsequently using the smaller elements to fill up the decreasing space remaining. However the largest candidate rule when applied to assembly line problems gives no acknowledgement of precedence relationships or element importance, an important difference from the general class of packing problem where the order of packing is not important, for this reason the use of some element and element follower duration is considered superior to the largest candidate duration when selecting elements for assignment.

A third criteria that of the number of followers has been used by Mukherjee and Basu (32), Arcus (1), Mastor (30) and Mansoor (5) as criteria for selecting candidates for assignment. Mukherjee and Basu suggested taking total number of followers i.e. immediate and subsequent followers but did not apply the suggestion in his balancing procedure, whereas Mansoor and Arcus applied number of followers in a balancing procedure. There appears only limited merit in taking number of followers when the same amount of calculation can produce the total duration of followers; a better indicator of relative importance. Tonge (43), Arcus (1), and Mansoor (5) also used the number of immediate followers only as a criteria for ranking but this is of even less merit than the total number of followers as it is only likely to indicate approximately the number of new elements that will be released should the candidate element be assigned.

Mansoor (5) did in practice produce ten different criteria with which to base ranking using 4 different approaches, i.e. the original rank positional weight equation, total followers, largest candidate duration, and total immediate followers, and additional six criteria were used by taking various combinations of the original four. Although discussed again later it should be noted now that Mansoor's intention was not to generate one solution but to generate ten solutions and to select the best results after the completion of the ten balances.

Arcus (1) produced nine different ranking criteria in his approach to assembly line balancing and used each as a means of weighting the random selection of elements from the candidates available. Two of the weighting methods: largest element duration and number of immediate followers have been used by others whilst the remaining seven rules of Arcus are permutations of various precedence and time values available, the seven hybrid criteria having no special consideration as criteria.

In one of the few detailed comparative studies of balancing procedures (discussed in more detail in section 3.2.5), Mastor (30) used two further ranking criteria, random selection and lexicographic order, as the means of selecting elements for assignment. They are mentioned here for completeness but are not intended as true ranking criteria, more a means of producing bench mark solutions for comparison.

After having examined the different alternative weighting formulation for ranking elements the conclusion is drawn that the original rank positional weight has the strongest merits, by being simple to understand and computationally efficient and built from appropriate logic. As no widespread comparative investigation of different criteria has been published that indicates the original rank positional weight approach to be inferior over a number of trials with different problems the traditional rank positional weight approach with suitable modification for enlarged station calculating, has been accepted as the basis for ranking.

Alternative approaches to element assignment.

Continuous ranking.

The procedure used by Helgeson and Birnie of ranking all elements once and selecting from the entire list of elements each time an assignment to a station is about to be made requires minimal calculation, but is not the only assignment procedure in use. Moodie and Young (31) and Arcus (1) take the alternative approach of firstly selecting the subset of elements which are available at the time an assignment to a station is about to be made and then secondly to apply the ranking formula to the available subset only. Moodie and Young take elements for assignment in rank order from this subset until an element has been assigned whilst Arcus uses the positional weight of the elements in the subset to bias random selection, continuing until an assignment is successfully made. Once an element is assigned the ranked subset is destroyed and the process repeated all over again for the next element assignment, thus leading to the concept of continuous ranking. The advantage of continuous ranking is that it does not rank elements which have no prospect of assignment and unlike the original rank positional weight procedure no element is considered for allocation which has the prospect of failing to meet precedence relationships. However a severe disadvantage to continuous ranking is the number of times ranking calculations take place for it is conceivable that many elements will have gone repeatedly through the positional weight calculations before actually being assigned. Although no tests have been carried out to support the view, it is believed that continuous ranking will require more calculations than the traditional rank positional weight.

Rank positional weight with backtracking:

Three years after the introduction of the original rank positional weight approach Mansoor (26) introduced a modification to the problem and brought forward an amended procedure for applying rank positional weight. Essentially Mansoor was concerned with balancing an assembly line with a fixed number of stations and a given cycle time. This does not stop several line lengths being examined and the best solution chosen, a problem equivalent to an unlimited line length, but the important modification by Mansoor is that once assignment starts the line is considered fixed in length and consequently the total station time available is known and by deducting the total element time the total free time available is also known. This total free time available can be checked against the lost time at each station as the balance progresses so that should the lost time exceed the free time the balancing procedure can backtrack through the solution with a view of discovering an alternative answer.

It is this process of allowing backtracking through assignments already made to station and returning elements to the candidate list that is uniquely different from the traditional rank positional weight approach, and the main steps involved are:

Step 1:

Calculate the positional weight for all the elements and rank them is descending order (using the Helgeson and Brinie rank positional weight method).

Step 2:

Determine the possible range of number of work stations using the equations:

$$\text{Minimum number of work stations} = 1 \qquad (3.3)$$

$$\text{Maximum number of work stations} = \frac{\sum_{i=1}^{n} t_i}{t_{max}} \qquad (3.4)$$

rounded up to the nearest integer.

where: n = number of elements involved in the problem.

t_i = work duration for element i.

t_{max} = the maximum work duration for all elements.

Step 3:

For each possible number of stations calculate the lowest possible cycle time using the equation:

$$C = \frac{\sum_{i=1}^{n} t_i}{m} \qquad \text{round up to the next integer}$$

where

m = number of stations

t_i, n as before.

Step 4:

Calculate the slack time for the given number of stations and the calculated lowest cycle time using the equation:

$$\text{Slack time} = \{m \times c\} - \sum_{i=1}^{n} t_i \qquad (3.5)$$

where

c = cycle time to be used

m, n and t_i are as before.

Step 5:

Start a new work station, set the time available for the elements equal to the cycle time. Set the present rank to 1 (or to the lowest rank not yet assigned).

Step 6:

Find the element with the present ranking and make the following tests:

(a) Has the element been transferred to the list of elements abandoned by backtracking for the station.

(b) Is the element waiting to be assigned.

(c) Have all preceding elements been assigned.

(d) Does sufficient time remain at the station for the element to be placed.

If any answer is no, go to step 8.

Step 7:

Assign the element to the work station, reduce the time available by the element time and continue to step 8.

Step 8:

If the highest rank has been exceeded go to step 9.
Move to the next rank value and return to step 6.

Step 9:

If elements still remain to be assigned and the idle time is less or equal to the slack time, close the station and update the slack time remaining by deducting the station idle time from the slack time, go to step 5.

If elements still remain to be assigned and the idle time of the station is greater than the slack time available proceed to step 10.

Step 10:

From the original list of elements assigned to the station remove the last element and increase the station time available for assignment as appropriate, reset the present rank to 1 noting that some elements may have already been removed from the list in previous attempts at backtracking, return to step 6 and 7.

If none of the original list of assigned elements remain, then balancing is not possible at this cycle time and the cycle time should be increased by one before returning to step 4.

Step 11:

Select the number of stations that gave the minimum waste time solution.

With the minimum cycle time being selected for each number of stations there is not likely to be very much idle time available at the beginning of each balance. This is going to lead to a generally high level of backtracking calculations compared to the simpler solution approaches. The view that excessive calculations may be involved is supported in a general review of balancing procedure by Ignal (15) who stated that:

> "It is not clear that Mansoor's method is practical to get an optimal balance, "element" U_8, which is currently in the forth station must be moved up to the second station. This takes a fair amount of "backtracking" work even in this case, therefore it is not clear that Mansoor's method is practical for large lines."

Mansoor himself acknowledged the possibly excessive amount of calculation required in a later paper (6) in which he suggests four heuristic methods for reducing the amount of calculations involved, the new backtracking procedures have been referred to as the MALB balancing method.

One further point of interest was made by Ignal in his review regarding the idea of backtracking where after commenting on the possibility of excessive calculation Ignal stated:

> "However the idea of flagging the rank positional weight method when the idle time gets too large is very appealing, and selective (as opposed to exhaustive) application of backtracking may be very effective."

The reason why this flagging process has not been used by others is that up to this point the problem had been one of assigning elements to unlimited assembly line length which implies that idle time would always be infinitely high. It is only with limited line length that the idea of monitoring the progress of element assignments works.

Because of the computational difficulty encountered, backtracking is not considered suitable for pursuing as a basis for a new approach to assembly line design but the principle of monitoring progress where a limited line length problem is being balanced is worthy of note, particularly as it is anticipated that the new procedures to be developed in this work will have to deal with limited line length problems.

Reverse assignment with rank positional weight.

One further alternative approach to rank positional weight balancing was originally mentioned by Helgeson and Birnie (11) and mentioned again by Moodie and Young (31) and Hoffman (14). This modification involves the straight forward rank positional procedure with one single ranking stage and one single assignment stage but with the procedure reversed i.e. the arrows are reversed on the precedence diagram and the positional weights calculated on this basis giving highest positional weights to the last elements. Elements having been ranked in descending weight priority, were assigned to stations starting with the final station and moving towards the first station.

The nature of the assembly line balancing problem with the difficulty of packing various size work elements under precedence restrictions often means that the more solutions produced, the better possibility of finding the best solution. Reverse rank positional weight does not produce consistently better results but will by chance on occasion produce a better solution than the normal rank positional weight and therefore may be worth considering. This raises an interesting question discussed in more detail later in the review as to whether or not the best balancing procedures are a compromise between simple computationally efficient heuristics and total enumeration.

The rank positional weight procedures represent the most important contribution to simple single model balancing of all the alternative approaches. In considering the usefulness of R.P.W. for further investigation of the line balancing problem, the following general conclusions have been noted:

(a) Rank positional weight heuristics can produce reasonably good results with a relatively low amount of calculation, thus leaving the way open to undertake larger industrial problems.

(b) The rank positional weight approaches outlined are, in general, well defined and precise and therefore amenable to computer application.

(c) Of the alternative rank criteria available the traditional equation introduced by Helgeson and Birnie appears the most logical and has not been shown to be inferior.

(d) The nature of the assembly line problem indicates that the best approach for solving problems may be a compromise between balancing heuristics and some form of enumeration.

(e) Where a limited line length problem is to be balanced the continual monitoring of balancing progress is worth considering as a means of avoiding unwanted solutions.

3.2.3. Mathematical Enumeration Approaches

In reviewing the heuristic approaches to line balancing and in particular the ranking methods, the point was made that the nature of the relationship between the distribution of element time and the cycle time combined with the restrictions of precedence could mean that a solution procedure that gives several answers could be better than a solution procedure that gives one answer, particularly over a wide range of problems. If the idea of producing a set of answers, rather than a single answer, is extended then there are a number of procedures that produce balancing solutions by enumerating a wide selection of answers and selecting from these answers. Within this group can be included the work of Jackson (16), Tonge (41 and 42), Hoffman (14), Klien (20), Held, Karp and Shareshian (10), Gutjahr and Nemhauser (9), and Arcus (1).

The procedure introduced by Jackson fits well within this group as considerable enumeration is employed to find a solution to the problem of minimizing the number of stations for a given cycle time. Essentially Jackson first creates all the feasible first stations then creates all the feasible second station combinations that could go with each combination of first station and then determines each combination of the third station that could go with all first and second station combinations, and so on until a solution employing the minimum number of stations appears. This virtually total enumeration and the number of calculations will be very high for weakly ordered precedence diagrams, as can be demonstrated by taking the simple case of an eight element problem where each element has a duration of 5 time units and a cycle time of 10 time units exists, thus each station will contain a pair of elements. With an extremely weakly ordered precedence diagram i.e. no precedence relationships at all the number of combinations at each station can be calculated using:

$$\frac{N!}{2! \times (N-2)!} \qquad (3.6)$$

where

N = Number of elements available for assignment at the station.

Using the equation it can be calculated that 2520 possible sequences exist where for a very strongly ordered duration with all 8 elements in precedence sequence, the number of feasible solutions would be 1. Therefore it can be seen that Jackson's method may be two exhaustive in the amount of enumeration that takes place for practical problems.

The method introduced by Tonge included Jackson's approach but in addition effort was also made to smooth the line by repeatedly examining the current largest station i.e. the station with the largest sum of duration times. The number of calculations involved in Tonge's approach was therefore increased again above Jackson, making this procedure also unreasonable for large size problems.

Held, Karp, Shareshian investigated the possibilities of enumerating all answers and finding the optimal solution but reduced the vast number of possible sequences by pregrouping elements into feasible subsets, where a subset consists of a group of elements that can be undertaken together. Using, in addition, feasible subsequences i.e. a subset undertaken in the required order, the vast number of possible sequences is reduced to a smaller number of sequences made up of element subsets. The computing space required to store the subset however grows exponentially as a number of elements involved in a problem increases and therefore the approach of Held, Karp and Shareshian may be limited again to smaller problems.

Hoffman produced a more reasonable compromise in his enumeration approach by selecting the best solution for each station and continuing only from that solution i.e. all feasible sequences for the first station would be evaluated and the best solution selected, then all feasible sequences for the second station would be evaluated and the best solution selected for that station and so on until the complete solution had been found. This therefore involves much less calculation than total enumeration of all possible solutions and represents again that combination of heuristic and enumeration which may be the best approach to solving balancing problems.

The balancing procedures of Arcus (1) which have previously been discussed under alternative ranking methods may also be considered a form of enumeration for the procedure produces a number of solutions by selecting, at random, elements for assignment at each stage, baising the random selection by any one of nine ranking criteria. By random selection Arcus' approach can produce any number of possible answers that is desired by the designer, although the more answers produced the greater the chance that repeat solutions will appear.

Klien produced a method for partially solving the balancing problem by providing a means of determining the minimum idle time solution for a given feasible sequence. As these had to be combined, however, with a procedure for generating all possible feasible sequences, Klien's method will again only be suitable for small problems.

Summarizing on the enumeration approaches it is reasonable to conclude that total enumeration procedures required too great a level of computation for practical size problems. However it is worth noting as a point of principle that there is nothing wrong with enumeration when the amount of calculation is within feasible range. The objective after all is to produce an efficiently balanced assembly line and not to minimize the amount of calculation in providing a balancing solution. With the considerable increase in processing power of computers and the general reduction in the cost of computing, enumeration may yet have the last say in finding efficient balancing solutions.

3.2.4. Linear Programming Approaches

The three previous approaches to single model assembly line design are, apart from total enumeration, all heuristic in nature in that they use some form of procedure to obtain a good balance result. This balance may be efficient but there is no guarantee that the optimal answer has been found.

Optimal balances are possible however for simple formulations of the line balancing problem if linear programming is used, and three published references have been found regarding such application of linear programming including the work of Salveson (35), Bowman (2),(3), and White (46). The work of Salveson being the first published scientific approach to assembly line balancing. Salveson's linear programming model however did not use integer programming and as a consequence element tasks are allowed to be split between stations, thus raising a practical problem as in many cases work elements are logical tasks containing work which cannot easily be split or which can only be split with the introduction of considerable inefficiency. For this reason Salveson's model appears limited.

An integer programming approach was used by Bowman who proposed two separate models one of which was subsequently amended by White. The limitations of linear programming as a solution approach for line balancing were well identified by Ignal (15) in his review of assembly line balancing when he showed that even simple problems involved considerable numbers of equations and variables quoting that for an eleven element example Bowman's first model needed 50 equations and 66 variables whilst the second model needed 100 equations and 43 variables for the same eleven element example, the number of equations and variables in solution approaches using linear programming is related to the number of precedence relationships that exist as well as to the number of work elements and stations involved, the number of stations having to be specified.

In view of the considerable number of equations and variables needed, and remembering that the objective of this present research in part was to be able to introduce a more practical model of assembly lines it appears that linear programming is of only limited use, a point supported by Ignal (15) who stated:

> "Things do not get better as the assembly line gets bigger so this approach (LP) seems to be of cultural rather than practical interest, no matter how fast the integer linear programming algorithm of the future is."

For the reasons given linear programming was not pursued as the basis of a new balancing model.

3.2.5. Comparative Studies

In the detailed review of single model balancing procedures heuristic, enumeration and linear programming approaches have been discussed in terms of their method of operation advantages and limitations but no indication has been given of their relative performance for given problems. In attempting to compare the quality of results produced by these procedures, and the computational effort required there are three known comparative studies from which to draw comments, those of Mastor (30), Gehrlein and Patterson (8) and Mansoor (6).

Mastor comparative study.

The most exhaustive comparative study of balancing procedures was undertaken by Mastor (30) who used five published problems ranging from twenty-one to one hundred and eleven elements, together with twenty empirical cases of differing permutations of a fourty element problem and a further ten empirical cases of differing permutations of a twenty element problem to examine the efficiency of a given set of balancing heuristics. The number of tests was further increased by varying for the thirty test problems generated from empirical data the dominance of precedence relationships, by varying work element times, by varying the ratio between the number of stations and the number of work elements and finally by varying problem size. Using the basic problems seven hundred and twenty five cases were eventually examined.

The comparative study included comparison of five published procedures those of Arcus (1), Held, Karp and Shareshian (10), Helgeson and Birnie (11), Hoffman (14), and Kilbridge and Wester (17). In addition four alternative procedures were included for comparison:

- Random selection of elements.
- Selection of largest work element.
- Selection by largest number of immediate followers.
- Lexicographic order.

After carrying out more than one thousand trials the main conclusion put forward by Mastor was that there are consistent differences amongst the results achieved by the nine techniques across the whole range of line length precedence dominance, and problem size. Mastor mitigated his conclusion however by saying that the differences were not large but were consistent. The final order of effectiveness put forward by Mastor ranked the nine approaches as follows:

1. Held, Karp and Shareshian
2. Arcus
3. Hoffman
4. Random
5. Time order
6. Kilbridge and Wester
7. Immediate followers
8. Helgeson and Birnie
9. Lexicographic order.

It is noticeable that all three top procedures came from the enumeration group, and that the single solution methods were relatively low. Held, Karp and Shareshian and Hoffman being the two enumeration procedures that were able to bring the amount of calculation within reasonable bounds whilst Arcus' procedure simply produced as many random solutions as required.

Mastor was also able to comment uniquely on the approximate amount of computational effort required to achieve results, stating that significant differences occurred in computer time required. The Held, Karp, and Shareshian and Hoffman techniques required approximately ten times as much computing time as Arcus' technique and fifty times as much as the simpler heuristics. Mastor further indicated that as problem size increased the computing time required by Arcus' and the simple techniques grow in proportion to the number of elements but that the computing time required by the Held, Karp and Shareshian technique increased much faster with problem size.

In carrying out these tests the objective was to compare both the effectiveness of method investigated and to comment on the time consumed in calculating, with the measure of effectiveness being taken as the percentage excess of the cycle time required to achieve a balance over the absolute lower bound cycle time, this relationship is expressed in the formula:

$$100 \left\{ \frac{\text{minimum computed cycle time}}{\text{absolute lower bound cycle time}} - 1 \right\} \qquad (3.7)$$

The absolute lower bound cycle time is calculated for a given line length by dividing the total element durations by the number of stations.

Gehrlein and Patterson comparative study.

One of the results obtained by Mastor (30), namely that the Arcus technique was superior to the Hoffman procedure was challenged subsequently by a comparative study executed by Gehrlein and Patterson. Taking a range of industrial problems and examining them with integer task times instead of normalised task times (i.e. the sum of task times equals one), the conclusion was drawn that Hoffman's approach was superior to Arcus'. Both comparative studies could be correct for it is found that the result produced by many balancing procedures are sensitive to examples taken, remembering that the existence of procedure restraints makes the balancing assignment problem more difficult than more conventional linear programming problem.

Mansoor comparative study.

The third comparative study was carried out by Mansoor (6) and involved a comparison of two approaches developed by himself (5)(26), referred to as MALB and 10SP, against the random multi-path method of Arcus (1). The MALB procedure is an improved version of the back-tracking procedure described in section 3.2.2. whilst 10SP is a procedure which selected the best results from ten single path solutions obtained by using different ranking criteria (see section 3.2.2. for ranking comments).

The conclusion drawn by Mansoor after solving a wide range of large single model balancing problems was that his own 10SP technique gave consistently superior results over the Arcus approach, whilst Arcus' approach was in general shown to dominate the MALB procedure. Mansoor did not consider the differences in computational time to be significant and preferred to use as the objective criteria for comparison the balance delay of solutions, conducting his tests with a view to varying firstly the number of elements involved, secondly the precedence dominance of problem, thirdly the ratio between number of elements and number of stations, and forthly the range of work element durations. No details of the actual test problems were given, thereby making comparison with other comparative studies difficult.

Conclusion.

The conclusions that can be drawn from the three comparative studies are:

(a) Over all the procedures that are a reasonable compromise between total enumeration and single solution approaches pre-dominate over single solution approaches.

(b) No one technique dominates consistently through the three studies.

(c) Although extensive, the three studies have only compared seven of the published procedures available were tested. These tests were carried out under different circumstances making comparison difficult.

(d) Comments on the time required for calculation indicated two contrasting opinions, with Mastor indicating a very considerable difference in calculating time and Mansoor suggesting no significant difference.

(e) Each comparative study carried out tests on different problem conditions indicating the wide variety of the problems possible but opinion was consistent with regard to the fact that precedence dominance and the relationship between cycle time and element times were very strong influences on results obtained. This point will be remembered when examining the new balancing models suggested in this work.

The simple single model balancing procedures represent by far the largest group of procedures available and as a consequence of reviewing these single model solutions procedures, it is considered that the most suitable approach for further extension would be a compromise between a simple heuristic and total enumeration remembering that the objective is well balanced assembly lines and that the cost of a badly balanced assembly line over its life is going to be very much higher than the cost of carrying out more extensive computer trials.

3.3. Mixed Model Approaches

Although the majority of published balancing techniques are concerned with simple single model balancing in practice there are potentially more applications of mixed-model assembly line production then there are of single model production and therefore the relatively few mixed-model balancing procedures available are worthy of detailed consideration. In referring to mixed-model balancing the concern is to examine those situations where one assembly line has to deal with a variety of products with differing work content.

This means that mixed-model production involves not only the allocation of work elements to assembly line stations (traditional balancing) but may also have to consider the effect of the order in which the production program is launched onto the assembly line (the sequencing and operational problem).

There are four published approaches to the design of mixed-model assembly line design and in reviewing these four approaches (Wester and Kilbridge (4), Thomopoulos (5), (37), (39), (40), and Macaskill (22), (23), (24), (25)), the balancing and sequencing stages will be identified separately with a view to commenting on their field of application and suitability for further development.

3.3.1. Wester and Kilbridge mixed-model approach

The first approach to balancing a mixed-model production line was published by Wester and Kilbridge in 1964 and contained an outline of the tasks involved along with two possible sequencing procedures.

Balancing

Mixed-model balancing i.e. the assignment of work elements from a variety of models to stations on an assembly line will be strongly influenced by the number of common work elements between models. Two general cases exist, in the first case the products have no common elements and are entirely different products which will be referred to as balancing multi-product lines. The second case is the far more common production of a number of model derivations, i.e. several models with only limited variation in work elements, a case which will be referred to as mixed-model production.

Wester and Kilbridge suggest that the approach to balancing multiple product lines should involve producing individual balances for each product, in their case by reference to their single model balancing procedure (17), this is particularly suited to the Kilbridge and Wester approach as the number of stations can be fixed for each model and the procedure will minimize the cycle time required in each case. The justification for this approach was given by Wester and Kilbridge (45) as:

> "since there is no essential difference between balancing one model and the independent balancing of several models to be run on the same line, this aspect of the problem (balance stage) will not be discussed here."

Whilst this may be reasonably true for multi-product balancing it is not true for mixed-model balancing as the opportunity to take advantage of common work elements is not considered. However this does identify the point that different mixed-model procedures may be required for the two separate cases of multi-product and mixed-model balancing.

Sequencing

Having created an assembly line balance Wester and Kilbridge outlined two procedures for arranging the manufacture of the production program, namely variable rate launching and fixed rate launching.

The principle of variable rate launching can be encompassed in two main points:

(a) Models are launched onto the assembly line at time intervals dictated by the individual rates of production required (i.e. after a time equal to the previous model cycle time).

(b) Work stations are located sufficiently far apart on the assembly line to ensure that operators will be available to produce the next arriving product.

How this is achieved is fairly easy to demonstrate, consider a simple example taken from Wester and Kilbridge (45), five models are to be produced on one line with the following output required in each 480 minutes shift time, the total element time for each model being:

Model	Quantity	Work content per product	Total work content
A	80	5.52	441.6
B	120	2.76	331.2
C	200	3.60	720.0
D	160	3.60	576.0
E	80	5.40	432.0
	640		2500.8

The number of stations required can be calculated by firstly dividing for each model the total work content per shift by the shift duration, rounding up to the nearest integer where required, and by taking the subsequent largest number of stations. For the Wester and Kilbridge problem the number of stations would be 6 (5.21↑). The individual cycle times i.e. the rate at which each model can be launched (if produced alone on the line) can be calculated by dividing total work content per product by the number of stations, thus giving individual cycle times of 0.92, 0.46, 0.6, 0.6, and 0.9 for models "A" to "E" respectively. Model "A" can then be launched and 0.92 minutes later model "B" can be launched and so on through five models.

The second question is to ask how far apart should stations be spaced so as to avoid failure to complete work. This spacing of stations, expressed in terms of time for the fixed speed line, is referred to by Wester and Kilbridge as the operator cycle time, the optimum value of operator cycle time is equal to the largest model cycle time, as any value below the largest model cycle time will cause failure to meet the work targets, and a figure above the largest cycle time will introduce excessive operator idle time.

The weakness of variable rate launching is not in the theory but in practice, for the launching of products at times dictated only by the previous model will cause great difficulties in the timing of component arrivals and will not allow the work force to establish a consistent rate of performance, Wester and Kilbridge acknowledged this point themselves and therefore because of this high level of impracticability variable rate launching was not considered an area for future investigation.

The second approach to sequencing by Wester and Kilbridge concerned a fixed rate of launching for all models. With fixed rate launching the actual sequence of launches plays the key role for efficient manufacture. The first task is to determine the fixed rate of launching, this rate of launching referred to as the production cycle time, is calculated using the equation:

$$\gamma_{opt.} = \beta = \frac{\sum_{j=1}^{m}\{Q_j x C_j\}}{\sum_{j=1}^{m} Q_j} \qquad (3.8)$$

where:

$\gamma_{opt.} = \beta$ = The production cycle time (optimal generated cycle time).

Q_j = Number of units of the model j.

C_j = The cycle time of model j.

m = Number of models.

In the illustrating example the production cycle time was determined as 0.65125 minutes.

The method of determining the sequences of launches by Wester and Kilbridge was to select the model at each launching interval which minimized the function:

$$\{\sum_{j=1}^{i} C_j\} - \{i \times \gamma\} \qquad (3.9)$$

where:

C_j = The cycle time of the model launched.

i = The number of units launched to date.

γ = The production cycle time.

This gives a fairly simple heuristic procedure for choosing the next model at each step but does not avoid the occurrence of idle time or work congestion, with the possibility of resultant failure to complete work. Wester and Kilbridge made the further suggestion that if the entire production program could be scaled down in proportion to give a number of repeat cycles then the amount of calculation could be greatly reduced.

The fixed rate launching approach is therefore the first practical heuristic for mixed model balancing and although concerned with a simple closed definition of work stations, Wester and Kilbridge concluded by commenting that a more realistic definition including overlapping of stations would reduce the general level of inefficiency.

3.3.2. Thomopoulos mixed model approach

The first trial line balancing procedure to consider the mixed-model balancing problem was introduced by Thomopoulos (37) in 1967. The procedure developed was used for designing an assembly line concerned with the manufacture of a set of products which contained a reasonable proportion of common work elements, allowing emphasis therefore to be placed on the method of balancing as well as considering the subsequent question of sequencing work.

Balancing Model 1.

The procedure proposed by Thomopoulos is a modified form of the single model Kilbridge and Wester (17) balancing procedure (described previously in section 3.2), the essential changes to allow mixed-model balancing being:

(a) The element durations on the column oriented precedence diagram were replaced by the total amount of work involving that element in a production period. As a simple illustration, if the element duration is 16 and the element is involved in the production of 3 models A, B, and C whose respective production quantities are 80, 100, and 120, then the duration of 16 is replaced by total work content of 3200.

(b) The cycle time is replaced by the total production time available per production period and this is used in the Kilbridge and Wester balancing procedure to produce assignment of elements to work stations.

This results in a procedure which balances work tasks using an amended precedence diagram and shift time available as a replacement for the cycle time. It should be noted however that the precedence diagram is a composite of all the individual model precedence diagrams, and therefore works best where a substantial proportion of common elements exist, for there is only limited point in merging precedence diagrams of entirely different products. In the example included by Thomopoulos (38) in his thesis, of the 657 work elements (by far the largest balancing problem found) 592 elements were common to at least two of the six models involved.

The balancing example given by Thomopoulos in his paper works well because a large number of small values were to be found in the total aggregated work column. Looking closer however at the procedure it can be seen that if an aggregate work total for one element was to exceed the time available for the production period then the procedure breaks down just as the original Kilbridge and Wester method would if any element duration exceeds the cycle time. As there is a reasonable risk of this occurring in the aggregated total approach this first Thomopoulos model will need modification.

Balancing Model 2.

In 1970 Thomopoulos (40) introduced a modification to his procedure by including as a major objective the smooth balancing of the assembly line, this resulted in a radical departure from Thomopoulos' previous model and in reality represents a new multi-model balancing procedure, the outline of which is as follows:

(a) The composite precedence diagram with total element times are produced as before.

(b) Taking each work station in turn, all possible sequences of element assignments are determined along with the total work involved in each sequence.

(c) For each sequence the element time required by each model is determined and by multiplying by the required production of each model the total time at the station for each individual model can be determined.

(d) The average time per station for each model is calculated by multiplying production required by total element time for each model and by subsequently dividing by the number of stations.

(e) The smoothness function is then calculated as the sum, for all models, of the absolute value of average station time for the model minus the work content at the station for each model, determined by the sequence in question.

(f) The sequence with the minimum smoothness function is then selected and assigned to the station.

The procedure of working out the smoothness value for a given sequence can be demonstrated using a simple example where 100 each of 3 models "A", "B", and "C" are to be produced and the total element time involved in each model is 11.0, 6.0, and 18.0 respectively. The sequence in question being investigated involves 3 elements: element 1, element 2, and element 3 whose individual element times for each model are as follows:

	A	B	C
1	1.0	0.0	1.0
2	1.0	1.0	1.0
3	0.0	0.0	1.0
	2.0	1.0	3.0

The total time at the station for each model is:

(A) 2.0 x 100 = 200

(B) 1.0 x 100 = 100

(C) 3.0 x 100 = 300

The average time per station knowing 5 stations are to be employed is:

(A) $\frac{100 \times 11.0}{5} = 220$

(B) $\frac{100 \times 6.0}{5} = 120$

(C) $\frac{100 \times 18.0}{5} = 360$

Therefore the smoothness function can be calculated as:

$$\Delta = |220 - 200| + |120 - 100| + |360 - 300| = 100$$

If this were to be the minimum Δ value this sequence would be assigned to the station and the process repeated for the next station.

The second model proposed by Thomopoulos (40) fits within the category of a good heuristic rule combined with a controlled amount of enumeration, the type of approach which was indicated to be likely to produce better balancing solutions for single model balancing. The amount of calculation involved in determining the smoothness factor is more than would arise with a more simpler heuristic but as the calculation involved still appears to be well within the capability of a computer, then the amount of calculation cannot be criticised.

One point of concern with Thomopoulos' second model again arises from the nature of the problem demonstrated. The procedure generates an equivalent aggregate cycle time (total time available per period) by dividing the total time by the desired number of stations, and in relation to this aggregate cycle time each total time for individual elements is small. The procedure therefore does not explain what would happen if the total element time for one particular task was to exceed the aggregate cycle time, a reasonable possibility on occasions with this aggregating approach and an equivalent problem to attempting a single model balance with an element exceeding the cycle time. This comment regarding the total element time of any one individual element exceeding the equivalent cycle time has been brought forward in both Thomopoulos' models because they are both likely to have such a situation arise as a consequence of the nature of the aggregating procedure. This problem can be seen in an illustration of mixed-model balancing given by Wild (47) where in a problem with a 40 hour aggregate cycle time, four out of a possible eighteen elements exceeded the aggregate cycle time and were apparently balanced by allocating to double and triple stations, although no detailed explanation of how this was achieved was given.

In summary therefore Thomopoulos has put forward two true mixed balancing models which in the first case involves the relatively cumbersome Kilbridge and Wester method and in the second case involves limited enumeration in a similar manner to the single model balancing of Hoffman (14).

Sequencing

Having achieved a mixed model balance Thomopoulos then examines the question of sequencing the actual production program, working on the basis of the more practical fixed rate launching situation. The sequencing model put forward by Thomopoulos is distinctive in the manner in which stations are defined, and in the method by which the best sequence is determined.

Four different types of work stations were allowed for by Thomopoulos in his sequencing model, including closed stations, open stations, closed to the right and open to the left stations (upstream excess stations), and finally closed to the left and open to the right stations (downstream excess stations), the nature of these stations have been described in Chapter 2. The sequencing method of Thomopoulos allowed for the individual definition of each station and then calculated the behaviour of product and worker allowing for the type of stations involved. This represents a significant and noteworthy advance in that it is an acknowledgement that when analysing the actual behaviour of assembly lines, it is a simulation approach that is needed, for in practice the sequencing procedure of Thomopoulos was an introductory simulation study with individually specified station types and station dimensions.

The actual sequencing procedure given a particular arrangement of stations consisted of determining each of four types of inefficiency and converting these inefficiencies via penalty costs into the sequencing objective criteria. The four inefficiencies defined by Thomopoulos were:

Idleness:	Occurs where an operator is kept waiting for work to enter the upstream limit of his work area.
Work deficiency:	Occurs when an operator completes one task before the arrival of the next.
Utility work:	This is representative of the remedial work required when an operator fails to complete his task before the product leaves the station.
Work congestion:	This occurs when an operator moves out of his station to complete his work.

Each of the four penalty types has an associated individual penalty cost and the sequencing criteria is based on the total of these four penalty costs.

The sequencing procedure works as follows:

(a) For each model available consider launching the model in question and determine for each station the consequential penalty costs.

(b) Select the model with the smallest inefficiency cost and assign the model to the schedule.

(c) Update the position of each worker on the assembly line bearing in mind the work of the model just launched. For example after a number of models, the worker is currently 0.2 minutes downstream with a cyle time 2 minutes and a model has just been assigned to the sequence which has 2.6 minutes of work at the station in question, then the starting position for the next calculation is 0.2 + 2.6 - 2.0 = 0.8 minutes downstream from the start of the station.

(d) Remove the model accepted into the sequence from the list of models remaining in the production program. Continue until all models have been assigned into the sequence.

The concept of analysing in detail what theoretically occurs inside each work station is a major contribution by Thomopoulos and again emphasises the potential for a simulation contribution to mixed-model balancing. The practical weakness that exists in the Thomopoulos case is that when simulating in such detail the natural variance of human performance will, in a particular situation, give a considerably different result than Thomopoulos' theoretical sequence cost.

A second considerable difficulty arises when understanding Thomopoulos' suggestion that a penalty cost can be tolerated at all even though it is a minimum. Idle time by operators may be acceptable on a practical assembly line but persistent remedial work may not, it would perhaps be better to consider increasing the cycle time in order to reduce the possibility of poor quality production. Persistent remedial work at one station is an indication that perhaps double manning is desirable whilst if intermittent remedial work is involved then in practice the floating "work station" should be acknowledged in the calculation of assignments and line efficiency.

The calculation involved in this simulation type approach to sequencing can be considerable but Thomopoulos pointed out quite rightly that if the proportion of the total program can be broken down into smaller programs containing the same approximate proportions of models then a set of repeat cycles exist and sequencing need only be undertaken for one of the repeat cycles.

3.3.3. Macaskill mixed-model approaches

Balancing

The first reference to a mixed model balancing procedure by Macaskill (23) appeared in 1969 where in an article on the methods available for organizing the solution of balancing problems by computer the brief outline of a multi-product balancing procedure was given, although the program involved was not fully explained, reference was made to a procedure which sought to determine the lowest cycle time for a number of products to be manufactured on a line of given length.

A more detailed procedure was published in 1972 (24) where the aggregate total approach of Thomopoulos was adapted to a ranking procedure rather than the precedence diagram approach. Creating a precedence diagram with total aggregate time for each element and balance on a basis of a shift time available, the selection of elements was ranked on either positional weight or alternatively largest aggregate time order. Commenting on the subsequent problems of sequencing the products Macaskill indicated in support of Thomopoulos that a simulation approach would be required and further pointed out that two different product mixes will not achieve the same line balance.

This brings forward a very important principle for future work in the field of mixed-model balancing in a real and practical situation, a mixed-model assembly line will be designed on the basis of a provisional estimated production schedule and once built will have to operate on a variety of actual production schedules dictated by customer demand. A subject therefore needing investigation is the question of how will mixed-model assembly lines perform if the production schedule is varied.

A similar rank positional weight mixed-model balancing example to that of Macaskill was referred to by Wild (47) where ranking was performed once instead of continuously but no detailed explanation was subsequently found.

Sequencing

Macaskill further investigated the assembly line balancing problem by carrying out computerized simulation studies along the line proposed by Thomopoulos' hand simulation model for sequencing, identifying in a similar manner to Thomopoulos the various values of inefficiencies for a given example. Macaskill concluded that the weakness of his and Thomopoulos' simulation approach was that operator variability had not been taken into account, a point supporting a comment made earlier.

Having examined the four main approaches to mixed-model balancing, the general conclusions that can be drawn from the review as a guide to future developments in this area include:

(a) For the balancing of mixed-model assembly lines where models have substantial proportions of common elements then an approach which considers a composite equivalent of all models is preferable to an approach which balances for each model separately.

(b) Wherever possible the balancing of a mixed-model production line should be completely independent of any subsequent sequencing analysis for in practical applications of assembly line work, product mixes and product schedules will vary considerably over the life of the plant.

(c) An understanding of the behaviour of work within an assembly line station can make an important contribution to determining the effectiveness of an assembly line. The use of simulation suitably fits this role.

(d) When simulation is applied to investigating behaviour within assembly line stations employing manual operators it appears unrealistic not to take into account operator variability.

(e) Mixed-model production has two polar cases: that of the manufacture of entirely different products and that of the manufacture of products with common work elements. Where differing products are to be made in a mixed order i.e. not in batches, then a different form of multiple product balancing problem arises and a different solution procedure based on multiple element assignments may be appropriate compared to balancing mixed-model interrelated products with single element assignments.

3.4. Complex Balancing Approaches

The assembly line balancing problems so far examined have primarily dealt with a simplified definition of the tasks involved. This simplification concerns the use of deterministic element durations, where the maximum duration is generally less than or equal to the cycle time and an assumption that the assembly line is made up of a uniform collection of closed stations. Many practical assembly lines however would be unduly restricted were they to be balanced using such a simple definition of work stations, furthermore whilst deterministic element durations may represent the work content of an element, the actual time taken by operators will behave as a normal distribution with the deterministic duration as average.

Where any modification is made to either the treatment of work elements or assembly line stations the problem is then termed complex. Complex balancing problems represent the greatest prospect for future research. In reviewing the limited number of papers concerned with complex balancing two approaches will become apparent. In the first approach simple assembly line balancing procedures are modified to cope with additional difficulties and in the second balancing approach specially constructed solution procedures for solving more complex problems will be encountered.

3.4.1 Work Element Variations

Three forms of element variation can be encountered in a complex balancing problem each of which would rule out the conventional deterministic approach subject only to precedence restraint. These three forms of variation are:

(a) The use of variable work element durations.

(b) The existence of element durations greater than the cycle time.

(c) Additional restrictions which limit the possible locations of element or the method of completing the work involved.

Variable element durations.

A number of published papers of assembly line balancing including Moodie and Young (31), Ramsing and Downing (34), Mansoor and Ben Tuvia (28), and Mansoor (26), have acknowledged that whilst the majority of balancing approaches use deterministic element duration, the operation of an actual assembly line including manual work will result in variable not deterministic completion times.

There are two approaches to dealing with element time variance. In the first case all deterministic element durations are increased to compensate for the actual variable completion times and in the second case variable durations are allowed to replace deterministic times within the balancing procedure as part of specialised cost models.

It is not the intention in this review to include the many published articles on the nature of work on paced assembly lines, although a number of more commonly quoted references have been included in the Bibliography. A brief summary of these articles would acknowledge that the time taken to complete work tasks will vary according to two influences:

(a) The normal variation of human operators.

(b) The variation in performance over a period caused by fatigue and other factors.

The prime concern at this point is to review how allowance is made for element variance.

The published papers by Ramsing and Downing and Moodie and Young summarized the most common method of dealing with variable element time, this approach consists of increasing each element time to ensure that work can be completed on a specified percentage of occasions.

Knowing the average element times, the variance of element times, and assuming a normal distribution, the element durations taken in each balancing procedure is calculated using the equation:

$$t_i' = t_i + \sigma \sqrt{t_{vi}} \qquad (3.10)$$

where:

t_i' = Increased element time.

t_i = Average element time.

t_{vi} = Element variance.

σ = Number of standard deviations equal to the risk required.

This appears to be a simple and suitable method of dealing with element variance. The defence of this approach is to recognize that in many cases an important objective on assembly lines is the completion of work tasks, for remedial work is comparatively expensive and persistent remedial work could be both destructive to production and would ultimately result in deteriorating production quality. By ensuring therefore that the probability of failing to complete work is set at a level dictated by management the effect of uncompleted work can be controlled. Vrat and Virani (44) in a paper describing a practical application of balancing in an Indian company supported just this view with a balancing model designed to balance the cost of remedial work against the cost of work on the assembly line, under conditions of variable work duration.

Two alternative approaches to dealing with variable element times have been put forward, each of these approaches involving a specialised cost model not normally associated with assembly line balancing, in the first model Mansoor (27) proposes a model when operators with known performance rating are selected to man stations for a given cycle time, and work elements are subsequently assigned to these stations using the effective time available found by multiplying the cycle time by operator performance ratings. The method of Mansoor and Ben Tuvia (28) proposes that the more conventional additional time allowed be used, but that operator be encouraged by extra payment to work at higher performance level, thus allowing lower cycle time and more output.

The first model is a good example of the difference between academic concepts of assembly lines and assembly lines in practice, for it is certain that once an assembly line starts to function absenteeism, training, and staff turn-over will ensure that the same operators will not permanently man individual stations.

A major point in the philosophy being put forward in this thesis is the view that assembly lines do not often operate under the same conditions as those in which they are designed. Changes in product mix, the ability to alter line speed and variations in manning standards will all contribute to ensure this difference between an assembly line as designed and the assembly line as operated. For this reason it is considered that balancing heuristic or procedures should not be unduly influenced by assumption of subsequent operations and that simulation should be used to examine the balance solution after it has been produced, to investigate how well the line will perform under a variety of conditions and not just those estimated at the design stage.

By reason of the philosophy just proposed the conventional addition of a fixed proportion to compensate for element variance is supported in the work to be developed.

Large element durations.

As stated earlier the situation may arise with certain balancing problems that an element duration may be greater than the desired cycle time. Under these circumstances simple assembly line stations will not be able to yield a balancing solution. How large elements may be dealt with is particularly relevant to the balancing model proposed in this work but more appropriate comment on dealing with this problem will be found in section 3.4.2 as the question of considering versatile definitions of work stations is examined.

Miscellaneous element restrictions.

In a practical assembly line balancing situation elements are rarely free of all restrictions and a number of the simple balancing procedures have indicated an additional ability to deal with various forms of miscellaneous restrictions, these additional restrictions including element sharing, compulsory grouping of elements, location of elements at fixed line positions, multi-operator elements and zoning.

Element sharing and divisable element does not agree with the general definition of elements as self-contained collections of work but the point made by Mariotti that it may be preferable to pay the cost of one or two elements undertaken in highly inefficinet manner rather than paying the cost of a badly balanced line has limited appeal.

This practice however could not be supported without a more detailed analysis of what exactly is involved, for if this view is supported the logical conclusion is that the problem is not one of discrete integer assignments but simply one of equal distribution of a total amount of work between stations.

Fixed location elements, mutually exclusive element, and mutually inclusive elements can be considered in the same light as precedence restrictions for their effect is more one of restricting the choice of possible locations rather than of one requiring the development of a new approach to balancing. Only where in specific problems these extra restrictions require greater time than the time available at a given station or the number of stations available on the line is exceeded will new balancing procedures be required.

Zoned elements are a more difficult case to deal with for zoning raises a fundamental question about the definition of assembly lines. Wester and Kilbridge (18) alone defined nine categories of station zoning and did not elaborate on the question of dealing with overlapping zones (for example front and rear overlap with left and right which overlap with top and bottom) or with the question of dealing with mutually exclusive zoning. The general effect of including zoning consideration is to redefine an assembly line as a series of parallel working zone based sub-assembly lines and to raise the problem of multi-manning on stations.

The question of two-man elements as included by Mariotti is an interesting one of relevance to the enlarged multi-manned station models developed in Chapter 4. It is a reasonable assumption to assume that a number of elements cannot be efficiently undertaken by one operator alone (for example the decking of an engine to an automobile chassis) and when these elements occur the conventional simple one-man station will not produce a suitable balance solution. There is some surprise that the question of the minimum number of operators required by each task has not arisen more frequently in balance procedures, as it appears a logical problem likely to occur reasonably frequently. A balancing model allowing large stations will be more capable of dealing with this restriction than the more conventional single operator procedures.

As a general rule the view is supported that wherever possible, the balancing procedure should take into account miscellaneous restrictions as this will with time lead to more industrially applicable algorithms.

3.4.2 Work Station and Assembly Line Variation

Leaving aside the need to consider complex stations in order to satisfy wider definitions of work elements, the desire for improved efficiency on assembly lines can in itself justify the move away from simple station definitions to more complex stations. The variation on work stations will take place on one of two forms, either variation within the size of a station or variation in the organization of the station (e.g. zoning). The number of published balancing procedures that have either discussed or used complex stations is relatively small and for this reason their merits can be individually discussed noting that the type of work station variation is illustrated in table (3.5).

Wester and Kilbridge (1962), Mariotti (1970).

As mentioned before the first reference to balance a complex form of assembly line was published by Wester and Kilbridge in 1962 where in a general article discussing a practical balancing problem, the ideas of work zoning and fixed positional elements were introduced. The justification for elements being located at fixed work stations was that special equipment would be needed. This implies however that a certain amount of pre-knowledge is known about the final form of the assembly line, if this situation arises frequently then the balancing problem cannot be formulated in the same way as a balancing problem with no known

Author & Published Year	Reference	Work Station Definition							
		Extended		Zoned			Enlarged		
		Open without inter-ference	Open with inter-ference	Fixed element location	Element zoning	Overlap zoning	Parallel branches	Overlap working	Group working
Arcus (1966)	(1)			Computer appli-cation				Limited application	
Buxey (1974)	(4)				Balancing approach		Balancing approach		
Heskiaoff (1968)	(12)			Balancing approach				Balancing approach	
Wester and Kilbridge (1962)	(18)			Empirical case study					
Macaskill (1969,1972,1973)	(23)(24)(25)	Production sequenc-ing only (1972,1973)		Computer applica-tion (1969)				Computer applica-tion (1969)	
Mariotti (1970)	(29)							Discussion only	
Thomopoulos (1967,1968)	(37)(39)	Production sequencing							

TABLE (3.5)   WORK STATION AND ASSEMBLY LINE VARIATION positional restrictions, particularly when the balancing procedure does not initially define the number of stations on the line.

In the general article by Mariotti, in which four balancing problems were discussed, namely element sharing, divisible element, cycle time less than element times, and multiple stations. When dealing with cycle time less than the largest element time the suggestion of Mariotti is to use multiple station of the enlarged multi-man type. Mariotti did not however consider how the nature of group working would affect the element duration and consequently simply divided the element time by the number of operators to produce a new equivalent duration. There is an inherent weakness in this argument as this implies no loss of efficiency, a point that will be discussed in some detail when developing the new balancing model in later chapters.

The prospect for developing an efficient balancing procedure with enlargeable station is however strongly supported provided that the nature of group working can be rationalized, as enlarged multi-manned stations are capable of dealing with large elements.

COMSOL Arcus (1966)

In a paper concerning a balancing procedure for simple type problems which had been computerized, Arcus indicated that the computer program was additionally capable of handling task durations larger than the cycle time, two-operator tasks, and fixed-location elements. Suitable comments on the effect of fixed-location tasks has been made in the discussion of the respective approaches of Wester and Kilbridge, and Mariotti.

Arcus overcame the problem of large element durations by introducing the rotating use of double length stations, that is to say rather than branching to two physical stations each manned by one operator, one station is used and each operator works in rotation on each second product. Duplicated stations of either, the rotating or parallel kind, have three main disadvantages. Firstly they may be expensive in equipment as key items will be needed twice over and additional branching and merging machines may be required. Where rotating type of parallel work is undertaken there will still be a need for duplicated equipment but in addition care must be taken to ensure that equipment does not interfere as operator overlap. The second problem is the need for operators manning parallel stations to be trained to twice the level of other operators, a problem which may upset job harmony. The third potentially more serious problem arises when mixed-model production is being undertaken. With certain balancing procedures the sequencing of work after balancing is important to eliminate the risk of overworking. A typical example of this would be to sequence alternate large and small tasks. With parallel working however this will result in all large tasks being assigned to one operator and all small tasks being assigned to the other, this point, i.e. that where parallel stations exist sequencing of work becomes substantially more complicated has not been appreciated by those authors who claim both parallel stations and sequencing as part of their procedure.

Thomopoulos (1967, 1968), Macaskill (1969, 1972, 1973).

The work of Thomopoulos (37), (39) and Macaskill (22), (24), (25) does not strictly fit into balancing procedures capable of assigning elements to complex stations, as consideration of extending stations was reserved for the subsequent sequencing of mixed-model production. The more complex station definitions used included the principle of upstream and downstream working areas outside the normal station length, this is an acknowledgement of actual assembly line practice and therefore worthy of note at this point, the merits of using an open station definition having been discussed previously in this section.

Macaskill (22) did refer in one paper to an optimal facility being included in his computer programs for allowing double stations. The procedure works by examining the inefficiency of each single station and when unacceptably high inefficiency is found the station size is duplicated and balancing recommences from that point through to the end of the assembly line. The description of this procedure however does not clarify whether a single station size would be returned if the inefficiency of the double station were to be worse than the original inefficiency. If a double station is accepted the method of working outlined by Macaskill is that of operators working in rotation on double length stations as opposed to operators working independently on branched assembly stations. Comments on the difficulties that may arise with this approach have been made earlier and the comment with respect to mixed-model balancing is particularly relevant as Macaskill is one of the two authors most concerned with sequencing for mixed-model production.

Heskiaoff (1968) and Buxey (1974)

Two computerized procedures for balancing assembly lines that have specifically made provision for dealing with non-standard work stations are those of Heskiaoff (12) and Buxey (4). Heskiaoff modified the rank positional weight approach of Helgeson and Birnie to allow for fixed positional elements and multiple stations, the illustrating example included in the paper referred to the reconditioning of telephone handsets where certain elements of work were restricted to given stations, indicating once again the case of assumed pre-knowledge of the assembly line to be used. With regard to increasing the capacity of work stations Heskiaoff also included, along similar line to Macaskill, the ability to double the size of a station but went further than Macaskill by attempting double balancing at every station rather than just with those of low efficiency. The double station was expected to operate on the principle of overlapping operators as used by Macaskill and once again will result in increased training needs.

A more advanced method considering multiple stations was introduced by Buxey in a computerized procedure which was capable of providing multiple station sizes which expected to operate on the principle of parallel branches type, and which could accommodate certain element and line restrictions. The first significant extension by Buxey was to allow the station size to be dictated by a ratio involving the number of work element per station. Although empirical in approach i.e. not based on any scientific principle, this advance did allow consideration of more than just single or double stations, thus providing more opportunities for finding the most efficient balancing solution. It should be noted however that the empirical ratio used to dictate maximum station size would not cover all cases of problems with extra large element durations.

Amongst the useful additional feature of the Buxey balancing program is included the ability to deal in a limited manner with element zoning, desirable grouping of elements, mutually exclusive elements and element requiring more than one operator. Acknowledging the contribution of Heskiaoff in the development of his procedures Buxey identified that in certain assembly line balancing problems there are work elements that actually require more than one operator and therefore require assignments to extended or enlarged stations.

The inclusion of variable station size therefore represents a very useful addition to assembly line balancing procedures providing the theory behind enlarged stations is carefully analysed. Summarizing on the methods of varying station size included in this review the following general conclusions have been drawn:

(a) Extended work stations with upstream and downstream excess represent a means of overcoming variations in work-load caused by mixed-model production. Extended work stations represent only a temporary extension and over a period of time the work assigned to an extended station must fall within the station time available (cycle time) and therefore extended stations should not be considered at the balancing stage.

(b) Duplicated stations whether parallel or rotating in nature can deal with large work elements at some considerable expense in additional equipment and training. Duplicated stations cannot cope with those work elements needing two or more operators.

(c) Enlarged work stations can satisfy the needs of large elements and elements needing more than one operator, whilst at the same time giving the advantages of a group approach to job enrichment on assembly lines without requiring additional line space.

(d) Allowing for variable size stations in a balancing procedure increases the probability of finding a good balancing solution as more alternative choices of line configuration exist.

Balancing Criteria

3.5. Methods of Evaluation

The text of the literature review up to this point has been concerned with analysing the merits of each actual balancing procedure with a view to identifying the potential for further advances, it is worth however for the purpose of completeness to give separate consideration to the evaluation criteria used in each procedure. It is important to be able to show that the objectives of the various balancing heuristics are appropriate to the problem being examined and to subsequently consider whether new balancing models can use existing criteria or will need to develop new criteria formulae.

From table (3.6) it can be seen that three principle formulas are in use, two of which are alternative representations of the same efficiency criteria. The most common objective in the balancing techniques reviewed was that of minimizing idle time, where idle time can be expressed by the equation:

Idle time = Total time available - Total work time.

This is an imminently suitable criteria for balancing but as the formulation involves absolute values it may be difficult to compare idle time for different problems and therefore it may be difficult to assess the effectiveness of procedures over a variety of trials.

An alternative expression of the amount of waste time was introduced by Kilbridge and Wester (17). Referred to as Balance Delay, the equation involved is:

$$B.D. = \left\{\frac{P \times C - \sum_{i=1}^{n} t_i}{P \times C}\right\} \times 100 \quad [\%] \qquad (3.11)$$

Criteria	Idle Time	Balance Delay	Smoothness Index	Miscellaneous
Technique	Arcus Bowman Gutjahr and Nemhauser Helgeson and Birnie Hoffman Held, Karp, and Share-shian Jackson Klien Mastor Mansoor (slack time) Salveson Tonge White	Buxey (balance loss) Kilbridge and Wester Mukherjee and Basu Mastor Mariotti Thomopoulos **Balance efficiency** Heskiaoff Macaskill	Moodie and Young (Tonge) Prem Vart and Ajit Virani	Macaskill Thomopoulos idle time work congestion work deficiency work utility Kilbridge and Wester Idle time work congestion Mansoor and Ben Tuvia constant cost model cost of operator X output Vrat and Virani labour cost/unit production cost + incompletion cost

TABLE (3.6) EVALUATION CRITERIA USED IN BALANCING PROCEDURES.

where:

BD = Balance delay

C = Cycle time

P = Number of work stations

t_i,n As before

The advantage of Balance Delay is that it is a relative expression of efficiency and therefore can be used universally for comparing balancing results. For this reason the Balance Delay equation is worth maintaining in some form or another as a means of evaluating balancing results.

Nine of the balancing procedures reviewed used Balance Delay and in addition Macaskill (22) used a close approximation to Balance Delay where the balance efficiency was evaluated using the equation:

$$\text{Balance efficiency} = \frac{\text{Total work time}}{\text{Total time available}} \qquad (3.12)$$

The third major formula used for evaluating assembly line balances was introduced by Moodie and Young (31) and termed Smoothness Index, where Smoothness Index can be calculated using the following equation:

$$S.I. = \sqrt{\sum_{k=1}^{P} (S_{max} - S_k)^2}$$

where:

S.I. = Smoothness index

P = Number of work stations

S_k = Work time of station k

S_{max} = Maximum station time.

This equation is unique in that it actually represents the smoothness for the line. The title "line balancing" implies the sharing equally of work yet the criteria for assessing the equal sharing of work is only used by three procedures, whilst idle time and balance delay occurs twenty-three times in table (3.6). There are two reasons for this. Firstly if idle time is low then this automatically means that there is a reasonable distribution or balance of work so indirectly idle time and balance delay are representative of equal work distribution. The second reason for the lack of use of smoothness index is the fact that it is difficult to give anything but the broadest meaning to the actual values produced, a value of zero represents perfect balancing but what does the value of five or fifty represent. In future balancing procedure therefore it may be worth looking for a more readily understandable equation than the present absolute value formulae.

Idle time, balance delay, and smoothness index are all relevant to simple single model balancing and alternative formulations will have to be found for mixed-model balancing.

When examining the assembly line sequencing problem four more specific time calculations were proposed. Wester and Kilbridge (17) initially proposed that idle time and work congestion are considered as a means of examining the efficiency of an assembly line, where idle time and work congestion have the following definitions:

"Idle time occurs when operators have no work to perform."

"Work congestion occurs when operators are forced into the upstream area in order to work on a unit."

In two later articles on the sequencing of mixed-model production Thomopoulos (37) and Macaskill (25) added two more measures of time utilization to the two introduced by Wester and Kilbridge. The two additional measures of time utilize were work deficiency and work utility, defined as:

> "Work deficiency occurs when operators have no work."
>
> "Work utility occurs when operators cannot complete the work on a unit."

It should be noted that the additional measures of time apply only to work stations with an open definition i.e. with an upstream and downstream excess. The intention in later chapters is to provide a simulation model for assessing a given assembly line under a variety of conditions, and the four measures of time utilization are appropriate for inclusion in some form in that simulation program.

Two further criteria were proposed in papers dealing with specialized balancing problems, both of the criteria in question being financial. In the first application Mansoor (27) was examining the very special case of whether assembly line operators could be paid more to work faster and thereby allow increased output, the philosophy behind the method being one of constant cost production. In the second case Vrat and Virani (44) also examined a very specialized problem, that of balancing the cost of assembly line production against remedial work, where various rates of output and total cost of production gave a unit cost for output and to this was added the unit cost of remedial work caused by the output rate in question, giving a total cost per unit, the objective being to minimize this total cost.

As both cost models were very specialized no specific use can be made of them but it is a noteworthy principle that as all industrial manufacture has to be justified in financial terms, additional financial analysis of balancing procedure results might be of benefit.

In developing a new balancing and simulation approach a number of general principles can be established with respect to evaluation criteria. These are:

(a) For overall analysis Balance Delay and Smoothness Index are most appropriate and should be included where possible.

(b) When mixed-model production is being balanced Balance Delay and Smoothness Index equations will have to be adjusted to be more representative to the product mix.

(c) When simulating the operation of assembly lines in detail work congestion, work deficiency, idle time, and work utility are suitable sources of relevant information and should be included.

(d) Where mixed-model production is being contemplated a measure of the training needs of operators, i.e. the total span of work to be undertaken by each operator, would in addition be of benefit.

(e) The conventional rate of output, dictated by cycle time should also be produced.

3.6. Conclusions

Specific detailed conclusions with respect to each major section of the review have been given at the end of each section. The intention at this point is to draw out from the review the areas of potential for new balancing procedures. The areas identified and the reasons why new work would be of benefit are given as follows:

(a) Single model balancing of simple stations is an area that has been widely investigated and therefore may not be suitable for further work.

(b) The prospect of more efficient and practical balancing procedures held out by enlarged work stations is an area not so far closely examined and therefore worthy of further research.

(c) Any balancing model developed with increased capacity stations should examine both single and mixed-model production.

(d) As there is no guarantee that the estimated balancing conditions applicable when the line is balanced will be the actual conditions when the assembly line is in production the efficiency of balancing solutions produced by any given procedure should not be too sensitive to particular balancing conditions particularly in mixed-model balancing.

(e) Little work has been undertaken to examine the versatility of balancing solution. Acknowledging that once constructed assembly lines, rarely work under the exact conditions used to balance the line, a simulation approach which investigates the effect of differing production programmes would be of considerable benefit.

Acknowledging these general conclusions a new balancing procedure using enlarged work stations for single and mixed-model production will be developed in the next chapter and a simulation program for detailed assembly line analysis will be proposed in Chapter 5.

CHAPTER 4

A BALANCING MODEL FOR STATIONS EMPLOYING GROUP WORK

4. A BALANCING MODEL FOR STATIONS EMPLOYING GROUP WORK

4.1. Introduction

Within this chapter three new balancing procedures for assigning work elements to assembly line stations will be presented and illustrated. Using a combination of simple heuristic and limited enumeration, identified in the review as the approach most likely to produced efficient balancing solutions for industrial size cases, the three procedures will be required to deal with a broader, more practical, definition of the balancing problem.

The solution approach adopted in each of the three models is based upon an examination of group-manned or enlarged stations, which are to be used as a means of overcoming balancing restrictions and as a means of achieving higher performance. The time limits that apply on enlarged stations will be identified in this examination and subsequent analysis of group-working will be used to introduce the new concept of "work-compressibility". Work compressibility places a limit on how far the work content of a task can be subdivided between operators and will therefore be seen to control in a realistic manner the size of enlarged stations permitted.

This limitation arises from the acknowledgements that there is a natural minimum time in which any work element can be completed (minimum duration) no matter the number of operators present and resources available. As each multi-manned station has to complete work within the cycle time available the existence of a minimum time for each element will affect the number of task assignments to each station and will raise the question of how to determine the most effective size of station as well as how to determine the most efficient assignment of elements.

After fully explaining the new concept of work compressibility and analysing how to determine the range of station sizes to be considered, the three models will be presented as the first part of an integrated allocation and simulation approach to assembly line design, intended to study in depth both the balancing of assembly line work and the subsequent operation of the balanced line. The simulation model, given in Chapter 5, will in particular be concerned with examining the effect on efficiency of changes in production conditions after balancing has been completed.

4.2. The balancing problem examined

Leaving aside the question of simulating the operation of an assembly line after balancing has taken place, the primary objective of the balancing procedures given in this chapter can be stated as:

> "The assignment of given work elements to assembly line stations so as to minimise the total idle time on the line, subject to the problem conditions in existence."

Efficiency therefore is the prime concern of the three assignment procedures to be developed (designated ASSIGN 1 to ASSIGN 3) and the actual measures of efficiency and work distribution used for evaluating solutions (Balance Delay and Smoothness Index) will be stated in section 4.5.

From the review it can be seen that the detailed structure of solution approaches to assembly line balancing will be dependent upon decisions made with regard to two main areas; the type of assembly line production involved and the treatment given to restrictions and problem information. As a preamble therefore to presenting the case for an enlarged-station based set of balancing procedures the type of production to be considered and the treatment of information and restrictions will be given at this point.

Types of Assembly Line Manufacture Considered

The three balancing procedures in this chapter are designed to give three differing solution methods covering single and mixed model production, i.e.

ASSIGN 1 - Single model production.

ASSIGN 2 - Mixed-model production
Multiple element assignment.

ASSIGN 3 - Mixed-model production
Single element assignment.

Two approaches to mixed-model production have been included to cover the wide spectrum of mixed-model production possible. ASSIGN 2 is concerned with mixed-model manufacture where products are diverse and contain only limited common elements, whilst ASSIGN 3 will be developed for the more common situation of producing a number of variations of a basic model, thus giving a high proportion of common elements. In later chapters the performance of the two mixed-model procedures will be compared for it is suspected that ASSIGN 2 will give higher levels of efficiency but at considerable cost in work variation.

Treatment of Information and Restrictions

The balancing procedures ASSIGN 1 to ASSIGN 3 have been included in a computerised suite of programs under the global title ALB (Assembly Line Balancing), general details of which are given in section 4.9. and detailed instructions for use of the programs are given in the Users Guide, Appendix B.

In designing the programs the objective was to treat the three main sources of information in such a manner as to be as useful and practical as possible. The general treatement of work elements, stations and the overall line therefore includes allowance for the following:

Work elements: Deterministic or variable durations.

Large durations greater than cycle time.

Multi-operator elements.

Zoning restrictions.

Special resources.

Both variable and deterministic durations are considered relevant, particularly as a high proportion of assembly lines involve manual operations. The natural variation in performance will be accounted for by increasing average duration, using normal distribution theory, to a figure guaranteed to be achieved on a defined percentage of occasions.

Large durations greater than cycle time and multi-operator elements (i.e. elements that require two or more operators) are included as they do occur in practical assembly line problems. It was the examination of these problems that lead to the development of work compressibility and enlarged stations.

In setting out the information structure for a general approach to assembly line design it is acknowledged that elements will occur that have the need for special equipment or have zoning requirements in addition to precedence restriants, both of which affect the assignment of elements. For this reason provision is made for inputing and displaying special equipment and zoning information although it should be clearly understood that at this point neither is involved in the balancing procedures.

Assembly Line Stations: Extended type stations

Enlarged stations.

The more conventional treatment of assembly line stations as closed stations or as duplicated parallel stations is to be superceded in this work by enlarged group-manned stations, the theory of which will be developed later in this chapter. With regard to extended (upstream and downstream movement) stations the conclusion was drawn in the review that as this form of increased capacity was only temporary, having to achieve an average work load less than or equal to cycle time over any sustained production period, it was not wise to consider extended stations at the element assignment stage. Extended stations however have been included in the subsequent simulation as they occur frequently in practical assembly lines.

The review also highlighted duplicated stations as being useful for overcoming certain balancing restrictions but identified the need for further consideration of the effect of diverting work in the mixed-model production case. For this reason duplicated stations will not be considered further but a note on the possibility of including them at a later date is given in the future work section.

The Assembly Line: Limited/Unlimited Line Length.

The general assembly line problem is normally concerned with assigning work elements to an unlimited line length with a given cycle time, although the alternative of a fixed line length with variable cycle time has also been studied. A unique opportunity to study the combined problem, one of a fixed line length and desirable cycle time, is presented by the enlarged station models to be developed and therefore both alternatives, limited and unlimited line length have been included. In the future the limited line length case may well allow the pre-specification of elements and facilities to given stations, as evidenced in a number of the published balancing problems.

Having outlined therefore the balancing problem to be examined and the practical variations that are to be included, the concept of work compressibility and enlarged stations will be developed as the basis of the three allocation procedures put forward as solution approaches.

4.3. Enlarged stations and work compressibility.

The use of enlarged, multi-manned stations has been identified as the solution approach that can offer the prospect of higher efficiency and job enrichment whilst at the same time allow the balancing of large elements, multi-operator elements and limited line length-cycle time combinations. The use of enlarged stations is also supported by the knowledge that multi-manned stations are a common occurrence in the mass production of certain larger products, for example automobiles.

When examining the allocation procedure for assigning work elements to an enlarged multi-manned station however it is necessary to acknowledge the existence of two different time limitations at the station and to understand how group working will combine with these limitations to restrict the assignment of elements. The two time limitations that apply at enlarged stations are:

(a) The total time available, representative of the work content that can be assigned to the station, is limited to the product of cycle time multiplied by the number of operators manning the station.

(b) The actual time available at the station is limited to the cycle time.

The group of operators manning an enlarged station can complete tasks in one of two extreme ways. In the first case operators consider themselves independent and divide the tasks, working on separate elements individually as the product travels through the station. This situation could arise in a station that has mutually exclusive zoning and represents in practice two or more independent stations located at the same line position. There are severe limitations to this approach however when considering the problem to be examined and the nature of the assignment process. The undertaking of individual tasks rules out both multi-operator elements and elements greater than cycle time for by definition multi-operator elements can only be undertaken effectively by a group of operators working together and again by definition one operator cannot consistently complete an element with work content greater than cycle time.

An individual approach to work will also complicate the assignment procedure in two respects. Firstly if the work elements assigned to an enlarged station are to be subdivided the sum of element durations given to any one operator must not exceed the cycle time, creating another allocation problem within the overall allocation problem. Secondly the precedence logic of work assigned to different operators must be checked to ensure that operators are relatively independent of each other, remembering that a strongly ordered set of assigned elements will rule out operators working independently as the cycle time limit combined with the highly inefficient operationby each independent operator, will result in failure to complete work tasks.

For the reasons given therefore an individual approach to work on enlarged stations is rejected as inappropriate.

The second method of operating an enlarged station is to adapt a group approach to working i.e. to attempt each work task as a group, with the group therefore fulfilling the work of the single operator in a simple station. Four advantages of this approach can be readily seen:

(a) Multi-operator elements can be included.

(b) Precedence relationships between assigned elements do not have to be considered.

(c) There is no second problem of allocation within the elements assigned to a given station.

(d) Under appropriate conditions large elements can be undertaken.

A group approach to work therefore is the most appropriate for enlarged multi-manned stations but as stated earlier, before elements can be assigned to this type of station, a careful examination with respect to the actual time required for each task must be carried out.

Consider the general illustration of the task of fitting a wheel during the assembly of an automobile. With the conventional single operator available the task is a five part exercise involving broadly the location of the wheel and then the fastening of four nuts in any prescribed order. The time taken by the single operator at normal pace to achieve completion of this work is defined as the normal duration or time (t_i) of the element and represents the work content of the task. If the station size is increased to two operators the time taken to complete the mounting of the wheel would be approximately halved, whilst if the station size is further increased to five operators the time taken might approach one-fifth of the normal duration. There would appear to be little point in further increasing the station size as additional operators would be superfluous to requirements, having little or no work to do.

The conclusion to be drawn from the illustration is that work elements cannot be infinitely subdivided between unlimited operators and that there is a consequently natural minimum time in which any work element can be completed. This natural limit to the speed with which a task can be completed is to be defined as the minimum duration or time (tc_i) of an element and will represent the natural compressibility of an element. The work compressibility of elements will strongly influence the assignment of elements to enlarged group manned stations.

Returning to the example, the compressibility of fitting a wheel would probably not be greater than forty per cent as more than two operators would unreasonably overcrowd the workplace and the natural sequence of having to locate the wheel first before placing and tightening nuts would reduce the amount of compression possible. In general where group working is to be applied it is assumed that work will be distributed logically without inefficient working practices being introduced just as the conventional element definition includes logical units of work. Under these circumstances the compressibility of any element will be determined by:

(a) The extent of physical accessibility to the work element. Paced assembly lines are not particularly suitable for the production of large items and therefore physical accessibility will be a significant limiting factors on the extent of compressibility possible.

(b) The natural order of activities within the work elements.
Tasks that contain a number of activities that can be carried on in parallel can be highly compressed. Tasks that have a fixed sequence of activities that can be compressed little.

(c) The proportion of fixed process time to normal work time.
Elements that contain machine processes that require a given time cannot be compressed below that time.

The effect of normal and minimum element durations on the assignment of tasks to enlarged station can be illustrated by the example of an attempt to allocate three elements (A, B and C) to a triple-manned station with a cycle time of 7, the tasks being taken from the sixteen element illustrating problem where normal and minimum durations are:

Element	Durations		
	Normal	Minimum	Effective
E_i	t_i	tc_i	te_i
A	6	2	2
B	6	3	3
C	9	4	4

The actual or effective time taken by each element (te_i) is calculated as the greater value obtained from the two following equations:

$$te_i = tc_i \quad (4.1)$$

or $$te_i = \frac{t_i}{S_k} \quad (4.2)$$

Where:

te_i = Effective time for element i.

tc_i = Minimum time for element i.

t_i = Normal time for element i.

S_k = Current size of station k.

The two time constraints given earlier can be expressed mathematically in equation form as:

$$\sum_{i=1}^{n} t_i \ (A_k) \leq S_k \times C \qquad (4.3)$$

and

$$\sum_{i=1}^{n} te_i \ (A_k) \leq C \qquad (4.4)$$

Where:

$ti(A_k)$ = Normal duration of element i assigned to station k.

$te_i(A_k)$ = Effective duration of element i assigned to station k.

C = Cycle time.

n = Number of work elements.

S_k As before.

In the example equation (4.3) is satisfied by a total of 21 time units of work being assigned to the triple-size station with capacity for 21 time units of work. However the actual time taken to complete the three tasks as a consequent of work compressibility would be 9 time units, which exceeds the available actual time (cycle time) of 7 and therefore rules out the assignment of the combination A, B and C to a triple-manned station (equation 4.4).

Balancing assembly lines where enlarged multi-manned stations are to be allowed is therefore dependent on the extent of work compressibility possible and three new balancing procedures, which first identify the range of reasonable station sizes and then assign elements to minimize idle time, have been developed.

In practice a multi-manned assembly line station will undertake work in a combination of group working and individual tasks. This does not detract from the importance of considering work compressibility, which will ensure that it is possible to complete work assignments even though work practices might relax to take advantage of station idle time.

4.4. Determining the Range of Station Sizes

Where enlarged stations are to be permitted during the balancing process the question arises as to the suitable range of station sizes that should be considered as each station comes up for allocation. The greatest possible range of station sizes would be obtained if all work elements were assigned to the first station, giving a maximum station size (S1) of $\sum_{i=1}^{n} t_i/C$ rounded up to the next integer and a minimum station size (S2) of 1. This of course would lead to a single station solution with perfect balancing and would represent unacceptable working behaviour. Work compressibility however will ensure in practical cases that this does not arise, because only a limited number of elements will be accommodated at each station no matter what the range of sizes are available.

Assuming that initially only the largest station size necessary is to be considered then the maximum station size (S1) can be determined by:

$$S1 = \frac{t_{i\,max}}{C} \qquad (4.5)$$

rounded up to the next integer.

Where:

$S1$ = Maximum station size.

$t_{i\ max}$ = Maximum normal element duration.

C As before.

Equation (4.5) represents the station size needed for assignment of the largest element and will be greater than one in problems containing elements larger than the cycle time. Applied to problems with a low distribution task times where elements have high compressibility, equation (4.5) may rule out station sizes capable of producing highly efficient balancing solutions and therefore provision has been made for manually inputting an alternative maximum station size where required.

The lowest minimum station size under any condition is 1 and where the problem being investigated involves no limit on the length of the line this value is set, i.e.:

$$S2 = 1 \qquad (4.6)$$

no line length limit.

Where:

$S2$ = Minimum station size

Where a line length limit does exist for the problem being investigated the initial minimum station size is calculated using:

$$S2 = \frac{\sum_{i=1}^{n} t_i}{L \times C} \qquad (4.7)$$

rounded up to the next integer

minimum value = 1.

Where:

L = line length limit (in equivalent simple station units).

S2, C, n, t_i as before.

Equation (4.7) represents an average station size which will have the tendancy to encourage any enlarged station early in the line. This can be demonstrated by considering the sixteen element example shown in table (4.1), where the total normal element times are 173 time units and balancing involves a cycle time of 20 and a line length limit equivalent to 4 conventional stations. Under these conditions the minimum station size (S2) would be calculated as 3 (2.1625↑) and the first station would automatically become a triple-manned station as the maximum station size is also 3 (42/20 = 2.1↑).

An alternative approach, not used in the ASSIGN models, is to select the theoretical minimum station size, which can be calculated using the following equation:

$$S2 = \frac{\{\sum_{i=1}^{n} t_i\} - \{(L-1) \times C \times S1\}}{C} \qquad (4.8)$$

rounded up to the next integer

minimum value = 1

Where:

S2, n, t_i, L, C, S1 as before.

In the sixteen element example the minimum value of S2 that would result from equation (4.8) would be:

$$S2 = \frac{\{173\} - \{(4-1) \times 20 \times 3\}}{20}$$

$$= \frac{173 - 180}{20}$$

$$= -0.35$$

= 0 rounded up to next integer.

= 1 minimum value condition.

Thus the minimum station size equation (4.8) can be seen to favour a wider choice of station sizes at the beginning of assignment which has a tendency to push enlarged stations close to the end of a limited line length case.

As the determination of the minimum station size in the limited line case in dependent upon the total element time to be assigned and the number of stations available, the calculation of S2 using equation (4.7) should be repeated at the end of assigning elements to a given station, using the remaining unassigned normal element durations and the remaining number of equivalent simple station units.

Summarising on selecting the range of station sizes; maximum station size will be influenced by the largest element duration and possibly work compressibility, minimum station size will be dependent upon line length limits and the total element durations/cycle time ratio.

What now remains is to apply the work compressibility and station size equations in the development of the three balancing models ASSIGN 1 to ASSIGN 3. Before doing so however it would be appropriate to discuss the development of equations for assessing the balances obtained.

4.5. Evaluation Criteria

Within the review of existing balancing procedures two criteria were identified as being commonly used in evaluating assembly line balancing, the two criteria being Balance Delay (representative of line efficiency) and Smoothness Index (representative of relative allocation of work). When considering mixed model production and using work compressibility both Balance Delay and Smoothness Index equations will have alternative formulations as shown following.

Balance Delay

For mixed-model or single model production with enlarged stations the traditional Balance Delay formula becomes:

$$BD1 = \frac{\sum_{j=1}^{m} \sum_{k=1}^{p} \{(S_k \times C) - \sum_{i=1}^{n} t_i (A_{jk})\}}{\sum_{j=1}^{m} \sum_{k=1}^{p} (S_k \times C)} \times 100 \qquad (4.9)$$

where:

BD1 = Actual Balance Delay

m = Number of models

P = Actual number of stations

$t_i(A_{jk})$ = Normal element duration of element i assigned for model j to station k.

S_k,n,C as before.

The calculation of BD1 gives equal weighting to each model in mixed-model cases and this may not therefore accurately reflect the true efficiency of the balancing solution. A more representative Adjusted Balance Delay (BD2) can be calculated using:

$$BD2 = \frac{\sum_{j=1}^{m} ADJ_j \sum_{k=1}^{p} \{(S_k \times C) - \sum_{i=1}^{n} t_i (A_{jk})\}}{\sum_{k=1}^{p} (S_k \times C)} \times 100 \qquad (4.10)$$

where:

BD2 = Adjusted Balance Delay

ADJ_j = Adjustment for model j.

$m, P, n, S_k, C, t_i(A_{jk})$ as before.

The adjustment for each model is calculated using the equation:

$$ADJ_j = \frac{Q_j}{\sum_{j=1}^{m} Q_j} \qquad (4.11)$$

where:

Q_j = Quantity of model j in estimated production schedule.

ADJ_j, m as before.

Equations (4.9) and (4.10) represent the efficiency of the assembly line as the work content, represented by normal element durations, is contrasted against the time available. Two further apparent measures of Balance Delay however can be obtained if the normal durations are replaced by the actual time taken by the group of operators (te_i). The unadjusted apparent Balance Delay is obtained using:

$$BD3 = \frac{\sum_{j=1}^{m} \sum_{k=1}^{P} \{S_k \times C - \sum_{i=1}^{n} te_i\ (A_{jk})\}}{\sum_{j=1}^{m} \sum_{k=1}^{P} (S_k \times C)} \times 100 \qquad (4.12)$$

where:

BD3 = Apparent Balance Delay

$te_i(A_{jk})$ = Effective element duration of element i assigned for model j to station k, size S_k.

S_k, m, P, C, n as before.

The adjusted apparent Balance Delay is calculated using:

$$BD4 = \frac{\sum_{j=1}^{m} ADJ_j \sum_{k=1}^{P} S_k\ \{C - \sum_{i=1}^{n} te_i\ (A_{jk})\}}{\sum_{k=1}^{P} (S_k \times C)} \times 100 \qquad (4.13)$$

where:

S_k, ADJ_j, m, P, C, $te_i(A_{jk})$, n as before.

Smoothness Index

Mixed-model production and work compressibility will also provide four versions of Smoothness Index; Actual Smoothness Index, Adjusted Actual Smoothness Index, Apparent Smoothness Index and Adjusted Apparent Smoothness Index, each being calculated using the following equations:

$$SI1 = \sqrt{\frac{\sum_{j=1}^{m} \sum_{k=1}^{P} \{(S_k \times C) - \sum_{i=1}^{n} t_i \ (A_{jk})\}^2}{m}} \qquad (4.14)$$

where:

SI1 = Apparent Smoothness Index

m, P, C, S_k, n, $t_i(A_{jk})$ as before.

$$SI2 = \sqrt{\sum_{j=1}^{m} ADJ_j \sum_{k=1}^{P} \{(S_k \times C) - \sum_{i=1}^{n} t_i \ (A_{jk})\}^2} \qquad (4.15)$$

where:

SI2 = Adjusted Apparent Smoothness Index

ADJ_j, m, p, S_k, C, n, $t_i(A_{jk})$ as before.

$$SI3 = \sqrt{\frac{\sum_{j=1}^{m} \sum_{k=1}^{P} \{S_k \ (C - \sum_{i=1}^{n} te_i \ (A_{jk})\}^2}{m}} \qquad (4.16)$$

where:

SI3 = Actual Smoothness Index

m, P, S_k, C, $te_i(A_{jk})$, n as before.

$$SI4 = \sqrt{\sum_{j=1}^{m} ADJ_j \sum_{k=1}^{P} \{S_k(C - \sum_{i=1}^{n} te_i \ (A_{jk})\}^2} \qquad (4.17)$$

where:

SI4 = Adjusted Actual Smoothness Index

m, P, ADJ_j, S_k, C, $te_i(A_{jk})$, n as before.

In applying the eight equations the two most significant will be equations (4.10) and (4.16) for Balance Delay (BD2) and Smoothness Index (SI4) respectively, noting that whilst work content is important in calculating Balance Delay it is the actual time taken that will be important in calculating Smoothness Index. Results from each equation will be printed out as part of the ALB computer balancing programs.

With a computer available the opportunity has been taken to provide additional information with respect to the station allocations, and the information provided includes for each station:

Time available

Maximum work assigned

Minimum work assigned

Range of work assigned

Average work assigned

Standard deviation of assigned work

Average work assigned (weighted)

Standard deviation of assigned work (weighted)

Work variety.

In examining the individual station allocations, two particular pieces of information are of interest. Firstly mixed-model production will result in varying station loads with different models, the variation being described as station range and the total ranges for all stations being calculated as (WB1), representative of work variety.

With single or multiple element assignment possible the second important piece of information is the amount of training operators at each station will have to receive, expressed as work variety, with the total training needs or total work variety being calculated as (WB2).

4.6. Single Model Balancing - ASSIGN 1

The first balancing procedure which uses compressibility and enlarged stations is designed to balance single-model production on assembly lines of either limited or unlimited length. Capable of dealing with large work elements as described earlier, the procedure can also be modified to cover variable element durations and multi-operator elements, the modifications necessary for these two variations being described after the basic procedure.

ASSIGN 1 can be described as operating in three parts: preparation, balancing and evaluation, with the principal steps being as follows:

Preparation

Step 1:

The positional weight of each element is determined using the traditional rank positional weight formula:

$$W_i = t_i + \sum_{q=1}^{n} t_q \, (F_i) \qquad (4.18)$$

where:

W_i = Weight of element i

$t_q(F_i)$ = Normal element duration of task q for followers of task i.[*1]

t_i, n as before.

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*1 Followers are taken throughout this chapter to mean both immediate and succeeding followers.

Step 2:

Rank elements (R_i) in descending positional weight order and for equal weights in order of appearance.

Step 3:

Calculate the initial maximum (S1) and minimum (S2) station sizes using equations (4.5) and (4.6) or (4.7) as appropriate, noting that alternative S1 values may be input.

Balancing

Step 4:

Start new station and for each station size in turn set the current rank to 1 and go to step 5.

Step 5:

Select the next element in rank order, discounting those elements already permanently assigned. If no elements remain for selection go to step 8.

Step 6:

Check for the element selected:

(a) Is the element free for assignment.

(b) Does sufficient normal time remain to allow assignment (equation 4.3).

(c) Does sufficient effective time remain to allow assignment (equation 4.4), after determining the actual or effective time required to complete the task (equation 4.1 or 4.2).

If the answer to either (a), (b) or (c) is no the rank is increased by 1 and the procedure returns to step 5.

Step 7:

If conditions (a) to (c) are satisfactory temporarily assign the task to the station and station size in question and adapt the normal and effective time remaining. Return to step 5.

Step 8:

If further station sizes have yet to be evaluated repeat steps 5 and 6 for the next station size, resetting the starting rank to 1.

Step 9:

When all station sizes have been temporarily assigned elements select the station size with minimum idle time as defined by:

$$\{S_k \times C\} - \{\sum_{i=1}^{n} t_i \ (A_k)\} \qquad (4.19)$$

where:

$t_i(A_k)$ = Normal element duration for task i assigned to station size k.

S_k,C,n as before.

Smaller station sizes are selected for equal values of idle time.

Step 10:

For the selected station size permanently assign the elements temporarily assigned to the station size in question, noting that these elements will no longer take part in the balancing procedure. If at this point all elements have been permanently assigned go to step 12.

Step 11:

Recalculate the minimum station size (S2) using equations (4.6) or (4.7) for the next station, noting that only elements not permanently assigned are considered and that the available line length has decreased by 1 since the last station. Return to step 4.

Evaluation

Step 12:

Calculate Balance Delay (BD1) and Apparent Balance Delay (BD3) using equations (4.9) and (4.12) respectively.

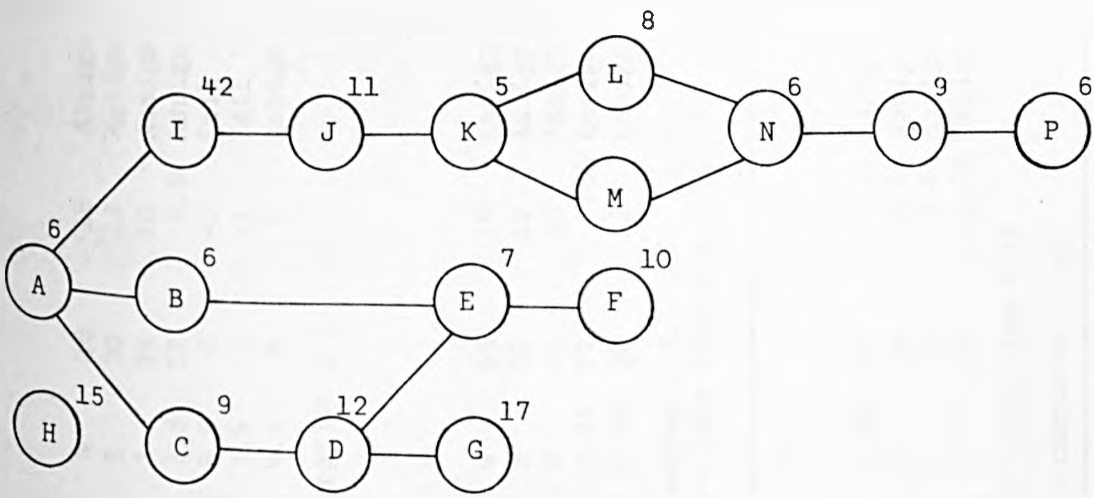
Calculate Smoothness Index (SI3) and Apparent Smoothness Index (SI1) using equations (4.16) and (4.14) respectively.

Note that for single model production BD1 and BD2, BD3 and BD4, SI1 and SI2 and SI3 and SI4 are respectively the same.

Calculate station analysis as described in section 4.5.

Two illustrations of the use of ASSIGN 1 are given in Table (4.1), (4.2) and (4.3), where the sixteen element problem has been balanced for both unlimited line length and a limited line length of four equivalent simple stations. The cycle time in use was 20 time units and the final results are given in Table (4.4) and Figure (4.1) alongside those of the two mixed model procedures.

Both limited and unlimited line length examples were able to balance the large 42 time unit element I without difficulty and the best results were obtained in five stations by the unlimited line length, which achieved a Balance Delay (BD1) of 3.88 percent and a



Element E_i	Duration t_i	tc_i	Weight w_i	Rank R_i
A	6	2	158	1
B	6	3	23	9
C	9	4	55	3
D	12	3	46	5
E	7	2	17	11
F	10	4	10	15
G	17	5	17	12
H	15	4	15	13
I	42	11	91	2
J	11	3	49	4
K	5	2	38	6
L	8	5	29	7
M	4	4	25	8
N	6	3	21	10
O	9	4	15	14
P	6	3	6	16

TABLE (4.1) SINGLE MODEL BALANCING - CALCULATION OF WEIGHTS AND RANKS.

E_i	R_i	Prec	t_i	tc_i	te_i	$S_kC-\Sigma t_i$	$C-\Sigma te_i$	Result
Station 1 $S_k = 3$								
A	1	✓	6	2	2	54	18	Assign
I	2	✓	42	11	14	12	4	Assign
C	3	✓	9	4	4	3	0	Assign
No effective time remaining								
Station size 3 assigned - Idle time = 3								
Station 2 $S_k = 2$								
J	4	✓	11	3	5.5	29	14.5	Assign
D	5	✓	12	3	6	17	8.5	Assign
K	6	✓	5	2	2.5	12	6	Assign
L	7	✓	8	5	5	4	1	Assign
No remaining minimum duration ≤ 1.								
Station 2, $S_k = 3$								
J	4	✓	11	3	3.66	49	16.33	Assign
D	5	✓	12	3	4	37	12.33	Assign
K	6	✓	5	2	2	32	10.33	Assign
L	7	✓	8	5	5	24	5.33	Assign
M	8	✓	4	4	4	20	1.33	Assign
No remaining minimum duration ≤ 1.33								
Station size 2 selected - Idle time = 4								

E_i	R_i	Prec	t_i	tc_i	te_i	$S_kC-\Sigma t_i$	$C-\Sigma te_i$	Result
Station 3 $S_k = 2$								
M	8	✓	4	4	4	36	16	Assign
B	9	✓	6	3	3	30	13	Assign
N	10	✓	6	3	3	24	10	Assign
E	11	✓	7	2	3.5	17	6.5	Assign
G	12	✓	17	5	8.5	0	-2	Fail
H	13	✓	15	4	7.5	2	-1	Fail
O	14	✓	9	4	4.5	8	2	Assign
No remaining minimum duration ≤ 2.								
Station 3 $S_k = 3$								
M	8	✓	4	4	4	56	16	Assign
B	8	✓	6	3	3	50	13	Assign
N	10	✓	6	3	3	44	10	Assign
E	11	✓	7	2	2.33	37	7.66	Assign
G	12	✓	17	5	5.66	20	2	Assign
No remaining minimum duration ≤ 2.								
Station size 2 selected - Idle time = 8								
Station 4 $S_k = 3$								
G	12	✓	17	5	5.66	43	14.33	Assign
H	13	✓	15	4	5	28	9.33	Assign
F	15	✓	10	4	4	18	5.33	Assign
P	16	✓	6	3	3	12	2.33	Assign
Station size 3 assigned - Idle time = 18								
Balance complete								

TABLE 4.2 SINGLE MODEL BALANCING - ILLUSTRATION OF LIMITED LINE LENGTH CASE.

E_i	R_i	Prec	t_i	tc_i	te_i	$S_kC-\Sigma t_i$	$C-\Sigma te_i$	Result
Station 1 $S_k = 1$								
A	1	✓	6	2	6	14	14	Assign
I	2	✓	42	11	42	-28	-28	Fail
C	3	✓	9	4	9	5	5	Assign
J	4	X						
D	5	✓	12	3	12	- 7	- 7	Fail
K,L&M		X						
B	9	✓	6	3	6	- 1	- 1	Fail
No remaining element normal duration ⩽ 5								
Station 1 $S_k = 2$								
A	1	✓	6	2	3	34	17	Assign
I	2	✓	42	11	21	- 8	- 4	Fail
C	3	✓	9	4	4.5	25	12.5	Assign
J	4	X						
D	5	✓	12	3	6	13	6.5	Assign
K,L&M		X						
B	9	✓	6	3	3	7	3.5	Assign
N	10	X						
E	11	✓	7	2	3.5	0	0	Assign
No remaining time in the station								
Station 1 $S_k = 3$								
A	1	✓	6	2	2	54	18	Assign
I	2	✓	42	11	14	12	4	Assign
C	3	✓	9	4	4	3	0	Assign
No effective time remaining								
Station size 2 selected - Idle time = 0								

E_i	R_i	Prec	t_i	tc_i	te_i	$S_kC-\Sigma t_i$	$C-\Sigma te_i$	Result
Station 2 $S_k = 1$								
I	2	✓	42	11	42	-22	-22	Fail
J,K,L,M&N		X						
G	12	✓	17	5	17	3	3	Assign
No remaining element normal duration ⩽ 3								
Station 2 $S_k = 2$								
I	2	✓	42	11	21	-2	-1	Fail
J,K,L,M&N		X	17	5	8.5	23	11.5	Assign
G	12	✓	17	5	8.5	23	11.5	Assign
H	13	✓	15	4	7.5	7	4.5	Assign
O	14	X						
F	15	✓	10	4	5	-2	-0.5	Fail
P	16	X						
No remaining elements								
Station 2 $S_k = 3$								
I	2	✓	42	11	14	18	6	Assign
J	4	✓	11	3	3.66	7	2.33	Assign
K	6	✓	5	2	2	2	0.33	Assign
No remaining element minimum duration ⩽ 0.33								
Station size 3 selected - Idle time = 2								
Station 3 $S_k = 1$								
L	7	✓	8	5	8	12	12	Assign
M	8	✓	4	4	4	8	8	Assign
N	10	✓	6	3	6	2	2	Assign
No remaining element duration ⩽ 2								

TABLE 4.3.A. SINGLE MODEL BALANCING - ILLUSTRATION OF UNLIMITED LINE LENGTH CASE.

Station 3 $S_k = 2$

E_i	R_i	Prec	t_i	tc_i	te_i	$S_k C-\Sigma t_i$	$C-\Sigma te_i$	Result
L	7	✓	8	5	5	32	15	Assign
M	8	✓	4	4	4	28	11	Assign
N	10	✓	6	3	3	22	8	Assign
G	12	✓	17	5	8.5	5	-5	Fail
H	13	✓	15	4	7.5	7	0.5	Assign

No remaining element minimum duration ≤ 0.5

Station 3 $S_k = 3$

E_i	R_i	Prec	t_i	tc_i	te_i	$S_k C-\Sigma t_i$	$C-\Sigma te_i$	Result
L	7	✓	8	5	5	52	15	Assign
M	8	✓	4	4	4	48	11	Assign
N	10	✓	6	3	3	42	8	Assign
G	12	✓	17	5	3.66	25	2.33	Assign
H	13	✓	15	4	5	10	-2.66	Fail
O	14	✓	9	4	4	16	-1.66	Fail
P	15	✓	10	4	4	16	-1.66	Fail
F	16	X						

No remaining elements

Station size 1 selected - Idle time = 2

Station 4 $S_k = 1$

E_i	R_i	Prec	t_i	tc_i	te_i	$S_k C-\Sigma t_i$	$C-\Sigma te_i$	Result
G	12	✓	17	5	17	3	3	Assign

No remaining element normal duration ≤ 3

Station 4 $S_k = 2$

E_i	R_i	Prec	t_i	tc_i	te_i	$S_k C-\Sigma t_i$	$C-\Sigma te_i$	Result
G	12	✓	17	5	8.5	23	11.5	Assign
H	13	✓	15	4	7.5	8	4	Assign
O	14	✓	9	4	4.5	-1	-0.5	Fail

E_i	R_i	Prec	t_i	tc_i	te_i	$S_k C-\Sigma t_i$	$C-\Sigma te_i$	Result
F	15	✓	10	4	5	-2	-1	Fail
P	16	X						

No remaining elements.

Station 4 $S_k = 3$

E_i	R_i	Prec	t_i	tc_i	te_i	$S_k C-\Sigma t_i$	$C-\Sigma te_i$	Result
G	12	✓	17	5	6.66	43	13.33	Assign
H	13	✓	15	4	5	28	8.33	Assign
O	14	✓	9	4	4	19	4.33	Assign
F	15	✓	10	4	4	9	0.33	Assign

No remaining element minimum duration ≤ 0.33

Station size 1 selected - Idle time = 3.

Station 5 $S_k = 1$

E_i	R_i	Prec	t_i	tc_i	te_i	$S_k C-\Sigma t_i$	$C-\Sigma te_i$	Result
H	13	✓	15	4	15	5	5	Assign

No remaining element normal duration ≤ 5

Station 5 $S_k = 2$

E_i	R_i	Prec	t_i	tc_i	te_i	$S_k C-\Sigma t_i$	$C-\Sigma te_i$	Result
H	13	✓	15	4	7.5	25	12.5	Assign
O	14	✓	9	4	4.5	16	8	Assign
F	15	✓	10	4	5	6	3	Assign
P	6	✓	6	3	3	0	0	Assign

No remaining elements

Station 5 $S_k = 3$

E_i	R_i	Prec	t_i	tc_i	te_i	$S_k C-\Sigma t_i$	$C-\Sigma te_i$	Result
H	13	✓	15	4	5	45	15	Assign
O	14	✓	9	4	4	36	11	Assign
F	15	✓	10	4	4	26	7	Assign
P	16	✓	6	3	3	20	4	

No remaining elements

Station size 2 selected - Idle time = 0. Balance complete.

TABLE 4.3.B. SINGLE MODEL BALANCING - ILLUSTRATION OF UNLIMITED LINE LENGTH CASE.

Single model

Limited line length

Station	Size	Elements	Time Normal	Time Effective
1	3	AIC	57	20
2	2	DJKL	36	19
3	2	BEMNO	32	18
4	3	FGHP	48	17.66

BD1 = 13.5%   SI1 = 15.56
BD3 = 6.82%   SI3 = 8.48

Unlimited line length

Station	Size	Elements	Time Normal	Time Effective
1	2	ABCDE	40	20
2	3	IJK	58	19.66
3	1	LMN	18	18
4	1	G	17	17
5	2	FHOP	40	20

BD1 = 3.88%   SI1 = 4.12
BD3 = 3.33%   SI3 = 3.73

Mixed model

Multi-element assignment - Limited line length (3 stations)

		Model I			Model II		
Station	Size	Elements	Time Normal	Time Eff.	Elements	Time Normal	Time Eff.
1	3	ADI	60	20	AIK	53	18
2	2	GJL	36	19	CELN	30	16
3	2	BHMP	31	17.5	FHO	34	17

BD1 = 12.86%   SI1 = 11.87
BD2 = 15.00%   SI2 = 12.93
BD3 = 9.64%   SI3 = 9.06
BD4 = 12.42%   SI4 = 10.66

Single element assignment

		Model I			Model II		
Station	Size	Elements	Time Normal	Time Eff.	Elements	Time Normal	Time Eff.
1	2	ABDH	39	19.5	ACEH	37	18.5
2	3	IJ	53	17.67	IKF	57	20
3	1	LMP	18	18	LN	14	14
4	1	G	17	17	O	9	9

BD1 = 12.86%   SI1 = 10.9
BD2 = 15.00%   SI2 = 12.06
BD3 = 11.78%   SI3 = 10.70
BD4 = 13.28%   SI4 = 12.06

TABLE (4.4) BALANCING RESULTS FOR SINGLE AND MIXED-MODEL ASSEMBLY CASES.

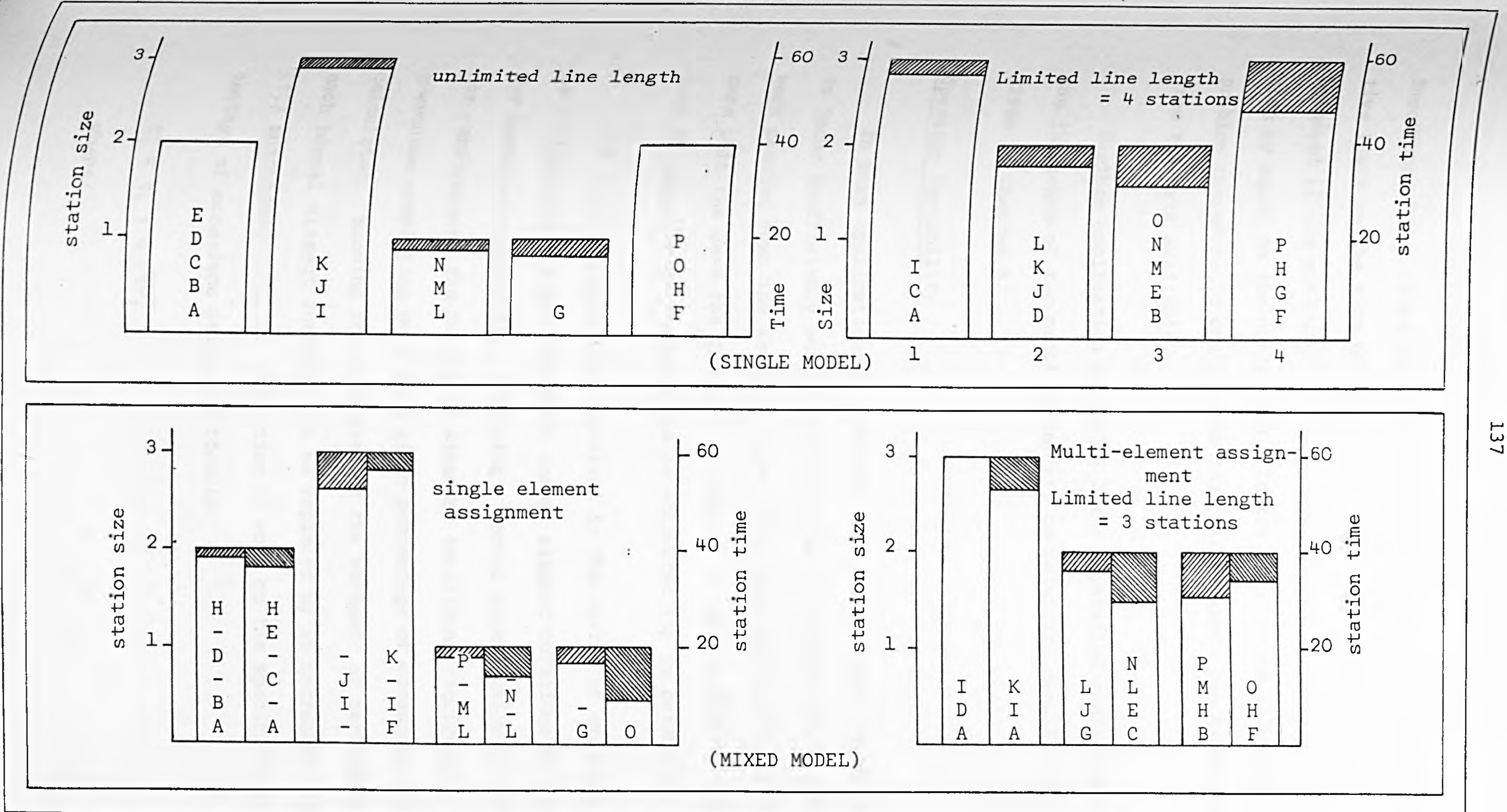


FIG. (4.1) BALANCING RESULTS FOR SINGLE AND MIXED-MODEL ASSEMBLY CASES.

Smoothness Index (SI3) of 3.74. Providing there is no unduly restrictive limit on the size of station possible, any element can be balanced if the minimum duration of the element in question is less than or equal to the cycle time. In the case of the illustrating problem therefore it can be seen that all elements can be balanced from the data available.

Further application of ASSIGN 1 and a detailed examination of the influence of the major parameters on balancing results will be given in Chapter 6.

Operator Variability

In many applications of assembly line balancing it is desirable to incur inefficiency on the assembly line in preference to unfinished work passing down the assembly line. When cost and quality factors make this the case the question arises as to how the natural variation of operator performance can be accounted for in balancing.

The solution approach, discussed in the review of existing work is to increase the deterministic normal element durations to allow for operator variability. Assuming a normal distribution of operator performances the number of standard deviations required to guarantee completing work on a given percentage of occasions can be calculated. Knowing for each element the variance of performance each normal element duration can be replaced by an increased figure (t_i') guaranteed to allow completion of work on the specified percentage of occasions using the formula:

$$t_i' = t_i + \sigma \sqrt{tv_i} \qquad (4.20)$$

where:

t_i' = Increased normal duration for element i

t_i = Deterministic normal duration for element i

tv_i = Variance of normal durations for element i

σ = Number of standard deviations required for guaranteed level of achievement.

All three balancing procedures ASSIGN 1 to ASSIGN 3 have the ability to allow for operator variability and do so by replacing every appearance of normal duration by the increased time figures. This will have the result of increasing maximum station size in certain cases and will reduce the number of elements assignable to stations for unlimited line lengths.

Note however that minimum element durations (tc_i) are not affected by operator variability as they represent the shortest possible completion time for an element irrespective of operator performance.

Multi-Operator Elements

ASSIGN 1 can also be modified easily to allow for multi-operator elements, detectable from the list of resources and resource levels given with each element (see Users Guide Appendix C). Where multi-operator elements occur the recommended changes to ASSIGN 1 are:

(a) The maximum station size (S1) calculated in step 3 should be checked to ensure that its value is equal to or greater than the largest number of operators needed by any one element.

(b) When considering individual elements for assignment (step 6) ensure in addition to conditions (a) to (c) that the station size is equal to or greater than the number of operators needed by the element.

4.7. Mixed-Model Balancing - Multi-Element Assignment ASSIGN 2

The occurrence of single model production is comparatively less in todays manufacturing scene than the occurrence of mixed-model production. When mixed-model production is to take place on one assembly the relationship between models plays an important part in deciding the best approach to balancing. Where models have only a few work elements in common an approach allowing the assignment of these few elements to different stations for different models i.e. multi-element assignments, may yield the most efficient balance results. A balancing procedure for mixed-model production with multiple element assignments has therefore been derived using an extension of ASSIGN 1 and the principles of work compressibility and variable station size.

Called ASSIGN 2, the mixed-model multi-element assignment procedure involves the following principal steps:

Preparation

Step 1:

For each model in turn calculate the positional weight of all elements involved in the production of the model in question using:

$$W_{ij} = t_i (I_j) + \sum_{q=1}^{n} t_q (F_i I_j) \tag{4.21}$$

where:

W_{ij} = Positional weight of element i for model j

$t_i(I_j)$ = Normal duration of element i when involved in model j (if not = 0)

$t_q(F_i I_j)$ = Normal duration of element q when both a follower of element i for model j and itself involved in model j (if not = 0)

n as before.

Step 2:

For each model in turn rank all elements involved in the model in descending weight order (W_{ij}), to produce a rank set for each model (R_{ij}), with equal weights being ranked in order of appearance.

Step 3:

Calculate the maximum station size (S1) using equation (4.5), noting that an alternative value of S1 may be input.

Step 4:

For each model calculate the minimum station size required using:

$$S2_j = \frac{\sum_{i=1}^{n} t_i\ (I_j)}{L \times C} \qquad (4.22)$$

Limited line length case

Rounded up to next integer

Minimum value = 1

or

$$S2_j = 1 \qquad (4.23)$$

Unlimited line length case

Where:

$S2_j$ = Minimum station size for model j

$t_i(I_j)$,n,L and C as before.

Determine the actual minimum station size (S2) by taking the largest model minimum station size such that:

$$S2 = S2_{jmax} \qquad (4.24)$$

Balancing

Step 5:

Start a new station and for each station size in turn:

Step 6:

Start a new model and for each model in turn set the current rank to 1 and go to step 7.

Step 7:

Select the next element associated with the current model in rank order, discounting elements already permanently assigned for this model. If no elements remain go to step 10.

Step 8:

Check for the element selected:

(a) Is the element free for assignment with respect to the current model.

(b) Does sufficient normal time remain to allow assignment of element for the current model i.e. is

$$t_{ij} \leq \{(S_k \times C) - \sum_{q=1}^{n} t_q \; (I_j A_k)\} \qquad (4.25)$$

where:

$t_q(I_j A_k)$ = Normal duration of element q when involved in model j and assigned to station k, size S_k

t_{ij}, S_k, C and n as before.

(c) Does sufficient effective time remain to allow assignment, for the current model, after determining the actual or effective time required to complete the work task using equations (4.1) or (4.2), i.e. is:

$$te_i \leq \{C - \sum_{q=1}^{n} te_q\ (I_j A_k)\} \qquad (4.26)$$

where:

$te_q\ (I_j A_k)$ = Effective duration of element q when involved in model j and assigned to station k, size S_k.

te_i, C and n as before.

If the answer to either (a), (b) or (c) is no the rank is increased by 1 and the procedure returns to step 7.

Step 9:

If conditions (a) to (c) are satisfactory temporarily assign the task to the present list of temporary assigned elements for the current model, current station and current station size. Update the normal and effective time remaining for the current model at the current station and station size and return to step 7.

Step 10:

If further models have yet to be evaluated repeat steps 7 to 9 for the next model, resetting the rank to 1.

Step 11:

If further station sizes have yet to be evaluated repeat steps 6 to 9 for the next station size, resetting the rank to 1.

Step 12:

When all station sizes have been temporarily assigned elements for each individual model case select the station size with the least idle time as defined by:

$$\{S_k \times C \times m\} - \{\sum_{j=1}^{m} \sum_{q=1}^{n} t_q \ (A_k I_j)\} \quad (4.27)$$

where:

$t_q \ (A_k I_j), S_k, C, m$ and n as before.

Step 13:

For the selected station size permanently assign for each model the elements temporarily assigned to this station size, noting that these elements will no longer take part in the balancing procedure for each model in question but may be involved in further assignments for other models. If at this point all elements for all models have been assigned go to step 15.

Step 14:

Recalculate the minimum station size (S2) using equations (4.22) to (4.24) for the next station, noting only elements not permanently assigned are considered and that the available line length has decreased by 1 since the last station. Return to step 5.

Evaluation

Step 15:

Calculate Balance Delay (BD1), Adjusted Balance Delay (BD2), Apparent Balance Delay (BD3) and Adjusted Apparent Balance Delay (BD4) using equations (4.9), (4.10), (4.12) and (4.13) respectively.

Calculate Smoothness Index (SI3), Adjusted Smoothness Index (SI4), Apparent Smoothness Index (SI1) and Adjusted Apparent Smoothness Index (SI2) using equations (4.16), (4.17), (4.14) and (4.15) respectively.

Calculate station analysis as described in section 4.5.

Operator variability and multi-operator elements

The recommendations made with respect to operator variability and multi-operator elements under section 4.6 (ASSIGN 1) equally apply to ASSIGN 2.

Adjusted station size selection

In step 12 of ASSIGN 2 the station size is selected on the basis of the least idle time overall. When the estimated production schedule for mixed-model production contains a wide disparity in volumes required of each model it may be more appropriate to replace equation (4.27) with the following equation which takes relative model importance into account:

$$\{S_k \times C\} - \{\sum_{j=1}^{m} ADJ_j \sum_{q=1}^{n} t_q \, (A_k I_j)\} \qquad (4.28)$$

where:

$S_k, C, t_q \, (A_k I_j)$, m and n as before.

ADJ_j as before (equation 4.11).

In outlining the ASSIGN 2 procedure it is noticable that although models are relatively different they are not balanced separately (as used by Wester and Kilbridge (45)) but considered together as the overall balance is achieved station by station.

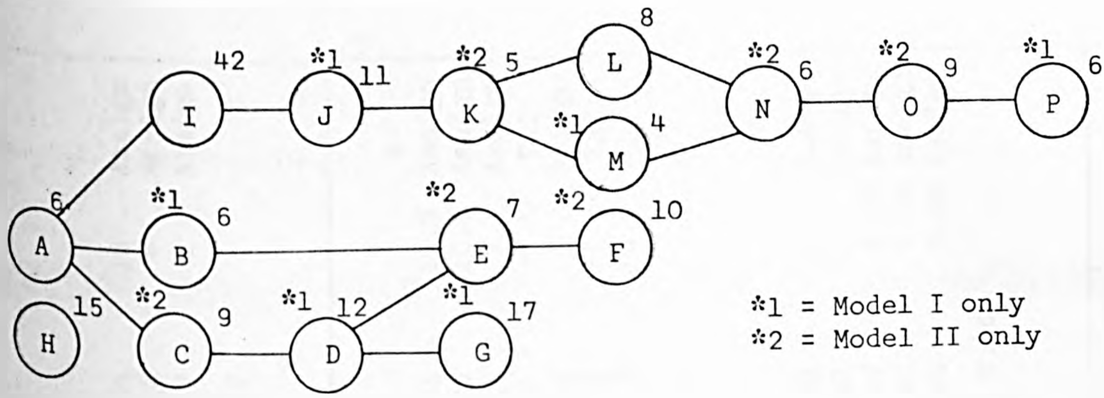
Furthermore balancing results will work under any product mix (variation in model quantities) although the efficiency levels will change with changes in mix. The solution does not need sequencing to be considered, trading line efficiency against line versatility.

An illustration of ASSIGN 2 is given in Tables (4.5) and (4.6) using the sixteen element problem as the basis for two separate models each of ten elements, to be balanced with a cycle time of 20 time units and a limited line of 3 stations. In the calculations adjustment of idle time was not considered and a balance was achieved with station sizes of 3, 3 and 2 respectively. The multi-element assignment procedure is suspected of trading off the duplication of elements, against efficiency but as can be seen from the results in Table (4.4) with a minimum number of assignments of sixteen (16 elements) exactly sixteen assignments was produced with no duplication. This is because, as intended the procedure has been applied to an example with few common elements (4 common elements A, H, I and L) and the common elements were assigned to the same station for both models.

Further applications of ASSIGN 2 with a view to examining the procedure in more detail are given in Chapter 6.

4.8. Mixed-Model Balancing - Single Element Assignment ASSIGN 3

The third assembly line balancing procedure has been developed to resolve one of the most commonly occurring balancing problems, that of producing a basic model and a number of derivatives which have a high proportion of common elements. With the existence of this high proportion of common elements there are two reasons to justify restricting each element to one single assignment that must apply for all models:



Model I				
E_i	t_i	tc_i	W_i	R_i
A	6	2	112	1
B	6	3	6	9
C	–	–	–	–
D	12	3	29	3
E	–	–	–	–
F	–	–	–	–
G	17	5	17	5
H	15	4	15	6
I	42	11	71	2
J	11	3	29	4
K	–	–	–	–
L	8	5	14	7
M	4	4	12	8
N	–	–	–	–
O	–	–	–	–
P	6	3	6	10

Model II				
E_i	t_i	tc_i	W_i	R_i
A	6	2	102	1
B	–	–	–	–
C	9	4	26	4
D	–	–	–	–
E	7	2	17	6
F	10	4	10	9
G	–	–	–	–
H	15	4	15	7
I	42	11	70	2
J	–	–	–	–
K	5	2	28	3
L	8	5	23	5
M	–	–	–	–
N	6	3	15	8
O	9	4	9	10
P	–	–	–	–

(a) Multi-element assignment.

Element	Models quantity I = 200	II = 800	t_i	tc_i	t_i	W_i	R_i
A	✓	✓	6	2	6	107.2	1
B	✓	X	6	3	1.2	14.8	10
C	X	✓	9	4	7.2	26.6	5
D	✓	X	12	3	2.4	19.4	7
E	X	✓	7	2	5.6	13.6	11
F	X	✓	10	4	8	8	14
G	✓	X	17	5	3.4	3.4	15
H	✓	✓	15	4	15	15	9
I	✓	✓	42	11	42	73.4	2
J	✓	X	11	3	2.2	31.4	3
K	X	✓	5	2	4	29.2	4
L	✓	✓	8	5	8	21.2	6
M	✓	X	4	4	4	17.2	8
N	X	✓	6	3	4.8	13.2	12
O	X	✓	9	4	7.2	8.4	13
P	✓	X	6	3	1.2	1.2	16

(b) Single element assignment.

TABLE (4.5) MIXED MODEL WEIGHTS AND RANKS.

Model I

Stn 1 $S_k = 3$

E_i	R_i	Prec	t_i	tc_i	te_i	$S_kC-\Sigma t_i$	$C-\Sigma te_i$	Result
A	1	✓	6	2	2	54	18	Assign
I	2	✓	42	11	14	12	4	Assign
D	3	✓	12	3	4	0	0	Assign

No remaining time

Model II

Stn 1 $S_k = 3$

E_i	R_i	Prec	t_i	tc_i	te_i	$S_kC-\Sigma t_i$	$C-\Sigma te_i$	Result
A	1	✓	6	2	2	54	18	Assign
I	2	✓	42	11	14	14	4	Assign
K	3	✓	5	2	2	7	2	Assign

No remaining minimum duration ≤ 2

Station size 3 assigned

Model I

Stn 2 $S_k = 2$

E_i	R_i	Prec	t_i	tc_i	te_i	$S_kC-\Sigma t_i$	$C-\Sigma te_i$	Result
J	4	✓	11	2	5.5	29	14.5	Assign
G	5	✓	17	3	8.5	12	6	Assign
H	6	✓	15	4	7.5	-3	-1.5	Fail
L	7	✓	8	5	5	4	1	Assign

No remaining minimum duration ≤ 1

Model II

Stn 2 $S_k = 2$

E_i	R_i	Prec	t_i	tc_i	te_i	$S_kC-\Sigma t_i$	$C-\Sigma te_i$	Result
C	4	✓	9	4	4.5	31	15.5	Assign
L	5	✓	8	5	5	23	10.5	Assign
E	6	✓	7	2	3.5	16	7	Assign
H	7	✓	15	4	7.5	1	-0.5	Fail
N	8	✓	6	3	3	10	4	Assign
F	9	✓	10	4	5	0	-1	Fail
O	10	✓	9	4	4.5	1	-0.5	Fail

No remaining elements

Total idle time = 4 + 10 = 14

Model I

Stn 2 $S_k = 3$

E_i	R_i	Prec	t_i	tc_i	te_i	$S_kC-\Sigma t_i$	$C-\Sigma te_i$	Result
J	4	✓	11	3	3.33	49	16.66	Assign
G	5	✓	17	5	6.66	32	10	Assign
H	6	✓	15	4	5	17	5	Assign
L	7	✓	8	5	5	9	0	Assign

No remaining effective time

Model II

Stn 2 $S_k = 3$

E_i	R_i	Prec	t_i	tc_i	te_i	$S_kC-\Sigma t_i$	$C-\Sigma te_i$	Result
C	4	✓	9	4	4	51	16	Assign
L	5	✓	8	5	5	43	11	Assign
E	6	✓	7	2	2.33	37	8.66	Assign
H	7	✓	15	4	5	22	3.66	Assign
N	8	✓	6	3	3	14	0.66	Assign

No remaining minimum duration ≤ 0.66

Total idle time = 9 + 14 = 23
Station size 2 selected

TABLE (4.6.A) MIXED-MODEL BALANCING - ILLUSTRATION OF MULTIPLE ELEMENT ASSIGNMENT.

E_i	R_i	Prec	t_i	tc_i	te_i	$S_k C-\Sigma t_i$	$C-\Sigma te_i$	Result
Stn 3	$S_k = 2$							
H	6	✓	15	4	7.5	25	12.5	Assign
M	8	✓	4	4	4	21	8.5	Assign
B	9	✓	6	3	3	15	5.5	Assign
P	10	✓	6	3	3	9	2.5	Assign
No remaining elements								

E_i	R_i	Prec	t_i	tc_i	te_i	$S_k C-\Sigma t_i$	$C-\Sigma te_i$	Result
Stn 3	$S_k = 2$							
H	7	✓	15	4	7.5	25	12.5	Assign
F	9	✓	10	4	5	15	7.5	Assign
O	10	✓	9	4	4.5	6	3	Assign
No remaining elements								

Total idle time = 9 + 6 = 15

Stn 3	$S_k = 3$							
H	6	✓	15	4	5	45	15	Assign
M	8	✓	4	4	4	41	11	Assign
B	9	✓	6	3	3	35	8	Assign
P	10	✓	6	3	3	29	5	Assign
No remaining elements								

Stn 3	$S_k = 3$							
H	7	✓	15	4	5	45	15	Assign
F	9	✓	10	4	4	35	11	Assign
O	10	✓	9	4	4	26	7	Assign
No remaining elements								

Total idle time = 29 + 26 = 55
Station size 2 selected
Balance complete.

TABLE (4.6.B) MIXED-MODEL BALANCING - ILLUSTRATION OF MULTIPLE ELEMENT ASSIGNMENT.

(a) Single assignment will be appropriate for this type of mixed-model production as there is an approximation to single model assembly for a high proportion of involved elements.

(b) Without the restriction to single assignments the extent of duplicated assignments will be high for basically similar products, giving unnecessarily large training needs for operators.

In practice any mixed-model problem can be examined by either the multiple or single assignment procedures ASSIGN 2 and ASSIGN 3 and there will be some value in comparing results for a range of problems.

The single assignment procedure ASSIGN 3 involves the following major steps:

Preparation

Step 1:

For each element calculate the adjusted positional weight using:

$$W_i = \sum_{j=1}^{m} ADJ_j \times \{t_i\ (I_j) + \sum_{q=1}^{n} t_q\ (F_iI_j)\} \qquad (4.29)$$

where:

$W_i, ADJ_j, t_i(I_j), t_q(F_iI_j)$, m and n as before.

Step 2:

Rank (R_i) all elements in descending order of their adjusted positional weights and for equal weights in order of appearance.

Step 3:

Calculate the initial maximum (S1) and minimum (S2) station sizes using equations (4.5) and (4.6) or (4.7) as appropriate, noting that alternative (S1) value may be input.

Balancing

Step 4:

Start a new station and for each station size in turn set the current rank to 1 and go to step 5.

Step 5:

Select the next element in rank order, discounting the elements already permanently assigned. If no element remain for selection go to step 9.

Step 6:

For each model in turn check whether the element is involved in its manufacture. If yes go to step 7, if no go to next model. When all models are complete go to step 8.

Step 7:

Check for the element and model in question:

(a) Is the element free for assignment with respect to the current model.

(b) Does sufficient normal time remain to allow assignment of element for the current model (equation 4.25).

(c) Does sufficient effective time remain to allow assignment for the current model (equation 4.26) after determining the actual or effective time required (equations (4.1) or (4.2)).

If the answer to questions (a), (b) or (c) is no for any model the rank is increased by 1 and the procedure returns to step 5.

Step 8:

If conditions (a) to (c) have been satisfactory for all models temporarily assign the task to the current list of temporary assigned elements for each model where appropriate with respect to the current station and station size. Update normal and effective time remaining for each model as a consequence of the new temporary assignment and return to step 5.

Step 9:

If further station sizes have yet to be evaluated repeat steps 5 to 8 for next station size, resetting the rank to 1.

Step 10:

When all station sizes have been temporarily assigned elements covering all models select the station size with the least idle time as defined by equation (4.27).

Step 11:

For the selected station size permanently assign the list of temporary assignments to this station size, noting that each element is permanently assigned for all models in which is involved and will take no further part in assignment.

If at this point all elements have been permanently assigned go to step 13.

Step 12:

Recalculate the minimum station size (S2) using equations (4.6) or (4.7) for the next station, noting that only elements not permanently assigned are considered and that the available line length has decreased by 1 since the last station.

Evaluation

Step 13:

Calculate Balance Delay (BD1), Adjusted Balance Delay (BD2), Apparent Balance Delay (BD3) and Adjusted Apparent Balance Delay (BD4) using equations (4.9), (4.10), (4.12) and (4.13) respectively.

Calculate Smoothness Index (SI3), Adjusted Smoothness Index (SI4), Apparent Smoothness Index (SI1) and Adjusted Apparent Smoothness Index (SI2) using equations (4.16), (4.17), (4.14) and (4.15) respectively.

Calculate station analysis as described in section 4.5.

Operator variability and multi-operator elements

The recommendations made with respect to operator variability and multi-operator elements under section 4.6 (ASSIGN 1) equally apply to ASSIGN 3.

Adjusted station size selection

The comments made with respect to an alternative method of selecting station size (equation 4.28) equally apply to ASSIGN 3 as they did to ASSIGN 2.

The ASSIGN 3 procedure has been applied to this sixteen element mixed-model problem used to demonstrate ASSIGN 2, as a means of illustrating major steps in single assignment mixed-model balancing with the resultant calculations being shown in Table (4.7). Further calculations are given as an unlimited line length case was taken for the same cycle time of 20. With twelve of the sixteen elements being relevant to one model only from the two models under production the multi-assigned procedure might have been favoured but as the twelve elements were evenly split between the two models the result was two approximately equal ten element problems each of which could provide independent candidates for assignment at each station. The result was an equal achievement between ASSIGN 2 and ASSIGN 3 on Balance Delay (12.86% for BD1), but Apparent Balance Delay for ASSIGN 2 (BD3 = 9.64%) was better than Apparent Balance Delay for ASSIGN 3 (BD3 = 11.78%). Smoothness Index cannot readily be compared as the limited line length case was applied to ASSIGN 3.

4.9. The ALB Computer Balancing Programs

The three assembly line balancing models ASSIGN 1 to ASSIGN 3 developed in this chapter for assigning work elements to stations, have been included in a computerised program suite designated the ALB programs. Intended to be the median by which the computationally efficient procedures for single and mixed model balancing can be applied to full practical size problems, five programs are included

Stn. 1 $S_k = 1$

E_i	R_i	t_i	tc_i	te_i	Model I Prec.	Model I $(S_kC-\Sigma t_i)$	Model I $(C-\Sigma te_i)$	Model II Prec.	Model II $(S_kC-\Sigma t_i)$	Model II $(C-\Sigma te_i)$	Result
A	1	6	2	6	✓	14	14	✓	14	14	Assign
I	2	42	11	42	✓	-28	-28	✓	-28	-28	Fail
J	3	11	3	11	X						
K	4	5	2	5				X			
C	5	9	4	9				✓	5	5	Assign
L	6	8	5	8	X			X			
D	7	12	3	12	✓	2	2				Assign
M	8	4	4	4	X						
H	9	15	4	15	✓	-13	-13	✓	-10	-10	Fail
B	10	6	3	6	✓	- 4	- 4				Fail
E	11	7	2	7				✓	- 2	- 2	Fail
N	12	6	3	6				X			
O	13	9	4	9				X			
F	14	10	4	10				X			
G	15	17	5	17	✓	-15	-15				Fail
P	16	6	3	6	X						

No remaining elements

Stn. 1 $S_k = 2$

E_i	R_i	t_i	tc_i	te_i	Model I Prec.	Model I $(S_kC-\Sigma t_i)$	Model I $(C-\Sigma te_i)$	Model II Prec.	Model II $(S_kC-\Sigma t_i)$	Model II $(C-\Sigma te_i)$	Result
A	1	6	2	3	✓	34	17	✓	34	17	Assign
I	2	42	11	21	✓	- 8	- 4	✓	- 8	- 4	Fail
J	3	11	3	5.5	X						
K	4	5	2	2.5				X			
C	5	9	4	4.5				✓	25	12.5	Assign
L	6	8	5	4	X			X			
D	7	12	3	6	✓	22	11				Assign
M	8	4	4	4	X						
H	9	5	4	7.5	✓	7	3.5	✓	10	5	Assign
B	10	6	3	3	✓	1	0.5				
E	11	7	2	3.5				✓	3	1.5	Assign

No remaining minimum duration ≤ 0.5

Stn. 1 $S_k = 3$

E_i	R_i	t_i	tc_i	te_i	Model I Prec.	Model I $(S_kC-\Sigma t_i)$	Model I $(C-\Sigma te_i)$	Model II Prec.	Model II $(S_kC-\Sigma t_i)$	Model II $(C-\Sigma te_i)$	Result
A	1	6	2	2	✓	54	18	✓	54	18	Assign
I	2	42	11	14	✓	12	4	✓	12	4	Assign
J	3	11	3	3.66	✓	1	0.33				Assign
K	4	5	2	2				✓	7	2	Assign
C	5	9	4	4				✓	- 2	- 2	Fail
L	6	8	5	5	✓	- 7	- 4.66	✓	- 1	- 3	Fail
D	7	12	3	4	✓	- 6	- 3.66				Fail
M	8	4	4	4	✓	- 3	- 3.66				Fail
H	9	15	4	5	✓	-14	- 4.66	✓	- 8	- 3	Fail
B	10	6	3	3	✓	- 5	- 2.66				Fail
E	11	7	2	2.33				X			

No remaining minimum duration ≤ 2

Station size 2 selected - Idle time = 4

TABLE (4.7.A) MIXED-MODEL BALANCING - ILLUSTRATION OF SINGLE ELEMENT ASSIGNMENT.

E_i	R_i	t_i	tc_i	te_i	Model I Prec.	Model I $(S_kC-\Sigma t_i)$	Model I $(C-\Sigma te_i)$	Model II Prec.	Model II $(S_kC-\Sigma t_i)$	Model II $(C-\Sigma te_i)$	Result
Stn. 2 $S_k = 1$											
I	2	42	11	42	✓	-22	-22	✓	-22	-22	Fail
J	3	11	3	11	X						
K	4	5	2	5				X			
L	6	8	5	8	X			X			
M	8	4	4	4	X						
N	12	6	3	6				X			
O	13	9	4	9				X			
F	14	10	4	10				✓	10	10	Assign
G	15	17	5	17	✓	3	3				Assign
P	16	6	3	6	✓	- 3	- 3				Fail
No remaining elements											
Stn. 2 $S_k = 2$											
I	2	42	11	21	✓	- 2	- 1	✓			
J	3	11	3	5.5	X				- 2	- 1	Fail
K	4	5	2	2.5				X			
L	6	8	5	5	X			X			
M	8	4	4	4	X						
N	12	6	3	3				X			
O	13	9	4	4.5				X			
F	14	10	4	5				✓	30	15	Assign
G	15	17	5	8.5	✓	-23	11.5				Assign
P	16	6	3	3	X						
No remaining elements											
Stn. 2 $S_k = 3$											
I	2	42	11	14	✓	18	6	✓	18	6	Assign
J	3	11	3	3.66	✓	7	2.33				Assign
K	4	5	2	2				✓	13	4	Assign
L	6	8	5	5	✓	- 1	- 2.66	✓	5	- 1	Fail
M	8	4	4	4	✓	3	- 1.66				Fail
N	12	6	3	3				X			
O	13	9	4	4				X			
F	14	10	4	4				✓	3	0	Assign
No remaining minimum duration ≤ 2.33											
Station size 3 selected - Idle time = 10											
Stn. 3 $S_k = 1$											
L	6	8	5	8	✓	12	12	✓	12	12	Assign
M	8	4	4	4	✓	8	8				Assign
N	12	6	3	6				✓	6	6	Assign
O	13	9	4	4				✓	- 3	- 3	Fail
G	15	17	5	17	✓	- 9	- 9				Fail
P	16	6	3	6	✓	2	2				Assign
No remaining elements											

TABLE (4.7.B) MIXED-MODEL BALANCING - ILLUSTRATION OF SINGLE ELEMENT ASSIGNMENT.

E_i	R_i	t_i	tc_i	te_i	Model I Prec.	Model I $(S_kC-\Sigma t_i)$	Model I $(C-\Sigma te_i)$	Model II Prec.	Model II $(S_kC-\Sigma t_i)$	Model II $(C-\Sigma te_i)$	Result
Stn. 3 $S_k = 2$											
L	6	8	5	5	✓	32	15	✓	32	15	Assign
M	8	4	4	4	✓	28	11				Assign
N	12	6	3	3				✓	26	12	Assign
O	13	9	4	4.5				✓	17	7.5	Assign
G	15	17	5	8.5	✓	11	2.5				Assign
P	16	6	3	3	✓	5	- 2.5				Fail
No remaining elements											
Stn. 3 $S_k = 3$											
L	6	8	5	5	✓	52	15	✓	52	15	Assign
M	8	4	4	4	✓	48	11				Assign
N	12	6	3	3				✓	46	12	Assign
O	13	9	4	4				✓	37	8	Assign
G	15	17	5	5.66	✓	31	5.33				Assign
P	16	6	3	3	✓	25	2.33				Assign
No remaining elements											
					Station size 1 selected - Idle time = 8						
Stn. 4 $S_k = 1$											
O	13	9	4	4				✓	11	11	Assign
G	15	17	5	17	✓	3	3				Assign
No remaining elements											

Other station sizes automatically less efficient.

Station size 1 selected - Idle time = 14

Balance complete.

TABLE (4.7.C) MIXED-MODEL BALANCING - ILLUSTRATION OF SINGLE ELEMENT ASSIGNMENT.

(ALB1 to ALB5) and a full description of how they are operated is given in Appendix B, the User's Guide to the ALB suite. In addition detailed listings of programs and relevant flow charts have been included in Appendix C.

Reserving comment on the simulation programs for Chapter 5, the balancing of assembly lines is achieved in programs ALB1 and ALB2, illustrated in Figure (4.2), with ALB1 performing the role of data validation and program ALB2 executing the three balancing models ASSIGN 1 to ASSIGN 3 according to instructions received from file 2A. The program suite has been developed over a period of two years and the extensive testing of influential parameters presented in Chapter 6, involving over two hundred and forty test cases, was carried out on the ALB program suite.

The first program ALB1 is solely concerned with validating as far as possible the considerable information required by each problem, the main data checks carried out being shown in Table (4.8), reproduced from Appendix B.

Data verification is carried out so as to reduce the number of balancing runs required and is carried out separately to avoid unnecessary repetition once the data has been confirmed correct.

Where faults occur ALB1 is designed to print out guiding information with respect to the location of the fault and the nature of the fault, continuing as far as possible through the data even when a fault is found so as to again reduce the number of runs required.

The main balancing program, ALB2, has been designed in a similar three stage manner to the balancing procedures, the three stages being:

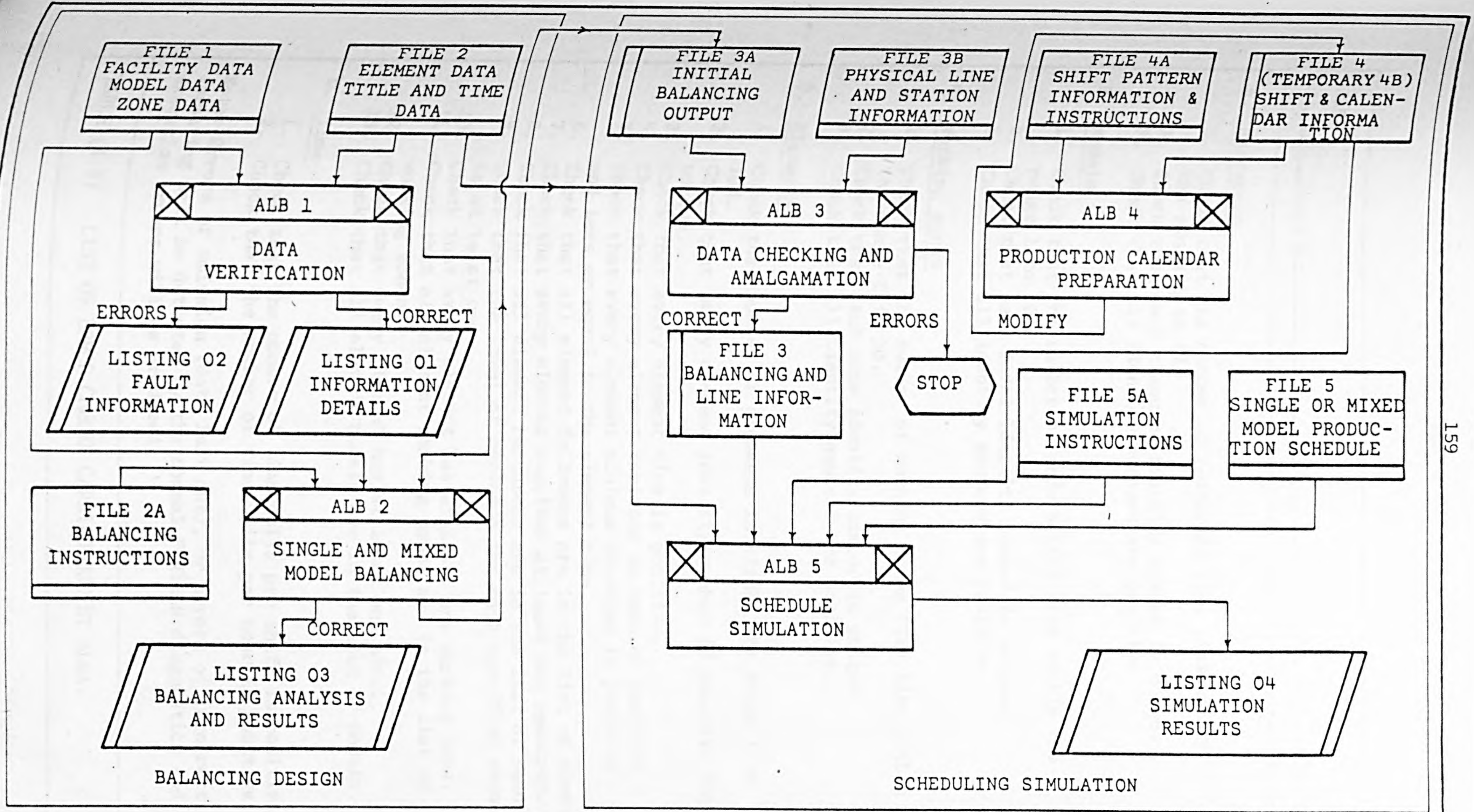


FIG. (4.2) PROGRAM AND FILE ARRANGEMENT ALB PROGRAM SUITE.

ALB1

A. Resources

1. Check that the number of resources (T3) lies within the range 1 to 3Ø.
2. Check that each resource identity number is unique.
3. Check that all identity numbers are positive.

B. Models

1. Check that the number of models (T6) lies within the range 1 to 1Ø.
2. Check that each model identity number is unique.
3. Check that all identity numbers are positive.

C. Working zones

1. Check that the number of working zones (T8) lies within the range 1 to 1Ø.
2. Check that each zone identity number is unique.
3. Check that all identity numbers are positive.

D. Elements

1. Check that number of elements is within the range 1 to 1ØØ.
2. Check that every element identity number is positive and unique.
3. Check that every element time is positive.
4. Check that every element variance is zero or positive.
5. Check that every element minimum duration is positive and less or equal to the element time.
6. Check that all element followers are in the list of elements.
7. Check that every element requires at least one resource.
8. Check that all element resources are in the list of resources.
9. Check that the level of resource for each specified resource is at least one.
10. Check that every element has at least one working zone.
11. Check that all element working zones are in the list of working zones.
12. Check that every element has at least one model.
13. Check that all element models are in the list of models.

E. Time

1. Check that the number of time units per shift is positive.
2. Check that the number of time units per hour is positive.

Note: Errors of omission (data left out), or errors of incorrect formating will be detected by the normal FORTRAN diagnostics and execution errors will be produced.

TABLE (4.8) LIST OF ERROR CHECKS CARRIED OUT BY ALB1.

Information display;

Balancing allocations;

Results printout.

Information display

The first task of the balancing programs, after validation of data, is to provide balancing information to aid the assembly line designer, and to this end information is provided as follows:

Individual work elements -

work content;

minimum duration;

work variance.

Associated models;

list of followers;

list of working zones.

list of required resources;

quantity of resources required.

Analysis of elements

maximum/minimum normal and minimum time;

mean/standard deviation normal and minimum time;

range/total normal and minimum time.

Resources

distribution of resource requirements.

Models

number of elements per model;

total work content per model.

Precedence

precedence distribution.

number of precedence columns;

maximum/minimum column size;

precedence difficulty (elements/columns).

Balancing strategy

cycle time, number of stations, average shift output and Balance Delay values for varying cycle times.

maximum and minimum cycle time.

The balancing procedures ASSIGN 1 to ASSIGN 3, built into ALB2 are strongly influenced by the initial balancing conditions set by the assembly line designer and it is for this reason that a detailed analysis is provided as part of the balancing programs.

The decisions the designer will have to input via file 2A are:

For all production:

Selected cycle time;

Minimum/maximum station size (replaced by calculated values if unacceptable - section 4.4);

Line length limit if applicable;

Variable or deterministic durations (plus confidence level for deterministic).

For mixed-model production:

Single/multi-element assignment;

Schedule adjusted/unadjusted station size selection.

After making the eight decisions and inputting via file 2A the ALB2 program will output the progressive temporary assignments made at each station size, giving for each assignment:

Model number;

Element number;

Normal element time;

Effective element time;

Effective station time remaining.

When all temporary assignments have been made for a given station size, a summary of the assignment efficiency is given including:

Cycle time/maximum work duration;

Time available/work content assigned;

Estimated lost time.

When all temporary assignments have been made a note is printed of the station size selected.

On completion of balancing the assignments to each station for each model are given along with the station size selected and for each model the work content (normal duration), work duration (effective time) and minimum duration.

The final output from the balancing program ALB2 is the various Balance Delay, Smoothness Index and Work Distribution calculations described in section 4.5.

With the desire to deal with practical sized problems and a substantial number of tests to be carried out in examining the models the ALB1/ALB2 programs proved a most suitable answer and carried out balancing within acceptable limits on computing time.

CHAPTER 5

SIMULATING THE OPERATION OF ASSEMBLY LINES

5. SIMULATING THE OPERATION OF ASSEMBLY LINES

5.1. Introduction

Amongst the many balancing procedures that have been reviewed in Chapter 3 there is an implicit assumption that the conditions applicable when balancing is carried out will continue to be the conditions under which the actual assembly line will operate. In practical applications of assembly line production however this assumption of continuity is not so certain when the total life-span of an assembly line is taken into account. The information available at balancing relates to the work elements involved in the product, the detailed estimated production schedule and the anticipated output (which determines cycle time), and from this information the assignment of elements to stations is determined. The value of the balance solution produced will therefore be affected by the consistency of these three forms of information over the period in which the assembly line is constructed and subsequently operated.

Taking each major factor in turn, the work elements involved in the manufacture of a product should remain reasonably consistent over the life-span of the assembly line. Where this is not the case product changes will tend to be one of two kinds. Firstly minor changes caused by cosmetic product updating which can be absorbed into the existing line or secondly major changes in product specification which will affect the basis on which the assembly line has been balanced and constructed, as a consequence of which the need for a new assembly line may well arise. When assessing whether a particular assembly line can accommodate a given product specification change the capital cost of constructing the assembly line will play an important part. This can be illustrated by contrasting the difference between an assembly line for building automobile bodies and one for assembling small refrigerators. In the former case investment is high and involves expensive heavy specialised assembly equipment that must last a considerable period of time and in the latter equipment is generally inexpensive, versatile and far more amenable to assembly line changes.

The anticipated output and subsequent cycle time used in balancing is also subject to possible change for at the point of balancing anticipated output must be considered to be a provisional estimate. The anticipated output is provisional because in many cases until the product is actually available the exact demand will not be known. Furthermore over the life of the assembly line demand for a product will be affected by the forces of the market place, with competition and the general economic scene being strong influencing factors on demand. As a consequence of these conditions it would be unusual if no fluctuation in demand and therefore theoretical output occurred. Assembly lines are relatively inflexible to changes in volume and their ability to respond can be illustrated by taking the two polar cases of large scale and small scale change. Persistent large scale increases in demand will be satisfied where possible by increasing the actual number of assembly lines to meet demand or by alternatively allowing marketing conditions (price and delivery) to change and thus discourage customers until output and demand balance. Large scale decreases in demand will be dealt with by decreasing the number of assembly lines producing the product where this is possible and the decrease in volume is expected to be long term. Where the decrease in demand is considered to be temporary an alternative solution may be to follow a policy of reduced hours of operation. As can be seen therefore individual assembly lines do not deal very well with major changes in volume.

The question of dealing with variation in demand becomes more interesting when examining how to deal with minor but persistent changes. Where minor changes fluctuate either side of the average line output then the finished product inventory can be used to smooth out demand by selecting a suitable size of stock level. Where the minor change however is persistently above or below the average line output the finished product inventory will either disappear or reach the capacity limit and the question then arises as to adjustment of assembly conditions. For persistent minor variation the answer is to consider the question of changing the operating speed of the assembly line and where this is permitted the result is that the line cycle time at a given point in the life of the assembly line will not be the same as the original balancing cycle time and the question then arises as to whether the line will still operate as required under the new conditions.

In the case of mixed-model production it is the product mix that makes up the detailed production schedule that is most likely to undergo repeated changes throughout the life span of an assembly line. This is of some concern as the product mix has a strong influence on the assignment of elements and the subsequent balancing efficiency. In the two mixed-model balancing procedures included in the ALB programs the product-mix affects the individual ranking of elements (ASSIGN 3) i.e. priority of assignment, the choice of station size and consequently the efficiency of the line. Should subsequently the model proportions change the assembly line will still function physically as the balancing solutions produced by ASSIGN 2 and ASSIGN 3 allows manufacture of all models in any proportions but as commented earlier the efficiency of the line may be dramatically affected. This physical independence from model-mix is not always the case, for example the three sequencing based approaches to mixed-model assembly line production reviewed in Chapter 3 (section 3.3) have a weakness in that the estimated product-mix are used to minimise the inefficiencies on the line by determining a low averaged cycle time and therefore the solutions produced may not be able to physically operate with changes in product-mix.

A need to study the versatility of balancing solutions has therefore been identified and within this chapter a simulation model for examining the reaction of solutions proposed by balancing models ASSIGN 1 to ASSIGN 3 to variations in the production conditions will be given. In describing the concepts and detail of the simulation model two major areas for consideration come forward; setting the simulation conditions and obtaining detailed simulation results. The simulation conditions can be further subdivided into two groups, those conditions that are related to the previous balancing conditions and those conditions that have not been involved at balancing but which are concerned with bridging the gap between the balancing stage and practical assembly line operation. The major variables associated with setting the simulation conditions, each of which can be specified independent of the relevant balancing solutions, are:

Variables related to balancing:

Line speed

Model-mix

Station definition

Element variability

Variables related to assembly line operation:

Production timetable

Continuous or independent scheduling.

The second major area of consideration in the simulation model is the collection and output of relevant detailed information. This information has been organised into three main sets associated with:

Original balancing and production planning information

Detailed work station information

Detailed assembly line analysis.

5.2. The Simulation Model

The simulation studies are carried out within the ALB computer program suite by the program ALB 5 and draws upon five separate sources of information as can be seen in Figure (5.1) reproduced from Appendix B. Element and general information is drawn from the balancing file FILE 2 along with details of the balancing solution (FILE 3A). The balancing solution is merged with the selected physical layout of the assembly line (FILE 3B) by program ALB 3 which also performs data validation checks on the new physical line information. Details of the production time available over a five year calendar is prepared by program ALB 4 and placed in file FILE 4 for collection by ALB 5. Finally specific simulation instructions and the production schedule to be simulated are input via FILE 5A and FILE 5 respectively. Detailed instruction on using the simulation program is given in the Users Guide shown in Appendix B.

The simulation program operates on a relatively simple integer basis where each product in the production programme is moved in order successively through each station. As each product moves from one station to the next calculations are made with respect to

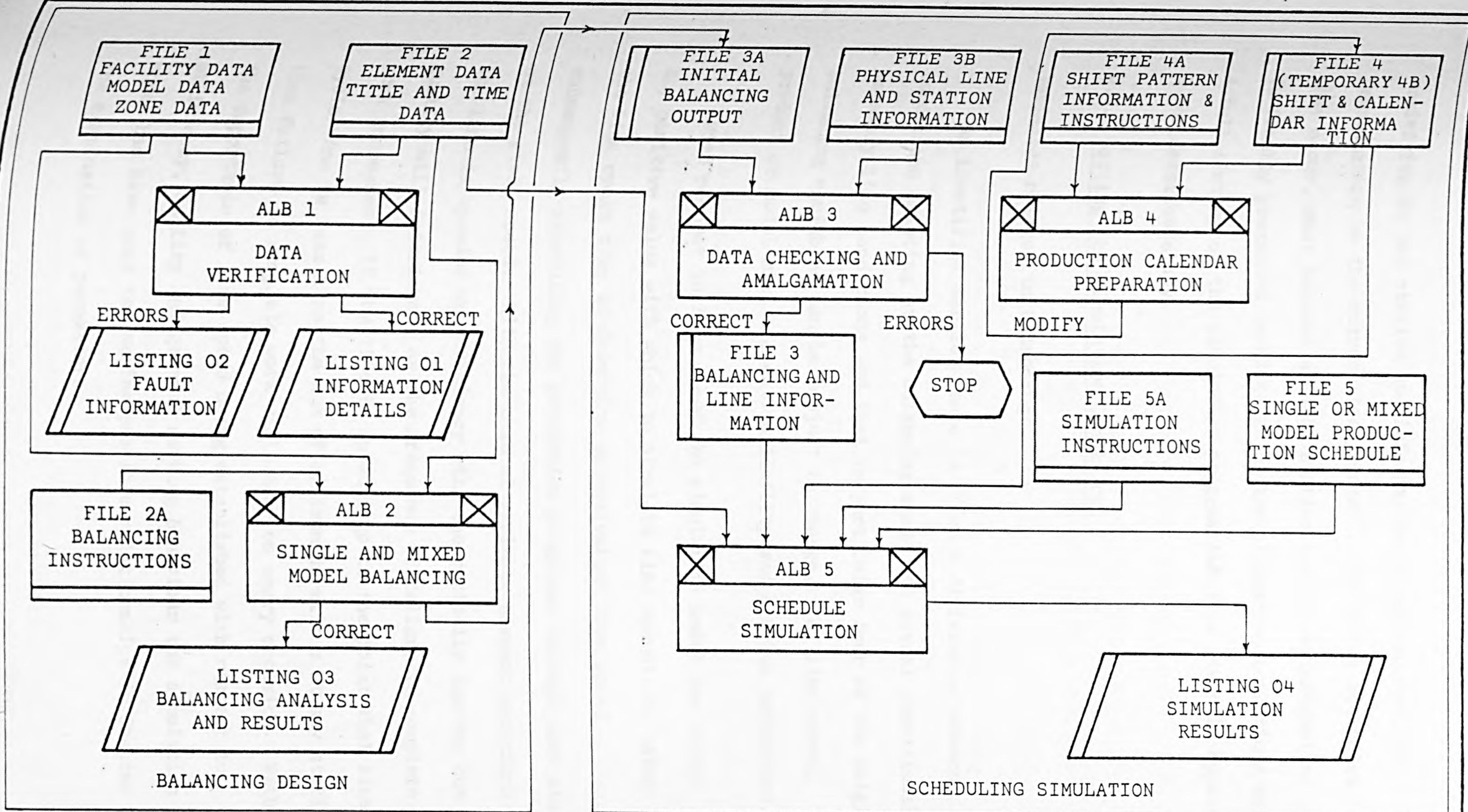


FIG. (5.1.) PROGRAM AND FILE ARRANGEMENT.

activities at the station and information is accumulated for presentation on the output line printer. The number of cycles that occur, what happens at each station and which information is finally presented is dictated by the simulation conditions set. A full listing of the simulation program ALB 5 is given in Appendix C for detailed study.

5.3. Setting the Simulation Conditions

Variables related to Balancing:

As identified earlier there is often a difference between conditions existing at the balancing stage and actual operational assembly line conditions and that in particular four of the original balancing variables can be subject to change, i.e. line speed, product or model-mix, element variability and station definition.

With respect to line speed the simulation model can accept any positive value with which to simulate line operation, using the line cycle time to determine an equivalent line speed subsequently scheduling the production programme through each station at the given speed. With the case of variable element durations as the line is speeded up efficiency will theoretically improve but quality will deteriorate as the frequency of failure to complete work increases. If the time is speeded up to the point that line cycle time is less than the sum of minimum durations at any station then failure to complete work will occur on every occasion. With the importance of line speed being established with respect to efficiency, quality and general working behaviour the simulation model has been used to examine possible relationships in Chapter 6, the examination of parameters.

In producing a balancing solution for a given problem the designer is given the choice of a deterministic or variable treatment of element durations, with the variable approach increasing average or normal element durations to guarantee a given probability of completion. Irrespective of the particular treatment of element durations during balancing however the simulation model allows three choices when estimating by Monte-Carlo methods the actual time taken at each station during production. The first choice, where automated machinery is involved, is to take a deterministic view of element durations and to allocate the average or normal duration each time, suspending the use of Monte-Carlo random numbers. When operation is considered to involve operators and subsequently mean the use of variable element durations the simulation model allows two alternative forms of variability:

(a) Element variability

(b) Station variability.

In the case of element variability each element is considered to be subject to normal distribution variance independent of other elements and therefore random variation is applied to each individual element duration and variance to give actual element durations and these are totalled to give actual station time. Element variability can be expressed in equation form as:

$$t'_i = t_i + (RD \times \sqrt{tv_i}) \qquad (5.1)$$

where

t'_i = Simulated element duration for element i.

t_i = Normal element duration for element i.

tv_i = Element variance for element i.

RD = Random generated number (range -3.5 to +3.5).

and

$$T_k = \sum_{i=1}^{n} t'_i \; (P_k) \qquad (5.2)$$

where

T_k = Station time for station k.

n = Number of elements.

$t'_i \; (P_k)$ = Simulated element duration for element i being performed at station k.

In the case of station variability random variation is applied to the total station time and the total station variance to give actual station time. Station variability can therefore be expressed in equation form as:

$$T_k = \{\sum_{i=1}^{n} t_i \; (P_k)\} + \{RD \times \sqrt{\sum_{i=1}^{n} tv_i \; (P_k)}\} \qquad (5.3)$$

where

$tv_i(P_k)$ = Element variance for element i being performed at station k.

T_k, n, $t_i(P_k)$ and RD as before.

Although the two alternative treatments of variability are available station variability is preferred, being considered the more realistic for operators are unlikely to change pace from element to element but are more likely to show variation from model to model. In principle element variation will produce a narrower more consistent distribution of station times than station variability.

In the balancing algorithms enlarged stations are permitted but upstream and down extended stations were considered inappropriate as only temporary increases in capacity are obtained in this method.

In developing the simulation model however it has been felt appropriate to allow open stations as they are used frequently on actual assembly lines. In addition the widest choice of assembly line configuration can be obtained by allowing the designer to specify the exact position of each station along with the individual amounts of upstream and downstream excess working space. By allowing the specification of station position and upstream-downstream working to be combined with station size total control is given to the assembly line designer particularly with respect to the amount of transit length or overlap working area available.

The strongest probability for a difference between balancing and actual production conditions in the mixed-model case lies in the actual product mix. The simulation model is designed to input any production schedule and as a consequence considerable changes in product mix can be examined. One difficulty that arises however with respect to product mix is the mathematical determination of relative product dominance, the most important aspect of model-mix. As a preliminary approach to overcoming this difficulty the term model dominance ratio has been introduced where model dominance is defined as:

$$MDR = \frac{Q_{max}}{\{\sum_{j=1}^{m} Q_j\}/m} \qquad (5.4)$$

where

MDR = Model dominance ratio.

Q_{max} = The maximum quantity required of any given model.

Q_j = The quantity required of model j.

m = Number of models at balancing stage.

In applying variation in product mix it is possible to leave out completely in the production simulation models that have been involved at the balancing stage and therefore the entire range of product mix from equal product quantities (model dominance = 1) to single model production (model dominance = m) can be accommodated.

By allowing in addition the input of an actual production schedule which involves the specification of the sequence of model launches further information can be obtained than by simply inputting the relative quantities of each product. In particular the simulation model, when associated with a production schedule, can be used for detailed analysis of behaviour at stations and for analysing the effect of particular schedules, for example analysis with respect to average model runs and work variation.

Variables Related to Practical Assembly Line Operation.

The four simulation subjects so far discussed are concerned with the development of a practical assembly line simulation program and in addition two further variables have been included as a step towards the use of the simulation program for production planning and control.

The first new variation is to allow the choice between continuous or independent scheduling. In the case of continuous scheduling the production programme being simulated is considered to follow on immediately behind an unspecified previous programme and is considered to be followed in turn by another unspecified production programme. This has the effect that as the production schedule starts stations with no product from the correct schedule are not counted in any of the line efficiency calculations and similarly at the end of the production schedule as stations complete the schedule they are no longer counted in calculations. In the case of independent scheduling all stations are counted from the arrival of the first model at the first station to the departure of the last model from the last station. In consequence continuous scheduling, which is accepted in this work as the norm, will give higher efficiency results.

As a further move towards using the ALB 5 program for planning a production timetable has also been included in the simulation information. In the form of a calendar covering five years, fifty two weeks a year, seven days a week and four shifts per day the calendar contains a list of shifts not available for production (for example holiday breaks, industrial disputes or unused shifts). When simulating the actual production schedule the starting time, time of each cycle and completion time are calculated using the calendar to move past time not available. The production timetable therefore does not affect the efficiency calculations in any way but does provide for planning purposes estimates of start and finish times with respect to the schedule in question.

The simulation model in ALB 5 can therefore be seen to provide a mechanism for testing out under a wide range of more practical conditions balancing solutions obtained by models ASSIGN 1 to ASSIGN 3. The simulation program plays a significant part in test series 7 to 9, Chapter 6, where the effect of changing conditions from those relevant at the balancing stage are examined.

5.4. Detailed Simulation Information

In designing the ALB 5 simulation program it was considered that the value of the contribution made to the understanding of assembly line operations would be influenced strongly by the quality of the information printed by the program. Considerable care has therefore been taken in deciding the right quantity of information and type of information to be produced in order to achieve a reasonable compromise between a simulation program that works well but produces no output and a simulation program that produces so much information that considerable further work is required to evaluate the output.

The output produced by ALB 5 can be sub-divided into three groups: original balancing and production planning information; detailed station information, and finally detailed assembly line analysis.

Original Balancing and Production Planning Information:

Before the simulation begins in earnest and as an aid to the assembly line designer summaries of the information used by the simulation program are printed first. The information printed falls under the following general headings:

A. Title and Identification of Simulation.
   Production Timetable.
   Programme Disruptions.
   Weekly Timetable.
   Shift Times.

B. Production Schedule Summary.
   Model Ratios.
   Actual Schedule.

C. Simulation Information.

D. Assembly Line Information.

The first set of information provides the designer or production controller with details drawn from the five year calendar and time-table file FILE 4. Using the calendar, simulation cycle time and number of products in the production run the expected start and finish times for the current schedule is identified along with any anticipated breaks in production time over the current manufacturing period. The production breaks in question could arise from any internal or external source (e.g. holidays, disputes or planned maintenace), the breaks being entered into the five year shift calendar. Information on production time available is completed by printing the weekly shift pattern and the working hours of each shift.

The second set of introductory information provides details of the production programme to be manufactured. This information includes the number of models involved, the total number of units produced and the Model Dominance Ratio which is accompanied by the quantities, proportions and original balancing proportions of each individual model as well as the actual production schedule. This information is provided for two purposes: firstly as a formal record of simulation details and secondly as a means of identifying changes in model-mix from the original balancing conditions.

The third set of introductory information provides a formal record of the original balancing and present simulation conditions related to the current exercise. From the original balancing exercise is drawn the balancing cycle time, variable or deterministic treatment of element durations and whether originally single or mixed-model balancing. The simulation conditions with respect to frequency of work station printout, type of work station printout, type of scheduling (continuous or independent) and type of variability (deterministic, station or element) is then printed. This information set is completed by printing the simulation cycle time and consequent time available at each station.

The final information set contains details of the physical layout of the assembly line, starting with line length, total upstream and downstream working length, total overlap length and unused transit length. This is followed by details of station sizes and then by the specific location of each working and transit zone.

Preliminary information is provided primarily as a formal record of simulation conditions and secondly as an analytical guide to the program user. A fuller description and illustration of the preliminary information can be obtained by reference to the Users Guide, Appendix B.

Detailed Station Information:

Throughout the actual simulation the designer can request a printout of station information for any given interval of simulation cycles. When this is done the information shown in Figure (5.2), or an abbreviated version, is produced. Initially the schedule and timetable are identified along with the number of cycles in the production programme, and the current cycle and finally the time and date at which the current cycle ends.

The station information can be sub-divided into four groups; station condition, station output, time statistics and distribution of time. Station condition information includes station number and size, the current model at the station and whether the station is waiting, working or finished in the current programme. The number of models that theoretically have passed through the station and the actual number of models (excludes models not involved at station) is

STATIONS INFORMATION :

SCHEDULE NUMBER = 2 TIMETABLE NUMBER = 1

PROGRAM LENGTH =2406 CYCLE NUMBER = 800

TIME = 8,00 SHIFT = 1 DAY =TUESDAY WEEK = 9 YEAR = 1980

STATION NUMBER :	1	2	3	4	5	6	7
STATION SIZE :	1	3	1	1	1	1	1
MODEL NUMBER :	200	200	200	200	200	200	200
STATION CONDITION :	WORKING	WORKING	WORKING	WORKING	WORKING	WORKING	WORKING
NOMINAL M. OUTPUT :	800	799	798	797	796	795	794
ACTUAL M. OUTPUT :	800	799	798	797	796	795	240
STATION WORK TIME :	14,9	45,5	17,1	14,6	21,8	15,5	0,0
MAXIMUM WORK TIME :	22,3	62,7	24,0	22,9	21,8	23,0	8,7
MINIMUM WORK TIME :	8,9	43,2	8,3	7,1	7,8	10,4	0,0
WORK ASSIGNED :	12494,7	42363,1	11599,1	12001,8	11411,0	12773,5	1434,2
TIME AVAILABLE :	14400,0	43146,0	14364,0	14346,0	14328,0	14310,0	14292,0
DOWNSTREAM WORKING:	154,3	692,2	3,8	11,4	0,0	0,0	0,0
FREQUENCY :	120	180	3	11	0	0	0
UPSTREAM WORKING :	0,0	2555,6	2778,8	3820,7	0,0	2600,3	1238,0
FREQUENCY :	0	619	795	786	0	778	240
NORMAL WORKING :	12340,5	39099,9	8813,9	8169,7	11378,5	10162,9	196,2
FREQUENCY :	800	799	798	797	796	795	167
OVERLAP WORK TIME :	340,8	2270,6	2215,1	296,7	607,4	790,1	194,1
FREQUENCY :	231	976	916	182	371	470	110
NEXT START POS'N :	5,0	14,0	23,0	32,3	45,0	53,0	62,0
TOTAL LOST WORK :	0,0	15,3	7,6	0,0	32,4	10,3	0,0
FREQUENCY :	0	7	1	0	37	17	0

FIG. (5.2) DETAILED STATION INFORMATION (SIMULATION PROGRAM).

then printed.

The time statistics provided are a cumulative record of the maximum and minimum work time at the station so far found in the production schedule along with the total work assigned and total time available up to the current point. The current station work time is included in this group.

Of greater interest is the actual distribution of work over each station and therefore the cumulative quantity and frequency of occurrence is printed for downstream, normal, upstream and lost work. The distribution of time figures are completed by printing the next start position for the operation (assuming continuous work) and the initial estimate of overlap work.

When the assembly line designer is concerned in particular with how individual stations will perform it is the station information that provides the necessary data. On occasions the full printout of information may not be required and therefore an abbreviated station printout excluding the distribution of time is available.

Detailed Assembly Line Analysis:

On completion of the simulation run a final detailed assembly line analysis is produced on which the overall performance of the assembly line can be assessed. The information provided in this final analysis can be sub-divided into three groups: planning details, production details and efficiency measures.

The planning information is simply a repeat identification of the schedule being simulated, the completion time and a confirmation for record purposes that simulation is complete.

With respect to production information, this consists initially of output details covering the number of assembly line cycles, subsequent number of finished units produced, average production per model and model dominance. Included in this section of information is data on the consistency of model runs, where a model run is defined as the number of consecutive products associated with a single model. In particular the Average Run Length (ARL) and the Standard Deviation of Run Length (SDRL) are calculated, these two values being indicative of the number of occasions on which the work pattern at stations will change. Average Run Length and Standard Deviation of Run Length can be expressed in equation form as:

$$ARL = \frac{\sum_{i=1}^{N_r} N_x}{N_r} \tag{5.5}$$

where:

ARL = Average Run Length.

N_r = Number of model runs in production schedule

N_x = Number of models in model run x.

and:

$$SDRL = \sqrt{\frac{\sum_{x=1}^{N_r} (N_x{}^2) - \{\sum_{x=1}^{N_r} N_x/N_r\}^2}{N_r}} \tag{5.6}$$

where:

SDRL = Standard Deviation of Run Length

N_r, N_x as before.

Average production per model (APPM) and model dominance (MDR_s) are calculated using the equations:

$$APPM = \frac{\sum_{j=1}^{m} Q_j}{M_s} \quad (5.7)$$

where:

APPM = Average production per model

M_s = Number of models in simulation schedule

M and Q_j as before.

$$MDR_s = \frac{Q_{max}}{\{\sum_{j=1}^{m} Q_j\}/M_s} \quad (5.8)$$

where:

Q_{max}, M, Q_j, M_s as before.

Note that APPM and MDR_s are related to the number of models in the simulation schedule and therefore will produce different values that the equivalent balancing equation (equation 5.4) when a model is not present in a particular simulation run.

The final section of the detailed assembly line analysis starts by presenting a comparison of Balance Delay and Smoothness Index from the balancing and simulation stages. At the balancing stage four versions of Balance Delay (BD1 to BD4) and four versions of Smoothness Index (SI1 to SI4) were calculated to allow for the effect of model adjustment and effective time. The theory and calculations involved are given in Chapter 4, equations (4.9) to equation (4.17). When calculating Balance Delay and Smoothness Index in the simulation stage the actual time taken to complete work is used in place of work content. Under these conditions the equivalent of normal duration is given by T_k, where T_k has been obtained using equation (5.2) for element variability or equation (5.3) for station variability. The equivalent of effective time allowing for compressibility, is the greater of the two equations:

$$Te_k = \frac{T_k}{S_k} \tag{5.9}$$

or $$Te_k = \sum_{i=1}^{n} te_i\ (P_k) \tag{5.10}$$

taking the greater value

where:

Te_k = Effective time for station k

$te_i(P_k)$ = Minimum element duration for element i being performed at station k.

n = number of elements.

S_k = Station size of station k.

T_k as before.

As the effect of model dominance is automatically accounted for when actual completion times are taken in the simulation model it is BD2, BD4, SI2 and SI4 equivalents that are produced by the following equations:

$$BD2_s = \frac{\sum_{y=1}^{N_c} \sum_{k=1}^{p} \{(S_k \times C_s) - T_{ky}\} \times 100}{\{\sum_{k=1}^{p} S_k\} \times C_s \times N_c} \tag{5.11}$$

where:

$BD2_s$ = Model adjusted Balance Delay for simulation.

N_c = Number of production cycles in the simulation.

p = Number of stations in the line.

C_s = Simulation cycle time.

T_{ky} = Normal station time for station k cycle y.

S_k as before.

$$BD4_s = \frac{\sum_{y=1}^{N_c} \sum_{k=1}^{P} \{S_k \times (C_s - Te_{ky})\} \times 100}{\{\sum_{k=1}^{P} S_k\} \times C_s \times N_c} \tag{5.12}$$

where:

$BD4_s$ = Model adjusted effective Balance Delay for simulation.

Te_{ky} = Effective station time for station k cycle y.

N_c, P, S_k and C_s as before.

$$SI2_s = \sqrt{\sum_{y=1}^{N_c} \sum_{k=1}^{P} \{(S_k \times C_s) - T_{ky}\}^2} \tag{5.13}$$

where: $SI2_s$ = Model adjusted Smoothness Index for simulation.

N_c, P, S_k, C_s and T_{ky} as before.

$$SI4_s = \sqrt{\sum_{y=1}^{N_c} \sum_{k=1}^{P} \{S_k \times (C_s - Te_{ky})\}^2} \tag{5.14}$$

where:

$SI4_s$ = Model adjusted effective Smoothness Index for simulation.

N_c, P, S_k, C_s and Te_{ky} as before.

The comparison of balancing and simulation values for Balance Delay and Smoothness Index does in practice print eight values for simulation by making $BD1_s$, $BD3_s$, $SI1_s$ and $SI3_s$ equal to $BD2_s$, $BD4_s$, $SI2_s$ and $SI4_s$ respectively. As Balance Delay and Smoothness Index are the main criteria by which balancing results are judged the calculations printed at this point are the most valuable part of the simulation output.

The detailed assembly line analysis and the simulation output is completed by a listing of the total upstream, downstream and normal working time used along with time available and lost time that occurred in manufacturing the production progamme.

5.5. Summary

As stated earlier the simulation program has been designed to examine the effect on assembly lines of changing the conditions under which they were balancing. This has been done because the view is put forward that on many occasions actual assembly lines will operate under varied conditions and therefore there is a need to examine assembly line versatility.

Accepting this need a simulation model has been built to cover two main requirements:

(a) A wide variety of simulation conditions can be easily set.

(b) A well balanced collection of resultant information will be provided as output by the simulation model.

What remains on completion of this model is to test out the model and background theory on a suitable collection of problems.

CHAPTER 6

EXAMINATION OF THE ALB PROGRAMS

6. EXAMINATION OF THE ALB PROGRAMS

6.1. Test cases and significant parameters

In introducing three new balancing models based upon work compressibility and enlarged stations and subsequently developing extensive computer programs for their use, the need arises to thoroughly test the accuracy and efficiency of the programs and at the same time to make a preliminary examination of the influence of the more significant parameters.

For this purpose five test problems have been selected and various permutations of the basic data will be used to carry out program testing and analysis of variables. The five problems selected to cover a suitable range of problem sizes are:

1. 16 Element Driscoll-Shafi Balancing Problem

   This problem was initially developed for this research as a basic problem on which to carry out program validation and model development.

2. 21 Element Wild (48)

   This problem was originally used to demonstrate the Kilbridge and Wester single model balancing method (48) (Pg. 62) and is used in this thesis with the same normal element durations.

3. 30 Element Sawyer (36)

   This problem was adopted by Sawyer to demonstrate the Helgeson and Birnie rank positional weight procedure (36) (Pg. 86) and has been used in this thesis with the same element durations but without the original zoning considerations.

4. 45 Element Problem Kilbridge and Wester (17)

   This problem appears in a paper on balancing given by Kilbridge and Wester and has been used unaltered.

5. 70 Element Problem Tonge (42)

   Extracted from Tonge's thesis (42) (Pg. 66), this problem has again been used with unaltered element durations.

The five problems represent a spread of elements from 16 to 70, noting that the computer programs are designed for a maximum of 100 elements, and will represent an original range of cycle times from 36 to 176 time units. The precedence diagrams for single model balancing are shown in Appendix A, figures (A.1) to (A.5) and the selection of elements for the various mixed model balancing tests based on these five exercises are shown in Tables (A.1) to (A.5), Appendix A.

In developing the test program for the ALB suite the following major influences on assembly line efficiency were identified for particular attention with respect to the newly developed ASSIGN models:

Balancing

Element compressibility

Confidence level

Line length limitations

Single or multi-element assignment

Mixed model weighting

Simulation

Assembly line speed

Work station definition

Variation on product mix

In addition a limited attempt has been made to reproduce similar solutions to those obtained by the original authors for the four previously published test cases. In all 273 test runs were executed in examining these major influences and the results have been given for each case in Appendix A, along with the conditions under which the tests were run.

Balancing

6.2. The Effect of Work Compressibility

The concept of work compressibility represents one of the major significant new introductions associated with the ASSIGN balancing models and is considered to be capable of both allowing the balancing of problems that cannot be balanced by conventional means and of being potentially capable of giving more efficient solutions over a number of trials.

To examine whether these assumptions are true, test series 1, containing sixteen trials on four of the five test problems, has been carried out with varying levels of compressibility. The four problems selected were the 16, 21, 30 and 45 element problems and for each problem 0, 50, 75 and 90 percent compressibility of normal element durations was allowed for each element. This range of compressibility is in practice quite considerable as it would theoretically allow at one extreme only single-man stations and at the other extreme ten-man stations. The results of the sixteen trials in test series 1 are shown graphically in Figure (6.1) to (6.4).

Figure (6.1) demonstrates the relationship between Balance Delay and compressibility and can be seen to support the case that the use of enlarged stations is likely to lead to better efficiency over a number of trials. None of the four test cases showed deterioration in Balance Delay as compressibility was increased but no change at all was detected in the case of the 30 and 45 element problems, whilst the 21 element problem showed a significant improvement in balance delay from 20.56 to 0.69 percent as the compressibility increased from 50 to 75 percent. This confirms that whilst enlarged stations will not give improved results on every occasion the potential for better line efficiency exists.

The relationship between Smoothness Index and compressibility is however not so clear as evidenced in Figure (6.2) where the 21, 30 and 45 element problems all show an initial deterioration in the equality of work assignments to stations and only the 21 element problem eventually improved, going from a worst Smoothness Index value of 30.33 to a final value of 1.00. There is however a very sound explanation for this behaviour. As work elements are more efficiently packed into the earlier stations the eventual result could be the creation of a final station with only limited assigned elements and this final station will severely affect the calculation of Smoothness Index. In the case of 30 element problem with ninety percent compressibility the final station contained only two elements

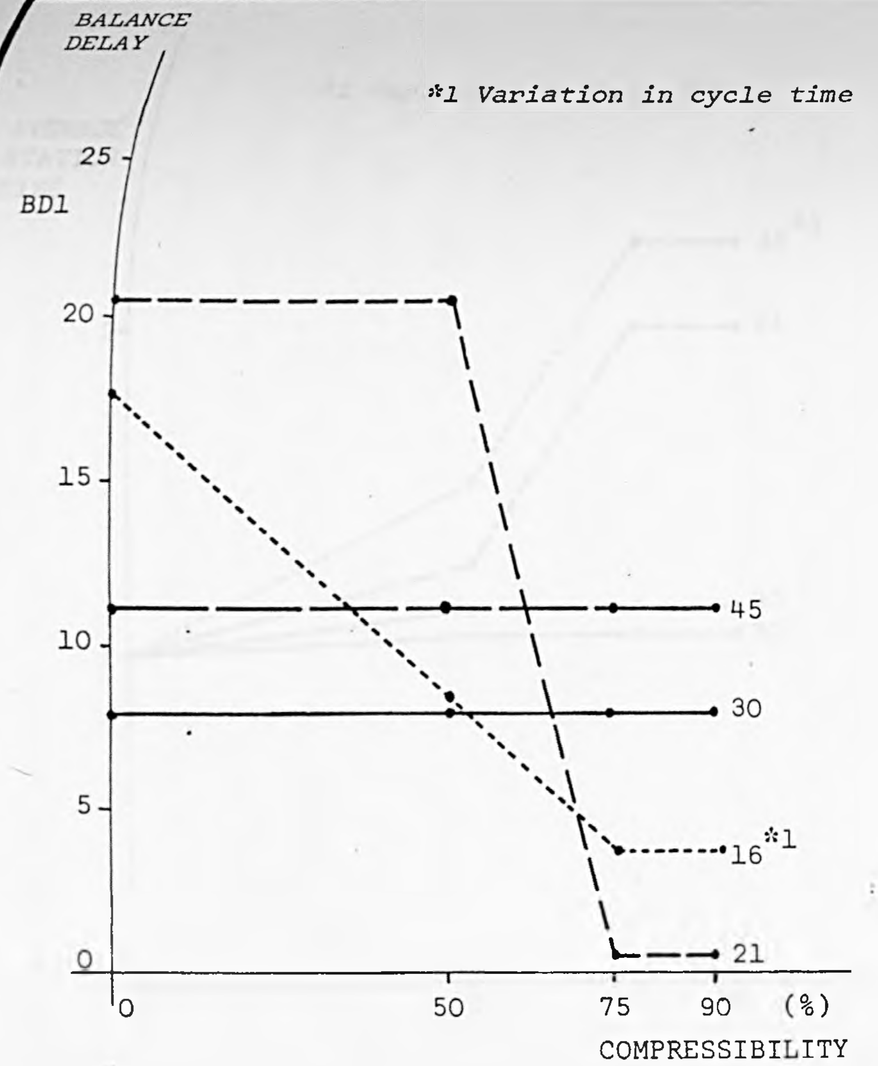


FIG. (6.1) BALANCE DELAY AGAINST COMPRESSIBILITY.

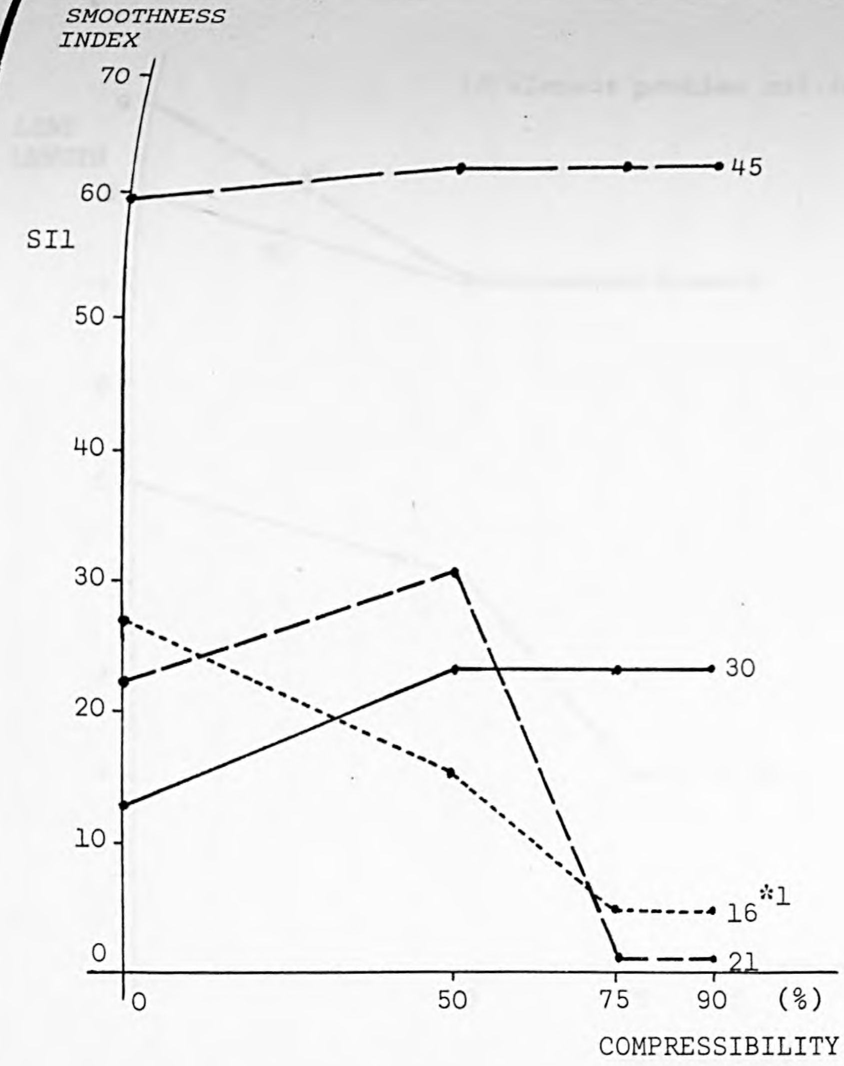


FIG. (6.2) SMOOTHNESS INDEX AGAINST COMPRESSIBILITY.

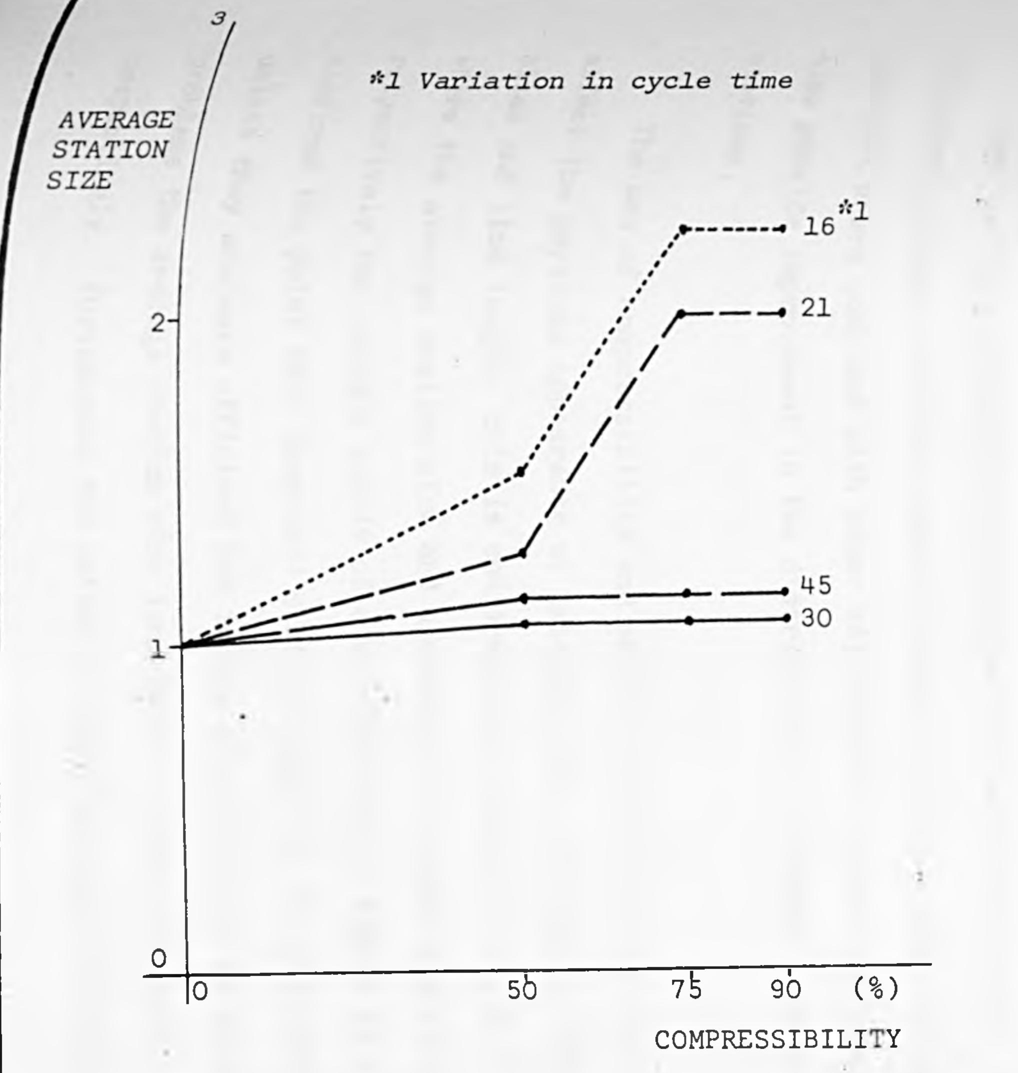


FIG. (6.3) AVERAGE STATION SIZE AGAINST COMPRESSIBILITY.

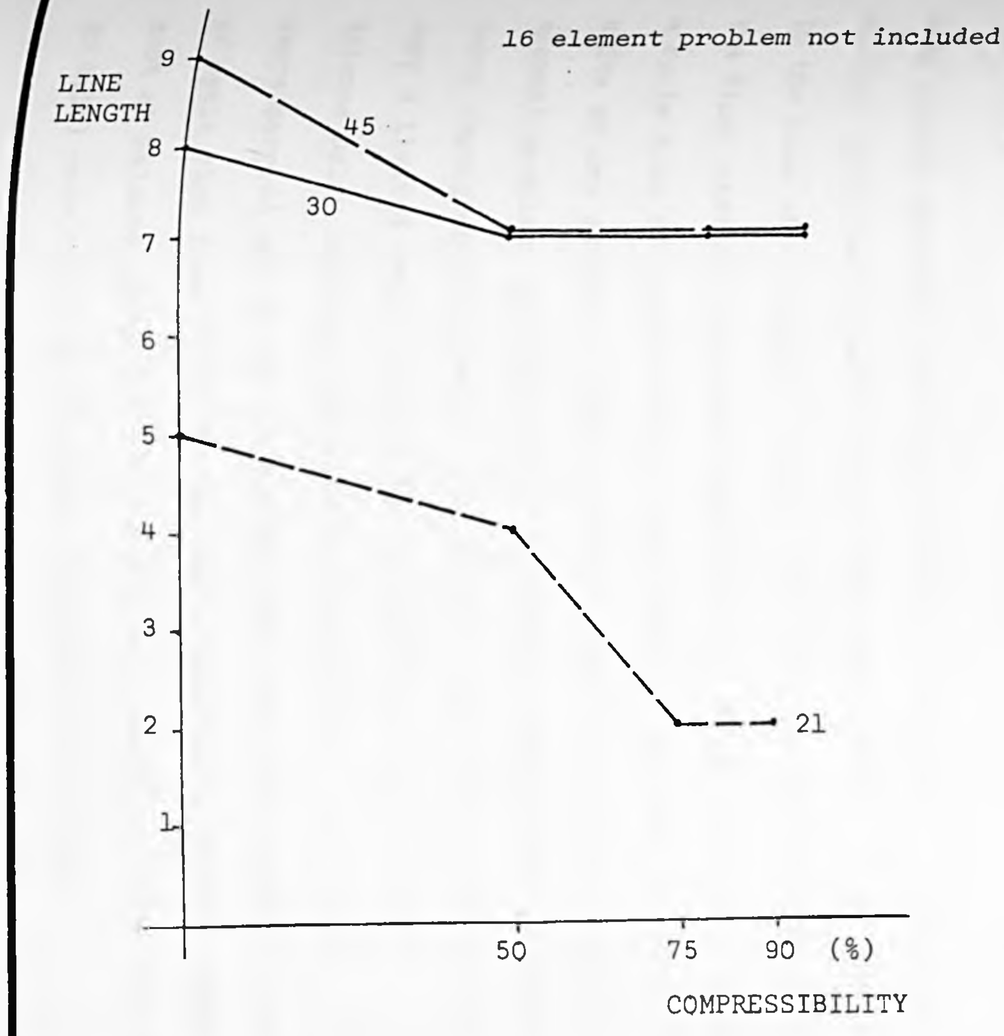


FIG. (6.4) LINE LENGTH AGAINST COMPRESSIBILITY.

with normal duration totalling 21 for a cycle time of 44, having up to that point had at worst three time units wasted at any station. In the case of 45 element problem at ninety percent compressibility the final station contained one element of normal duration 5 against a cycle time of 69, having to that point had at worst 4 wasted time units at any station. This situation arose in the 21, 30 and 45 element problems because the cycle time was kept fixed for consistency throughout all tests. Should the cycle time be allowed to vary a limited amount then both the Smoothness Index and the Balance Delay could be improved as shown in the first three tests carried out on the 16 element case, where the slight increase of cycle time from 20 to 21 time units resulted in both an improvement of Balance Delay (17.67 to 3.89) and Smoothness Index (27.29 to 4.58) over the 0 to 75 percent compressibility range.

Test series 1 therefore can be seen to confirm that more efficient balance solutions can be possible with enlarged stations and that where combined with minor adjustments to cycle time can also provide improvement in the distribution of elements between work stations.

The use of compressibility and enlarged work stations would also affect the physical appearance of assembly lines in terms of station sizes and line length, this is confirmed by Figures (6.3) and (6.4) where the average station size and assembly line length are plotted respectively for various levels of compressibility. Figure (6.3) confirms the point that increased station sizes are not selected unless they are more efficient for in the case of 30 and 45 element problems the average station size increased to only 1.143 and 1.286 respectively. Furthermore the extent to which enlarged stations will be used will depend on the particular relationship in any given problem as evident that the 21 element problem had an average station size 2.0 for the same ninety percent level of compressibility.

One further point of considerable importance can be drawn from Figure (6.3). The test allowed up to a maximum station size of a six-man station but the balancing procedure kept the station size at lower levels in each case, with the largest station used in any of the sixteen tests being a three-man station, thus the possibility of a single station solution containing all elements being proposed as the perfect but unrealistic answer has been eliminated. This criticism that enlarged stations could theoretically be a unfeasible one station solution has been controlled by two factors:

(a) The maximum station size that would have been allowed by work compressibility would have been ten (90% compressibility).

(b) The ASSIGN 1 model tends to favour smaller station sizes as smaller station sizes are selected for equal values of efficiency.

Figure (6.4) shows the change in line length as compressibility is permitted and as suspected line length either remains the same or decreases as compressibility increases. In the three cases shown (45, 30 and 21 element problems) line length changes were recorded. The 16 element problem has not been included on this graph as the change in the cycle time would produce misleading results. The value of Figure (6.4) is that it confirms that where there is going to be a limited line length available then the ASSIGN balancing model are likely to be able to produce acceptable solutions, a point further examined in section (6.4).

6.3. The Influence of Confidence Level

Within the ALB computer programs there is the ability to consider variable element durations as an alternative to deterministic completion times. This has been included because the nature of many assembly lines is that the work is carried out by manual operators who are subjected to natural variation. Assuming this natural variation behaves according to the normal distribution the normal element durations can be increased to allow for this natural variation up to specified levels of confidence (see Chapter 4).

The tests carried out in test series 2 were designed to confirm the strongly suspected relationship that if variable element durations were considered and element durations increased then larger assembly lines would be needed. Two problems, the 16 and 30 element examples were tested with four different levels of compressibility (90, 75, 50 and 0 percent) and at four levels of confidence (50, 75, 95 and 99 percent confidence of completing work), noting that 50 percent confidence is equivalent to deterministic element durations.

The resultant graphs showing the effect of confidence level on equivalent number of simple stations (total size of assembly line) is shown in Figure (6.5). As suspected there is not a linear increase in equivalent number of simple stations but as element times are increased the spare time available at stations will firstly absorb minor duration increases until an additional equivalent station is required and will then absorb more increases until yet further equivalent stations are required in a step type function. The fairly straight forward conclusion that increase element durations will result in a trend towards increased station size is therefore confirmed.

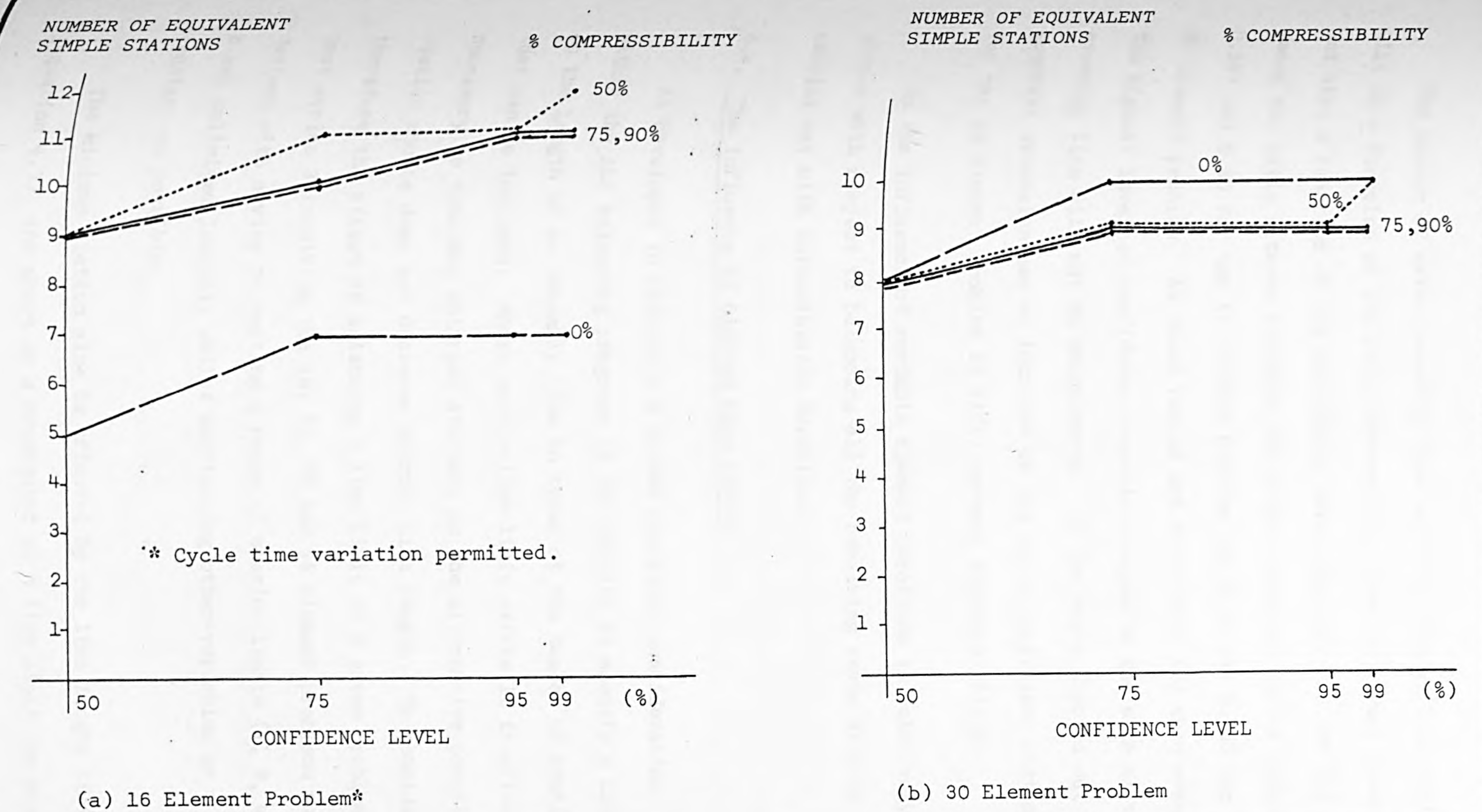


FIG. (6.5) EFFECT OF CONFIDENCE LEVEL ON EQUIVALENT NUMBER OF SIMPLE STATIONS.

The amount of extra assembly line capacity that will be needed will be a function of the ratio between variance and normal durations and also a function of the confidence level desired. In the two test cases the ratio between variance and normal duration varied between 0.167 and 0.30 for the 16 element problem and 0.12 and 0.333 for the 30 element problem. As these ratios are relatively low then even at the highest level of confidence dramatic changes in the size of the assembly line will not be encountered. In the tests carried out the greatest extension was an increase of the three equivalent stations for the 16 element problem at fifty percent compressibility.

As the influence of variable element durations is relatively simple with respect to balancing all the remaining tests will be carried out with deterministic durations.

6.4. The Influence of Limited Line Length

As developed in Chapter 4 a second practical consideration within the ALB balancing programs is the ability to specify a limit on the length of an assembly line in terms of the number of stations that can be included. Where such a line limit exists it is often necessary to consider enlarged stations as the alternative parallel station choice does not decrease overall line length. To consider therefore the effect of balancing a line limit on a given problem test series 3 involving the 16, 21, 30 and 45 element problems was devised with a view to testing a range of station limits (1, 2, 4, 8 and unlimited length), whilst maintaining other variables as constant as possible.

The minimum station size is affected by the line length limit (equation 4.7) and where as a consequent of a line limit the minimum station size is greater than the maximum station size (equation 4.5) then the maximum station size will also be affected by the line length limit as the maximum station size is automatically raised to the greater minimum station size. In order to examine this effect no pre-specified maximum station size was input for the problems, thus leaving the maximum station size to be determined by equation (4.5).

The result of the decision not to input a manual maximum station size is demonstrated in table (A.12) where of the seventy-three stations that were assigned elements during the twenty test cases only thirteen of the station assignments had any choice of station size, this occurred because the largest element duration in three of the problems was less than the cycle time, thus setting maximum station size by equation (4.5) to 1. The nett result of this approach is that each solution for specified line length contained exactly the number of stations in the line length limit.

This tendency to give the longest line possible is demonstrated in Figure (6.7) where the unlimited line length cases with no maximum station size produced a set of solutions of single size stations. Only the 16 element problem, with an element duration greater than cycle time produced an enlarged station in the unlimited line length case (test 53). This can be contrasted with the solutions to tests 1, 5, 9 and 13, extracted from test series 1. Where identical conditions applied except that a maximum station size of six was specified. In this case the solutions produced were shorter than those produced with no specified maximum station size.

Of greater importance perhaps is that by eliminating any choice of station size potentially more efficient solutions are being ruled out as can be seen from Figure (6.6) where the same two sets of tests (53, 58, 63, 68 and 1, 5, 9, 13) are being compared.

For the 16 element, 30 element and 45 element problems the same Balance Delays were obtained but with a shorter line length whilst for the 21 element problem a considerably more efficient solution (20.56 reduced to 0.69) was obtained with again a shorter line length.

The importance of not restricting the choice of station size where efficiency is the goal can be seen in Table (A.12) which also contains the station choice for tests 1, 5, 9 and 13. In these tests where alternative station sizes were available, out of the twenty stations that were assigned elements, nine of the station sizes selected had alternative stations sizes of equal efficiency, supporting the view that where station size choice is available more efficient solutions will be found.

Summarizing on the effect of limited line length therefore the procedure does work efficiently to ensure that balancing is possible within the number of stations available but care must be taken to ensure that as minimum station size increases it does not unduly reduce the range of station sizes available.

One further point of interest arises where a limited line length case is encountered. The inclusion of a line length limit may under certain circumstances prohibit the production of a feasible solution. This situation arises when the total minimum element durations for all elements is greater than the product of cycle time and a limiting number of stations, for in this case no matter the size of the stations the work will never be completed within the line length limit.

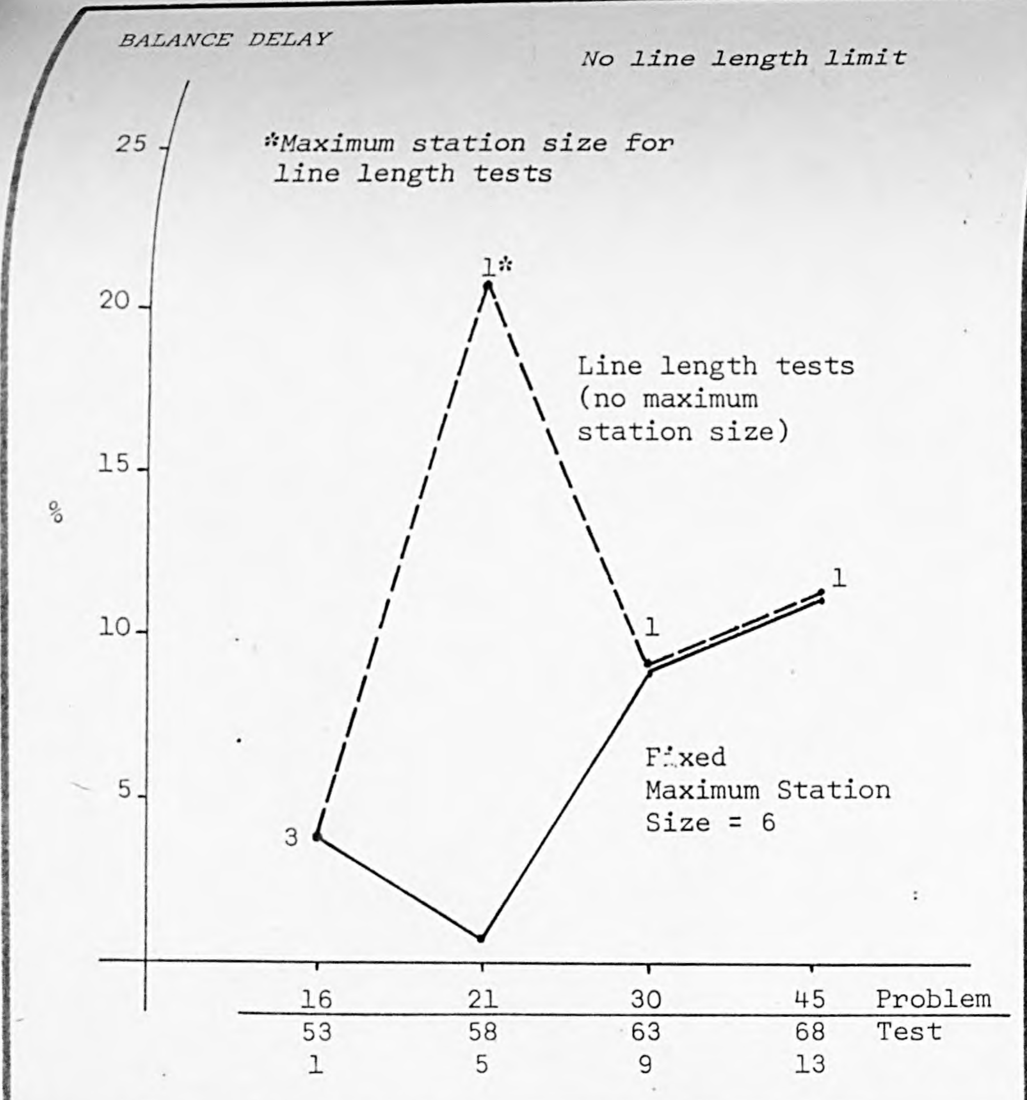


FIG. (6.6) BALANCE DELAYS OBTAINED WITH VARYING MAXIMUM STATION SIZE.

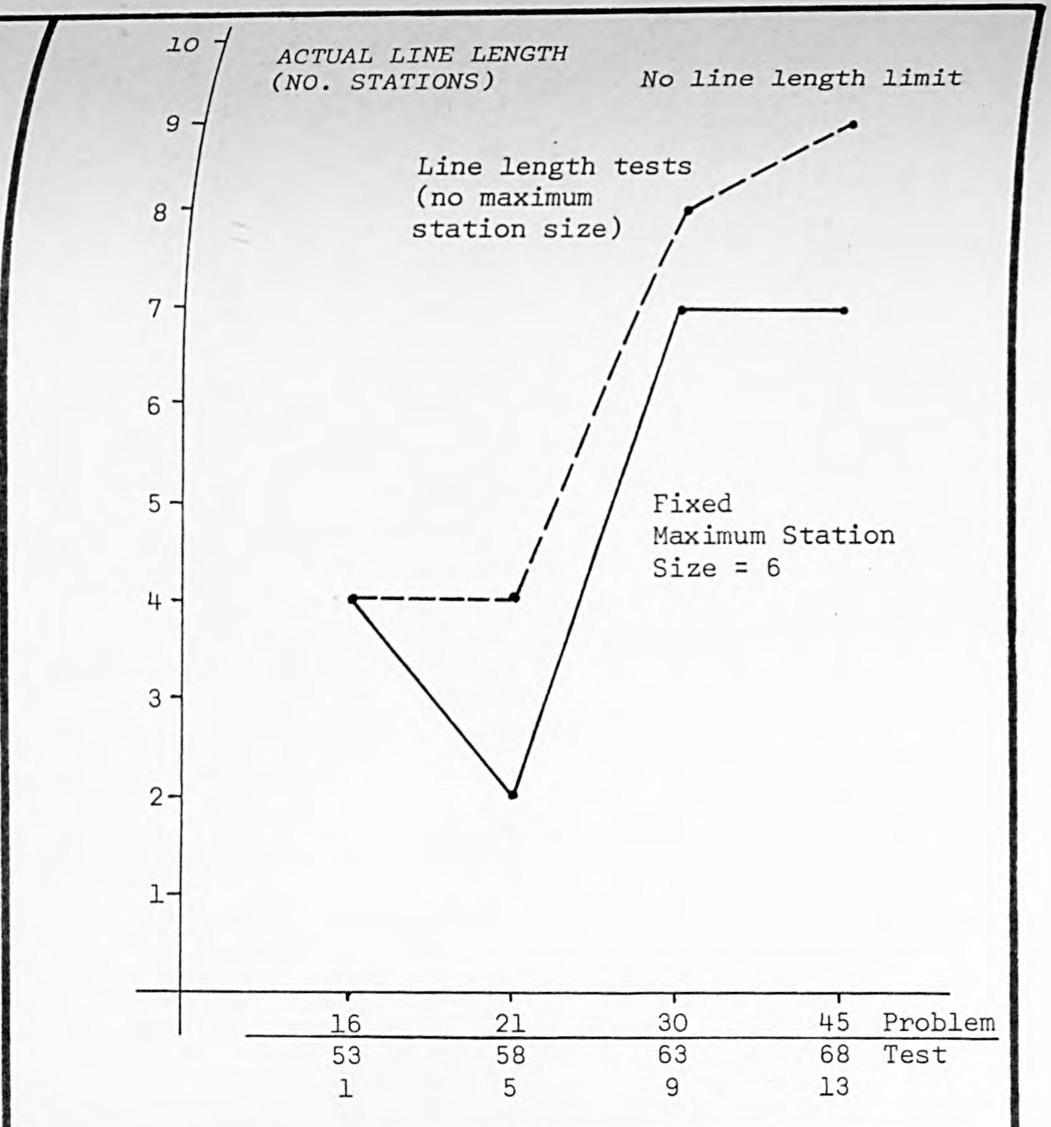


FIG. (6.7) LINE LENGTH OBTAINED WITH VARYING MAXIMUM STATION SIZE.

6.5. Single Versus Multiple Element Assignment

When the question arises as to the balancing of mixed-model production there are two models available in the ALB program suite. As detailed in Chapter 4 the two models, which both employing work compressibility, differ in the number of occasions on which an element can be assigned. The ASSIGN 2 model is generally related to mixed-model production when models have only limited commonality of elements and therefore multiple assignments of elements, where each model being treated separately is preferred. The ASSIGN 3 balancing procedure is related to mixed-model production when elements have a high level of common elements and therefore single element assignments may be preferable.

In practice any mixed-model balancing problems can be tackled by either procedure and therefore there is some value in comparing the results that would be obtained from each method for identical problems. For this purpose test series 4 has been carried out. The test series contains thirty tests carried out on all five problems (16, 21, 30, 45 and 70 elements) with both single element and multi-element procedures being applied to three mixed-model permutations of each problem. The mixed-model versions of each originally single model problem has been obtained by taking five models in each case (models 200 to 204) and removing at random elements under three different circumstances: random removal from the entire precedence diagram, random removal from the early portion of the precedence diagram and random removal from later portions of the precedence diagram. The actual elements involved in each model are shown in tables (A.1) to (A.5) at the beginning of Appendix A, with approximately twenty-six percent of elements removed overall, the number of individual elements removed for each example being 27.5, 23.8, 24.4, 24.5 and 27.8 percent respectively for the 16 to 70 element problems. In practice only thirty-four occasions arose in the five problems in which an element was assigned uniquely to one model and therefore the test series should theoretically be more appropriate to single element assignments.

Figure (6.8) shows the Balancing Delays obtained from test series 4 for single and multi-element assignments and it can be clearly seen that the multi-element assignment is producing more efficient solutions than the single element assignments. This is logical when it is understood that multi-element assignments are capable of filling up each station according to individual model needs where as single element assignments will always produce inefficient lost time when the element in question is not involved in all other models.

Figure (6.9) shows the resultant Smoothness Indices for single versus multi-element assignments and again multi-element assignments are producing consistently better results. This again arises because of the inefficient lost time that will be obtained in single element assignments.

The price to be paid for the more efficient packing of elements obtained with multi-element assignment is increased variety in work assigned to each station as is clearly shown in Figure (6.10) where the total training need of each assembly line for both single and multi-element assignment is given. In the five sets of tests carried out on average the multi-element assignment required 57.1 percent more operator training than single element assignment confirming the suspected trade-off of work variety against efficiency.

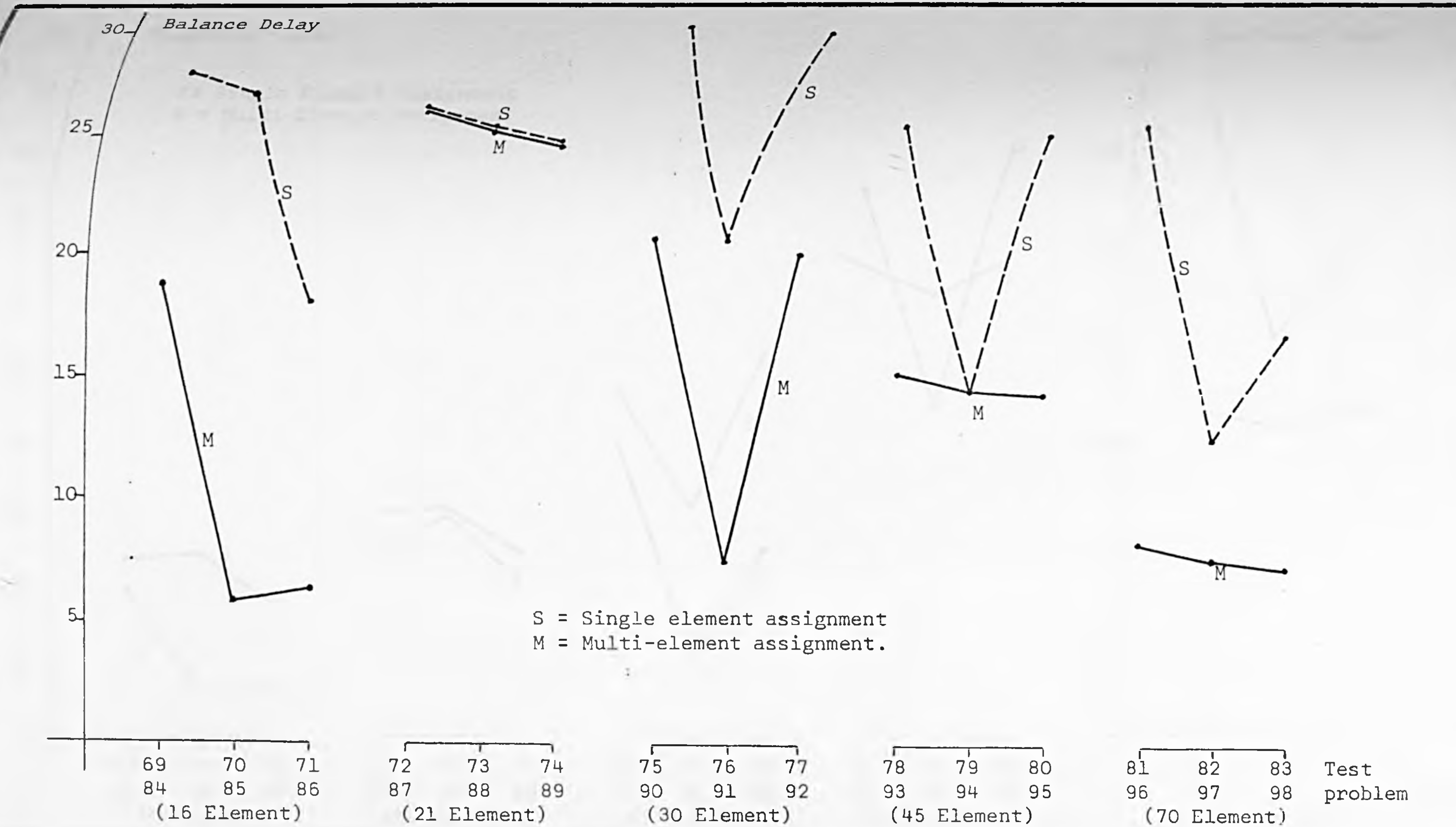


FIG. (6.8) COMPARATIVE BALANCE DELAYS FOR SINGLE AND MULTI-ELEMENT ASSIGNMENTS.

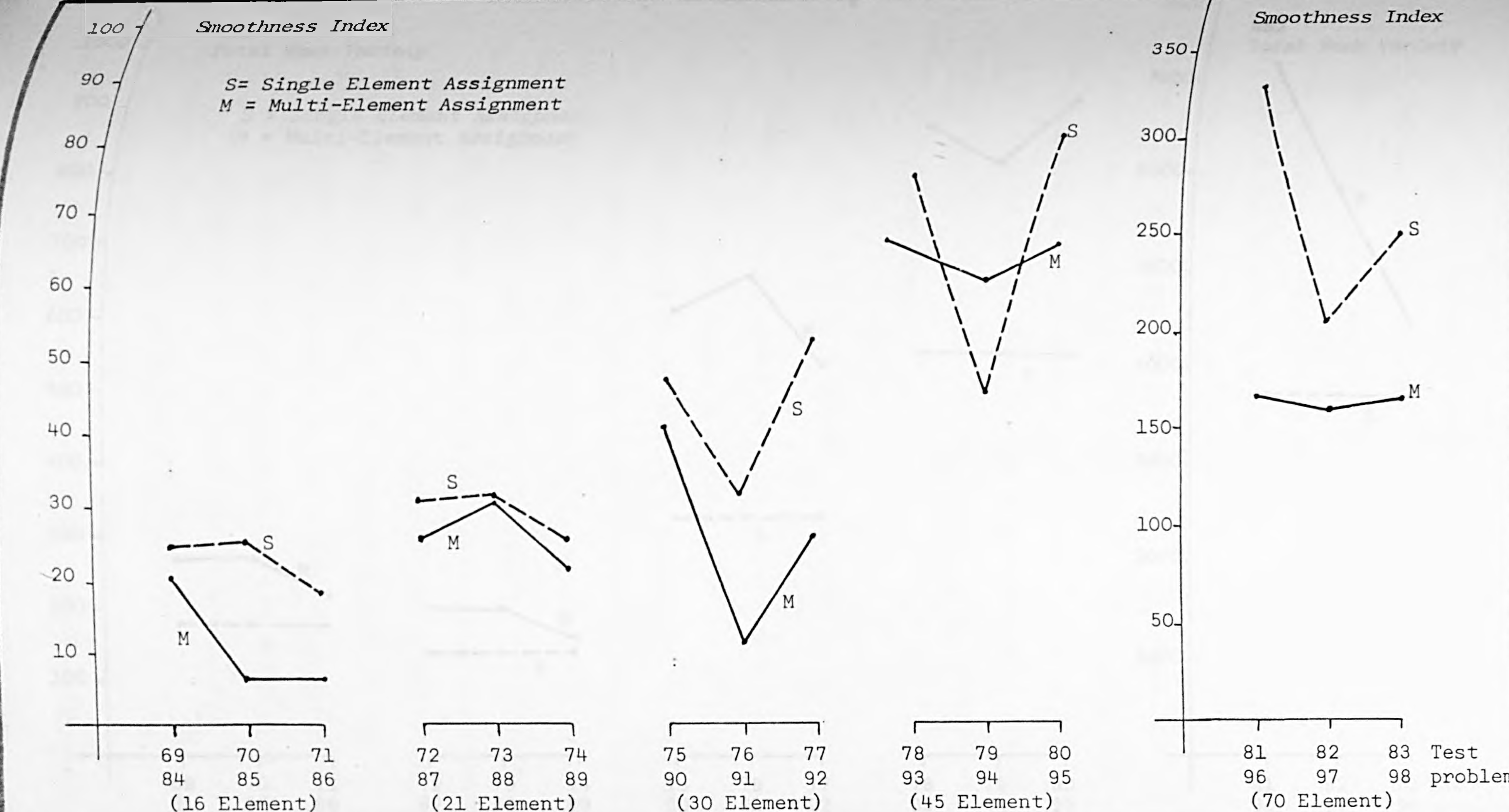


FIG. (6.9) COMPARATIVE SMOOTHNESS INDICES FOR SINGLE AND MULTI-ELEMENT ASSIGNMENT.

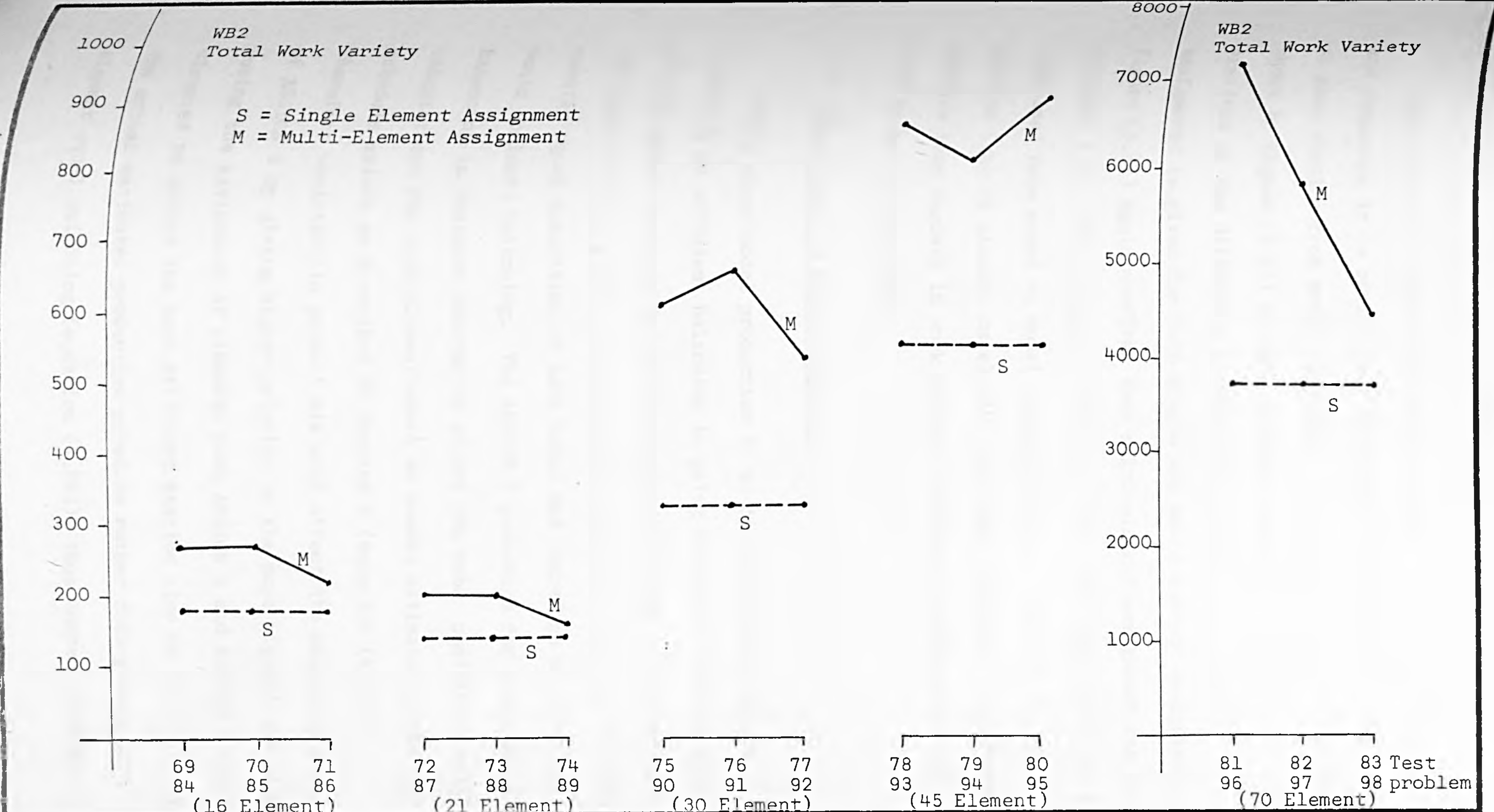


FIG. (6.10) COMPARATIVE WORK VARIETY FOR SINGLE AND MULTI-ELEMENT ASSIGNMENT.

Test series 4 represent the first mixed-model production test and therefore it is of interest to examine the change in work loading at each station from model to model. A representation of this is shown in Figure (6.11) where the total range, i.e. the sum for all stations of the difference between the greatest and smallest work assignment is given for both single and multi-element assignment. Figure (6.11) again confirms that multi-element assignment can pack stations more efficiently and therefore will have less variation in work load from model to model at each station. Only in one test problem (the 21 element case) did the single assignment procedure produce less variety in work and the difference in this case can be seen to be insignificant.

6.6. The Effect of Model Weighting

Where mixed-model production is to be undertaken a second influence on efficient balancing is going to be the relative quantities of each model involved in the production programme. In mixed-model, the tests to this point, the estimated production schedule contains exactly equal quantities of each model and therefore no one model would dominate balancing. The ASSIGN 3 procedure for mixed-model balancing is designed however to adjust the rank positional weight calculations for each element where an uneven estimated production schedule exists as described in Chapter 4 (equation (4.29)). Therefore variation in product mix will affect the balancing results of ASSIGN 3 by giving higher priority to the more significant elements. During the assignment of elements both ASSIGN 2 and ASSIGN 3 can be directed to select the most efficient station size on the basis of the actual estimated production schedule rather than giving each element equal weighting (equation (4.28)), thus uneven estimated

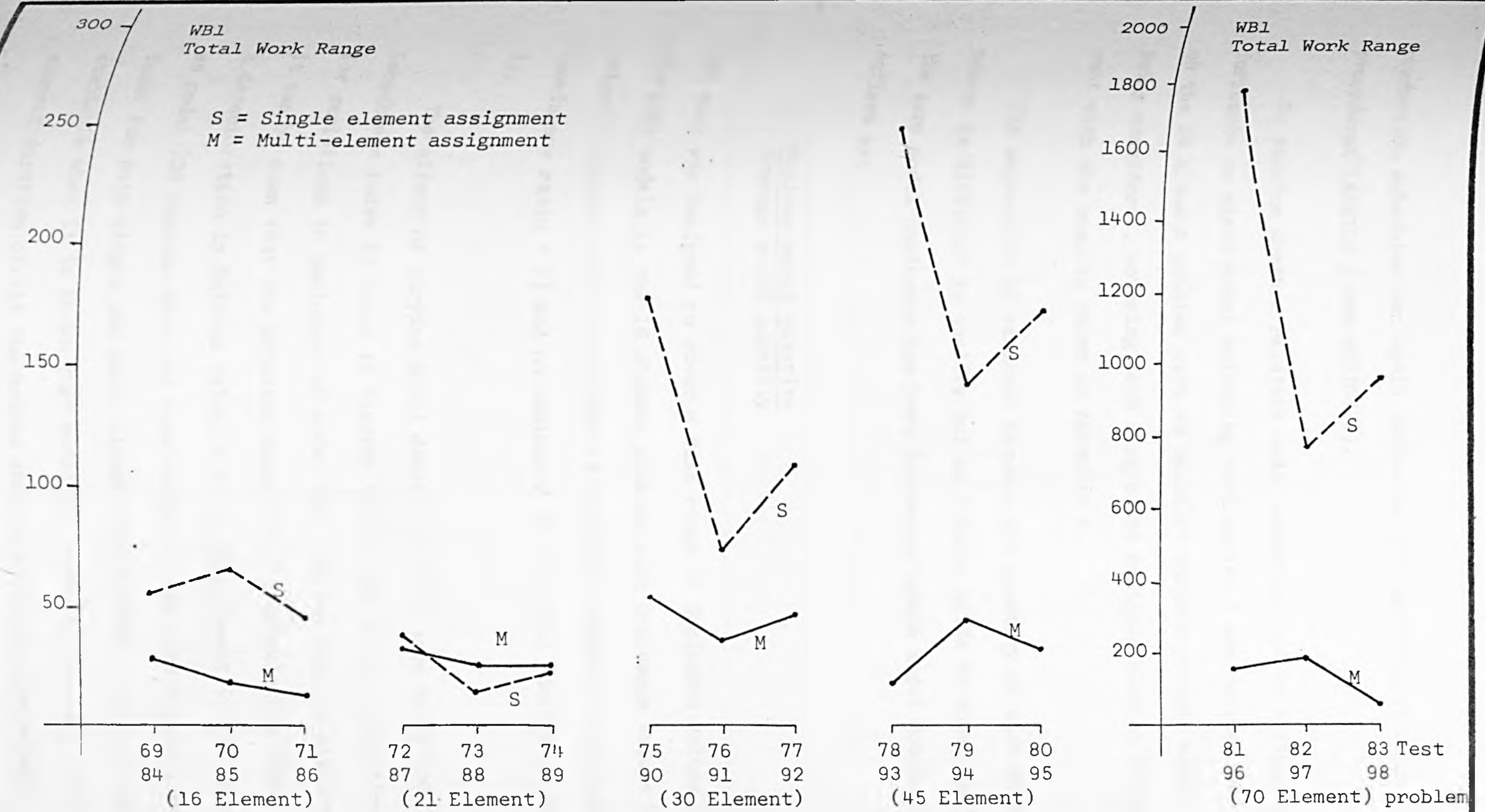


FIG. (6.11) COMPARATIVE VARIATION IN STATION WORK LOADS FOR SINGLE AND MULTI-ELEMENT ASSIGNMENT.

production schedules can again influence both mixed-model balancing procedures (ASSIGN 2 and ASSIGN 3).

To examine whether relative model weighting can be a significant influence on mixed-model balancing test series 5 was carried out on the 16 element problem with 42 tests at various product mixes being considered, covering both single and multiple element assignment with the results shown in Appendix A.

The expression of variance between the quantity of each model needed is difficult to qualify but as a basic guide to model variance the term model dominance has been introduced where model dominance is defined as:

$$\frac{\text{Maximum model quantity}}{\text{Average model quantity}}$$

The test was designed to cover a full range of dominance values for the five models in the 16 element problem with dominance values being selected between the two extremes of complete dominance by one model (dominance ratio = 5) and no dominance of any model (dominance ratio = 1).

The effect of varying model dominance on Balance Delay and Smoothness Index is shown in Figures (6.12) and (6.13) respectively for variations in dominance of model 200. In the case of balance delay it can be seen that the Adjusted Balance Delay calculation (BD2) shows a deterioration in Balance Delay, i.e. an improvement in efficiency as model 200 becomes more and more dominant, the same relation being found for both single and multi-element assignments. This is understandable when it is known that model 200 contains the largest total element duration of all the models and therefore as more models

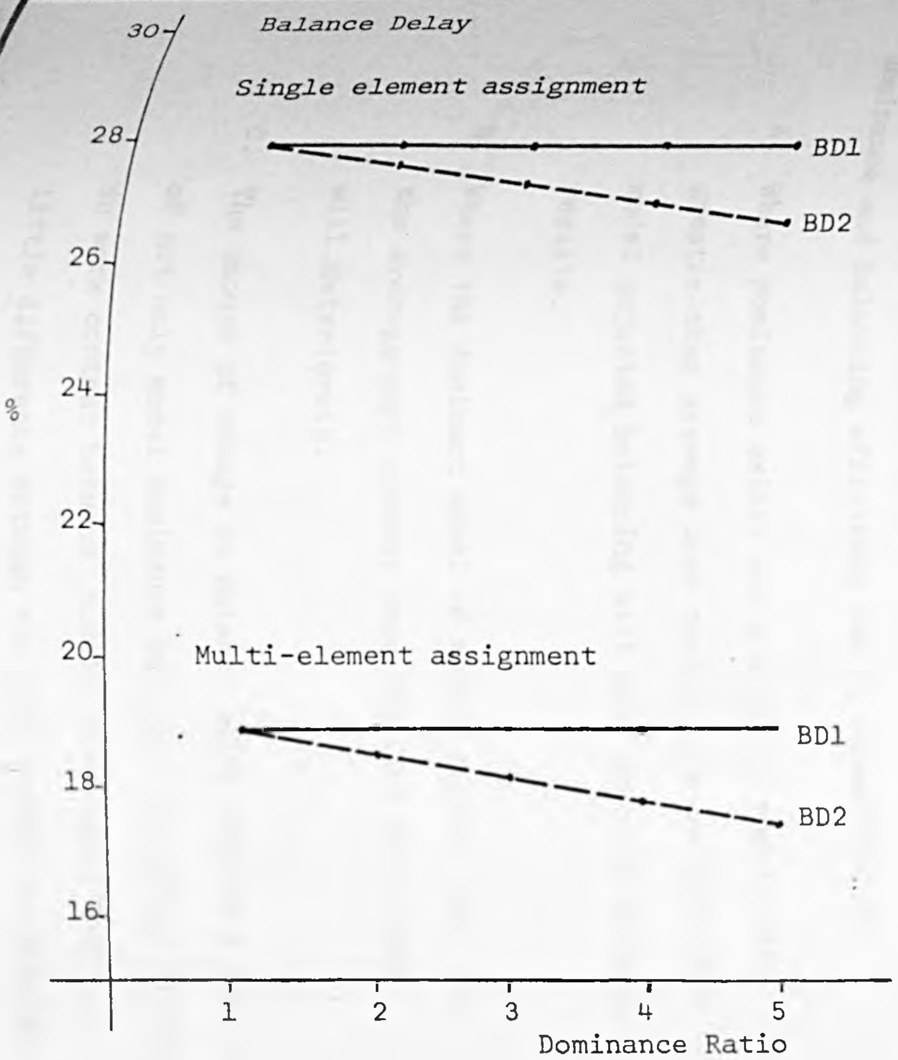


FIG. (6.12) EFFECT OF MODEL DOMINANCE ON BALANCE DELAY (MODEL 200)

FIG. (6.13) EFFECT OF MODEL DOMINANCE ON SMOOTHNESS INDEX (MODEL 200) are produced less time will be wasted overall. This is confirmed by Figure (6.14) which shows the change in Balance Delay as model 203 becomes dominant. Model 203 has the least work content (125 time units) and therefore as more model 203s are produced the amount of inefficient production will increase. The change in Balance Delay as models become dominant is however relatively small, the greatest difference between unadjusted Balance Delay (BD1) and Adjusted Balance Delay (BD2) being 3.09 in the case of model 200. The question arises therefore as to why there is so little change. The answer lies in the fact that there is little difference in the work content in the five models 200 to 204 (work content 132, 131, 130, 125 and 131 time units respectively). Had there been a considerable difference between the work content of each model then the change in Balance Delay would have been far more significant.

With respect to test series 5 the relationship between model dominance and balancing efficiency can be summarized as:

A. Where dominance exists and a model or models with greater than average work content are dominant then model adjusted balancing will give improved balance results.

B. Where the dominant model or models contain less than the average work content then the line efficiency will deteriorate.

C. The amount of change in Balance Delay will be a function of not only model dominance but also the actual difference in work content between models, i.e. where there is little difference between the work content of models,

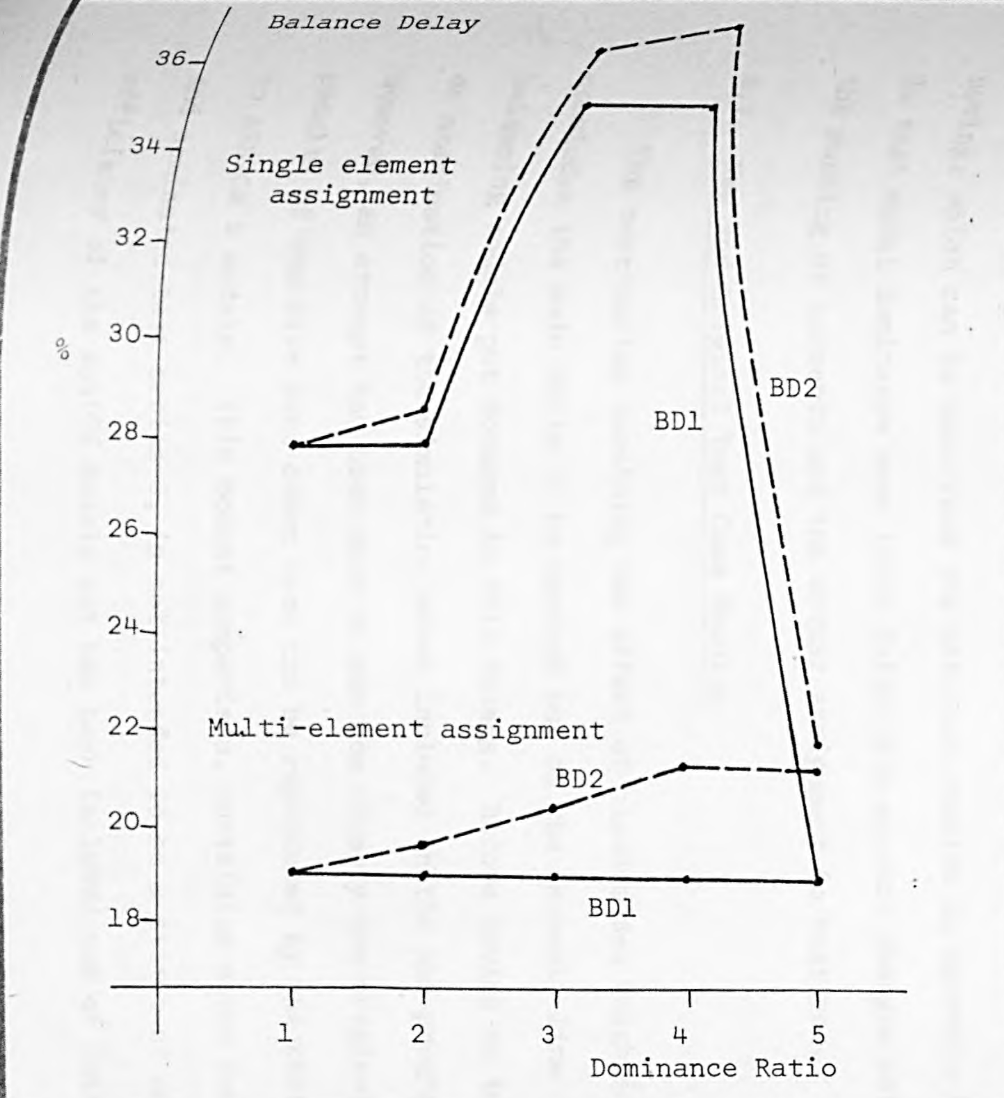


FIG. (6.14) EFFECT OF MODEL DOMINANCE ON BALANCE DELAY (MODEL 203)

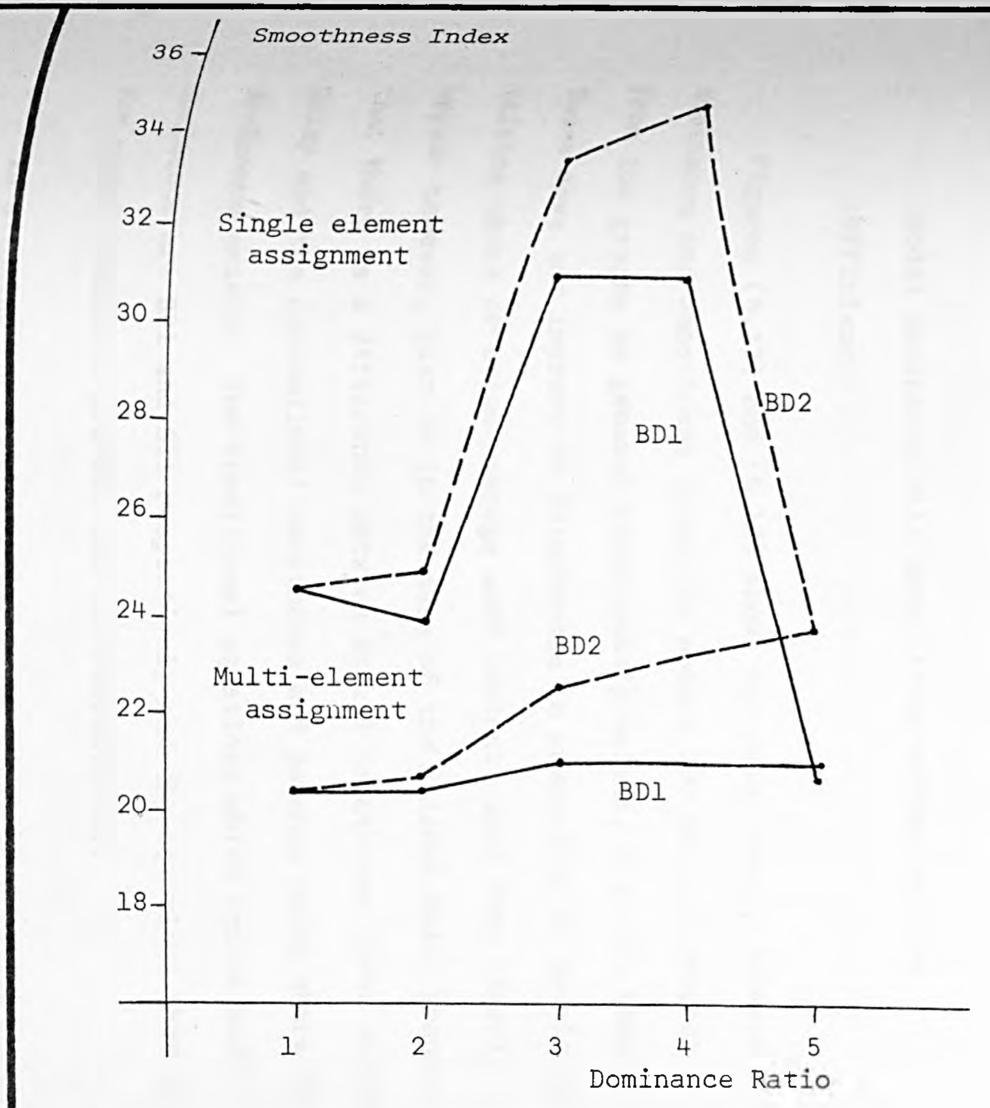


FIG. (6.15) EFFECT OF MODEL DOMINANCE ON SMOOTHNESS INDEX (MODEL 203) model dominance will have little effect on line efficiency.

Figures (6.13) and (6.15) shows the relationship between model dominance and Smoothness Index for models 200 and 203 respectively. From the graphs no general relationship exists, i.e. the Smoothness Index does not improve or deteriorate in proportion to models containing above or below average work content, what does clearly appear however, just as in the case of the balance delay graphs, is that there is a difference between actual Smoothness Index and Balance Delay and the conventional smoothness and Balance Delay where model dominance exists. The traditional equations which ignore model dominance are BD1 and SI1 respectively and the equations that adjust for model dominance are BD2 and SI2 respectively.

In allowing for model dominance the final observation worth noting, which can be seen from the detailed results in Appendix A, is that model dominance when taken fully into account changes both the ranking of elements and the actual assignment to stations.

6.7. New and Original Test Case Results

The test series examining the effect of mixed-model weighting concludes the main tests to be carried out on the assembly line balancing models put forward in this thesis. Before moving on to an examination of the simulation model included in the ALB programs, however, an attempt has been made to see how closely the original results of the five test cases used can be reproduced by the ASSIGN 1 to ASSIGN 3 models. This modest comparison, containing seven tests and nominated test series 6, is not intended to be a statement on the efficiency of the ASSIGN models but has been included out of interest and as further verification that the computer programs operate effectively. A summary of the results drawn from Appendix A are shown in the following table:

Problem	Original Solution	Test	Test solution
16 Element		141	CT=16, BD=1.7, SI=3.00
		142	CT=59, BD=2.26, SI=2.83
21 Element	CT=36, BD=0.7, SI=1.0	143	CT=37, BD=3.38, SI=4.12
30 Element	CT=44, BD=7.95, SI=11.22	144	CT=43, BD=5.81, SI=10.68
	CT=41, BD=1.2, SI=2.0		
45 Element	CT=69, BD=0.0, SI=0.0	145	CT=71, BD=2.82, SI-10.68
70 Element	CT=176, BD=8.95	146	CT=179, BD=1.94, SI=32.39
		147	CT=319, BD=3.71, SI=63.37

<u>TABLE (6.1) New and Original Test Case Results</u>

The 16 element problem was developed specifically to test out the computer program and has not therefore been published previously, examining a wide possible range of cycle times at varying levels of compressibility during this development, the best results achieved were a Balance Delay of 1.7 and a Smoothness Index of 3.0 under conditions of a cycle time of 16 and ninety percent compressibility. In the conventional balancing problem, i.e. allowing no compressibility, the best result achieved was a Balance Delay of 2.26 and Smoothness Index of 2.83 with cycle time of 59. In both cases the single station solution has been excluded from consideration and these results are given for record purposes.

The 21 element problem originating from Wild (48) was originally used to demonstrate the Kilbridge and Wester balancing method and, as commented earlier in the review of balancing procedures, this problem was eminently suitable for the cycle time and procedure in question as evidenced by the resulting Balance Delay of 0.7 and Smoothness index 1.0. Using ASSIGN 1, with no compressibility, the best result achieved by the ALB programs was a Balance Delay of 3.38 and a smoothness index 4.12 for a cycle time of 37.

The 30 element problem given by Sawyer (36) was applied to both Kilbridge and Wester and rank positional weight procedures, noting that the problem involved a small amount of element grouping and fixed station elements. Ignoring these limitations and treating the problem as a straight forward balancing case, the best result achieved by ASSIGN 1 was a Balance Delay of 5.81 and Smoothness Index of 10.68 at a cycle time 43. Although this represents a better result than the rank positional weight solution of Sawyer's, this is not in reality a fair comparison as results are sensitive to the cycle time taken and therefore different results would have been obtained for cycle times of 41 and 44.

The 45 element problem, originating from Kilbridge and Wester, is an excellent example of a problem eminently suited to a particular technique, at a cycle time of 69 perfect balancing was achieved using Kilbridge and Wester approach. The best result obtained with the ASSIGN procedures was a Balance Delay of 2.82 and Smoothness Index 10.68 under conditions of no compressibility and 71 cycle time.

The 70 element problem published by Tonge (42) achieved a Balance Delay of 8.94 at a cycle time of 176. In order to achieve the cycle time of 176 Tonge allowed the breaking up of elements with work content greater than 176, to approximate to this condition therefore the ALB version of the problem allowed fifty percent compressibility on all elements and resulted in a Balance Delay of 1.94 at a cycle time of 179. Running the problem without compressibility produced a Balance Delay of 3.71 at a cycle time of 319.

Test series 6 conclude examination of balancing models.

Simulation

6.8. Line Speed Variation

In the development of the balancing and assembly line design models an important distinction has been made between the balancing of an assembly line and the subsequent operation of that line. In particular three of the balancing parameters are likely to change from the estimated conditions used for balancing when full production is taking place. These three changes are changes in line speed, the use of extended stations for overcoming temporary work variation and, in the case of mixed model production, possible changes to the product mix. In test series 7 the effect of changing line speed is examined with respect to differing balancing strategies.

The simulation model was used on a twenty unit single model program where line speed was allowed to vary between -25 and +25 percent of the estimated conditions at balancing (actual line speed variation used -25, -10, -5, 0, +5, +10 and +25 percent). The simulation exercise was run on four of the 16 element balancing problem solutions, i.e. 50%, 75%, 95% and 99% confidence on variable element durations.

Figures (6.16) and (6.17) show the unused time available and the lost time respectively that resulted from the simulation studies, noting that closed work stations were specified and that station variability, as given in Chapter 5, was used. Examining firstly the

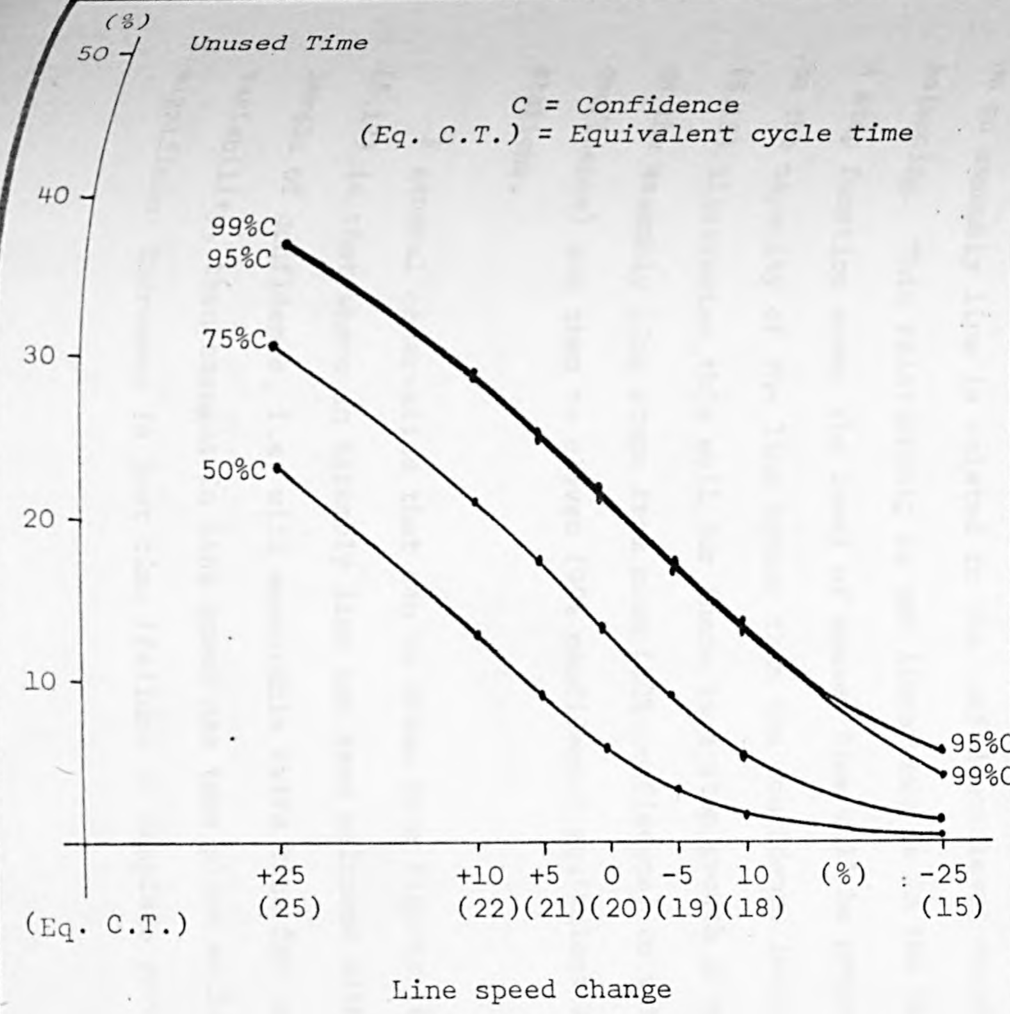


FIG.(6.16) EFFECT OF LINE SPEED ON PERCENT UNUSED TIME.

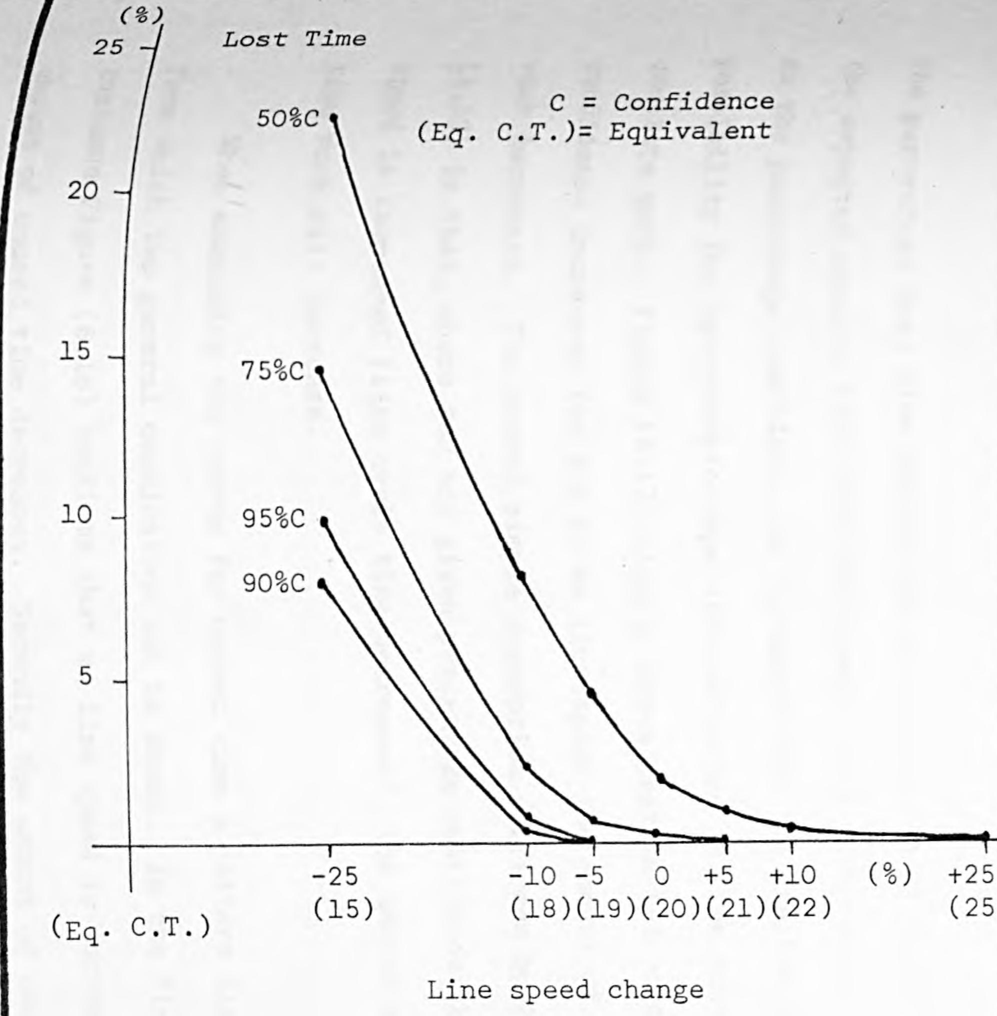


FIG. (6.17) EFFECT OF LINE SPEED ON PERCENT LOST TIME.

the percentage lost time curves for varying levels of confidence the expected results have been confirmed. This expectation was that as the percentage confidence is increased then the greater the possibility for operators to cope with variation in time taken to complete work. Figure (6.17) clearly shows that as the percentage confidence increases for any given line speed the amount of lost work decreases. The second simple assumption confirmed by Figure (6.17) is that, where for any given percentage confidence the line speed is increased (line cycle time decreases), the amount of lost time work will increase.

When examining the curves for unused time a pattern also emerges from which two general conclusions can be drawn. In the first instance Figure (6.16) confirms that as line speed is increased the amount of unused time decreases. Secondly the amount of unused time on an assembly line is related to the confidence level required at balancing. This relationship is not linear but is in the nature of a step function where the level of unused time will be proportional to the capacity of the line rather than the confidence level. Figure (6.16) illustrates this well for there is a step growth is unused time as the assembly line steps from nine (50% confidence) to ten (75% confidence) and then to eleven (99% confidence) equivalent simple stations.

A general observation that can be drawn from Figures (6.16) and (6.17) is that where an assembly line has been balanced with high levels of confidence, i.e. with measurable extra time for operator variability, then changes in line speed can take place without significant increases in lost time (failure to complete work).

When operating an actual assembly line the opportunity to change line conditions from those of the estimated balancing conditions will mean that the original estimates of balancing efficiency (Balance Delay) and evenness of work distribution (Smoothness Index) could be substantially different from those actually achieved. Taking the actual simulation times as each model is manufactured, actual simulation Balance Delay and Smoothness Index can be calculated as illustrated for the four confidence level test cases at line cycle time 20, which are shown in Figures (6.18) and (6.19). These figures show that there is a general relationship between balancing and simulation results but that the actual simulation figures are worse proportionally than those produced at the balancing stage. The explanation for this widening gap between simulation and balance results is that at balancing it is assumed that every element will take the additional time to be allowed, whilst in reality, as the simulation shows, the actual time will be based on an average of the ordinary normal duration, thus time taken on average will be less than the confidence allowance and greater idle time and work variability will result.

Examining this relationship more closely for changes in line speed it can be seen that as the line speed decreases (available time increases) more idle time will be encountered, thus increasing Smoothness Index and Balance Delay. These increases are shown for the test problems in Figures (6.20) and (6.21).

6.9. Extended Stations

In the review of assembly line balancing procedures and in the subsequent creation of the ASSIGN balancing models the view was put forward that extended type stations should not be considered at the

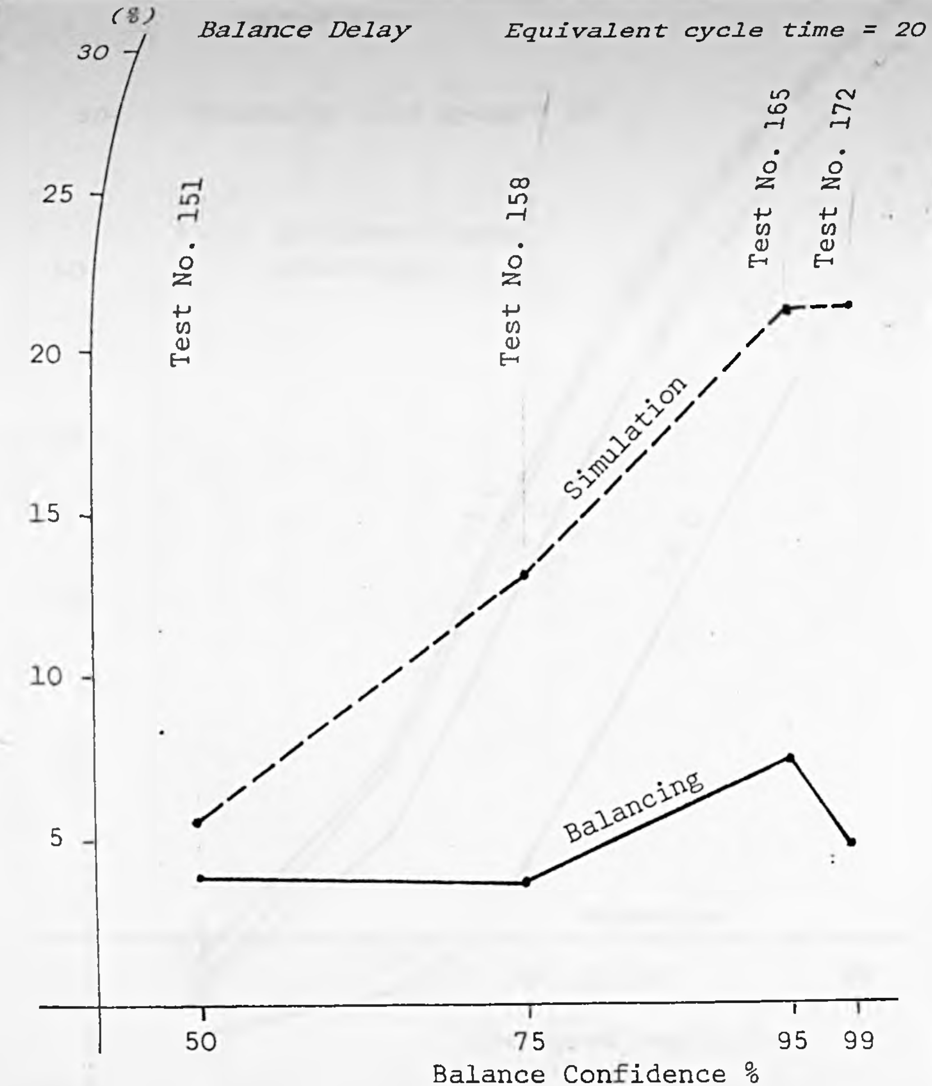


FIG. (6.18) RELATIONSHIP BETWEEN SIMULATION BALANCE DELAY AND BALANCING CONFIDENCE.

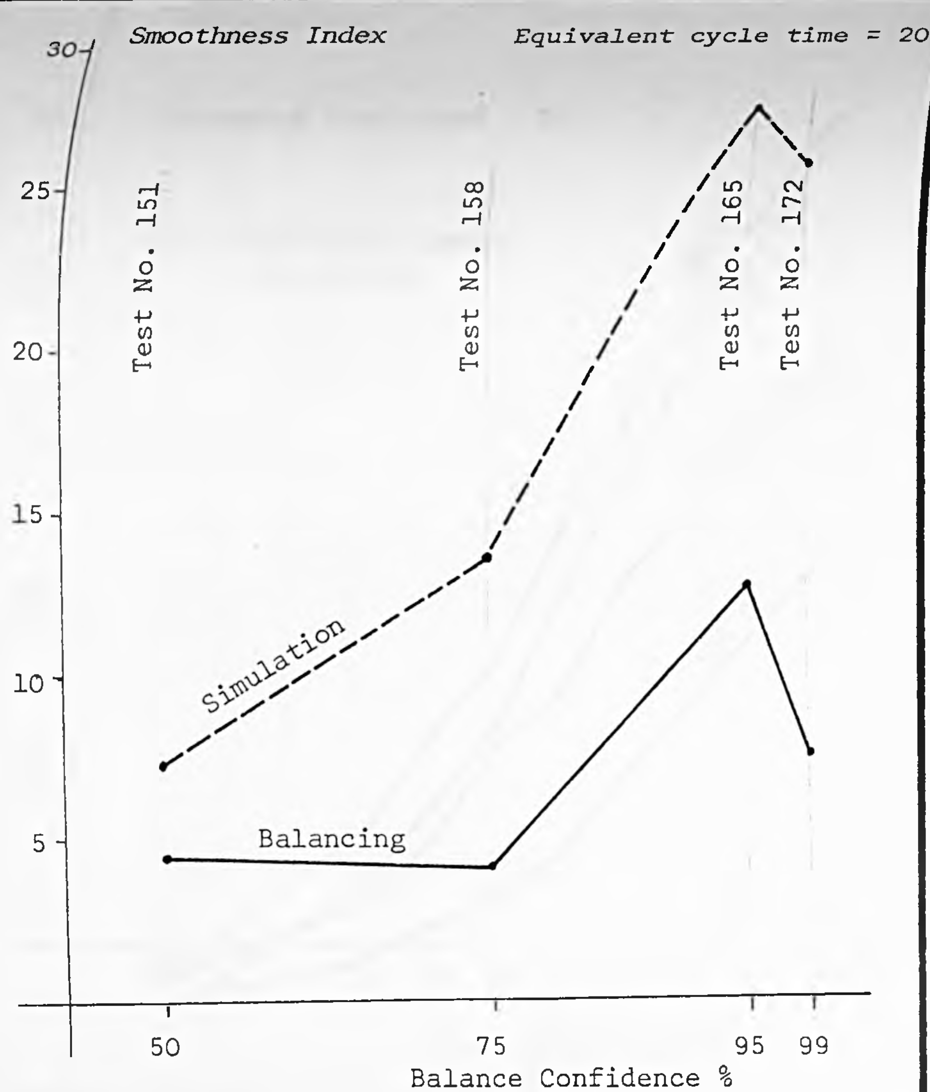


FIG. (6.19) RELATIONSHIP BETWEEN SIMULATION SMOOTHNESS INDEX AND BALANCING CONFIDENCE.

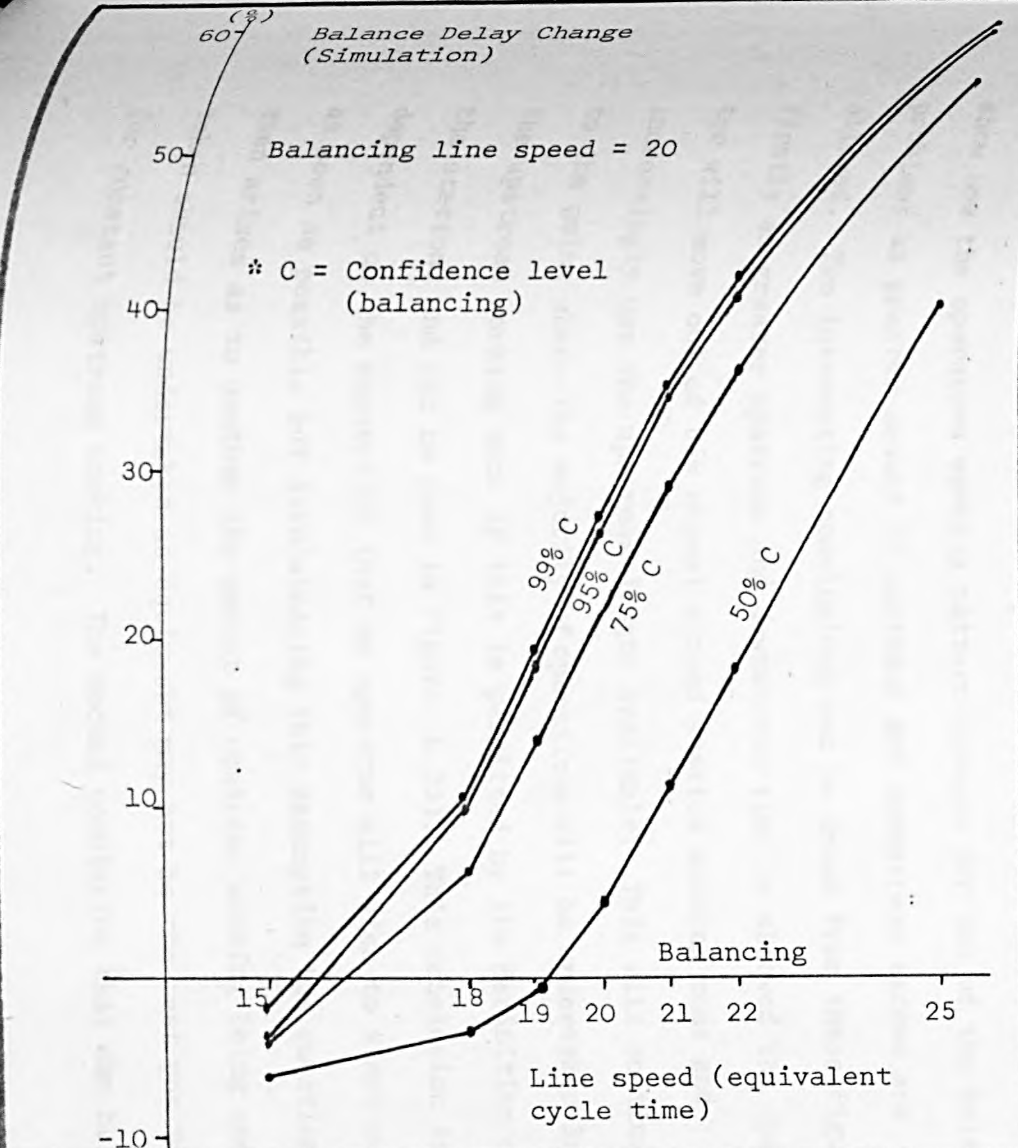


FIG. (6.20) EFFECT OF LINE SPEED ON BALANCE DELAY.

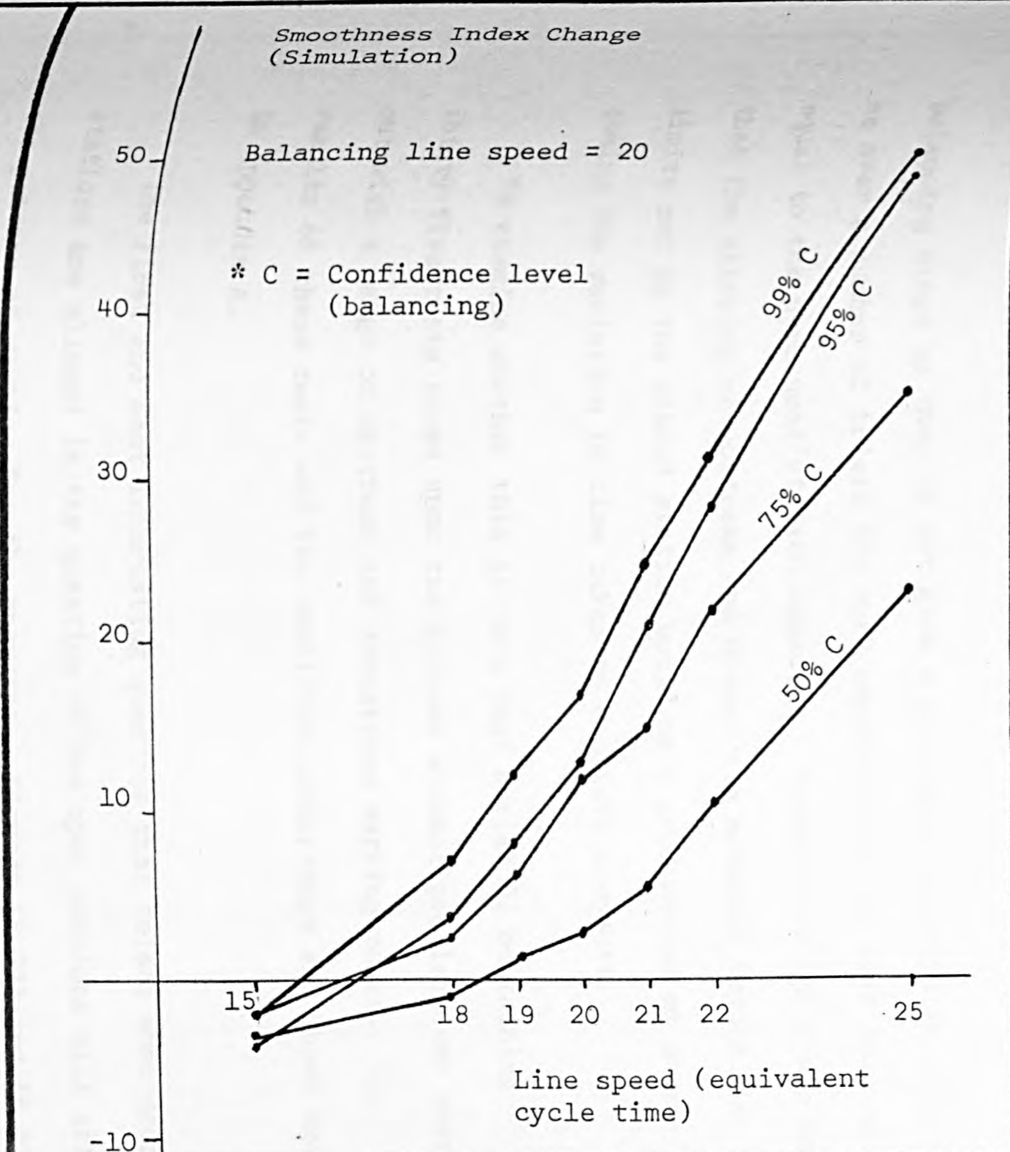


FIG. (6.21) EFFECT OF LINE SPEED ON SMOOTHNESS INDEX.

balancing stage as they do not give a permanent increase in capacity as over a number of trials the work assigned must be less than or equal to the permanent station capacity. However the point was made that the allowing of upstream and downstream movement beyond the limits set by the closed station would be a good method of overcoming the variation in time taken to complete elements.

To examine whether this is true test series 8, containing thirty-five tests based upon the sixteen element problem, was carried out with a range of upstream and downstream working zones. The results of these tests and the conditions undertaken are shown again in Appendix A.

The first and most interesting question that arises when open stations are allowed is the question of how open stations will affect the pattern of working for the operator. Figures (6.22) and (6.23) show how the operators working pattern changes for two of the balancing problems as greater amount of upstream and downstream excess are allowed. Two interesting conclusions can be drawn from these figures. Firstly as greater upstream and downstream time is allowed the operator will move out of his normal closed station working zone and increasingly use the upstream length available. This will continue to the point where the majority of operations will be undertaken in the upstream working zone if this is permitted by the definition of the station, and can be seen in Figure (6.23). This conclusion is dependent on the assumption that an operator will wish to start work as soon as possible but acknowledging this assumption the question then arises as to whether the amount of upstream working being undertaken should be undertaken as equipment may not be the best position for constant upstream working. The second conclusion that can be

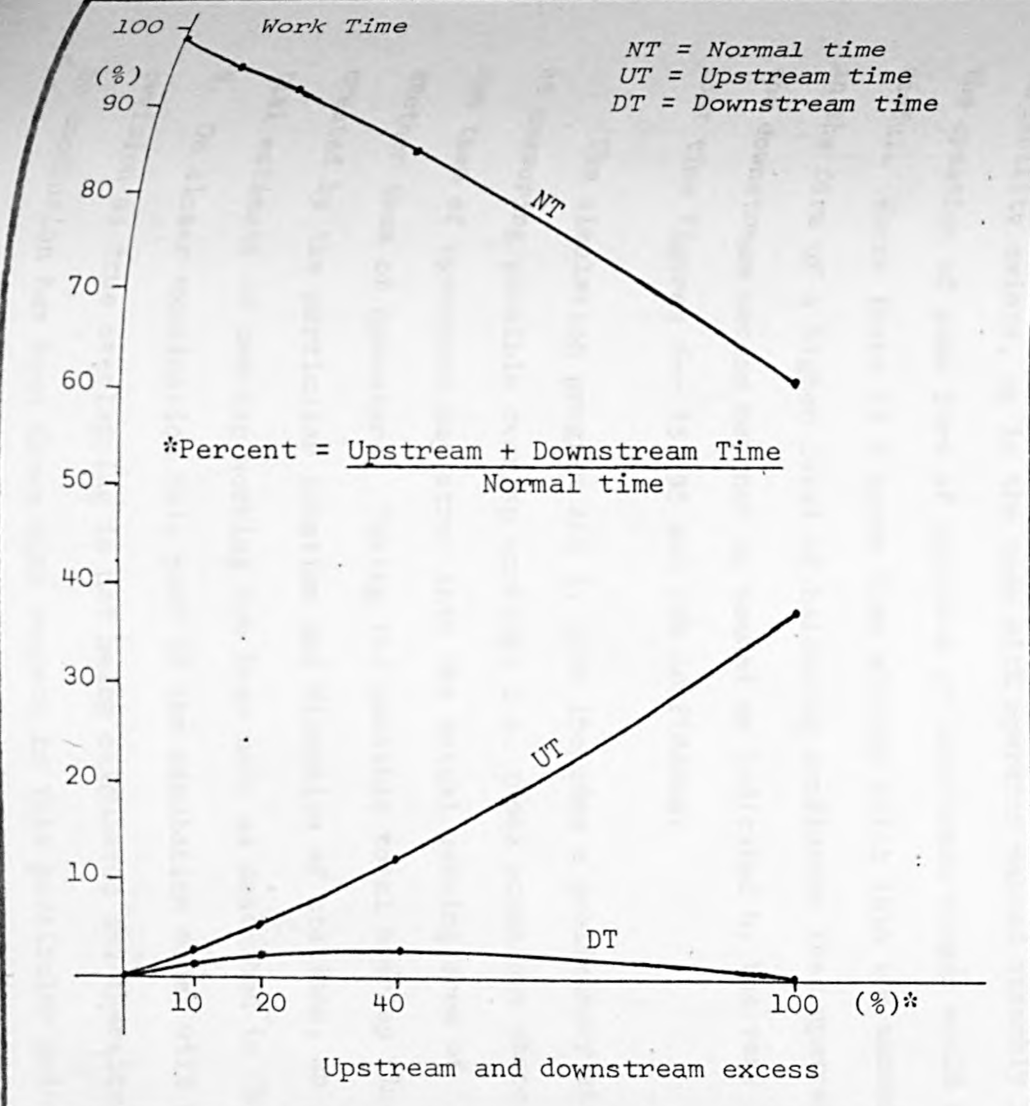


FIG. (6.22) DISTRIBUTION OF WORK WITH 50% BALANCING CONFIDENCE AND OPEN STATIONS.

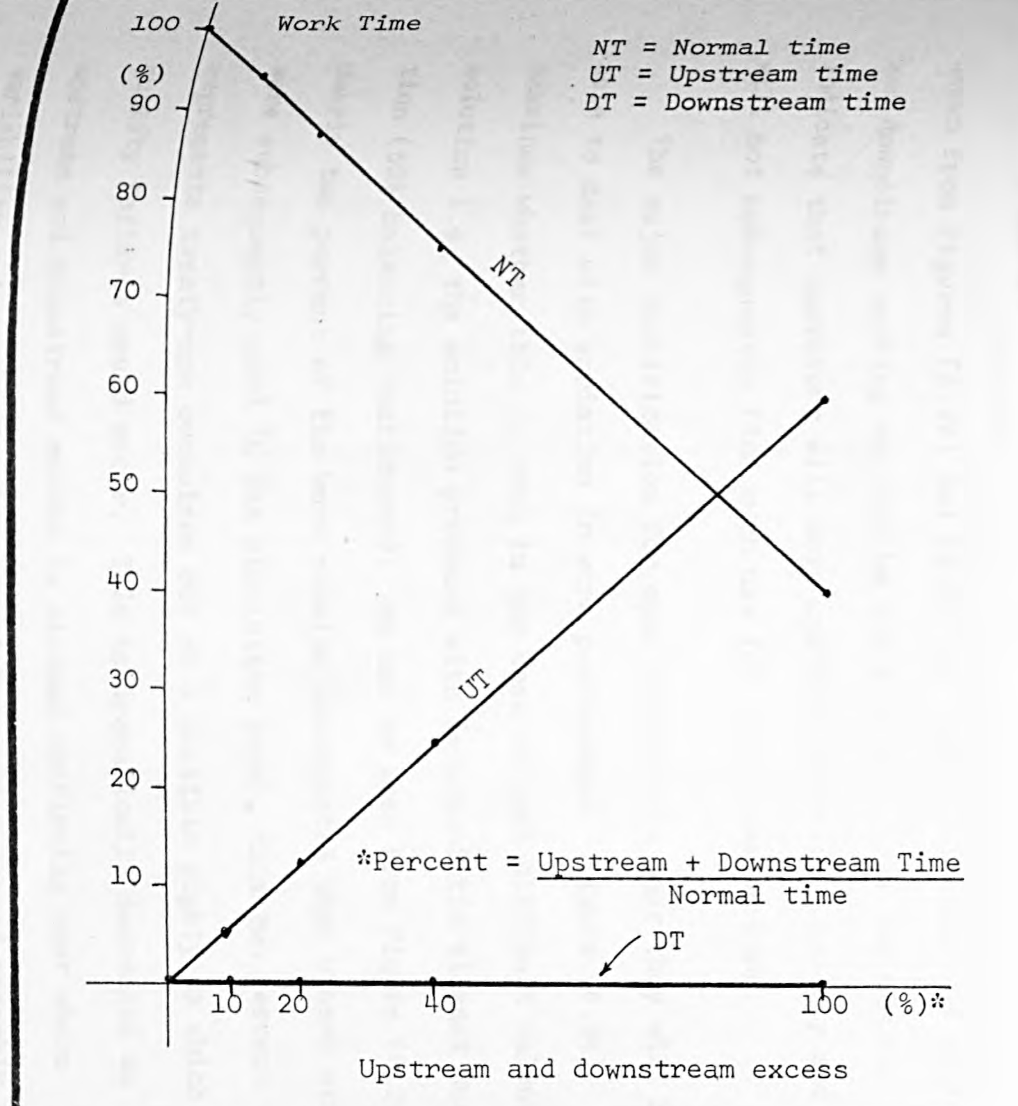


FIG. (6.23) DISTRIBUTION OF WORK WITH 99% BALANCING CONFIDENCE AND OPEN STATIONS.

drawn from Figures (6.22) and (6.23) is that equal amount of upstream and downstream working may not be the best policy as the figures indicate that operators will move upstream relatively quickly and will not subsequently find much use for downstream working.

The major justification for open stations is that they will be able to deal with variation in work performance. Figure (6.24) examines whether this is true in the case of most difficult balancing solution i.e. the solution produced with deterministic element duration (50% balancing confidence). As can be seen from Figure (6.24) nearly two percent of the work remains uncompleted when closed stations were subsequently used in the simulation model, this two percent represents twenty-one occasions out of a possible eighty on which quality failures would occur. This is dramatically decreased as upstream and downstream excess is allowed confirming that where variability exists, as is the case with operator manned assembly lines, the creation of some form of upstream or downstream excess would be useful. Where there is a spare time already built into the assembly in the form of a higher level of balancing confidence then upstream and downstream excess may not be needed as indicated by the very low lost time figures for 75, 95 and 99% confidence.

The simulation program ALB 5, also includes a preliminary attempt at measuring possible overlap working, i.e. those occasions where one team of operators may stray into the actual working area of another team of operators. Taking the possible total overlap time created by the particular location and dimension of stations, an initial estimate of overlap working has been made as described in Chapter 5. On closer examination this part of the simulation model will need revision as true overlapping is not being calculated and therefore no conclusion has been drawn with respect to this particular point.

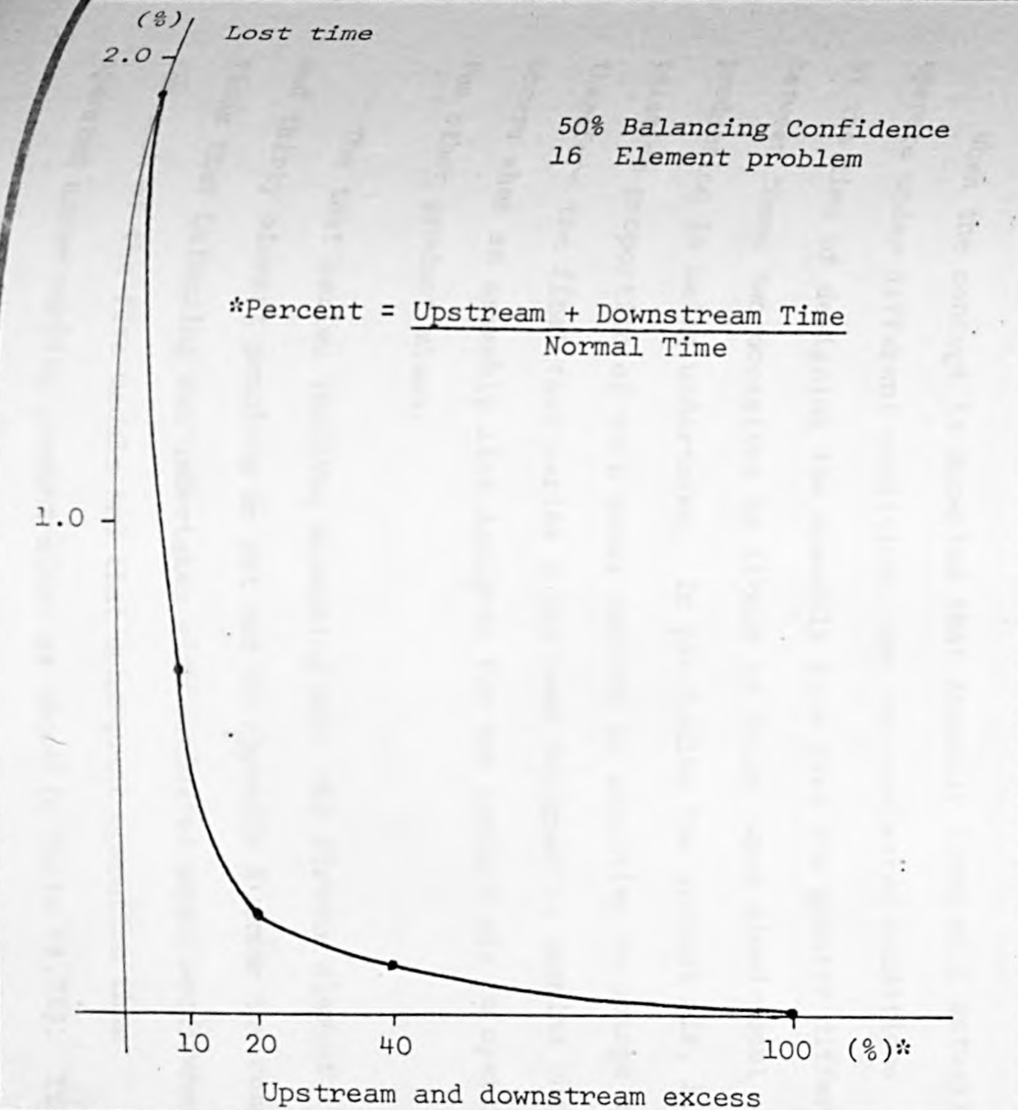


FIG. (6.24) DISTRIBUTION OF LOST TIME WITH 50% BALANCING CONFIDENCE AND OPEN STATION.

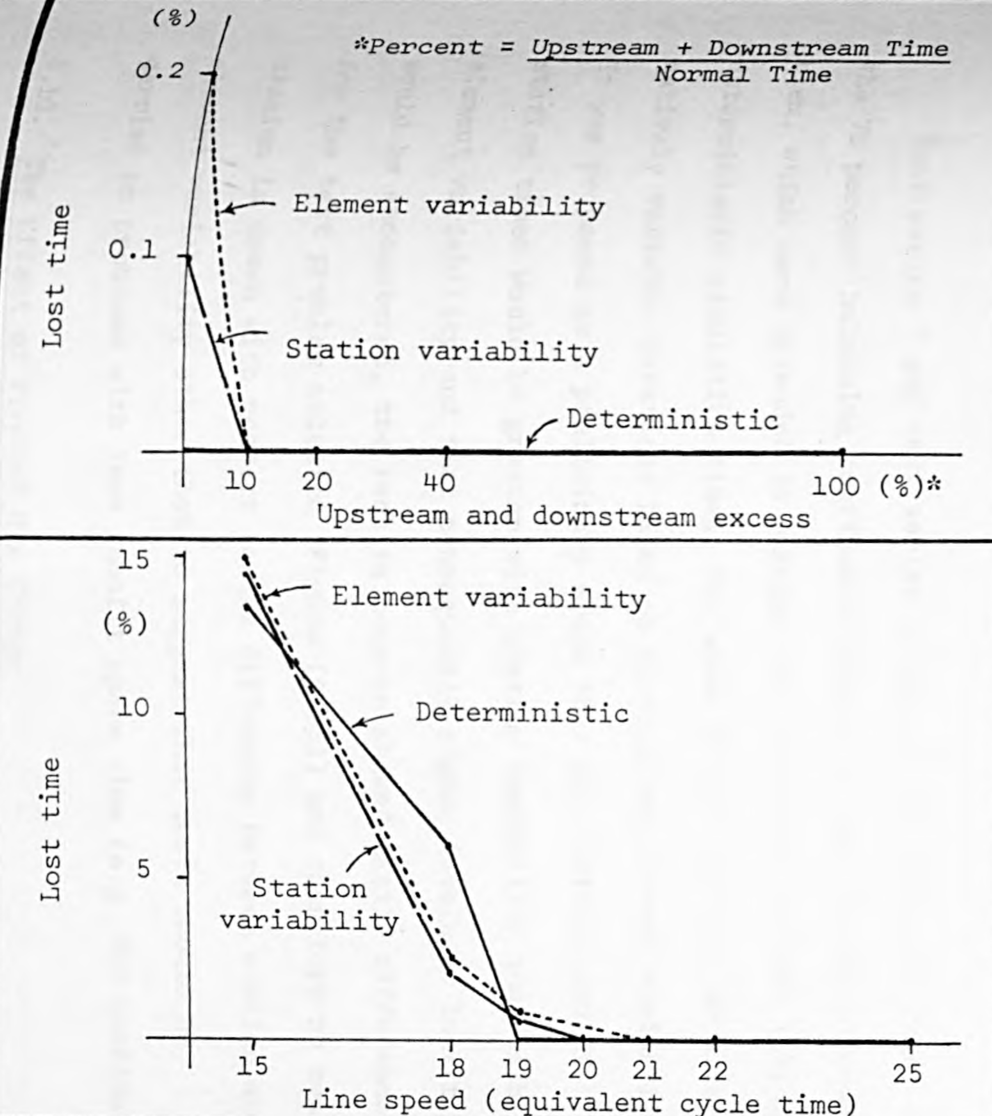


FIG. (6.25) DISTRIBUTION OF LOST TIME WITH DETERMINISTIC, STATION AND ELEMENT VARIABILITY.

Test series 7 and test series 8 contain six test sets based on the 75 percent balancing confidence version of the 16 element problem, which were intended to examine the difference between taking deterministic simulation times, for work at each station, or alternatively variable durations based on station and element variability. It was proposed as a preliminary stage that the distribution of station times would be greater with station variability than with element variability and that consequently higher levels of lost time would be encountered, the results however showed little difference for the test problem selected (Figure (6.25)) and therefore no conclusion is drawn with respect to the difference between station and element variability other than to suggest that tests should be carried on problems with less inbuilt spare time (e.g. 50% confidence).

6.10. The Effect of Product Mix Change

When the concept is accepted that assembly lines will actually operate under different conditions then the estimated conditions at the time of designing the assembly line then the greater difference between these two occasions is likely to arise when mixed-model production is being undertaken. In particular the product mix, i.e. relative proportion of each model desired is sensitive to change and therefore the final test series 9 has been designed to examine what occurs when an assembly line designed for one product mix is operated for other product mixes.

The test series involves examining both the sixteen element and thirty element problems as set out in Appendix A under the conditions that balancing was undertaken with estimated equal requirement for each of the five models and that subsequent operation then operated under varying product mixes as shown in Table (A.21). It should be noted in the results presented that as balancing involved ninety percent compressibility and equal weighting for all four possible Balance Delay (BD1 - BD4) and Smoothness Index (SI1 - SI4) values were the same, and that as the simulation program also involved ninety percent compressibility the two values of Balance Delay possible (BD1 and BD3 equivalent) and Smoothness Indices (SI1 and SI3 equivalent) were also equal.

The effect on Balance Delay of varying product dominance for each of the five models is shown in Figures (6.26) and (6.27) for the sixteen element and thirty element problems respectively. From these figures three conclusions can be drawn. Firstly when actual completion times are taken into account rather than work content time durations the estimated Balance Delay and Smoothness Index will not be obtained even under the same simulation conditions as existed under balancing. The only exception to this would be where simulation and balancing have both been based on deterministic duration. The second conclusion that appears is that as model dominance increases the balance delay will change. Where the increasingly dominant model contains more than the average work content then efficiency will improve and where the increasingly dominant model contains less than the average work content line efficiency will deteriorate. The models containing above work content were model 200 and 203 for the sixteen element and thirty element problem respectively and both show decreasing Balance Delay values and again the models with the lowest work content (203 and 200 for the sixteen and thirty element problem respectively) both showed increases in Balance Delay values as their dominance increased. The conclusion is drawn therefore that if product mixes change the efficiency of the line will depend upon whether models with greater than average work content become dominant or not.

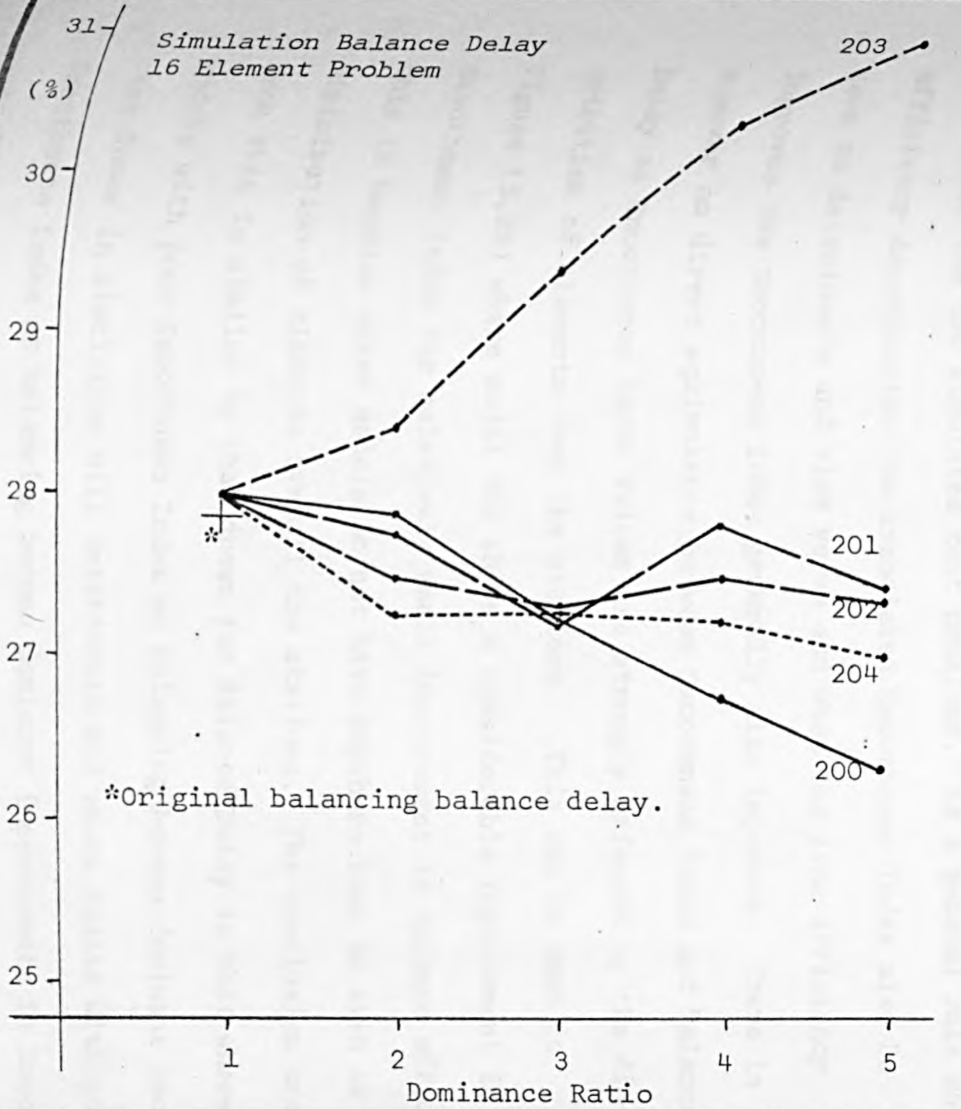


FIG. (6.26) VARIATION OF BALANCE DELAY FOR 16 ELEMENT PROBLEM DURING SIMULATION.

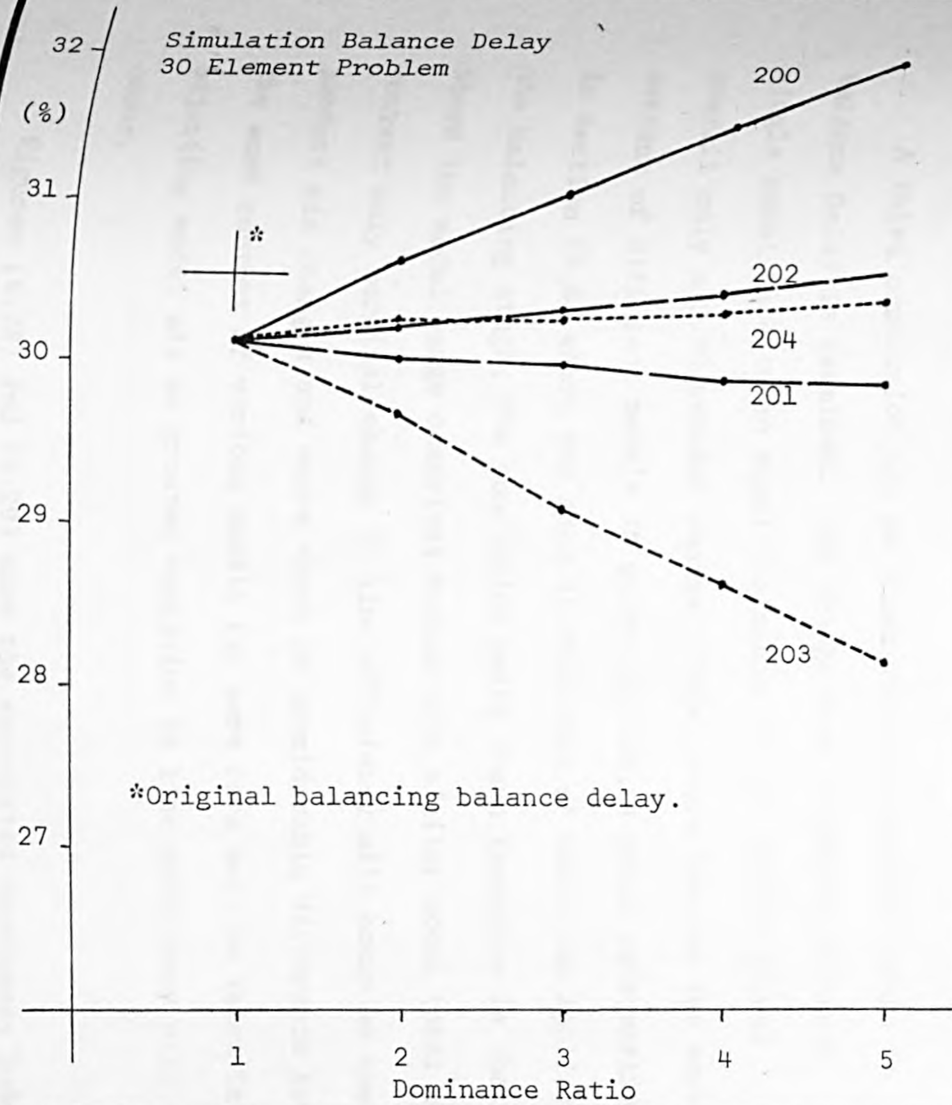


FIG. (6.27) VARIATION OF BALANCE DELAY FOR 30 ELEMENT PROBLEM DURING SIMULATION.

A third conclusion can be drawn when the overall change in Balance Delay is examined. The change from a totally dominant single model case to an equal dominance for all models showed overall only a 2.90 percent change. This occurs because the work content of different models is quite similar, a point made earlier in section (6.6) where the same distribution of model was applied at the balancing stage, the conclusion being drawn therefore is that where the model range comprises models with similar model total work content only marginal change in line efficiency will occur as the product mix changes and where there is considerable difference between the work content of various models far more care must be taken in adjusting model mix as greater variation in line efficiency will occur.

Figures (6.28) and (6.29) show the associated Smoothness Index values for the two simulated test problems. As a general rule when efficiency deteriorates the associated Smoothness Index also be seen to deteriorate and vice versa and when the line efficiency improves the Smoothness Index generally also improves. There is however no direct equivalence between Smoothness Index and Balance Delay as Smoothness Index values are strongly affected by the distribution of elements over the stations. This can be seen in Figure (6.29) where model 201 shows a considerable improvement in Smoothness Index for relatively small improvement in balance efficiency, this is because other models do not have anywhere near as even as distribution of elements overall the stations. The conclusion drawn from this is similar to that drawn for Balance Delay in that where models with poor Smoothness Index at balancing become dominant Smoothness Index in simulation will deteriorate and where models with good Smoothness Index at balancing become dominant improvements in Smoothness Index can be expected.

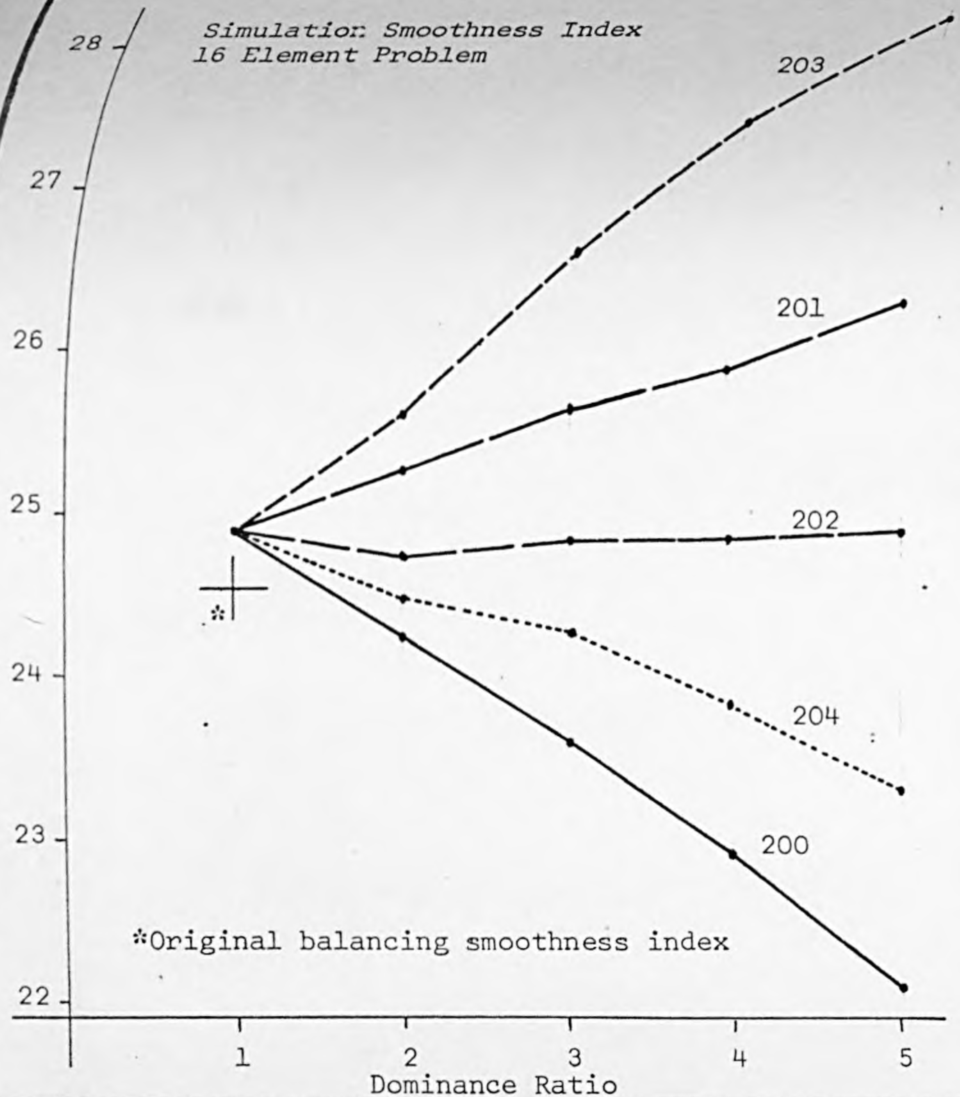


FIG. (6.28) VARIATION OF SMOOTHNESS INDEX FOR 16 ELEMENT PROBLEM DURING SIMULATION.

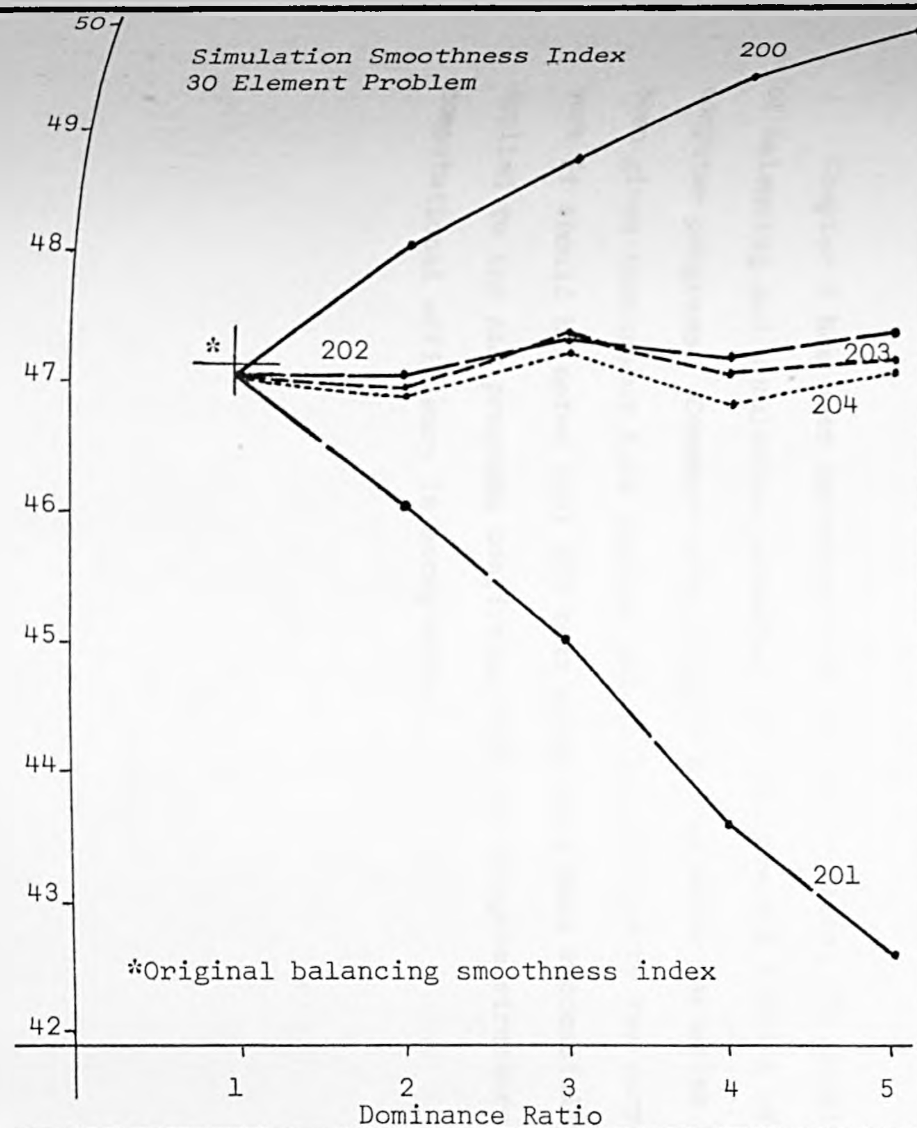


FIG. (6.29) VARIATION OF SMOOTHNESS INDEX FOR 30 ELEMENT PROBLEM DURING SIMULATION.

Chapter 6 has been concerned with two major tasks, the examination of balancing and simulation parameters and the overall testing of the computer programs. Comments with respect to the major variables have been given throughout this chapter and as a conclusion to the current work it should be noted that 273 test cases have been successfully applied to the ALB programs confirming that the program structure and computational efficiency is acceptable.

CHAPTER 7

FUTURE WORK

7. FUTURE WORK

The models for balancing and simulating assembly line operations that have been developed in Chapters 4 and 5 and the subsequent examination of the major influences on design and operation of assembly lines in Chapter 6 each suggest potential areas for further development. Amongst the more important developments brought forward by the existing work can be included:

7.1. Advances in the Balancing Models

Accounting for the effect of station zoning

The balancing models ASSIGN 1 to ASSIGN 3 consider only the basic restriction of precedence ordering when assigning elements to work stations. A step towards wider applications of the models would be achieved if in addition zoning restrictions imposed on work elements could also be taken into account, particularly as provision has already been made in the ALB computer programs and files for inputing the necessary zoning information (see Appendix B). This would require the development of modified models for assignment, which because of the increased level of restrictions may not produce the same levels of efficiency in balancing results.

Multi-operator elements

For certain balancing problems it is not unknown for specific work elements to require at least two or more operations for effective completion. As the three balancing models are specifically designed to cope with enlarged multi-operator stations specific multi-operator elements can be allowed for after minor modification to each model. The following two minor changes to ASSIGN 1, ASSIGN 2 and ASSIGN 3 are recommended:

(a) The maximum station size should be checked to ensure that it is equal to or greater than the largest number of operators needed by any one element.

(b) When considering individual elements for assignment, ensure in addition to other acceptance checks that the station size is equal to or greater than the number of operators needed.

Pregrouping of elements

With assembly line production there may arise the need for the use of very expensive equipment or equipment that needs isolation from other work. To solve this problem it may be necessary to develop balancing models which allow for pregrouping of work elements. This will require the development of new ASSIGN models but it is worth noting that again provision has been made for inclusion of the necessary information within the existing ALB programs and files. (See Appendix B.)

Further examination of assignment criteria

The introduction of work compressibility and the existence of mixed model production gave rise to four differing values of both Balance Delay (BD1-BD4) and Smoothness Index (SI1-SI4). These formulae challenge the accuracy of traditional Balance Delay and Smoothness Index under the new balancing conditions and futher work, particularly with the simulation model, may identify the more suitable criteria. In addition future work should consider in more detail the suitability of the information provided by the simulation model.

Multiple solution approach

The approach taken with the problems used in this thesis has been one of assuming a single specific cycle time and subsequently producing the single most appropriate solution according to the relevant balancing models.

When seeking the highest balancing efficiency however a better solution may be found by taking a limited set of cycle time based close to the desired output range and to produce a set of solutions using appropriate models, with the objective of selecting eventually the most efficient. At present this can be achieved by repeating a particular problem at differing cycle times however a more formal inclusion of examining a cycle time range would be an improvement.

Two points can be put in support of this additional approach; firstly it is not normally the case that the output rate of assembly lines is super critical i.e. output must be met exactly. Quality control losses alone usually make output rates slightly uncertain. Secondly in comparing results obtained originally in the problems used in Chapter 6 with the best results obtained by the three models ASSIGN 1 to ASSIGN 3, results could be seen to be sensitive to actual cycle time and that improved results could be obtained with minor changes in output and hence acceptable cycle time.

Mixed manual-automated work stations

Increasingly assembly lines for large products are becoming a mixture of automated and manually operated stations and therefore it may be suitable to consider new balancing models to allow for this case. At present the assignment models can consider elements as either all deterministic or all variable, with a given level of confidence for the normal variance involved. A more suitable approach for future models may be to pre-specify stations as either automated (deterministic element durations) or manually operated (variable element durations) and in combination with this to specify selected stations for elements where desirable.

7.2. Advances in the Simulation Model

Mixed manual-automated simulation

Just as the balancing models are either all deterministic or all variable in their treatment of work elements so the simulation model gives the same uniform treatment to work elements. In the case of the simulation model however it would be particularly appropriate to allow mixed combinations of manual and automated stations as the use of the simulation model is the most suitable approach for deciding whether to automate particular stations or not.

This change to the simulation model can be achieved with relative ease by including in the simulation information structure a list of stations to be treated as automated. The computer program ALB 5 will then use this list to suppress any variability.

Overlap station operation

The simulation model presented in Chapter 5 included an initial attempt at identifying overlap working between stations but this was found not to be truly representative of actual overlap working on the occasions where overlap working was possible. A more accurate record of overlap working should therefore be developed particularly for those cases where quality deterioration may result as a consequence of successive stations attempting to work at the same point.

Abbreviated simulation model

The simulation model ALB 5 is very detailed and can be time consuming for large production schedules. Management however may not require all the simulation output in certain cases, particularly where planning decisions are the main interest. In this situation it would be appropriate to have the facility to abbreviate the simulation and to restrict output and calculations to those associated with relevant planning decisions. Within this type of information would be included:

Expected start time

Expected finish time

Shut-down periods during production run

Final analysis of performance.

Specification of operating conditions

The investigations carried out by the simulation model show that the conditions under which assembly lines are operated can affect considerably the estimated efficiency of the assembly line produced at the balancing stage. A future development of this approach therefore could be the specification of operating conditions for assembly lines as part of the requirements for achieving required levels of performance, the operating conditions being obtained through the use of the simulation model.

7.3. General Future Work

Increased work station choice

Within the three assignment models presented two choices of work station type were available; simple single manned stations and enlarged stations, the choice between the two being made on the basis of balancing efficiency. In the simulation model the versatility of station definition is increased by allowing for any combination of open, partially open or closed stations. A further development in model versatility however would be to allow also the inclusion of the two types of extended station in the balancing and simulation models. By adding the two extended station types i.e. parallel duplicated stations and parallel rotating type stations, a wider choice of solution is obtained and consequently the possibility of higher efficiency levels is also improved.

Examination of minimum and effective time

The concept of work compressibility creates in addition to the more conventional normal element duration two further time intervals; minimum element duration and effective element duration. In subsequently simulating the operation of enlarged stations, where work compressibility takes place, average time is taken as the sum of element normal durations plus a random proportion of the standard deviation of all elements (obtained by taking the square root of the sum of element variances). This time is then divided by station size and compared against minimum duration to obtain effective element duration.

This treatment assumes a linear and relatively simple relationship between operations, their colleagues and their work. As a consequence a further examination of the behavioural aspects of group working and in particular studies of operating practices on actual assembly lines would enhance further practical development of the assignment and simulation models.

Computing improvements

At present the ALB computer programs are operated in batch mode on an ICL 1906S computer and therefore has the disadvantages of comparatively slow turnaround i.e. job processing time. The first recommendation for future work with respect to computing facilities therefore is to recommend a move towards an interactive computing service as a means of decreasing job turnaround time and thereby making the ALB programs a more powerful management aid.

The second general recommendation with respect to computing is to move towards making greater use of computing facilities available, with the computer being made capable of automatic provision of precedence diagrams, line layouts and balance results in graphic output form.

CHAPTER 8

CONCLUSIONS

8. CONCLUSIONS

Review and the Assembly Line Problem

Single Model Production

1. Single model balancing of simple stations is an area that has been widely investigated using enumeration, mathematical linear programming and heuristic approaches.

2. Enumeration procedures are capable of determining good or optimal solutions for limited size problems only. For practical balancing problems the considerable computing required would need to be justified, acknowledging that for some problems the computing time required would be beyond reason.

3. Linear programming approaches are also unsuitable for practical balancing problems due to the excessive numbers of equations and variables required to cover balancing limitations.

4. The nature of the assembly line balancing problem indicates that the best solution approach is a balance of heuristic procedure and limited enumeration.

5. Rank positional weight procedures can produce good results for practical size problems and are well defined and precise routines. For this reason Rank Position Weight is suitable for further extension.

6. So far only limited comparative studies between balancing procedures have been carried out. The three comparisons available covered diverse examination conditions and did not

indicate that any one procedure dominated.

7. Of the different types of solution approach examined compromises between simple heuristic and limited enumeration pre-dominated over single-solution methods, supporting conclusion 4.

Mixed Model Production

8. Mixed model production can vary between the two extremes of totally dissimilar products and products with a high proportion of common elements. A single mixed model balancing procedure will not produce satisfactory results with such a wide variety of possible problems.

9. When mixed model balancing is to take place the relative importance of each model should be capable of influencing both the balancing procedure and the evaluation formulae used.

10. Existing mixed model balancing procedures have treated the problem as a two stage exercise consisting of firstly producing an assignment of elements and secondly the sequencing of given production schedules.

11. This attempt to integrate balancing and sequencing together makes the solutions produced highly sensitive to changes in production program and therefore suspect.

12. In practice the balancing of mixed model assembly lines should be independent of any subsequent sequencing analysis for in practical applications of assembly line work product mixes and schedules will vary considerably over the life of the assembly line.

Complex Balancing

13. As a general rule assembly line balancing procedures should be capable of dealing with practical assembly line conditions. Two major limitations at present are the treatment given to work elements and assembly line stations.

14. Four problems that may arise with work elements have been identified: element variability, fixed location elements, element durations greater than cycle time and multi-operator elements. An acceptable solution to element variability has been identified as the increasing of element durations to allow for variance and fixed location elements are a simple procedural problem.

15. Both large element durations and multi-operator elements require a more complex definition of assembly line station. Three possible variations from closed simple stations have been identified: extended, duplicated and enlarged stations.

16. Extended work stations with upstream and downstream excess represent a means of overcoming variation in work load caused by mixed model production. As extended stations represent only a temporary increase in capacity they should not be considered at the balancing stage.

17. Duplicate stations, where parallel or rotating in operation, can give increased capacity for dealing with large elements but as they remain single manned they cannot deal with multi-operator elements.

18. Enlarged stations represent a method of dealing with large elements, multi-operator elements and limited line length

whilst giving the additional benefits of group working and possible higher efficiency.

19. The majority of balancing procedures reviewed were restricted to simple station definitions. Two applications of extended stations related to mixed model sequencing were found and three applications of duplicate station procedures. This implies that a severe practical limitation exists with a large proportion of existing balancing procedures.

20. The prospect of more efficient and practical balancing procedures held out by the use of enlarged stations is an area not so far closely examined and therefore is worthy of development into balancing models.

General

21. Little work has been undertaken to examine the versatility of balancing solutions. Acknowledging that once constructed assembly lines rarely operate under the exact conditions used to balance the line a simulation model for investigating the effect of changing conditions would be of considerable benefit.

22. An understanding of the behaviour of work within an assembly line station can make an important contribution to determining the effectiveness of an assembly line. A simulation model should therefore include a full diagnosis of station behaviour.

23. The justification for accepting many balancing solutions is the efficiency claimed through values of Smoothness Index and Balance Delay. A simulation model provides the opportunity to determine actual Balance Delay and Smoothness Index over a wide range of real conditions and can therefore be used to comment on the validity of suggested solutions.

24. A useful contribution to assembly line design theory can be achieved by the development of a two stage balancing and simulation approach, using enlarged stations for balancing and allowing subsequent examination of solutions under a wide variety of operating conditions.

The Balancing Models ASSIGN 1 to ASSIGN 3

25. A suite of assembly line balancing programs entitled the ALB programs (ALB 1 and ALB 2) have been developed to use enlarged station theory and a modified rank positional weight approach for both single and mixed-model production.

The three models developed are:

ASSIGN 1 - Single model balancing.

ASSIGN 2 - Multi-element assignment mixed model (for diverse products).

ASSIGN 3 - Single element assignment mixed model (for similar products).

26. A practical model of behaviour at enlarged stations has been developed for use in the three balancing cases, identifying the new concept of work compressibility. Work compressibility acknowledges that there is a natural minimum time in which any work element can be completed no matter the resources available. This has been shown to place a realistic limit on the size of station allowed along the assembly line.

27. The ALB programs, using the model of enlarged station behaviour and work compressibility, are capable of dealing with large element durations, element variability, limited length assembly lines and are suitable for multi-operator elements. This

results in a more practical balancing approach.

28. The ALB programs have been demonstrated to work effectively in over one hundred and forty test applications and to have produced acceptable results in pursuing the objective of line efficiency.

The Simulation Model

29. The assembly line balancing package of ALB programs has been extended to include an integrated simulation model (programs ALB 3 to ALB 5). Capable of merging a given balancing solution with production planning and physical line data a wide variety of simulation conditions can be set with a view to producing detailed analysis of station and line performance.

30. Amongst the major simulation conditions that have been successfully applied are included:

Variation of mixed model production schedules.

Variation of the location and extension of stations.

Variation in actual line speed.

31. The simulation model also successfully introduces a preliminary production planning function with the inclusion of shift patterns and a five year production calendar whilst providing accurate start and finish times for each schedule. In addition particular schedules can be integrated as continuous with respect to other schedules or can be treated from a production efficiency view as independent.

32. The simulation program ALB 5 has been demonstrated to work effectively in over one hundred and thirty further test applications and has produced acceptable sets of detailed station

and line information.

Test Cases

In developing the balancing and simulation models several variables were identified as being likely to have an effect on assembly line efficiency. To examine the possible relationships and to verify the computer programs two hundred and seventy-three tests were carried out in an organised programme. The main conclusions drawn from these tests with respect to the major variables are as follows:

Balancing

Work Compressibility

33. Work compressibility strongly influences the range of station sizes worth considering and in particular the maximum station size as station sizes greater than the maximum compressibility give increasing lost time. This rules out the unreasonable single station theoretical solution.

34. As work compressibility indirectly controls the range of station sizes so it controls the change of improved efficiency. As compressibility was increased a number of improvements in Balance Delay were noted on initially inefficient lines. No direct relationship between Smoothness Index and compressibility was detected.

35. As work compressibility increases so does the probability of accepting enlarged stations, as a consequence of which line length will decrease. Work compressibility therefore influences the physical appearance of assembly line solutions.

Confidence Level

36. As suspected allowing for variable element duration increased the size of assembly line required. As confidence level was increased assignments made were noted to change and eventually additional station capacity was required to deal with increased element times.

Limited Line Length

37. No major conclusion could be drawn with respect to the effect of a limit on line length other than to confirm that the procedure produced working solutions to overcome the problem on each occasion.

Single v. Multi-element Assignment

38. Over the test series carried out the multi-element assignment procedure was consistently producing more efficient solutions. This confirms the view that Balance Delay results will be better with multi-element assignment as better opportunities exist for packing elements into stations.

39. Smoothness Index values on average were also better with multi-element assignment but the difference was less discernable in cases of close values of Balance Delay. This reflects the general improvement in Smoothness Index as Balance Delay improves and does not indicate that multi-element assignment is better at distributing work.

40. As suspected the multi-element assignment procedure produced higher levels of work variety, i.e. will require greater operator training as elements had been assigned to a number of stations.

Effect of Model Weighting

Where model adjustment is included as part of a mixed model balancing procedure the following conclusions will be indicative of the consequences:

41. Model dominance will not influence balance results unless there is a noticeable difference between the work content of models.

42. Where the dominant model has more than the average work content then model adjusted balancing will produce a more efficient solution whereas when the dominant model has less than the average work content line efficiency will decrease.

Simulation

Line Speed Variation

43. As line speed is increased the amount of unused time decreases and the amount of lost time (indicative of quality) increases. This is confirmation of the expected relationships.

44. The actual effect of changes in line speed will be related to the amount of spare time built into the line to overcome work variability, i.e. where high confidence levels were set at balancing greater spare time exists and the less will be the effect of speeding up an assembly line.

45. As expected when a line is slowed down actual Balance Delay and Smoothness Indices increase and as a line is speeded up the converse occurs.

Extended Work Stations

46. Where both upstream and downstream excess working space is

available the simulation results show that work is concentrated under normal conditions into the upstream and normal working areas, the proportion of time spent in each being dictated by the amount of upstream working available. The explanation for this is the assumption that the operator or operators will move as far upstream as possible on each cycle.

47. As the amount of upstream and downstream working is increased the percentage of lost time decreases confirming the expected relationship.

Product Mix Change

48. When variation in actual product mix occurs during production as a result of which the mixed model balancing conditions change then the actual efficiency of the assembly will change.

49. When models with less than the average work content dominate the production schedule then actual Balance Delay and Smoothness Index will deteriorate. When the opposite occurs, i.e. models with greater than the average work content dominate efficiency improves.

50. The amount of change will be dependent on the different work content of each model. Conclusions 49 and 50 further support conclusions 41 and 42.

51. The relationship between balancing efficiency at the design stage and actual efficiency will depend on the original balancing model mix and the actual model mix, although it should be noted that the assumption that balancing element times will be at the confidence limit produces optimistic Balance Delay and Smoothness Index values when compared to simulation actual element times for the same model mix.

APPENDIX A

TEST RESULTS FOR ALB PROGRAMS

TEST PROBLEMS

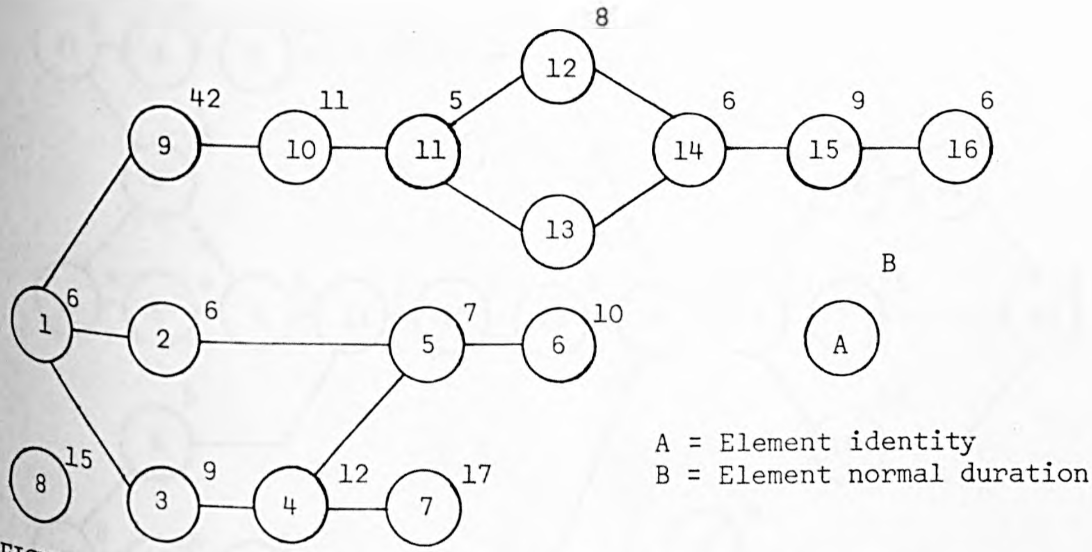


FIGURE (A.1) 16 ELEMENT DRISCOLL-SHAFI PRECEDENCE DIAGRAM

Models / Element	Random removals					Early random removals					Late random removals				
	200	201	202	203	204	200	201	202	203	204	200	201	202	203	204
1	✓	✓	✓	✓		✓		✓			✓	✓	✓	✓	✓
2	✓	✓	✓					✓		✓		✓	✓	✓	✓
3		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓
4				✓	✓	✓		✓		✓		✓			✓
5	✓	✓		✓	✓			✓	✓		✓				
6	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	
7	✓		✓		✓	✓	✓	✓	✓	✓		✓			✓
8	✓	✓	✓				✓	✓	✓		✓	✓	✓	✓	
9	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
10	✓	✓	✓	✓	✓			✓	✓		✓		✓	✓	✓
11	✓			✓		✓	✓	✓				✓	✓	✓	
12	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
13	✓			✓		✓	✓	✓	✓	✓	✓			✓	✓
14		✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	
15				✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓
16	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

16 Element mixed-model element list

TABLE (A.1) 16 ELEMENT DRISCOLL-SHAFI PROBLEM.

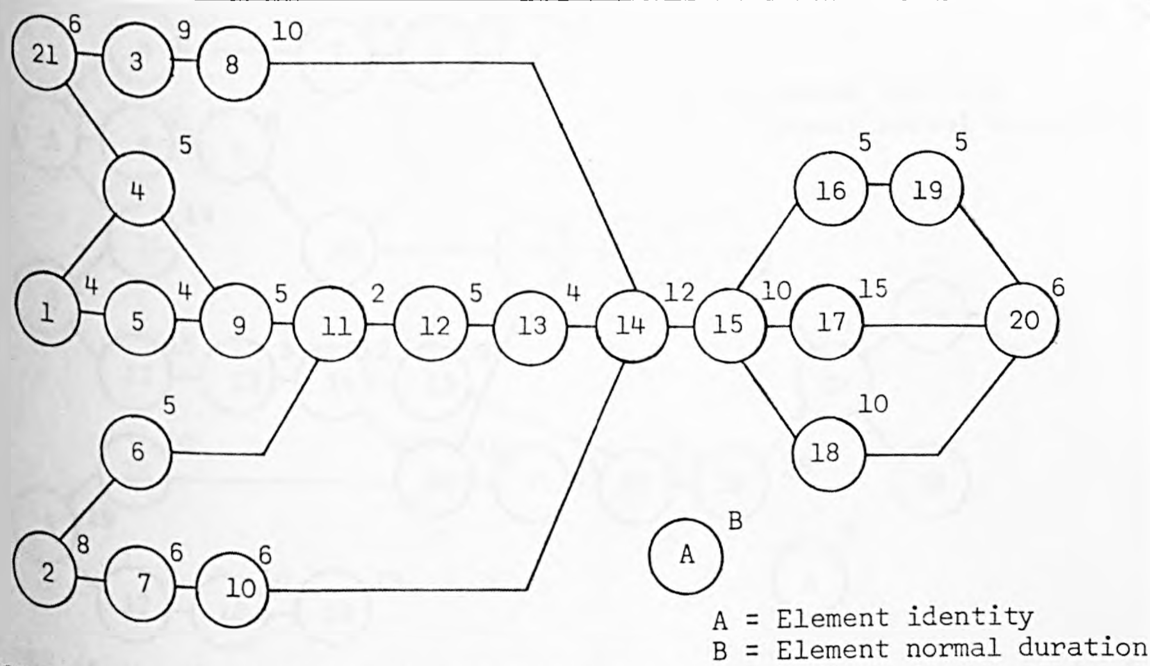


FIGURE (A.2) 21 ELEMENT WILD PRECEDENCE DIAGRAM

Removals / Models / Element	Random removals					Early random removals					Late random removals				
	200	201	202	203	204	200	201	202	203	204	200	201	202	203	204
1		✓	✓	✓	✓				✓	✓	✓	✓	✓	✓	✓
2	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓	✓
3	✓	✓	✓	✓			✓			✓	✓	✓	✓	✓	✓
4		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
5		✓	✓	✓		✓	✓			✓	✓	✓	✓	✓	✓
6	✓				✓			✓			✓	✓	✓	✓	✓
7	✓	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓
8	✓	✓	✓		✓			✓	✓		✓	✓	✓	✓	✓
9	✓	✓		✓	✓	✓	✓		✓		✓	✓	✓	✓	✓
10	✓			✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
11			✓	✓		✓	✓				✓	✓	✓	✓	✓
12	✓	✓	✓	✓	✓	✓	✓				✓	✓	✓	✓	✓
13		✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓	✓
14					✓	✓	✓	✓	✓	✓				✓	
15	✓	✓		✓		✓	✓	✓	✓	✓			✓	✓	
16	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓	✓
17	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
18	✓		✓		✓	✓	✓	✓	✓	✓	✓				
19		✓	✓	✓	✓	✓	✓	✓	✓	✓			✓		
20	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
21	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

21 Element mixed model element list

TABLE (A.2) 21 ELEMENT WILD PROBLEM.

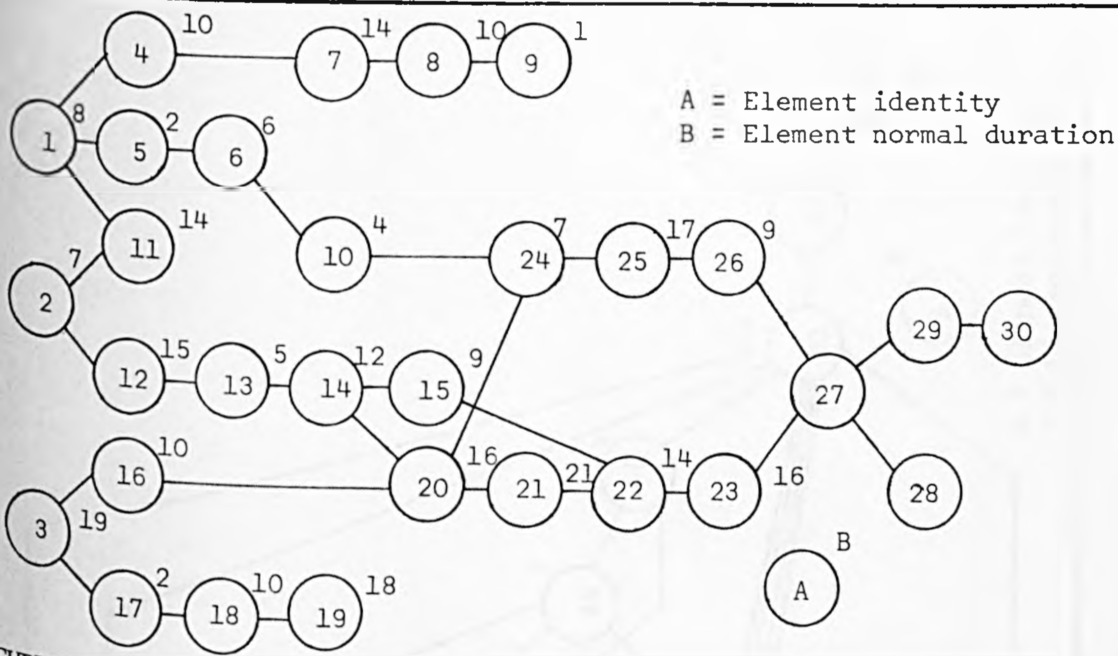


FIGURE (A.3) 30 ELEMENT SAWYER PRECEDENCE DIAGRAM

Removals / Models / Elements	Random removals					Early random removals					Late random removals				
	200	201	202	203	204	200	201	202	203	204	200	201	202	203	204
1	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓	✓	✓
2		✓		✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓
3	✓		✓	✓	✓					✓	✓	✓	✓	✓	✓
4	✓		✓	✓		✓					✓	✓	✓	✓	✓
5	✓		✓	✓	✓		✓	✓			✓	✓	✓	✓	✓
6			✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓
7	✓	✓		✓	✓				✓	✓	✓	✓	✓	✓	✓
8	✓		✓	✓		✓	✓	✓	✓	✓		✓		✓	✓
9	✓			✓		✓	✓	✓	✓	✓	✓		✓	✓	
10	✓		✓	✓			✓		✓		✓	✓	✓	✓	✓
11	✓	✓	✓		✓	✓	✓			✓	✓	✓	✓	✓	✓
12		✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓
13		✓	✓	✓	✓				✓		✓	✓	✓	✓	✓
14	✓	✓	✓		✓	✓		✓	✓		✓	✓	✓	✓	✓
15	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
16	✓	✓	✓	✓	✓		✓				✓	✓	✓	✓	✓
17	✓		✓	✓	✓	✓			✓		✓	✓	✓	✓	✓
18	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓
19	✓	✓					✓	✓	✓	✓	✓	✓	✓	✓	✓
20	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓
21		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		
22	✓	✓		✓		✓	✓	✓	✓	✓	✓			✓	
23	✓	✓		✓	✓	✓	✓	✓	✓	✓				✓	
24	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
25	✓	✓	✓		✓	✓	✓	✓	✓	✓			✓	✓	
26	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	
27		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓
28			✓	✓		✓	✓	✓	✓	✓			✓	✓	
29	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
30	✓				✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

30 Element mixed model element list

TABLE (A.3) 30 ELEMENT SAWYER PROBLEM.

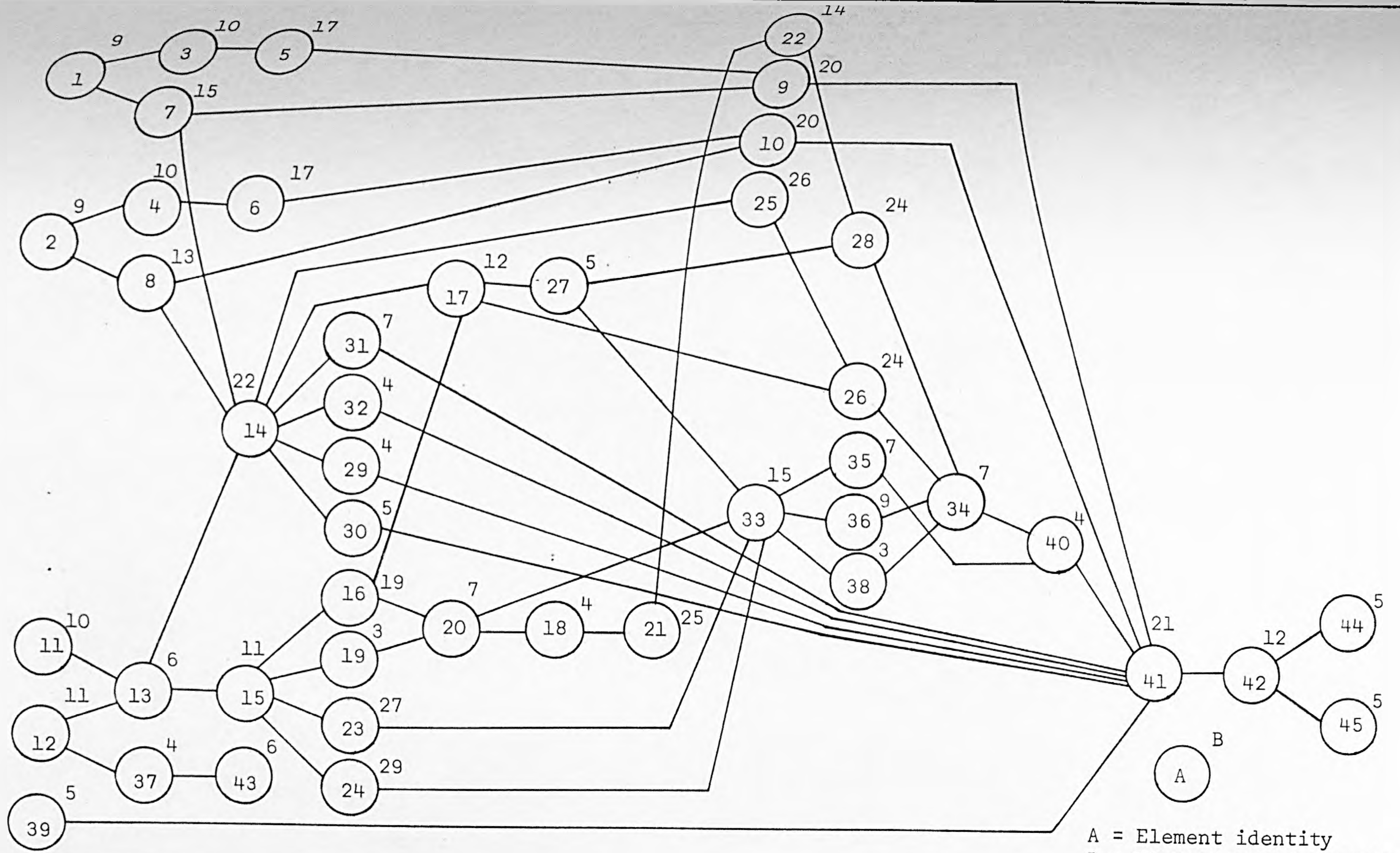


FIGURE (A.4) 45 ELEMENT KILBRIDGE AND WESTER PRECEDENCE DIAGRAM.

Removals / Model / Element	Random removals					Early random removals					Late random removals				
	200	201	202	203	204	200	201	202	203	204	200	201	202	203	204
1	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓
2	✓	✓	✓				✓	✓	✓		✓	✓	✓	✓	✓
3		✓					✓				✓	✓	✓	✓	✓
4	✓	✓	✓	✓	✓		✓		✓		✓	✓	✓	✓	✓
5		✓	✓		✓			✓		✓	✓	✓	✓	✓	✓
6	✓		✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓
7	✓	✓	✓	✓	✓	✓		✓	✓		✓	✓	✓	✓	✓
8	✓		✓	✓	✓				✓		✓	✓	✓	✓	✓
9		✓		✓		✓	✓	✓	✓	✓			✓	✓	✓
10	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
11	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
12	✓	✓		✓	✓	✓	✓				✓	✓	✓	✓	✓
13	✓	✓	✓						✓		✓	✓	✓	✓	✓
14	✓	✓		✓						✓	✓	✓	✓	✓	✓
15	✓	✓	✓			✓	✓				✓	✓	✓	✓	✓
16	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓	✓	✓
17	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓
18	✓	✓	✓	✓		✓	✓	✓	✓	✓			✓	✓	
19	✓		✓	✓	✓	✓	✓			✓	✓	✓	✓	✓	✓
20	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓			✓
21	✓		✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		
22	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				
23			✓	✓					✓	✓	✓	✓	✓	✓	✓
24	✓	✓				✓		✓	✓	✓	✓	✓	✓	✓	✓
25		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓
26	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	
27	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
28		✓	✓	✓	✓	✓	✓	✓	✓	✓				✓	✓
29	✓	✓		✓	✓	✓	✓				✓	✓	✓	✓	✓
30	✓		✓		✓	✓	✓				✓	✓	✓	✓	✓
31	✓	✓	✓		✓	✓	✓			✓	✓	✓	✓	✓	✓
32	✓				✓		✓			✓	✓	✓	✓	✓	✓
33	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓
34	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓			
35	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	
36	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				✓	
37	✓	✓	✓	✓	✓		✓		✓		✓	✓	✓	✓	✓
38	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓		
39	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓
40	✓	✓		✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
41	✓	✓			✓	✓	✓	✓	✓	✓	✓		✓		✓
42			✓	✓	✓	✓	✓	✓	✓	✓					✓
43	✓	✓		✓	✓	✓	✓				✓	✓	✓	✓	✓
44		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	
45		✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓	

45 Element mixed model element list

TABLE (A.4) 45 ELEMENT KILBRIDGE AND WESTER PROBLEM.

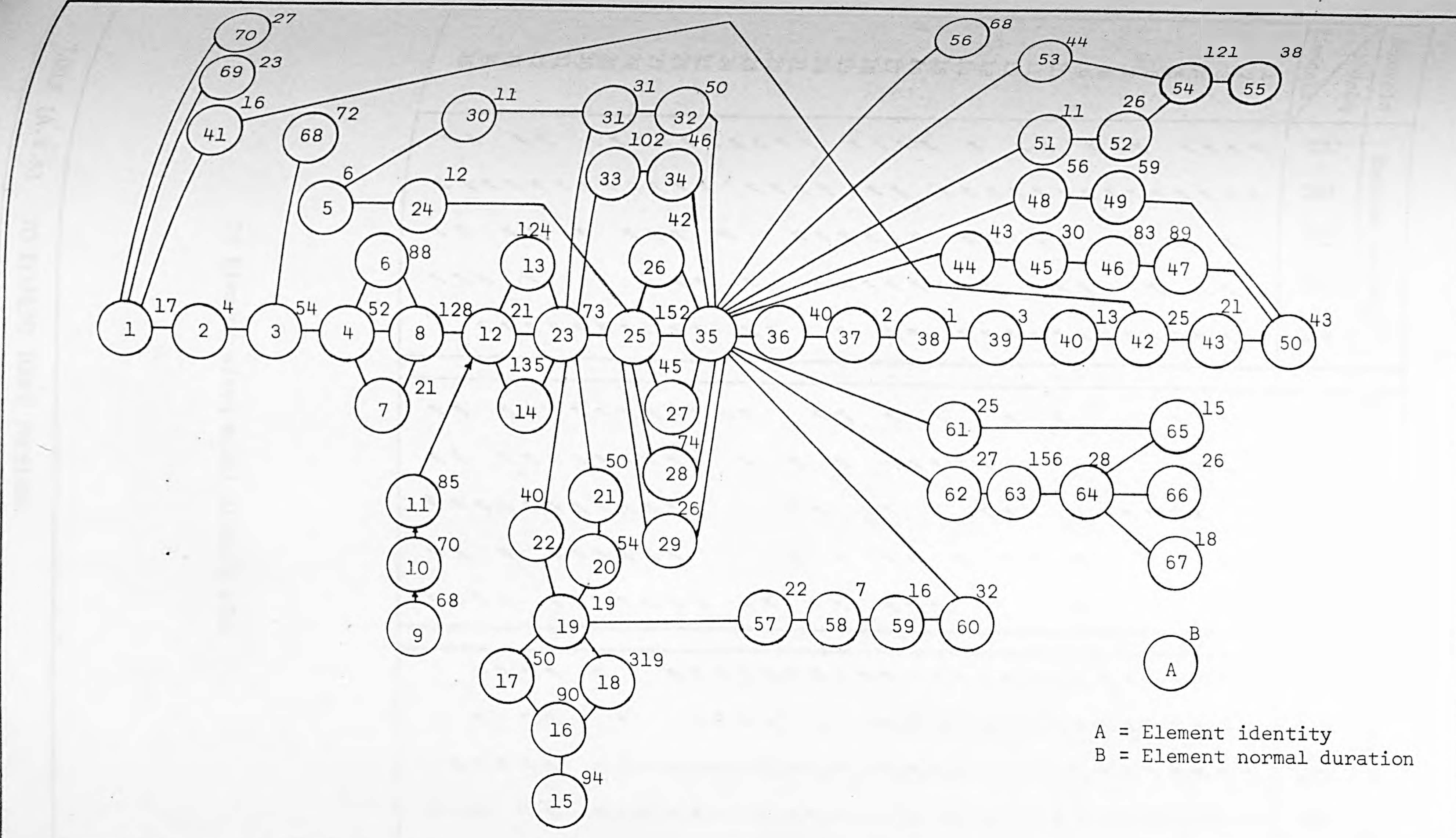


FIGURE (A.5) 70 ELEMENT TONGE PRECEDENCE DIAGRAM.

Removals / Models / Elements	Random removals					Early random removals					Late random removals				
	200	201	202	203	204	200	201	202	203	204	200	201	202	203	204
1	√	√			√		√	√	√	√	√	√	√	√	√
2	√	√	√	√	√	√	√		√		√	√	√	√	√
3	√	√		√	√		√	√			√	√	√	√	√
4	√	√			√	√		√			√	√	√	√	√
5		√		√	√			√	√	√	√	√	√	√	√
6	√	√	√	√	√			√			√	√	√	√	√
7	√	√			√		√	√			√	√	√	√	√
8	√	√		√	√			√	√	√	√	√	√	√	√
9		√	√	√	√	√					√	√	√	√	√
10	√	√	√	√	√			√	√		√	√	√	√	√
11	√	√	√		√	√		√	√		√	√	√	√	√
12		√	√	√	√		√	√			√	√	√	√	√
13	√	√	√	√	√		√		√		√	√	√	√	√
14		√		√		√	√	√		√	√	√	√	√	√
15	√		√	√	√		√		√	√	√	√	√	√	√
16	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
17	√	√	√	√				√			√	√	√	√	√
18	√		√	√	√	√	√		√	√	√	√	√	√	√
19		√	√	√		√		√			√	√	√	√	√
20	√	√	√				√	√	√		√	√	√	√	√
21	√	√			√					√	√	√	√	√	√
22	√	√		√	√	√	√			√	√	√	√	√	√
23	√		√			√					√	√	√	√	√
24	√	√		√	√	√	√	√		√	√	√	√	√	√
25	√	√	√	√	√	√	√	√	√	√	√		√	√	√
26	√	√	√			√	√	√	√	√			√	√	
27	√	√	√		√	√	√	√	√	√		√	√	√	
28	√	√			√	√	√	√	√	√	√		√	√	
29	√	√	√		√	√	√	√	√	√					√
30		√			√		√	√	√	√	√	√	√	√	√
31	√	√	√	√	√		√	√			√	√	√	√	√
32	√	√	√		√	√	√	√	√	√	√		√		
33		√		√	√			√		√	√	√	√	√	√
34	√	√	√	√		√	√	√	√	√			√	√	√
35	√	√	√	√		√	√	√	√	√				√	

70 Element mixed model element list

TABLE (A.5.A) 70 ELEMENT TONGE PROBLEM.

Removals / Model / Element	Random removal					Early random removal					Late random removal				
	200	201	202	203	204	200	201	202	203	204	200	201	202	203	204
36		✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓
37					✓	✓	✓	✓	✓	✓					✓
38	✓			✓		✓	✓	✓	✓	✓			✓		✓
39		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				
40	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓					✓
41	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
42	✓	✓				✓	✓	✓	✓	✓	✓	✓	✓		✓
43	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓
44		✓	✓	✓		✓	✓	✓	✓	✓	✓			✓	
45		✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
46		✓		✓		✓	✓	✓	✓	✓	✓	✓	✓		
47	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
48	✓		✓	✓		✓	✓	✓	✓	✓					✓
49	✓	✓	✓	✓		✓	✓	✓	✓	✓					✓
50	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	
51				✓		✓	✓	✓	✓	✓			✓	✓	✓
52	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓		✓
53	✓	✓	✓			✓	✓	✓	✓	✓	✓				
54	✓		✓		✓	✓	✓	✓	✓	✓		✓			
55	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			✓		
56	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓				
57	✓	✓	✓		✓	✓	✓	✓	✓	✓		✓	✓		
58	✓	✓	✓	✓		✓	✓	✓	✓	✓		✓			
59	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓				
60	✓	✓	✓			✓	✓	✓	✓	✓					✓
61		✓	✓	✓	✓	✓	✓	✓	✓	✓			✓	✓	✓
62	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
63			✓	✓	✓	✓	✓	✓	✓	✓		✓		✓	✓
64		✓		✓		✓	✓	✓	✓	✓	✓	✓			✓
65		✓		✓		✓	✓	✓	✓	✓			✓		
66		✓	✓	✓		✓	✓	✓	✓	✓		✓		✓	
67	✓				✓	✓	✓	✓	✓	✓				✓	
68		✓	✓	✓	✓	✓				✓	✓	✓	✓	✓	✓
69	✓	✓	✓	✓		✓		✓		✓	✓	✓	✓	✓	✓
70		✓			✓	✓		✓	✓		✓	✓	✓	✓	✓

70 Element mixed model element list

TABLE (A.5.B) 70 ELEMENT TONGE PROBLEM.

BALANCING MODELS

USEFUL EQUATIONS AND DEFINITIONS

(See Chapters 4 and 5)

BD1: Actual balance delay

$$BD1 = \frac{\sum_{j=1}^{m} \sum_{k=1}^{p} \{(S_k \times C) - \sum_{i=1}^{n} t_i \, (A_{jk})\}}{\sum_{j=1}^{m} \sum_{k=1}^{p} (S_k \times C)} \times 100 \qquad \text{(Eqn. 4.9)}$$

BD2: Adjusted balance delay

$$BD2 = \frac{\sum_{j=1}^{m} ADJ_j \sum_{k=1}^{p} \{(S_k \times C) - \sum_{i=1}^{n} t_i \, (A_{jk})\}}{\sum_{k=1}^{p} (S_k \times C)} \times 100 \qquad \text{(Eqn. 4.10)}$$

BD3: Apparent balance delay

$$BD3 = \frac{\sum_{j=1}^{m} \sum_{k=1}^{p} \{S_k \times C - \sum_{i=1}^{n} te_i \, (A_{jk})\}}{\sum_{j=1}^{m} \sum_{k=1}^{p} (S_k \times C)} \times 100 \qquad \text{(Eqn. 4.12)}$$

BD4: Adjusted apparent balance delay

$$BD4 = \frac{\sum_{j=1}^{m} ADJ_j \sum_{k=1}^{p} S_k \{C - \sum_{i=1}^{n} te_i \, (A_{jk})\}}{\sum_{k=1}^{p} (S_k \times C)} \times 100 \qquad \text{(Eqn. 4.13)}$$

SI1: Apparent smoothness index

$$SI1 = \sqrt{\frac{\sum_{j=1}^{m} \sum_{k=1}^{p} \{(S_k \times C) - \sum_{i=1}^{n} t_i \, (A_{jk})\}^2}{m}} \times 100 \qquad \text{(Eqn. 4.14)}$$

SI2: Adjusted apparent smoothness index

$$SI2 = \sqrt{\sum_{j=1}^{m} ADJ_j \sum_{k=1}^{p} \{(S_k \times C) - \sum_{i=1}^{n} t_i \, (A_{jk})\}^2} \qquad \text{(Eqn. 4.15)}$$

SI3: Actual smoothness index

$$SI3 = \sqrt{\frac{\sum_{j=1}^{m} \sum_{k=1}^{p} \{S_k \, (C - \sum_{i=1}^{n} te_i \, (A_{jk})\}^2}{m}} \qquad \text{(Eqn. 4.16)}$$

SI4: Adjusted actual smoothness index

$$SI4 = \sqrt{\sum_{j=1}^{m} ADJ_j \sum_{k=1}^{p} \{S_k \, (C - \sum_{i=1}^{n} te_i \, (A_{jk})\}^2} \qquad \text{(Eqn. 4.17)}$$

WB1: Cumulative station range for the line

$$WB1 = \sum_{k=1}^{P} (T_{k\ max} - T_{k\ min})$$

WB2: Total work variety for the line

$$WB2 = \sum_{k=1}^{P} Tv_k$$

WT1: Average station range of work variety over the entire line.

$$WT1 = (\sum_{k=1}^{P} Tv_k)/P$$

WT2: Standard deviation of station range of work variety over the entire line.

$$WT2 = \sqrt{\sum_{k=1}^{P} (Tv_k - WT1)^2}$$

WT3: Range of work variety over the entire line.

$$WT3 = Tv_{max} - Tv_{min}$$

Where:

$T_{k\ max}$ Maximum work time assigned to the station k for any given model.

$T_{k\ min}$ Minimum work time assigned to the station k for any given model.

Tv_k Work variety assigned to the station k for all models i.e. the sum of work durations for each unique element assigned.

Tv_{max} The maximum individual station work variety over the entire line.

Tv_{min} The minimum individual station work variety over the entire line.

TEST SERIES 1

THE EFFECT OF COMPRESSIBILITY

FINAL ASSIGNMENTS AND RESULTS

TEST PROBLEMS

Tests 1 to 4	16 Element	Driscoll-Shafi
5 to 8	21 Element	Wild
9 to 12	30 Element	Sawyer
13 to 16	45 Element	Kilbridge and Wester

EXAMINATION CONDITIONS

No confidence effect

No line limit restriction

Single model

Maximum station size = 6 (Manual input)

Constant cycle time[*1]

[*1] Except 16 element problem.

Test Series 1

Test number	Problem	Minimum duration / Normal duration (%)	Element Compressibility (%)
1	16 Element	10	90
2		25	75
3		50	50
4		100	0
5	21 Element	10	90
6		25	75
7		50	50
8		100	0
9	30 Element	10	90
10		25	75
11		50	50
12		100	0
13	45 Element	10	90
14		25	75
15		50	50
16		100	0

TABLE (A.6) PROBLEMS INVOLVED IN TEST SERIES 1.

Test No. 1 (16 Element, Cycle time = 20 & 90% comp.)

Station Number	Size	Elements	Σt_i	Σte_i
1	2	1/2/3/4/5	40	20
2	3	9/10/11	58	19.33
3	3	7/8/12/13/14/15	59	19.67
4	1	6/16	16	16

Test No. 2 (16 Element, Cycle time = 20 & 75% comp.)

Station Number	Size	Elements	Σt_i	Σte_i
1	2	1/2/3/4/5	40	20
2	3	9/10/11	58	19.33
3	3	7/8/12/13/14/15	59	19.67
4	1	6/16	16	16

Test No. 3 (16 Element, Cycle time = 21 & 50% comp.)

Station Number	Size	Elements	Σt_i	Σte_i
1	1	1/2/3	21	21
2	2	9	42	21
3	1	10/11/13	20	20
4	2	4/5/12/14/15	42	21
5	2	6/7/8	42	21
6	1	16	6	6

Test No. 4 (16 Element, Cycle time = 42 & 0% comp.)

Station Number	Size	Elements	Σt_i	Σte_i
1	1	1/2/3/4/5	40	40
2	1	9	42	42
3	1	10/11/12/13/14	34	34
4	1	7/8/15	41	41
5	1	6/16	16	16

Test No. 5 (21 Element, Cycle time = 36 & 90% comp.)

Station Number	Size	Elements	Σt_i	Σte_i
1	3	21/1/2/3/4/5/6/7/8/9/10/11/12/13/14/15/16	107	35.67
2	1	17/18/19/20	36	36

Test No. 6 (21 Element, Cycle time = 36 & 75% comp.)

Station Number	Size	Elements	Σt_i	Σte_i
1	3	21/1/2/3/4/5/6/7/8/9/10/11/12/ 13/14/15/16	107	35.67
2	1	17/18/19/20	36	36

Test No. 7 (21 Element, Cycle time = 36 & 50% comp.)

Station Number	Size	Elements	Σt_i	Σte_i
1	2	21/1/2/3/4/5/6/7/8/9/11/12	70	35
2	1	10/13/14/15	32	32
3	1	16/17/18/19	35	35
4	1	20	6	6

Test No. 8 (21 Element, Cycle time = 36 & 0% comp.)

Station Number	Size	Elements	Σt_i	Σte_i
1	1	21/1/2/4/5/6	33	33
2	1	3/7/8/9/11	32	32
3	1	10/12/13/14	27	27
4	1	15/16/17/19	35	35
5	1	18/20	16	16

Test No. 9 (30 Element, Cycle time = 44 & 90% comp.)

Station Number	Size	Elements	Σt_i	Σte_i
1	2	1/2/3/5/6/10/12/13/14/16	88	44
2	1	20/21/24	44	44
3	1	4/7/8/9/15	44	44
4	1	17/22/25/26	42	42
5	1	23/27	41	41
6	1	18/19/29/30	44	44
7	1	11/28	21	21

Test No. 10 (30 Element, Cycle time = 44 & 75% comp.)

Station Number	Size	Elements	Σt_i	Σte_i
1	2	1/2/3/5/6/10/12/13/14/16	88	44
2	1	20/21/24	44	44
3	1	4/7/8/9/15	44	44
4	1	17/22/25/26	42	42
5	1	23/27	41	41
6	1	18/19/29/30	44	44
7	1	11/28	21	21

Test No. 11 (30 Element, Cycle time = 44 & 50% comp.)

Station Number	Size	Elements	Σti	Σte_i
1	2	1/2/3/5/6/10/12/13/14/16	88	44
2	1	20/21/24	44	44
3	1	4/7/8/9/15	44	44
4	1	17/22/25/26	42	42
5	1	23/27	41	41
6	1	18/19/29/30	44	44
7	1	11/28	21	21

Test No. 12 (30 Element, Cycle time = 44 & 0% comp.)

Station Number	Size	Elements	Σt_i	Σte_i
1	1	2/3/12/17	43	43
2	1	1/5/6/13/14/16	43	43
3	1	10/20/21	41	41
4	1	4/7/15/24	40	40
5	1	8/9/22/25	42	42
6	1	18/23/26	35	35
7	1	19/27	43	43
8	1	11/28/29/30	37	37

Test No. 13 (45 Element, Cycle time = 69 & 90% comp.)

Station Number	Size	Elements	Σt_i	Σte_i
1	1	1/2/7/11/12/13/15	69	69
2	1	8/14/16/18/19/20	68	68
3	2	3/17/21/23/24/27	138	69
4	2	4/5/6/22/25/26/28/33/36	138	69
5	1	9/10/30/31/34/35/38	69	69
6	1	29/32/37/39/40/41/42/43/44	65	65
7	1	45	5	5

Test No. 14 (45 Elements, Cycle time = 69 & 75% comp.)

Station Number	Size	Elements	Σt_i	Σte_i
1	1	1/2/7/11/12/13/15	69	69
2	1	8/14/16/18/19/20	68	68
3	2	3/17/21/23/24/27	138	69
4	2	4/5/6/22/25/26/28/33/36	138	69
5	1	9/10/30/31/34/35/38	69	69
6	1	29/32/37/39/40/41/42/43/44	65	65
7	1	45	5	5

Test No. 15 (45 Element, Cycle time = 69 & 50% comp.)

Station Number	Size	Elements	Σt_i	Σte_i
1	1	1/2/7/11/12/13/15	69	69
2	1	8/14/16/18/19/20	68	68
3	2	3/17/21/23/24/27	138	69
4	2	4/5/6/22/25/26/28/33/36	138	69
5	1	9/10/30/31/34/35/38	69	69
6	1	29/32/37/39/40/41/42/43/44	65	65
7	1	45	5	5

Test No. 16 (45 Elements, Cycle time = 69 & 0% comp.)

Station Number	Size	Elements	Σt_i	Σte_i
1	1	1/2/7/11/12/13/15	69	69
2	1	8/14/16/18/19/20	68	68
3	1	17/21	67	67
4	1	23/24/27/31	68	68
5	1	3/4/5/22/33/38	69	69
6	1	6/25/28	67	67
7	1	9/10/26/34/35/36	69	69
8	1	29/30/32/37/39/40/41/42/43	65	65
9	1	44/45	10	10

Test No.	BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	WB1	WB2	WT1	WT2	WT3
1	3.89	3.89	3.89	3.89	4.58	4.58	4.58	4.58	0.00	173.00	43.25	34.91	43.00
2	3.89	3.89	3.89	3.89	4.58	4.58	4.58	4.58	0.00	173.00	43.25	34.91	43.00
3	8.47	8.47	8.47	8.47	15.03	15.03	15.03	15.03	0.00	173.00	28.83	34.36	36.00
4	17.62	17.62	17.62	17.62	27.29	27.29	27.29	27.29	0.00	173.00	34.60	21.71	26.00
5	0.69	0.69	0.69	0.69	1.0	1.0	1.0	1.0	0.0	143.00	71.50	50.20	71.00
6	0.69	0.69	0.69	0.69	1.0	1.0	1.0	1.0	0.0	143.00	71.50	50.20	71.00
7	20.56	20.56	20.56	20.56	30.35	30.35	30.35	30.35	0.00	143.00	35.73	45.53	64.00
8	20.56	20.56	20.56	20.56	22.52	22.52	22.52	22.52	0.00	143.00	28.60	15.27	19.00
9	7.95	7.95	7.95	7.95	23.28	23.28	23.28	23.28	0.00	324.00	46.29	49.41	67.00
10	7.95	7.95	7.95	7.95	23.28	23.28	23.28	23.28	0.0	324.00	46.29	49.41	67.00
11	7.95	7.95	7.95	7.95	23.28	23.28	23.28	23.28	0.0	324.00	46.29	49.41	67.00
12	7.95	7.95	7.95	7.95	12.73	12.73	12.73	12.73	0.0	324.00	40.50	8.00	8.00
13	11.11	11.11	11.11	11.11	64.13	64.13	64.13	64.13	0.0	552.00	78.86	113.82	133.00
14	11.11	11.11	11.11	11.11	64.13	64.13	64.13	64.13	0.0	552.00	78.86	113.82	133.00
15	11.11	11.11	11.11	11.11	64.13	64.13	64.13	64.13	0.0	552.00	78.86	113.82	133.00
16	11.11	11.11	11.11	11.11	59.22	59.22	59.22	59.22	0.0	552.00	61.33	54.57	59.00

TABLE (A.7) SUMMARY EVALUATION RESULTS - TEST SERIES 1.

TEST SERIES 2

THE INFLUENCE OF CONFIDENCE LEVEL

FINAL ASSIGNMENTS AND RESULTS

TEST PROBLEMS

Tests 17 to 32	16 Element	Driscoll-Shafi
33 to 48	30 Element	Sawyer

EXAMINATION CONDITIONS

No line length restriction

Single model

Maximum station size = 6

Variable compressibility (0%, 50%, 75% and 90%)

16 Element Problem

Ratio $\frac{\text{variance}}{\text{normal duration}}$ in range 0.1667 to 0.3

30 Element Problem

Ratio $\frac{\text{variance}}{\text{normal duration}}$ in range 0.12 to 0.333

16 Element Problem

Element No.	Normal Duration	Variance
1	6.0	1.5
2	6.0	1.5
3	9.0	2.0
4	12.0	3.0
5	7.0	2.0
6	10.0	3.0
7	17.0	4.0
8	15.0	4.0
9	42.0	8.0
10	11.0	2.0
11	5.0	1.0
12	8.0	2.0
13	4.0	1.0
14	6.0	1.0
15	9.0	2.0
16	6.0	1.5

30 Element Problem

Element No.	Normal Duration	Variance
1	8.0	1.5
2	7.0	2.0
3	19.0	3.0
4	10.0	2.0
5	2.0	0.5
6	6.0	1.0
7	14.0	3.0
8	10.0	2.0
9	1.0	0.25
10	4.0	1.0
11	14.0	3.0
12	15.0	3.0
13	5.0	1.0
14	12.0	3.0
15	9.0	3.0
16	10.0	2.0
17	2.0	0.5
18	10.0	3.0
19	18.0	3.0
20	16.0	3.0
21	21.0	4.0
22	14.0	3.0
23	16.0	4.0
24	7.0	2.0
25	17.0	4.0
26	9.0	1.5
27	25.0	3.0
28	7.0	1.5
29	14.0	4.0
30	2.0	0.5

TABLE (A.8) NORMAL ELEMENT DURATIONS AND VARIANCES - TEST SERIES 2.

Test Series 2

Test Number	Problem	Element compressibility (%)	Confidence (%)
17	16 Element	10	50
18	"	75	50
19	"	50	50
20	"	0	50
21	"	90	75
22	"	75	75
23	"	50	75
24	"	0	75
25	"	90	95
26	"	75	95
27	"	50	95
28	"	0	95
29	"	90	99
30	"	75	99
31	"	50	99
32	"	0	99
33	30 Element	90	50
34	"	75	50
35	"	50	50
36	"	0	50
37	"	90	75
38	"	75	75
39	"	50	75
40	"	0	75
41	"	90	95
42	"	75	95
43	P	50	95
44	"	0	95
45	"	90	99
46	"	75	99
47	"	50	99
48	"	0	99

TABLE (A.9) PROBLEMS INVOLVED IN TEST SERIES 2.

Test No. 17

Station Number	Size	Elements	Σt_i	Σte_i
1	2	1/3/4/2/5	40	20
2	3	9/10/11	58	19.33
3	3	7/8/12/13/14/15	59	19.67
4	1	6/16	16	16

Test No. 18

Station Number	Size	Elements	Σt_i	Σte_i
1	2	1/3/4/2/5	40	20
2	3	9/10/11	58	19.33
3	3	7/8/12/13/14/15	59	19.67
4	1	6/16	16	16

Test No. 19

Station Number	Size	Elements	Σt_i	Σte_i
1	1	1/2/3	21	21
2	2	9	42	21
3	1	10/11/13	20	20
4	2	4/5/12/14/15	42	21
5	2	6/7/8	42	21
6	1	16	6	6

Test No. 20

Station Number	Size	Elements	Σt_i	Σte_i
1	1	1/3/4/2/5	40	40
2	1	9	42	42
3	1	10/11/12/13/14	34	34
4	1	7/8/15	41	41
5	1	6/16	16	16

Test No. 21

Station Number	Size	Elements	Σt_i	Σte_i
1	4	1/3/9/10/11	79.46	19.87
2	3	2/4/5/12/13/14/15	59.54	19.85
3	1	7	18.64	18.64
4	1.	8	16.64	16.64
5	1	6/16	18.42	18.42

Test No. 22

Station Number	Size	Elements	Σt_i	Σte_i
1	4	1/3/9/10/11	79.46	19.87
2	3	2/4/5/12/13/14/15	59.54	19.85
3	1	7	18.64	18.64
4	1	8	16.64	16.64
5	1	6/16	18.42	18.42

Test No. 23

Station Number	Size	Elements	Σt_i	Σte_i
1	1	1/3	17.16	17.16
2	1	2/4	20.42	20.42
3	1	5/6	19.58	19.58
4	1	7	18.64	18.64
5	1	8	16.64	16.64
6	3	9	44.32	21
7	1	10/11	17.98	17.98
8	1	12/13/14	20.80	20.80
9	1	15/16	17.16	17.16

Test No. 24

Station Number	Size	Elements	Σt_i	Σte_i
1	1	1/2/3/4	37.59	37.59
2	1	5/6/7	38.22	38.22
3	1	8	16.64	16.64
4	2	9	44.32	42.00
5	1	10/11/12/13/14	38.78	38.78
6	1	15/16	17.16	17.16

Test No. 25

Station Number	Size	Elements	Σt_i	Σte_i
1	6	1/2/3/4/9/10/11/12/13	119.97	20
2	4	5/6/7/8/14/15	76.25	19.06
3	1	16	7.57	7.57

Test No. 26

Station Number	Size	Elements	Σt$_i$	Σte$_i$
1	1	1/3	18.38	18.38
2	4	4/9/10/11	78.93	19.73
3	2	2/5/12/13/14	38.75	19.38
4	1	7	19.56	19.56
5	1	8	17.56	17.56
6	1	15/16	18.38	18.38
7	1	6	12.22	12.22

Test No. 27

Station Number	Size	Elements	Σt$_i$	Σte$_i$
1	2	1/2/3/4	40.17	20.08
2	2	5/6/7	40.59	20.30
3	1	8	17.56	17.56
4	3	9	45.62	21.00
5	2	10/11/12/13/14	41.47	20.73
6	1	15/16	18.38	18.38

Test No. 28

Station Number	Size	Elements	Σt$_i$	Σte$_i$
1	1	1/2/3/4	40.17	40.17
2	1	5/6/7	40.59	40.59
3	1	8	17.56	17.56
4	2	9	45.62	42
5	1	10/11/12/13/14	41.47	41.47
6	1	15/16	18.38	18.38

Test No. 29

Station Number	Size	Elements	Σt$_i$	Σte$_i$
1	5	1/3/4/9/10/11	99.62	19.92
2	4	2/5/7/8/12/13/14	78.29	19.57
3	1	15/16	19.01	19.01
4	1	6	12.63	12.63

Test No. 30

Station Number	Size	Elements	Σt_i	Σte_i
1	1	1/3	19.01	19.01
2	3	9/10	59.45	19.82
3	4	2/4/5/8/11/12/13/14	79.40	19.85
4	2	7/15/16	39.05	19.53
5	1	6	12.63	12.63

Test No. 31

Station Number	Size	Elements	Σt_i	Σte_i
1	2	1/2/3/4	41.51	20.75
2	2	5/6/7	41.83	20.91
3	1	8	18.04	18.04
4	3	9	46.30	21
5	1	10/11	19.67	19.67
6	1	12/13	15.67	15.67
7	1	14/15	18.67	18.67
8	1	16	7.86	7.86

Test No. 32

Station Number	Size	Elements	Σt_i	Σte_i
1	1	1/2/3/4	41.51	41.51
2	1	5/6/7	41.83	41.83
3	1	8	18.04	18.04
4	2	9	46.30	42.0
5	1	10/11/12/13	35.34	35.34
6	1	14/15/16	26.53	26.53

Test No. 33

Station Number	Size	Elements	Σt_i	Σte_i
1	2	1/2/3/5/6/10/12/13/14/16	88	44
2	1	20/21/24	44	44
3	1	4/7/8/9/15	44	44
4	1	17/22/25/26	42	42
5	1	23/27	41	41
6	1	18/19/29/30	44	44
7	1	11/28	21	21

Test No. 34

Station Number	Size	Elements	Σt_i	Σte_i
1	2	1/2/3/5/6/10/12/13/14/16	88	44
2	1	20/21/24	44	44
3	1	4/7/8/9/15	44	44
4	1	17/22/25/26	42	42
5	1	23/27	41	41
6	1	18/19/29/30	44	44
7	1	11/28	21	21

Test No. 35

Station Number	Size	Elements	Σt_i	Σte_i
1	2	1/2/3/5/6/10/12/13/14/16	88	44
2	1	20/21/24	44	44
3	1	4/7/8/9/15	44	44
4	1	17/22/25/26	42	42
5	1	23/27	41	41
6	1	18/19/29/30	44	44
7	1	11/28	21	21

Test No. 36

Station Number	Size	Elements	Σt_i	Σte_i
1	1	2/3/12/17	43	43
2	1	1/5/6/13/14/16	43	43
3	1	10/20/21	41	41
4	1	4/7/15/24	40	40
5	1	8/9/22/25	42	42
6	1	18/23/26	35	35
7	1	19/27	43	43
8	1	11/28/29/30	37	37

Test No. 37

Station Number	Size	Elements	Σt_i	Σte_i
1	4	1/2/3/4/5/6/7/10/12/13/14/15 16/20/21	175.68	43.92
2	4	8/9/11/17/18/19/22/23/24/25 26/27/29/30	175.91	43.98
3	1	28	8.0	8.0

Test No. 38

Station Number	Size	Elements	Σt_i	Σte_i
1	4	1/2/3/4/5/6/7/10/12/13/14 15/16/20/21	175.68	43.92
2	4	8/9/11/17/18/19/22/23/24/25 26/27/29/30	175.91	43.98
3	1	28	8.00	8.00

Test No. 39

Station Number	Size	Elements	Σt_i	Σte_i
1	2	1/2/3/5/12/13/14/16	86.93	43.49
2	1	4/6/10/17/20	42.80	42.80
3	1	15/21/24	41.22	41.22
4	1	7/8/9/22	43.21	43.21
5	2	18/23/25/26/27	84.12	42.06
6	1	19/28/29	43.06	43.06
7	1	11/30	18.00	18.00

Test No. 40

Station Number	Size	Elements	Σt_i	Σte_i
1	1	2/3/16/17	42.32	42.32
2	1	12/13/14	35.66	35.66
3	1	1/5/6/10/20	40.64	40.64
4	1	4/21/24	41.96	41.96
5	1	7/15/22	41.26	41.26
6	1	8/9/25/26	41.21	41.21
7	.	18/23	29.06	29.06
8	1	27/29	42.06	42.06
9	1	11/19/28	42.84	42.84
10	1	30	2.58	2.58

Test No. 41

Station Number	Size	Elements	Σt_i	Σte_i
1	6	1/2/3/4/5/6/7/8/9/10/12 13/14/15/16/20/21/22/23/24/25	262.23	43.70
2	1	17/26/27	40.69	40.69
3	1	18/19/28	41.01	41.01
4	1	11/29/30	35.69	35.69

Test No. 42

Station Number	Size	Elements	Σt_i	Σte_i
1	1	2/3/16	41.84	41.84
2	2	1/4/5/6/12/13/14/20	87.50	43.75
3	3	7/8/10/15/21/22/23/24/25	131.24	43.75
4	1	9/16/26/27	42.33	42.33
5	1	18/19/28	41.01	41.01
6	1	11/29/30	35.69	35.69

Test No. 43

Station Number	Size	Elements	Σt_i	Σte_i
1	1	2/3/16	41.84	41.84
2	2	1/4/5/6/12/13/14/20	87.50	43.75
3	1	10/15/17/21	42.97	42.97
4	1	7/22/24	41.25	41.25
5	1	8/9/25/26	43.58	43.58
6	2	18/19/23/27/28	86.79	43.39
7	1	11/29/30	35.69	35.69

Test No. 44

Station Number	Size	Elements	Σt_i	Σte_i
1	1	2/3/16	41.84	41.84
2	1	12/13/14/17	40.62	40.62
3	1	1/5/6/10/20	43.25	43.25
4	1	4/21	35.37	35.37
5	1	7/15/24	36.25	36.25
6	1	22/25	35.78	35.78
7	1	8/9/23/26	42.58	42.58
8	1	18/27	39.44	39.44
9	1	19/29/30	39.69	39.69
10	1	11/28	24.79	24.79

Test No. 45

Station Number	Size	Elements	Σt_i	Σte_i
1	5	1/2/3/4/5/6/7/10/12/13/14 15/16/17/20/21/22/24	219.66	43.93
2	4	8/9/11/18/19/23/25/26/27 28/29/30	170.37	42.59

Test No. 46

Station Number	Size	Elements	Σt_i	Σte_i
1	1	2/3/16	42.94	42.94
2	3	1/4/5/6/10/12/13/14/15/20/21	131.23	43.74
3	2	7/8/9/22/24/25/26	87.23	43.62
4	3	11/17/18/19/23/27/28/29/30	128.63	42.88

Test No. 47

Station Number	Size	Elements	Σt_i	Σte_i
1	1	2/3/16	42.94	42.94
2	2	1/5/6/10/12/13/14/17/20	86.48	43.24
3	2	4/7/8/9/15/21/24	87.52	43.76
4	1	22/25	36.68	36.68
5	2	18/23/26/27/29	87.21	43.61
6	1	11/19/30	40.34	40.34
7	1	28	8.86	8.86

Test No. 48

Station Number	Size	Elements	Σt_i	Σte_i
1	1	2/3/16	42.94	42.94
2	1	12/13/14/17	41.86	41.86
3	1	1/5/6/20	39.09	39.09
4	1	4/10/21	41.71	41.71
5	1	7/15/24	37.42	37.42
6	1	22/25	36.68	36.68
7	1	8/9/23/26	43.81	43.81
8	1	18/27	40.27	40.27
9	1	19/29/30	40.75	40.75
10	1	11/28	25.50	25.50

Test No.	BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	WB1	WB2	WT1	WT2	WT3
17	3.99	3.89	3.89	3.89	4.58	4.58	4.58	4.58	0.0	173.00	43.25	34.91	43.00
18	3.89	3.89	3.89	3.89	4.58	4.58	4.58	4.58	0.0	173.00	43.25	34.91	43.00
19	8.47	8.47	8.47	8.47	15.03	15.03	15.03	15.03	0.0	173.00	28.83	34.36	36.00
20	17.62	17.62	17.62	17.62	27.29	27.29	27.29	27.29	0.0	173.00	34.6	21.71	26.00
21	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02	0.0	189.15	37.83	57.33	62.00
22	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02	0.0	189.15	37.93	57.33	62.00
23	16.58	16.58	8.49	8.49	20.36	20.36	8.10	8.10	0.0	189.15	21.02	24.60	27.00
24	34.45	34.45	20.96	20.96	53.65	53.65	36.11	36.11	0.0	189.15	31.53	26.55	27.00
25	7.37	7.37	7.37	7.37	12.99	12.99	12.99	12.99	0.0	212.44	70.81	83.26	116.00
26	7.37	7.37	7.37	7.37	8.64	8.64	8.64	8.64	0.0	212.44	30.35	59.32	69.00
27	11.78	11.78	4.26	4.26	18.06	18.06	4.93	4.93	0.0	212.44	35.41	28.98	28.00
28	30.68	30.68	17.63	17.63	51.32	51.32	34.07	34.07	0.0	212.44	35.41	28.98	28.00
29	4.75	4.75	4.75	4.75	7.64	7.64	7.64	7.64	0.0	228.59	57.15	80.72	93.00
30	4.75	4.75	4.75	4.75	7.54	7.54	7.54	7.54	0.0	228.59	47.72	60.79	73.00
31	16.84	16.84	10.22	10.22	22.27	22.27	14.74	14.74	0.0	228.59	28.57	41.28	40.00
32	28.72	28.72	15.90	15.90	47.74	47.74	29.29	29.29	0.0	228.59	38.10	25.48	29.00

TABLE (A.10.A) SUMMARY EVALUATION RESULTS - TEST SERIES 2 (TESTS 17-32)

Test No.	BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	WB1	WB2	WT1	WT2	WT3
33	7.95	7.95	7.95	7.95	23.28	23.28	23.28	23.28	0.0	324.00	46.29	49.41	67.00
34	7.95	7.95	7.95	7.95	23.28	23.28	23.28	23.28	0.0	324.00	46.29	49.41	67.00
35	7.95	7.95	7.95	7.95	23.28	23.28	23.28	23.28	0.0	324.00	46.29	49.41	67.00
36	7.95	7.95	7.95	7.95	12.73	12.73	12.73	12.73	0.0	324.00	40.50	8.00	8.00
37	9.19	9.19	9.19	9.19	36.00	36.00	36.00	36.00	0.0	353.17	117.72	134.60	165.00
38	9.19	9.19	9.19	9.19	36.00	36.00	36.00	36.00	0.0	353.17	117.72	134.60	165.00
39	9.19	9.19	9.19	9.19	26.51	26.51	26.51	26.51	0.0	353.17	50.45	60.37	68.00
40	18.28	18.28	18.28	18.28	45.25	45.25	45.25	45.25	0.0	353.17	35.32	36.84	40.00
41	4.14	4.14	4.14	4.14	9.60	9.60	9.60	9.60	0.0	395.23	98.81	201.45	236.00
42	4.14	4.14	4.14	4.14	9.29	9.29	9.29	9.29	0.0	395.23	65.87	89.43	99.00
43	4.14	4.14	4.14	4.14	9.18	9.18	9.18	9.18	0.0	395.23	56.46	57.43	54.00
44	13.72	13.72	13.72	13.72	25.09	25.09	25.09	25.09	0.0	395.23	39.52	17.02	20.00
45	1.51	1.51	1.51	1.51	5.64	5.64	5.64	5.64	0.0	424.40	212.20	39.01	55.00
46	1.51	1.51	1.51	1.51	3.70	3.70	3.70	3.70	0.0	424.40	106.10	78.48	97.00
47	11.36	11.36	11.36	11.36	36.14	36.14	36.14	36.14	0.0	424.40	60.63	83.88	86.00
48	11.36	11.36	11.36	11.36	22.34	22.34	22.34	22.34	0.0	424.40	42.44	17.11	20.00

TABLE (A.10.B) SUMMARY EVALUATION RESULTS - TEST SERIES 2 (TESTS 33-48)

TEST SERIES 3

THE INFLUENCE OF LINE LENGTH

FINAL ASSIGNMENTS AND RESULTS

TEST PROBLEMS

Tests 49 to 53	16 Element	Driscoll-Shafi
54 to 58	21 Element	Wild
59 to 63	30 Element	Sawyer
64 to 68	45 Element	Kilbridge and Wester

EXAMINATION CONDITIONS

No confidence effect.

Minimum duration = 10% of normal duration.

Single model.

Fixed cycle time:

16 Element = 20

21 Element = 36

30 Element = 44

45 Element = 69

Test Series 3

Test Number	Problem	Line length (Number of Stations)
49	16 Element	1
50		2
51		4
52		8
53		No limit
54	21 Element	1
55		2
56		4
57		8
58		No limit
59	30 Element	1
60		2
61		4
62		8
63		No limit
64	45 Element	1
65		2
66		4
67		8
68		No limit

TABLE (A.11) PROBLEMS INVOLVED IN TEST SERIES 3.

Test No.	Station No.	Station Size Min.	Max.	Selected
49	1	9	9	9
50	1	5	5	5
	2	4	5	4
51	1	3	3	3
	2	2	3	2
	3	2	3	2
	4	2	3	2
52	1	2	3	2
	2	1	3	3
	3	1	3	1
	4	1	3	1
53	1	1	3	2
	2	1	3	3
	3	1	3	1
	4	1	3	1
54	1	1	4	4
56	1	2	2	2
	2	3	3	3
57	1	1	1	1
	2	1	1	1
	3	1	1	1
	4	1	1	1
58	1	1	1	1
	2	1	1	1
	3	1	1	1
	4	1	1	1
59	1	8	8	8
60	1	4	4	4
	2	4	4	4
61	1	2	2	2
	2	2	2	2
	3	2	2	2
	4	2	2	2
62	1	1	1	1
	2	1	1	1
	3	1	1	1
	4	1	1	1
	5	1	1	1
	6	1	1	1
	7	1	1	1
	8	1	1	1
63	1	1	1	1
	2	1	1	1
(63 cont.)	3	1	1	1
	4	1	1	1
	5	1	1	1
	6	1	1	1
	7	1	1	1
	8	1	1	1
64	1	8	8	8
65	1	4	4	4
	2	5	5	5
66	1	2	2	2
	2	3	3	3
	3	2	2	2
	4	3	3	3
67	1	1	1	1
	2	1	1	1
	3	2	2	2
	4	1	1	1
	5	1	1	1
	6	1	1	1
	7	1	1	1
	8	1	1	1
68	1	1	1	1
	2	1	1	1
	3	1	1	1
	4	1	1	1
	5	1	1	1
	6	1	1	1
	7	1	1	1
	8	1	1	1
	9	1	1	1
1	1	1	6	2*
	2	1	6	3
	3	1	6	3
	4	1	6	1
5	1	1	6	3*
	2	1	6	1
9	1	1	6	2*
	2	1	6	1*
	3	1	6	1*
	4	1	6	1
	5	1	6	1*
	6	1	6	1
	7	1	6	1
13	1	1	6	1
	2	1	6	1*
	3	1	6	2*
	4	1	6	2*
	5	1	6	1
	6	1	6	1
	7	1	6	1

TABLE (A.12) SELECTION OF STATION SIZES FOR TEST SERIES 3.

Test No. 49

Station Number	Size	Elements	Σt_i	Σte_i
1	9	1/2/3/4/5/6/7/8/9/10/11/12/13 14/15/16	173.00	19.22

Test No. 50

Station Number	Size	Elements	Σt_i	Σte_i
1	5	1/3/4/9/10/11/12/13	97.00	19.40
2	4	2/5/6/7/8/14/15/16	76.00	19.00

Test No. 51

Station Number	Size	Elements	Σt_i	Σte_i
1	3	1/3/9	57.00	19.00
2	2	4/10/11/12/13	40.00	20.00
3	2	2/5/7/14	36.00	18.00
4	2	6/8/15/16	40.00	20.00

Test No. 52

Station Number	Size	Elements	Σt_i	Σte_i
1	2	1/2/3/4/5	40.00	20.00
2	3	9/10/11	58.00	19.33
3	3	7/8/12/13/14/15	59.00	19.67
4	1	6/16	16.00	16.00

Test No. 53

Station Number	Size	Elements	Σt_i	Σte_i
1	2	1/2/3/4/5	40.00	20.00
2	3	9/10/11	58.00	19.33
3	3	7/8/12/13/14/15	59.00	19.67
4	1	6/16	16.00	16.00

Test No. 54.

Station Number	Size	Elements	Σt_i	Σte_i
1	4	21/1/2/3/4/5/6/7/8/9/10 11/12/13/14/15/16/17/18/19/20	143.00	35.75

Test No. 55

Station Number	Size	Elements	Σt_i	Σte_i
1	2	21/1/2/3/4/5/6/7/8/9/11/12	70.00	35.00
2	3	10/13/14/15/16/17/18/19/20	73.00	24.33

Test No. 56

Station Number	Size	Elements	Σt_i	Σte_i
1	1	21/1/2/4/5/6	33.00	33.00
2	2	3/7/8/9/10/11/12/13/14/15	69.00	34.00
3	1	16/17/18/19	35.00	35.00
4	1	20	6.00	6.00

Test No. 57

Station Number	Size	Elements	Σt_i	Σte_i
1	1	21/1/2/4/5/6	33.00	33.00
2	1	3/7/8/9/11	32.00	32.00
3	1	10/12/13/14	27.00	27.00
4	1	15/16/17/19	35.00	35.00
5	1	18/20	16.00	16.00

Test No. 58

Station Number	Size	Elements	Σt_i	Σte_i
1	1	21/1/2/4/5/6	33.00	33.00
2	1	3/7/8/9/11	32.00	32.00
3	1	10/12/13/14	27.00	27.00
4	1	15/16/17/19	35.00	35.00
5	1	18/20	16.00	16.00

Test No. 59

Station Number	Size	Elements	Σt_i	Σte_i
1	8	1/2/3/4/5/6/7/8/9/10/11/12 13/14/15/16/17/18/19/20/21 22/23/24/25/26/27/28/29/30	324.00	40.5

Test No. 60

Station Number	Size	Elements	Σt_i	Σte_i
1	4	1/2/3/4/5/6/7/8/9/10/12/13/14 15/16/20/21/24	176.00	44.00
2	4	11/17/18/19/22/23/25/26/27 28/29/30	148.00	37.00

Test No. 61

Station Number	Size	Elements	Σt_i	Σte_i
1	2	1/2/3/5/6/10/12/13/14/16	88.00	44.00
2	2	4/7/8/9/15/20/21/24	88.00	44.00
3	2	17/22/23/25/26/27	83.00	41.50
4	2	11/18/19/28/29/30	65.00	32.50

Test No. 62

Station Number	Size	Elements	Σt_i	Σte_i
1	1	2/3/12/17	43.00	43.00
2	1	1/5/6/13/14/16	43.00	43.00
3	1	10/20/21	41.00	41.00
4	1	4/7/15/24	40.00	40.00
5	1	8/9/22/25	42.00	42.00
6	1	18/23/26	35.00	35.00
7	1	19/27	43.00	43.00
8	1	11/28/29/30	37.00	37.00

Test No. 63

Station Number	Size	Elements	Σt_i	Σte_i
1	1	2/3/12/17	43.00	43.00
2	1	1/5/6/13/14/16	43.00	43.00
3	1	10/20/21	41.00	41.00
4	1	4/7/15/24	40.00	42.00
5	1	8/9/22/25	42.00	42.00
6	1	18/23/26	35.00	35.00
7	1	19/27	43.00	43.00
8	1	11/28/29/30	37.00	37.00

Test No. 64

Station Number	Size	Elements	Σt_i	Σte_i
1	8	1/2/3/4/5/6/7/8/9/10/11/12/13 14/15/16/17/18/19/20/21/22/23 24/25/26/27/28/29/30/31/32/33 34/35/36/37/38/39/40/41/42/43 44/45	552.00	69.00

Test No. 65

Station Number	Size	Elements	Σt_i	Σte_i
1	4	1/2/3/7/8/11/12/13/14/15/16 17/18/19/20/21/23/24/27	275.00	68.75
2	5	4/5/6/9/10/22/25/26/28/29/30 31/32/33/34/35/36/37/38/39 40/41/42/43/44/45	277.00	55.40

Test No. 66

Station Number	Size	Elements	Σt_i	Σte_i
1	2	1/2/7/8/11/12/13/14/15/16/18 19/20	137.00	68.50
2	3	3/4/17/21/22/23/24/25/27/33 38	206.00	68.67
3	2	5/6/9/10/26/28/29/31/34/35 36	138.00	69.00
4	2	30/32/37/39/40/41/42/43/44 45	71.00	35.50

Test No. 67

Station Number	Size	Elements	Σt_i	Σte_i
1	1	1/2/7/11/12/13/15	69.00	69.00
2	1	8/14/16/18/19/20	68.00	68.00
3	2	3/17/21/23/24/27	138.00	69.00
4	1	4/22/25/33/38	68.00	68.00
5	1	5/6/28/36	67.00	67.00
6	1	9/10/26/31/34/35	67.00	67.00
7	1	29/30/32/37/39/40/41/42/43	65.00	65.00
8	1	44/45	10.00	10.00

Test No. 68

Station Number	Size	Elements	Σt_i	Σte_i
1	1	1/2/7/11/12/13/15	69.00	69.00
2	1	8/14/16/18/19/20	68.00	68.00
3	1	17/21	67.00	67.00
4	1	23/24/27/31	68.00	68.00
5	1	3/4/5/22/33/38	69.00	69.00
6	1	6/25/28	67.00	67.00
7	1	9/10/26/34/35/36	69.00	69.00
8	1	29/30/32/37/39/40/41/42/43	65.00	65.00
9	1	44/45	10.00	10.00

Test No.	BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	WB1	WB2	WT1	WT2	WT3
49	3.89	3.89	3.89	3.89	7.00	7.00	7.00	7.00	0.00	173.00	173.00	0.00	0.00
50	3.89	3.89	3.89	3.89	5.00	5.00	5.00	5.00	0.00	173.00	86.50	14.85	21.00
51	3.89	3.89	3.89	3.89	5.00	5.00	5.00	5.00	0.00	173.00	43.25	16.21	21.00
52	3.89	3.89	3.89	3.89	4.58	4.58	4.58	4.58	0.00	173.00	43.25	34.91	43.00
53	3.89	3.89	3.89	3.89	4.58	4.58	4.58	4.58	0.00	173.00	43.25	34.91	43.00
54	0.69	0.69	0.69	0.69	1.0	1.0	1.0	1.0	0.00	143.00	143.00	0.00	0.00
55	20.56	20.56	20.56	20.56	35.06	35.06	35.06	35.06	0.00	143.00	71.50	2.12	3.00
56	20.56	20.56	20.56	20.56	35.32	35.32	35.32	35.32	0.00	143.00	35.75	44.71	63.00
57	20.56	20.56	20.56	20.56	22.52	22.52	22.52	22.52	0.00	143.00	28.60	15.27	19.00
58	20.56	20.56	20.56	20.56	22.52	22.52	22.52	22.52	0.00	143.00	28.60	15.27	19.00
59	7.95	7.95	7.95	7.95	28.00	28.00	28.00	28.00	0.00	324.00	324.00	0.00	0.00
60	7.95	7.95	7.95	7.95	28.00	28.00	28.00	28.00	0.00	324.00	162.00	19.80	28.00
61	7.95	7.95	7.95	7.95	23.54	23.54	23.54	23.54	0.00	324.00	81.00	18.92	23.00
62	7.95	7.95	7.95	7.95	12.73	12.73	12.73	12.73	0.00	324.00	40.50	8.00	8.00
63	7.95	7.95	7.95	7.95	12.73	12.73	12.73	12.73	0.00	324.00	40.50	8.00	8.00
64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	552.00	522.00	0.00	0.00
65	11.11	11.11	11.11	11.11	68.01	68.01	68.01	68.01	0.00	552.00	267.00	1.41	2.00
66	11.11	11.11	11.11	11.11	67.01	67.01	67.01	67.01	0.00	552.00	138.00	95.47	135.00
67	11.11	11.11	11.11	11.11	59.22	59.22	59.22	59.22	0.00	552.00	69.00	90.93	128.00
68	11.11	11.11	11.11	11.11	59.22	59.22	59.22	59.22	0.00	552.00	61.33	54.47	59.00
1	3.89	3.89	3.89	3.89	4.58	4.58	4.58	4.58	0.00	173.00	43.25	43.91	43.00
5	0.69	0.69	0.69	0.69	1.00	1.00	1.00	1.00	0.00	143.00	71.50	50.20	71.00
9	7.95	7.95	7.95	7.95	23.28	23.28	23.28	23.28	0.00	324.00	46.29	42.41	67.00
13	11.11	11.11	11.11	11.11	64.13	64.13	64.13	64.13	0.00	552.00	78.86	113.82	133.00

TABLE (A.13) SUMMARY EVALUATION RESULTS - TEST SERIES 3.

TEST SERIES 4

SINGLE VERSUS MULTI ELEMENT ASSIGNMENT

MIXED MODEL BALANCING

FINAL ASSIGNMENT AND RESULTS

TEST PROBLEMS

Tests 69 to 71 and 84 to 86	16 Element Problem	Driscoll-Shafi
72 to 74 and 87 to 89	21 Element Problem	Wild
75 to 77 and 89 to 92	30 Element Problem	Sawyer
78 to 80 and 93 to 95	45 Element Problem	Kilbridge & Wester
81 to 83 and 96 to 98	70 Element Problem	Tonge

EXAMINATION CONDITIONS

No confidence effect.

Minimum duration = 10% of normal duration.

No line limit.

5 models.

Equal model weights schedule.

Case (a) Random Removal of Elements.

Case (b) Random Removal of Elements -
Early Part of Precedence Diagram.

Case (c) Random Removal of Elements -
Late Part of Precedence Diagram.

Single and Multi Element Assignment.

Test Series 4

Test Number: Single Element	Test Number: Multi Element	Problem
69	84	16 Element (Random removal)
70	85	16 Element (Random early removal)
71	86	16 Element (Random late removal)
72	87	21 Element (Random removal)
73	88	21 Element (Random early removal)
74	89	21 Element (Random late removal)
75	90	30 Element (Random removal)
76	91	30 Element (Random early removal)
77	92	30 Element (Random late removal)
78	93	45 Element (Random removal)
79	94	45 Element (Random early removal)
80	95	45 Element (Random late removal)
81	96	70 Element (Random removal)
82	97	70 Element (Random early removal)
83	98	70 Element (Random late removal)

TABLE (A.14) PROBLEMS INVOLVED IN TEST SERIES 4.

Test No. 69

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	1/2/-/-/5/6	29.00	14.50
		201	1/2/3/-/5/6	38.00	19.00
		202	1/2/3/-/-/6	31.00	15.00
		203	1/-/3/4/5/-	34.00	17.00
		204	-/-/3/4/5/6	38.00	19.00
2	3	200	9/10/-	53.00	17.67
		201	9/10/11	58.00	19.33
		202	9/10/-	53.00	17.67
		203	9/10/11	58.00	19.33
		204	9/10/-	53.00	17.67
3	1	200	12/13/-	12.00	12.00
		201	12/-/14	14.00	14.00
		202	12/-/14	14.00	14.00
		203	12/13/14	18.00	18.00
		204	12/-/-	8.00	8.00
4	1	200	7	17.00	17.00
		201	-	0.00	0.00
		202	7	17.00	17.00
		203	-	0.00	0.00
		204	7	17.00	17.00
5	1	200	8/-	15.00	15.00
		201	8/-	15.00	15.00
		202	8/-	15.00	15.00
		203	-/15	9.00	9.00
		204	-/15	9.00	9.00
6	1	200	16	6.00	6.00
		201	16	6.00	6.00
		202	-	0.00	0.00
		203	16	6.00	6.00
		204	16	6.00	6.00

Test No. 70

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/-/3/9/-	57.00	19.00
		201	-/-/3/9/-	51.00	17.00
		202	1/2/3/-/10	32.00	10.67
		203	-/-/-/9/10	53.00	17.67
		204	-/2/3/9/-	57.00	19.00
2	1	200	4/11	17.00	17.00
		201	-/11	5.00	5.00
		202	4/11	17.00	17.00
		203	-/-	0.00	0.00
		204	4/-	12.00	12.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
3	1	200	12/13/14	18.00	18.00
		201	12/13/14	18.00	18.00
		202	12/13/14	18.00	18.00
		203	12/13/14	18.00	18.00
		204	12/13/14	18.00	18.00
4	1	200	7	17.00	17.00
		201	7	17.00	17.00
		202	7	17.00	17.00
		203	7	17.00	17.00
		204	7	17.00	17.00
5	1	200	-/15	9.00	9.00
		201	-/15	9.00	9.00
		202	5/15	16.00	16.00
		203	5/15	16.00	16.00
		204	-/15	9.00	9.00
6	1	200	6/16	16.00	16.00
		201	6/16	16.00	16.00
		202	6/16	16.00	16.00
		203	6/16	16.00	16.00
		204	6/16	16.00	16.00
7	1	200	-	0.00	0.00
		201	8	15.00	15.00
		202	8	15.00	15.00
		203	8	15.00	15.00
		204	-	0.00	0.00

Test No. 71

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/10	59.00	19.67
		201	1/9/-	48.00	16.00
		202	1/9/10	59.00	19.67
		203	1/9/10	59.00	19.67
		204	1/9/10	59.00	19.67
2	1	200	-/3/-/13	13.00	13.00
		201	2/3/11/-	20.00	20.00
		202	2/3/11/-	20.00	20.00
		203	2/-/11/13	15.00	15.00
		204	2/3/-/13	19.00	19.00
3	1	200	-/5/12	15.00	15.00
		201	4/-/12	20.00	20.00
		202	-/-/12	8.00	8.00
		203	-/-/12	8.00	8.00
		204	4/-/12	20.00	20.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
4	2	200	6/-/8/14/15	40.00	20.00
		201	-/7/8/14/-	38.00	19.00
		202	6/-/8/14/15	40.00	20.00
		203	6/-/8/14/15	40.00	20.00
		204	-/7/-/-/15	26.00	13.00
5	1	200	16	6.00	6.00
		201	16	6.00	6.00
		202	16	6.00	6.00
		203	16	6.00	6.00
		204	16	6.00	6.00

Test No. 72

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	21/-/2/-/-/6/9/11	24.00	24.00
		201	21/1/2/4/5/-/9/11	33.00	33.00
		202	21/1/2/4/5/-/-/11	30.00	30.00
		203	21/1/2/4/5/-/9/11	35.00	35.00
		204	-/1/2/4/-/6/9/-	28.00	28.00
2	1	200	3/7/8/10/12/-	36.00	36.00
		201	3/7/8/-/12/13	34.00	34.00
		202	3/7/8/-/12/13	34.00	34.00
		203	3/7/-/10/12/13	30.00	30.00
		204	-/7/8/10/12/13	31.00	31.00
3	1	200	-/15/16/17/-	30.00	30.00
		201	-/15/16/17/19	35.00	35.00
		202	-/-/16/17/19	25.00	25.00
		203	-/15/16/17/19	35.00	35.00
		204	14/-/-/17/19	32.00	32.00
4	1	200	18/20	16.00	16.00
		201	-/20	6.00	6.00
		202	18/20	16.00	16.00
		203	-/20	6.00	6.00
		204	18/20	16.00	16.00

Test No. 73

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	21/-/-/4/5/-/7/9/10/11	34.00	34.00
		201	21/-/-/4/5/-/-/9/10/11	28.00	28.00
		202	21/-/2/4/-/6/7/-/10/-	36.00	36.00
		203	21/1/2/4/-/-/-/9/10/-	35.00	35.00
		204	21/1/2/-/5/-/7/-/-/-	29.00	29.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
2					
	1	200	-/-/12/13/14/15	31.00	31.00
		201	3/-/12/-/14/15	36.00	36.00
		202	-/8/-/-/14/15	32.00	32.00
		203	-/8/-/13/14/15	36.00	36.00
		204	3/-/-/13/14/15	35.00	35.00
3					
	1	200	16/17/18/19	35.00	35.00
		201	16/17/18/19	35.00	35.00
		202	16/17/18/19	35.00	35.00
		203	16/17/18/19	35.00	35.00
		204	16/17/18/19	35.00	35.00
4					
	1	200	20	6.00	6.00
		201	20	6.00	6.00
		202	20	6.00	6.00
		203	20	6.00	6.00
		204	20	6.00	6.00

Test No. 74

Station Number	Size	Model	Elements	Σt_i	Σte_i
1					
	1	200	21/1/2/4/5/6	33.00	33.00
		201	21/1/2/4/5/6	33.00	33.00
		202	21/1/2/4/5/6	33.00	33.00
		203	21/1/2/4/5/6	33.00	33.00
		204	21/1/2/4/5/6	33.00	33.00
2					
	1	200	3/7/8/9/11	32.00	32.00
		201	3/7/8/9/11	32.00	32.00
		202	3/7/8/9/11	32.00	32.00
		203	3/7/8/9/11	32.00	32.00
		204	3/7/8/9/11	32.00	32.00
3					
	1	200	10/12/13/-	15.00	15.00
		201	10/12/13/-	15.00	15.00
		202	10/12/13/-	15.00	15.00
		203	10/12/13/14	27.00	27.00
		204	10/12/13/-	15.00	15.00
4					
	1	200	-/-/17/18/-/20	31.00	31.00
		201	-/16/17/-/-/20	26.00	26.00
		202	15/16/-/-/19/20	26.00	26.00
		203	15/16/-/-/-/20	21.00	21.00
		204	-/16/17/-/-/20	26.00	26.00

Test No. 75

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	-/3/-/17	21.00	21.00
		201	2/-/12/-	22.00	22.00
		202	-/3/12/17	36.00	36.00
		203	2/3/12/17	43.00	43.00
		204	2/3/12/17	43.00	43.00
2	1	200	-/14/16/20	38.00	38.00
		201	13/14/16/20	43.00	43.00
		202	13/14/16/20	43.00	43.00
		203	13/-/16/20	31.00	31.00
		204	13/14/16/-	27.00	27.00
3	1	200	1/5/-/10/-	14.00	14.00
		201	1/-/-/-/21	29.00	29.00
		202	1/5/6/10/21	41.00	41.00
		203	1/5/6/10/21	41.00	41.00
		204	1/5/6/10/21	37.00	37.00
4	1	200	4/7/15/24	40.00	40.00
		201	-/7/15/-	23.00	23.00
		202	4/-/-/24	17.00	17.00
		203	4/7/15/24	40.00	40.00
		204	-/7/15/24	30.00	30.00
5	1	200	8/9/22/25	42.00	42.00
		201	-/-/22/25	31.00	31.00
		202	8/-/-/25	27.00	27.00
		203	8/9/22/-	25.00	25.00
		204	-/-/-/25	17.00	17.00
6	1	200	18/23/26	35.00	35.00
		201	18/23/-	26.00	26.00
		202	18/-/26	19.00	19.00
		203	18/23/-	26.00	26.00
		204	18/23/26	35.00	35.00
7	1	200	-/29/30	16.00	16.00
		201	27/29/-	39.00	39.00
		202	27/29/-	39.00	39.00
		203	27/29/-	39.00	39.00
		204	27/29/30	41.00	41.00
8	1	200	11/19/-	32.00	32.00
		201	11/19/-	32.00	32.00
		202	11/19/28	21.00	21.00
		203	-/-/28	7.00	7.00
		204	11/-/-	14.00	14.00

Test No. 76

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	-/2/-/4/-/12/-/14/-	44.00	44.00
		201	1/2/-/-/5/12/-/-/16	42.00	42.00
		202	1/2/-/-/5/12/-/14/-	44.00	44.00
		203	1/-/-/-/-/-/13/14/-	25.00	25.00
		204	-/2/3/-/-/-/-/-/-	26.00	26.00
2	1	200	6/20/21	43.00	43.00
		201	-/20/21	37.00	37.00
		202	6/20/21	43.00	43.00
		203	6/20/21	43.00	43.00
		204	-/20/21	37.00	37.00
3	1	200	-/15/17/22/24	32.00	32.00
		201	10/15/-/22/24	34.00	34.00
		202	-/15/-/22/24	30.00	30.00
		203	10/15/17/22/24	36.00	36.00
		204	-/15/-/22/24	30.00	30.00
4	1	200	-/8/9/25	28.00	28.00
		201	-/8/9/25	28.00	28.00
		202	-/8/9/25	28.00	28.00
		203	7/8/9/25	42.00	42.00
		204	7/8/9/25	42.00	42.00
5	1	200	18/23/26	35.00	35.00
		201	-/23/26	25.00	25.00
		202	18/23/26	35.00	35.00
		203	18/23/26	35.00	35.00
		204	-/23/26	25.00	25.00
6	1	200	27/29/30	41.00	41.00
		201	27/29/30	41.00	41.00
		202	27/29/30	41.00	41.00
		203	27/29/30	41.00	41.00
		204	27/29/30	41.00	41.00
7	1	200	11/-/28	21.00	21.00
		201	11/19/28	39.00	39.00
		202	-/19/28	25.00	25.00
		203	-/19/28	25.00	25.00
		204	11/19/28	39.00	39.00

Test No. 77

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	2/3/12/17	43.00	43.00
		201	2/3/12/17	43.00	43.00
		202	2/3/12/17	43.00	43.00
		203	2/3/12/17	43.00	43.00
		204	2/3/12/17	43.00	43.00
2	1	200	1/5/6/13/14/16	43.00	43.00
		201	1/5/6/13/14/16	43.00	43.00
		202	1/5/6/13/14/16	43.00	43.00
		203	1/5/6/13/14/16	43.00	43.00
		204	1/5/6/13/14/16	43.00	43.00
3	1	200	4/7/10/20	44.00	44.00
		201	4/7/10/20	44.00	44.00
		202	4/7/10/20	44.00	44.00
		203	4/7/10/-	28.00	28.00
		204	4/7/10/20	44.00	44.00
4	1	200	-/9/15/21/24	38.00	38.00
		201	8/9/15/-/24	26.00	26.00
		202	-/9/15/21/24	38.00	38.00
		203	8/-/-/-/-	10.00	10.00
		204	8/-/15/-/24	26.00	26.00
5	1	200	22/-/26	23.00	23.00
		201	-/-/26	9.00	9.00
		202	-/25/-	17.00	17.00
		203	22/25/26	40.00	40.00
		204	-/-/-	0.00	0.00
6	1	200	18/-/-/-	10.00	10.00
		201	18/-/27/-	35.00	35.00
		202	18/-/-/28	17.00	17.00
		203	18/23/-/28	33.00	33.00
		204	18/-/27/-	35.00	35.00
7	1	200	19/29/30	34.00	34.00
		201	19/29/30	34.00	34.00
		202	19/29/30	34.00	34.00
		203	19/29/30	34.00	34.00
		204	19/29/30	34.00	34.00
8	1	200	11	14.00	14.00
		201	11	14.00	14.00
		202	11	14.00	14.00
		203	11	14.00	14.00
		204	11	14.00	14.00

Test No. 78

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	1/2/-/8/11/12/13/15	69.00	69.00
		201	1/2/3/-/11/12/13/15	66.00	66.00
		202	1/2/-/8/11/-/13/15	58.00	58.00
		203	1/-/-/8/-/12/-/-	33.00	33.00
		204	1/-/-/8/11/12/-/-	43.00	43.00
2	1	200	7/14/16/18/19/20	68.00	68.00
		201	7/14/16/18/-/20	65.00	65.00
		202	7/-/16/18/19/20	46.00	46.00
		203	7/14/16/18/19/20	68.00	68.00
		204	7/-/16/-/19/20	42.00	42.00
3	1	200	17/21	67.00	67.00
		201	17/-	12.00	12.00
		202	17/21	67.00	67.00
		203	17/21	67.00	67.00
		204	17/21	67.00	67.00
4	1	200	4/22/-/24/27/29/31	69.00	69.00
		201	4/22/-/24/27/29/31	69.00	69.00
		202	4/22/23/-/27/-/31	63.00	63.00
		203	4/22/23/-/-/29/-	55.00	55.00
		204	4/22/-/-/27/29/31	40.00	40.00
5	1	200	6/-/33/36	41.00	41.00
		201	-/25/33/36	50.00	50.00
		202	6/25/33/36	67.00	67.00
		203	6/25/33/36	67.00	67.00
		204	6/25/33/36	67.00	67.00
6	1	200	-/10/26/-	26.00	26.00
		201	5/10/26/28	67.00	67.00
		202	5/10/26/28	67.00	67.00
		203	-/10/26/28	50.00	50.00
		204	5/10/26/28	67.00	67.00
7	1	200	-/30/32/34/35/38/39/40/41 -/-	56.00	56.00
		201	9/-/-/34/35/38/-/40/41 -/45	67.00	67.00
		202	-/30/-/-/35/38/39/-/-/42 45	37.00	37.00
		203	9/-/-/34/-/38/39/40/-/42/45	56.00	56.00
		204	-/30/32/34/35/38/39/40/41 42/-	68.00	68.00
8	1	200	37/43/-	10.00	10.00
		201	37/43/44	15.00	15.00
		202	37/-/44	11.00	11.00
		203	37/43/44	15.00	15.00
		204	37/43/44	15.00	15.00

Test No. 79

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	1/-/-/-/12/-/-/16/19/39	47.00	47.00
		201	-/2/-/11/12/-/15/16/19/39	68.00	68.00
		202	1/2/-/11/-/-/15/16/-/39	63.00	63.00
		203	1/2/8/11/-/13/-/-/-/39	52.00	52.00
		204	-/-/-/11/-/-/-/-/19/-	13.00	13.00
2	1	200	-/-/6/7/-/17/18/20/27/29	62.00	62.00
		201	3/4/6/-/-/17/18/20/27/29	69.00	69.00
		202	-/-/-/7/-/17/18/20/27/-	41.00	41.00
		203	-/4/-/7/-/17/18/20/27/-	51.00	51.00
		204	-/-/6/-/14/17/18/20/27/-	67.00	67.00
3	1	200	21/22	69.00	69.00
		201	21/22	69.00	69.00
		202	21/22	69.00	69.00
		203	21/22	69.00	69.00
		204	21/22	69.00	69.00
4	1	200	-/24/30/31/-/-/43	47.00	47.00
		201	-/-/30/31/32/37/43	26.00	26.00
		202	-/24/-/-/-/-/-	29.00	29.00
		203	23/24/-/-/-/-/-	60.00	60.00
		204	23/24/-/31/32/-/-	67.00	67.00
5	1	200	25/28/33/38	68.00	68.00
		201	25/28/33/38	68.00	68.00
		202	25/28/33/38	68.00	68.00
		203	25/28/33/38	68.00	68.00
		204	25/28/33/38	68.00	68.00
6	1	200	-/9/10/36	49.00	49.00
		201	-/9/10/36	49.00	49.00
		202	5/9/10/36	66.00	66.00
		203	-/9/10/36	49.00	49.00
		204	5/9/10/36	66.00	66.00
7	1	200	26/34/35/40/41/42/44/45	67.00	67.00
		201	26/34/35/40/41/42/44/45	67.00	67.00
		202	26/34/35/40/41/42/44/45	67.00	67.00
		203	26/34/35/40/41/42/44/45	67.00	67.00
		204	26/34/35/40/41/42/44/45	67.00	67.00

Test No. 80

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	1/2/8/11/12/13/15	69.00	69.00
		201	1/2/8/11/12/13/15	69.00	69.00
		202	1/2/8/11/12/13/15	69.00	69.00
		203	1/2/8/11/12/13/15	69.00	69.00
		204	1/2/8/11/12/13/15	69.00	69.00
2	1	200	7/14/16/-/19/-/30	62.00	62.00
		201	7/14/16/-/19/20/30	69.00	69.00
		202	7/14/16/18/19/-/30	66.00	66.00
		203	7/14/16/18/19/-/30	66.00	66.00
		204	7/14/16/-/19/20/30	69.00	69.00
3	1	200	17/23/24	68.00	68.00
		201	-/23/24	56.00	56.00
		202	-/23/24	56.00	56.00
		203	17/23/24	68.00	68.00
		204	17/23/24	68.00	68.00
4	1	200	4/-/23/29	28.00	28.00
		201	4/21/-/29	69.00	69.00
		202	4/21/-/29	69.00	69.00
		203	4/-/-/29	14.00	14.00
		204	4/-/-/29	14.00	14.00
5	1	200	3/5/6/-/33/-/39	64.00	64.00
		201	3/5/6/27/33/-/39	69.00	69.00
		202	3/5/6/27/-/38/39	57.00	57.00
		203	3/5/6/27/33/-/39	69.00	69.00
		204	3/5/6/27/33/-/39	69.00	69.00
6	1	200	10/25/26/-/34/35/-	66.00	66.00
		201	10/25/-/-/34/-/-	53.00	53.00
		202	10/-/26/-/-/35/-	33.00	33.00
		203	10/-/26/28/-/35/36	66.00	66.00
		204	-/25/-/28/-/-/-	50.00	50.00
7	1	200	-/31/32/37/-/41/43	42.00	42.00
		201	-/31/32/37/40/-/43	25.00	25.00
		202	9/31/32/37/40/41/43	66.00	66.00
		203	9/31/32/37/40/-/43	45.00	45.00
		204	9/31/32/37/40/41/43	66.00	66.00
8	1	200	-/44/45	10.00	10.00
		201	-/-/-	0.00	0.00
		202	-/-/45	5.00	5.00
		203	-/44/45	10.00	10.00
		204	42/-/-	12.00	12.00

Test No. 81

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	1/2/3/-/24/-	149.00	149.00
		201	1/2/3/5/24/30	166.00	166.00
		202	-/2/-/-/-/-	66.00	66.00
		203	-/2/3/5/24/-	138.00	138.00
		204	1/2/3/5/24/30	166.00	166.00
2	2	200	4/7/-/15/16/17/41	323.00	161.50
		201	4/7/9/-/16/17/41	297.00	148.50
		202	-/-/9/15/16/17/41	318.00	159.00
		203	-/-/9/15/16/17/41	318.00	159.00
		204	4/7/9/15/16/-/41	341.00	170.50
3	1	200	6/10	158.00	158.00
		201	6/10	158.00	158.00
		202	6/10	158.00	158.00
		203	6/10	158.00	158.00
		204	6/10	158.00	158.00
4	1	200	8/69	151.00	151.00
		201	8/69	151.00	151.00
		202	-/69	23.00	23.00
		203	8/-	128.00	128.00
		204	8/69	151.00	151.00
5	2	200	18/-/-	319.00	159.00
		201	-/19/70	64.00	23.00
		202	18/19/-	338.00	169.00
		203	18/19/-	338.00	169.00
		204	18/-/70	346.00	173.00
6	1	200	11/-/20	139.00	139.00
		201	11/12/20	160.00	160.00
		202	11/12/20	160.00	160.00
		203	-/12/-	21.00	21.00
		204	11/12/-	106.00	106.00
7	1	200	13/22	174.00	174.00
		201	13/22	174.00	174.00
		202	13/-	134.00	134.00
		203	13/22	174.00	174.00
		204	13/22	174.00	174.00
8	2	200	-/21/23/25	275.00	275.00
		201	14/21/-/25	337.00	337.00
		202	-/-/23/25	225.00	225.00
		203	14/-/-/25	287.00	287.00
		204	-/21/-/25	202.00	202.00
9	1	200	26/31/-	73.00	73.00
		201	26/31/33	175.00	175.00
		202	26/31/-	73.00	73.00
		203	-/31/33	133.00	133.00
		204	-/31/33	133.00	133.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
10	1	200	28/32/34	170.00	170.00
		201	28/32/34	170.00	170.00
		202	-/32/34	96.00	96.00
		203	-/-/34	46.00	46.00
		204	28/32/-	124.00	124.00
11	1	200	27/29/35/-/-/62	133.00	133.00
		201	27/29/32/44/-/-	149.00	149.00
		202	27/29/32/44/-/62	176.00	176.00
		203	-/-/32/44/51/62	116.00	116.00
		204	27/29/-/-/-/62	98.00	98.00
12	1	200	-/-/48/53	100.00	100.00
		201	45/46/-/53	157.00	157.00
		202	45/-/48/53	130.00	130.00
		203	45/46/48/-	169.00	169.00
		204	45/-/-/-	30.00	30.00
13	1	200	-/-/38/-/40/47/52	129.00	129.00
		201	36/-/-/39/40/47/52	171.00	171.00
		202	36/-/-/39/40/47/52	171.00	171.00
		203	-/-/38/39/40/47/52	132.00	132.00
		204	36/37/-/39/40/47/52	173.00	173.00
14	1	200	42/-	25.00	25.00
		201	42/-	25.00	25.00
		202	-/63	156.00	156.00
		203	-/63	156.00	156.00
		204	-/63	156.00	156.00
15	1	200	43/54/57/58/-	171.00	171.00
		201	43/-/57/58/64	78.00	78.00
		202	43/54/57/58/-	171.00	171.00
		203	43/-/-/58/64	56.00	56.00
		204	43/54/57/-/-	164.00	164.00
16	1	200	59/55/67/-	115.00	115.00
		201	59/55/-/68	169.00	169.00
		202	49/55/-/68	169.00	169.00
		203	49/55/-/68	169.00	169.00
		204	-/55/67/68	128.00	128.00
17	1	200	50/56/59/60/-/-	159.00	159.00
		201	-/56/59/60/61/65	156.00	156.00
		202	50/56/-/60/61/-	168.00	168.00
		203	50/56/59/-/61/65	167.00	167.00
		204	50/-/59/-/61/-	84.00	84.00
18	1	200	-	0.00	0.00
		201	66	26.00	26.00
		202	66	26.00	26.00
		203	66	26.00	26.00
		204	-	0.00	0.00

Test No. 82

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	-/2/-/4/-/-/-/9/-/16/68	348.00	174.00
		201	1/2/3/-/-/-/7/-/15/16/-	342.00	171.00
		202	1/-/3/4/5/6/7/-/-/16/-	328.00	164.00
		203	1/2/-/-/5/-/-/-/15/16/-	273.00	136.00
		204	1/-/-/-/5/-/-/-/15/16/68	279.50	139.00
2	2	200	-/18/19/24/30	350.00	175.00
		201	-/18/-/24/30	342.00	171.00
		202	17/-/19/24/30	92.00	46.00
		203	-/18/-/-/30	330.00	165.00
		204	-/18/-/24/30	342.00	171.00
3	1	200	-/11/22/41	141.00	141.00
		201	-/-/22/41	56.00	56.00
		202	10/11/-/-	155.00	155.00
		203	10/11/-/41	171.00	171.00
		204	-/-/22/41	56.00	56.00
4	2	200	-/-/-/14/-/-/23	208.00	104.00
		201	-/12/13/14/20/-/-	344.00	172.00
		202	8/12/-/14/20/-/-	338.00	169.00
		203	8/-/13/-/20/-/-	316.00	158.00
		204	8/-/-/14/-/21/-	313.00	156.00
5	1	200	25/57	174.00	174.00
		201	25/57	174.00	174.00
		202	25/57	174.00	174.00
		203	25/57	174.00	174.00
		204	25/57	174.00	174.00
6	1	200	28/-	74.00	74.00
		201	28/-	74.00	74.00
		202	28/33	176.00	176.00
		203	28/-	74.00	74.00
		204	28/33	176.00	176.00
7	2	200	26/27/29/-/32/34/35/44/58 62	321.00	160.50
		201	26/27/29/31/32/34/35/44/ 58/62	352.00	176.00
		202	26/27/29/31/32/34/35/44/ 58/62	352.00	176.00
		203	26/27/29/-/32/34/35/44/ 58/62	321.00	160.50
		204	26/27/29/-/32/34/35/44 58/62	321.00	160.50
8	2	200	45/46/51/52/53/63	350.00	175.00
		201	45/46/51/52/53/63	350.00	175.00
		202	45/56/51/52/53/63	350.00	175.00
		203	45/46/51/52/53/63	350.00	175.00
		204	45/56/51/52/53/63	350.00	175.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
9	2	200	36/37/38/39/40/42/47/48/49	350.00	175.00
		201	36/37/38/39/40/42/47/48/49	350.00	175.00
		202	36/37/38/39/40/42/47/48/49	350.00	175.00
		203	36/37/38/39/40/42/47/48/49	350.00	175.00
		204	36/37/38/39/40/42/47/48/49	350.00	175.00
10	1	200	43/49/56/64	176.00	176.00
		201	43/49/56/64	176.00	176.00
		202	43/49/56/64	176.00	176.00
		203	43/49/56/64	176.00	176.00
		204	43/49/56/64	176.00	176.00
11	1	200	50/55/59/60/61/67	172.00	172.00
		201	50/55/59/60/61/67	172.00	172.00
		202	50/55/59/60/61/67	172.00	172.00
		203	50/55/59/60/61/67	172.00	172.00
		204	50/55/59/60/61/67	172.00	172.00
12		200	65/66/69/70	91.00	91.00
		201	65/66/-/-	41.00	41.00
		202	65/66/69/70	91.00	91.00
		203	65/66/-/70	68.00	68.00
		204	65/66/69/-	64.00	64.00

Test No. 83

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	1/2/3/5/15/16/24/30	350.00	175.00
		201	1/2/3/5/15/16/24/30	350.00	175.00
		202	1/2/3/5/15/16/24/30	350.00	175.00
		203	1/2/3/5/15/16/24/30	350.00	175.00
		204	1/2/3/5/15/16/24/30	350.00	175.00
2	2	200	4/6/7/9/10/17	349.00	174.50
		201	4/6/7/9/10/17	349.00	174.50
		202	4/6/7/9/10/17	349.00	174.50
		203	4/6/7/9/10/17	349.00	174.50
		204	4/6/7/9/10/17	349.00	174.50
3	1	200	8/41/70	171.00	171.00
		201	8/41/70	171.00	171.00
		202	8/41/70	171.00	171.00
		203	8/41/70	171.00	171.00
		204	8/41/70	171.00	171.00
4	2	200	18/19	338.00	169.00
		201	18/19	338.00	169.00
		202	18/19	338.00	169.00
		203	18/19	338.00	169.00
		204	18/19	338.00	169.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
5	2	200	11/12/14/20/21	345.00	172.50
		201	11/12/14/20/21	345.00	172.50
		202	11/12/14/20/21	345.00	172.50
		203	11/12/14/20/21	345.00	172.50
		204	11/12/14/20/21	345.00	172.50
6	1	200	13/22	174.00	174.00
		201	13/22	174.00	174.00
		202	13/22	174.00	174.00
		203	13/22	174.00	174.00
		204	13/22	174.00	174.00
7	1	200	23/33	175.00	175.00
		201	23/33	175.00	175.00
		202	23/33	175.00	175.00
		203	23/33	175.00	175.00
		204	23/33	175.00	175.00
8	1	200	25/69	175.00	175.00
		201	-/69	23.00	23.00
		202	25/69	175.00	175.00
		203	25/69	175.00	175.00
		204	25/69	175.00	175.00
9	1	200	28/-/31/-/-/-/59	121.00	121.00
		201	-/-/31/-/57/58/-	60.00	60.00
		202	28/-/31/34/57/-/-	173.00	173.00
		203	28/-/31/34/-/-/-	151.00	151.00
		204	-/29/31/34/-/-/-	103.00	103.00
10	1	200	-/-/32/-/44/-/-/-/-/53/62	164.00	164.00
		201	-/-/-/-/-/-/-/-/-/-/62	72.00	72.00
		202	26/27/32/-/-/-/-/5-/52/-/-	174.00	174.00
		203	26/27/-/35/44/-/-/51/-/-/-	176.00	176.00
		204	-/-/-/-/-/48/49/51/52/-/-	152.00	152.00
11	1	200	56/-	68.00	68.00
		201	-/63	156.00	156.00
		202	-/-	0.00	0.00
		203	-/63	156.00	156.00
		204	-/63	156.00	156.00
12	1	200	36/-/-/39/-/-/46/-	126.00	126.00
		201	36/-/-/-/-/45/46/-	153.00	153.00
		202	36/-/38/-/-/45/47/-	154.00	154.00
		203	-/-/-/-/-/45/-/-	30.00	30.00
		204	36/37/38/-/40/45/-/60	118.00	118.00
13	1	200	47/-/68	161.00	161.00
		201	47/-/68	161.00	161.00
		202	-/61/68	97.00	97.00
		203	-/61/68	97.00	97.00
		204	-/61/68	97.00	97.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
14	1	200	42/-/-/64/-/-	53.00	53.00
		201	42/54/-/64/-/-	174.00	174.00
		202	42/-/55/-/65/-	78.00	78.00
		203	-/-/-/-/-/67	18.00	18.00
		204	42/-/-/64/-/-	53.00	53.00
15		200	-/-/-	0.00	0.00
		201	43/50/66	90.00	90.00
		202	43/-/-	21.00	21.00
		203	-/50/66	69.00	69.00
		204	43/-/-	21.00	21.00

Test No. 84

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/10	59.00	19.67
		201	1/9/10	59.00	19.67
		202	1/3/9	57.00	19.00
		203	1/9/10	59.00	19.67
		204	3/9	51.00	17.00
2	1	200	2/5/13	17.00	17.00
		201	2/3/11	20.00	20.00
		202	2/10	17.00	17.00
		203	11/12/13	17.00	17.00
		204	4/5	19.00	19.00
3	2	200	7/8/12	40.00	20.00
		201	5/8/12/14	36.00	18.00
		202	7/8/12	40.00	20.00
		203	3/4/14/15	36.00	18.00
		204	7/10/12	36.00	18.00
4	1	200	6/16	16.00	16.00
		201	6/16	16.00	16.00
		202	6/14	16.00	16.00
		203	5/16	13.00	13.00
		204	6/15	19.00	19.00
5	1	200	-	0.00	0.00
		201	-	0.00	0.00
		202	-	0.00	0.00
		203	-	0.00	0.00
		204	16	6.00	6.00

Test No. 85

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	1/3/4/6	37.00	18.50
		201	3/6/7	36.00	18.00
		202	1/3/4/10	38.00	19.00
		203	5/7/8	39.00	19.50
		204	3/4/7	38.00	19.00
2	3	200	9/11/12/13	59.00	19.67
		201	9/11/12/13	59.00	19.67
		202	2/5/7/11/12/13/14	53.00	17.67
		203	9/10/13	57.00	19.00
		204	9/12/13/14	60.00	20.00
3	2	200	7/14/15/16	38.00	19.00
		201	8/14/15/16	36.00	18.00
		202	6/8/15/16	40.00	20.00
		203	6/12/14/15/16	39.00	19.50
		204	2/6/15/16	31.00	15.50

Test No. 86

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/11	59.00	19.67
		201	1/3/9	57.00	19.00
		202	1/9/11	59.00	19.67
		203	1/9/11	59.00	19.67
		204	1/3/9	57.00	19.00
2	3	200	3/5/8/12/13/14/15	58.00	19.33
		201	4/7/8/11/12	57.00	19.00
		202	2/3/8/11/12/14/15	58.00	19.33
		203	2/8/11/12/13/14/15	59.00	19.67
		204	2/4/7/10/12/13	58.00	19.33
3	1	200	6/16	16.00	16.00
		201	2/14/16	18.00	18.00
		202	6/16	16.00	16.00
		203	6	10.00	10.00
		204	15/16	15.00	15.00

Test No. 87

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	21/2/3/6/7	34.00	34.00
		201	21/1/2/3/4	33.00	33.00
		202	21/1/2/3/4	33.00	33.00
		203	21/1/2/4/5/9/11	35.00	35.00
		204	1/2/4/6/7/9	34.00	34.00
2	1	200	8/9/10/12/15	36.00	36.00
		201	5/7/8/9/12/13	34.00	34.00
		202	4/7/8/11/13/16	36.00	36.00
		203	3/7/10/12/13	30.00	30.00
		204	8/10/12/13	25.00	25.00
3	1	200	16/17/18/20	36.00	36.00
		201	15/16/17/19	35.00	35.00
		202	17/18/19/20	36.00	36.00
		203	15/16/17/19	35.00	35.00
		204	14/17/19	32.00	32.00
4	1	200	-	0.00	0.00
		201	20	6.00	6.00
		202	-	0.00	0.00
		203	20	6.00	6.00
		204	18/20	16.00	16.00

Test No. 88

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	21/4/5/7/9/11/12	33.00	33.00
		201	21/3/4/5/9/11/12	36.00	36.00
		202	21/2/7/8/10	36.00	36.00
		203	21/1/2/4/8	34.00	34.00
		204	21/1/2/3/5/13	36.00	36.00
2	1	200	10/13/14/15	32.00	32.00
		201	10/14/15/16	33.00	33.00
		202	4/6/14/15	32.00	32.00
		203	9/10/13/14	27.00	27.00
		204	7/14/15/16	33.00	33.00
3	1	200	16/17/18/19	35.00	35.00
		201	17/18/19/20	36.00	36.00
		202	16/17/18/19	35.00	35.00
		203	15/16/17/19	35.00	35.00
		204	17/18/19/20	36.00	36.00
4	1	200	20	6.00	6.00
		201	-	0.00	0.00
		202	20	6.00	6.00
		203	18/20	16.00	16.00
		204	-	0.00	0.00

Test No. 89

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	21/1/2/4/5/6	33.00	33.00
		201	21/1/2/4/5/6	33.00	33.00
		202	21/1/2/4/5/6	33.00	33.00
		203	21/1/2/4/5/6	33.00	33.00
		204	21/1/2/4/5/6	33.00	33.00
2	1	200	3/7/8/9/11	32.00	32.00
		201	3/7/8/9/11	32.00	32.00
		202	3/7/8/9/11	32.00	32.00
		203	3/7/8/9/11	32.00	32.00
		204	3/7/8/9/11	32.00	32.00
3	1	200	10/12/13/17	30.00	30.00
		201	10/12/13/16/17	35.00	35.00
		202	10/12/13/15/16/19	35.00	35.00
		203	10/12/13/14	27.00	27.00
		204	10/12/13/16/17	35.00	35.00
4	1	200	18/20	16.00	16.00
		201	20	6.00	6.00
		202	20	6.00	6.00
		203	15/16/20	21.00	21.00
		204	20	6.00	6.00

Test No. 90

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	1/3/5/14/17	43.00	43.00
		201	2/12/13/14	39.00	39.00
		202	1/3/5/12	44.00	44.00
		203	2/3/12/17	43.00	43.00
		204	2/3/12/17	43.00	43.00
2	1	200	4/10/16/20	40.00	40.00
		201	1/15/16/20	43.00	43.00
		202	13/14/16/20	43.00	43.00
		203	1/5/13/16/20	41.00	41.00
		204	1/5/6/13/14/16	43.00	43.00
3	1	200	7/15/22/24	44.00	44.00
		201	21/22	35.00	35.00
		202	4/6/10/24/25	44.00	44.00
		203	6/10/15/21	40.00	40.00
		204	15/21/24	37.00	37.00
4	1	200	8/9/23/25	44.00	44.00
		201	18/23/25	43.00	43.00
		202	8/17/21/26	42.00	42.00
		203	4/7/22	38.00	38.00
		204	7/25/26	40.00	40.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
5	1	200	18/19/26	37.00	37.00
		201	7/27	39.00	39.00
		202	11/27	39.00	39.00
		203	8/9/18/23/24	44.00	44.00
		204	23/27	41.00	41.00
6	1	200	11/29/30	30.00	30.00
		201	11/19	32.00	32.00
		202	18/28/29	31.00	31.00
		203	27/29	39.00	39.00
		204	11/18/29/30	40.00	40.00
7	1	200	-	0.00	0.00
		201	29	14.00	14.00
		202	-	0.00	0.00
		203	28	7.00	7.00
		204	-	0.00	0.00

Test No. 91

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	2/6/12/14/17	42.00	42.00
		201	1/2/5/12/16	42.00	42.00
		202	1/2/5/12/14	44.00	44.00
		203	1/13/14/17/20	43.00	43.00
		204	2/3/20	42.00	42.00
2	1	200	20/21/24	44.00	44.00
		201	10/20/21	41.00	41.00
		202	6/20/21	43.00	43.00
		203	6/10/15/21	40.00	40.00
		204	7/15/21	44.00	44.00
3	1	200	4/8/9/15/22	44.00	44.00
		201	8/9/15/22/24	41.00	41.00
		202	8/9/15/22/24	41.00	41.00
		203	7/22/24	35.00	35.00
		204	22/24/25	38.00	38.00
4	1	200	23/25/26	42.00	42.00
		201	23/25/26	42.00	42.00
		202	23/25/26	42.00	42.00
		203	8/9/23/25	44.00	44.00
		204	8/9/23/26	36.00	36.00
5	1	200	27/29/30	41.00	41.00
		201	19/27	43.00	43.00
		202	18/27/28	42.00	42.00
		203	18/26/27	44.00	44.00
		204	19/27	43.00	43.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
6	1	200	11/18/28	31.00	31.00
		201	11/28/29/30	37.00	37.00
		202	19/29/30	34.00	34.00
		203	19/28/29/30	41.00	41.00
		204	11/28/29/30	37.00	37.00

Test No. 92

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	2/3/12/17	43.00	43.00
		201	1/2/3/5/6/17	44.00	44.00
		202	2/3/12/17	43.00	43.00
		203	1/2/3/16	44.00	44.00
		204	1/2/3/5/6/17	44.00	44.00
2	1	200	1/5/6/13/14/16	43.00	43.00
		201	4/12/13/14	42.00	42.00
		202	1/5/6/13/14/16	43.00	43.00
		203	5/6/10/12/13/14	44.00	44.00
		204	4/12/13/14	42.00	42.00
3	1	200	10/20/21	41.00	41.00
		201	7/10/16/20	44.00	44.00
		202	4/10/20/24	37.00	37.00
		203	4/7/17/22	40.00	40.00
		204	7/10/16/20	44.00	44.00
4	1	200	4/7/9/15/24	41.00	41.00
		201	8/15/24/26	35.00	35.00
		202	21/25	38.00	38.00
		203	8/23/25	43.00	43.00
		204	8/15/18/24	36.00	36.00
5	1	200	18/22/26	33.00	33.00
		201	18/27	35.00	35.00
		202	7/9/15/18/28	41.00	41.00
		203	18/19/26/28	44.00	44.00
		204	19/27	43.00	43.00
6	1	200	19/29/30	34.00	34.00
		201	19/29/30	34.00	34.00
		202	19/29/30	34.00	34.00
		203	11/29/30	30.00	30.00
		204	11/29/30	30.00	30.00
7	1	200	11	14.00	14.00
		201	11	14.00	14.00
		202	11	14.00	14.00
		203	-	0.00	0.00
		204	-	0.00	0.00

Test No. 93

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	2/11/12/13/15/16/19	69.00	69.00
		201	1/2/7/11/12/13/15	69.00	69.00
		202	1/2/11/13/15/16/19	67.00	67.00
		203	1/7/8/12/16/19	68.00	68.00
		204	1/8/11/12/16/19/37	69.00	69.00
2	1	200	1/7/8/14/18/20	69.00	69.00
		201	14/16/17/18/20/27	69.00	69.00
		202	4/7/8/17/18/20/27/30	69.00	69.00
		203	4/14/17/18/20/29/37/39	68.00	68.00
		204	4/7/17/20/27/29/33/38	69.00	69.00
3	1	200	17/21	67.00	67.00
		201	3/22/24/33	68.00	68.00
		202	21/22	69.00	69.00
		203	21/22	69.00	69.00
		204	21/22	69.00	69.00
4	1	200	4/24/27/33/36	68.00	68.00
		201	5/25/28	67.00	67.00
		202	6/23/33/36	68.00	68.00
		203	23/25/33	68.00	68.00
		204	6/25/28	67.00	67.00
5	1	200	6/10/22/26/34/38	67.00	67.00
		201	4/9/10/26/36/38	68.00	68.00
		202	5/25/28	67.00	67.00
		203	6/9/26/28	67.00	67.00
		204	5/10/26/34/35/36	66.00	66.00
6	1	200	29/30/31/32/35/37/39/40 41/43	67.00	67.00
		201	29/31/34/35/37/40/41/43/44	65.00	65.00
		202	10/26/31/35/37/38/39/42/44	69.00	69.00
		203	10/34/36/38/40/42/43/44	66.00	66.00
		204	30/31/32/39/40/41/42/43/44	69.00	69.00
7	1	200	-	0.00	0.00
		201	45	5.00	5.00
		202	45	5.00	5.00
		203	45	5.00	5.00
		204	-	0.00	0.00

Test No. 94

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	1/7/12/16/18/19/20	66.00	66.00
		201	2/11/12/15/16/19/30	68.00	68.00
		202	1/7/11/15/16/20	69.00	69.00
		203	1/2/7/8/11/13/20	67.00	67.00
		204	11/14/17/18/19/20/27/32	67.00	67.00
2	1	200	17/21	67.00	67.00
		201	18/20/21	66.00	66.00
		202	2/18/21	68.00	68.00
		203	4/18/21	69.00	69.00
		204	21/22	69.00	69.00
3	1	200	22/24/27/33/38	66.00	66.00
		201	3/4/17/22/27/33/38	69.00	69.00
		202	17/22/24/27/39	65.00	65.00
		203	17/22/24/27/37/39	69.00	69.00
		204	23/24/31	63.00	63.00
4	1	200	6/25/28	67.00	67.00
		201	6/25/28	67.00	67.00
		202	5/25/33/36	67.00	67.00
		203	23/25/33	68.00	68.00
		204	5/25/33/36	67.00	67.00
5	1	200	9/10/26/34/35/36	69.00	69.00
		201	9/10/26/34/35/36	69.00	69.00
		202	9/10/28/38	67.00	67.00
		203	9/10/28/38	67.00	67.00
		204	9/10/26/28	67.00	67.00
6	1	200	29/30/31/39/40/41/42/43/44	69.00	69.00
		201	29/31/32/37/39/40/41/42/43	67.00	67.00
		202	26/34/35/40/41/42/44/45	67.00	67.00
		203	26/34/35/36/40/41/42	66.00	66.00
		204	10/34/35/38/40/41	62.00	62.00
7	1	200	45	5.00	5.00
		201	44/45	10.00	10.00
		202	-	0.00	0.00
		203	44/45	10.00	10.00
		204	42/44/45	22.00	22.00

Test No. 95

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	1/2/8/11/12/13/15	69.00	69.00
		201	1/2/8/11/12/13/15	69.00	69.00
		202	1/2/7/11/12/13/15	69.00	69.00
		203	1/2/7/11/12/13/15	69.00	69.00
		204	1/2/7/11/12/13/15	69.00	69.00
2	1	200	4/7/14/16/19	67.00	67.00
		201	7/14/16/19/20/27	69.00	69.00
		202	8/14/16/18/19/27	66.00	66.00
		203	8/14/16/17/19	69.00	69.00
		204	8/14/16/17/19	69.00	69.00
3	1	200	17/23/24	69.00	69.00
		201	4/21/37	69.00	69.00
		202	3/21/29	69.00	69.00
		203	18/23/24/27/29	69.00	69.00
		204	3/5/20/24/27	68.00	68.00
4	1	200	3/6/25/33	68.00	68.00
		201	3/23/24	66.00	66.00
		202	4/23/24/38	69.00	69.00
		203	3/4/5/6/33	69.00	69.00
		204	4/23/25/30	68.00	68.00
5	1	200	5/10/22/26/30/31	69.00	69.00
		201	6/25/29/33/34	69.00	69.00
		202	5/6/9/26/35	67.00	67.00
		203	9/10/28/30	69.00	69.00
		204	9/28/31/33	66.00	66.00
6	1	200	29/32/34/35/37/39/41/43 44/45	68.00	68.00
		201	5/10/30/31/32/39/40/43	68.00	68.00
		202	10/30/31/32/39/40/41	66.00	66.00
		203	26/31/32/35/36/37/39/40 43/44/45	62.00	62.00
		204	6/29/32/39/40/41/42	67.00	67.00
7	1	200	-	0.00	0.00
		201	-	0.00	0.00
		202	37/43/45	15.00	15.00
		203	-	0.00	0.00
		204	37/43	10.00	10.00

Test No. 96

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	1/2/3/15/16/24/41	349.00	174.50
		201	1/2/3/4/5/6/9	351.00	175.50
		202	2/9/15/16/41	334.00	167.00
		203	2/3/5/15/16/24/41	338.00	169.00
		204	1/2/3/5/15/16/24/30	350.00	175.00
2	2	200	18/69	342.00	171.00
		201	7/8/10/11/12/24/30	348.00	174.00
		202	18/69	342.00	171.00
		203	6/8/9/17	334.00	167.00
		204	18/41	335.00	167.50
3	2	200	4/6/7/10/17/20	335.00	167.50
		201	14/16/17/19/20	348.00	174.00
		202	6/10/11/12/17/19	333.00	166.50
		203	18/19/58	345.00	172.50
		204	4/6/7/9/10/21	349.00	174.50
4	2	200	8/11/13	347.00	173.50
		201	13/21/22/33/57	348.00	174.00
		202	13/20/23/31/32	342.00	171.00
		203	10/12/14/22/68	338.00	169.00
		204	8/11/12/22/68	346.00	173.00
5	1	200	21/22/23	163.00	163.00
		201	25/41/58	175.00	175.00
		202	25/57	174.00	174.00
		203	13/31	165.00	165.00
		204	13/31	165.00	165.00
6	2	200	25/27/28/31/32	352.00	176.00
		201	26/27/28/29/31/32/34/35	349.00	174.50
		202	26/27/29/34/35/44/52/53 58/62	341.00	170.50
		203	25/33/34/35/38/39/40	352.00	176.00
		204	25/28/33/57	350.00	175.00
7	2	200	26/29/34/35/38/52/53/54	341.00	170.50
		201	36/39/40/44/45/46/47/53	345.00	172.50
		202	36/39/45/54/63	350.00	175.00
		203	44/45/46/51/62/63	350.00	175.00
		204	27/29/32/52/62/63/67	348.00	174.00
8	2	200	40/42/47/48/49/56/57/58	339.00	169.50
		201	42/49/52/56/59/60/61/64 68	351.00	175.50
		202	40/43/47/48/49/55/68	348.00	174.00
		203	43/47/48/49/52/56/64	347.00	173.50
		204	36/37/39/40/43/45/47/54 70	346.00	173.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
9	1	200	43/50/55/59/62/67	163.00	163.00
		201	43/55/65/66/69/70	150.00	150.00
		202	50/56/60/66	169.00	169.00
		203	50/53/59/61/65/66	163.00	163.00
		204	50/55/59/61/69	145.00	145.00
10	1	200	60	32.00	32.00
		201	-	0.00	0.00
		202	61	25.00	25.00
		203	-	0.00	0.00
		204	-	0.00	0.00

Test No. 97

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	2/9/11/16/24/41	337.00	168.50
		201	1/2/3/7/15/16	342.00	171.00
		202	1/3/4/5/6/7/10/24/30	331.00	165.50
		203	1/2/5/10/15/16	343.00	171.50
		204	1/5/8/15/16/24	347.00	173.50
2	2	200	18/19	338.00	169.00
		201	12/18/24	352.00	176.00
		202	8/11/12/16/70	351.00	175.00
		203	18/30/41	346.00	173.00
		204	18/30/41	346.00	173.00
3	1	200	4/22/57/58/59/70	164.00	164.00
		201	14/22	175.00	175.00
		202	17/19/20/57/58/59	168.00	168.00
		203	8/57/58/59	173.00	173.00
		204	14/22	175.00	175.00
4	2	200	14/23/32/34/69	327.00	163.50
		201	13/20/25/30	351.00	175.50
		202	14/25/29/31	344.00	172.00
		203	11/13/20/32/70	350.00	175.00
		204	21/25/33/34	350.00	175.00
5	2	200	25/26/27/28/29	339.00	169.50
		201	26/27/28/29/31/32/34/35	349.00	174.50
		202	27/28/32/33/34/69	340.00	170.00
		203	25/27/28/29/34	343.00	171.50
		204	26/27/28/29/32/35/44/62	342.00	171.00
6	2	200	35/44/45/51/53/62/63	346.00	173.00
		201	44/45/46/51/62/63	350.00	175.00
		202	26/35/44/45/51/62/63	344.00	172.00
		203	26/35/44/45/51/62/63	344.00	172.00
		204	45/46/51/52/53/63	350.00	175.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
7	2	200	36/37/38/39/40/46/48/52/54	345.00	172.50
		201	36/37/38/39/40/41/42/48 52/53/54	347.00	173.50
		202	46/48/52/53/54	330.00	165.00
		203	46/48/52/53/54	330.00	165.00
		204	36/37/38/39/40/42/47/48/54	350.00	175.00
8	1	200	42/47/49	173.00	173.00
		201	47/49/64	176.00	176.00
		202	36/37/38/39/40/42/47	173.00	173.00
		203	36/37/38/39/40/42/47	173.00	173.00
		204	43/49/57/58/59/64/69	176.00	176.00
9	1	200	56/64/68	168.00	168.00
		201	43/56/57/58/59/61/65	174.00	174.00
		202	43/49/56/64	176.00	176.00
		203	43/49/56/64	176.00	176.00
		204	56/61/68	165.00	165.00
10	1	200	43/50/55/60/61/65	174.00	174.00
		201	50/55/60/66/67	157.00	157.00
		202	50/55/60/61/66	164.00	164.00
		203	50/55/60/61/66	164.00	164.00
		204	50/55/60/65/66/67	172.00	172.00
11	1	200	66/67	44.00	44.00
		201	-	0.00	0.00
		202	65/67	33.00	33.00
		203	65/67	33.00	33.00
		204	-	0.00	0.00

Test No. 98

Station Number	Size	Models	Elements	Σt_i	Σte_i
1	2	200	1/2/3/5/15/16/24/30	350.00	175.00
		201	1/2/3/5/15/16/24/30	350.00	175.00
		202	1/2/3/5/15/16/24/30	350.00	175.00
		203	1/2/3/5/15/16/24/30	350.00	175.00
		204	1/2/3/5/15/16/24/30	350.00	175.00
2	2	200	4/6/7/9/10/17	349.00	174.50
		201	4/6/7/9/10/17	349.00	174.50
		202	4/6/7/9/10/17	349.00	174.50
		203	4/6/7/9/10/17	349.00	174.50
		204	4/6/7/9/10/17	349.00	174.50
3	1	200	8/41/70	171.00	171.00
		201	8/41/70	171.00	171.00
		202	8/41/70	171.00	171.00
		203	8/41/70	171.00	171.00
		204	8/41/70	171.00	171.00

Station Number	Size	Model	Elements	t_i	te_i
4	2	200	18/19	338.00	169.00
		201	18/19	338.00	169.00
		202	18/19	338.00	169.00
		203	18/19	338.00	169.00
		204	18/19	338.00	169.00
5	2	200	11/12/14/20/21	345.00	172.50
		201	11/12/14/20/21	345.00	172.50
		202	11/12/14/20/21	345.00	172.50
		203	11/12/14/20/21	345.00	172.50
		204	11/12/14/20/21	345.00	172.50
6	1	200	13/22	174.00	174.00
		201	13/22	174.00	174.00
		202	13/22	174.00	174.00
		203	13/22	174.00	174.00
		204	13/22	174.00	174.00
7	1	200	23/33	175.00	175.00
		201	23/33	175.00	175.00
		202	23/33	175.00	175.00
		203	23/33	175.00	175.00
		204	23/33	175.00	175.00
8	1	200	25/69	175.00	175.00
		201	27/31/36/45/62	173.00	173.00
		202	25/69	175.00	175.00
		203	25/69	175.00	175.00
		204	25/62	175.00	175.00
9	2	200	28/31/32/36/39/44/46/62	351.00	175.50
		201	46/47/57/63	350.00	175.00
		202	26/27/28/31/32/34/45/51/57	351.00	175.50
		203	26/27/28/31/34/35/44/45	346.00	173.00
		204	29/31/34/48/51/52/63	352.00	176.00
10	1	200	47/68	161.00	161.00
		201	42/43/54	174.00	174.00
		202	42/46/52	175.00	175.00
		203	63/67	174.00	174.00
		204	36/37/38/40/42/43/68	174.00	174.00
11	1	200	42/53/56/64	165.00	165.00
		201	50/64/66/68	169.00	169.00
		202	43/55/61/65/68	171.00	171.00
		203	50/61/66/68	166.00	166.00
		204	45/49/60/61/64	174.00	174.00
12	1	200	59	16.00	16.00
		201	69	23.00	23.00
		202	–	0.00	0.00
		203	51	11.00	11.00
		204	–	0.00	0.00

Test No.	BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	WB1	WB2	WT1	WT2	WT3
69	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55	53.00	173.00	28.83	45.83	52.00
70	26.67	26.67	26.67	26.67	24.71	24.71	24.71	24.71	64.00	173.00	24.71	53.29	59.00
71	18.00	18.00	18.00	18.00	18.53	18.53	18.53	18.53	44.00	173.00	34.60	45.66	53.00
72	26.11	26.11	26.11	26.11	26.45	26.45	26.45	26.45	37.00	143.00	35.75	23.51	31.00
73	25.42	25.42	25.42	25.42	30.55	30.55	30.55	30.55	13.00	143.00	35.75	36.78	46.00
74	24.72	24.72	24.72	24.72	22.45	22.45	22.45	22.45	22.00	143.00	35.75	18.19	24.00
75	30.57	30.57	30.57	30.57	47.13	47.13	47.13	47.13	179.00	324.00	40.50	6.93	8.00
76	20.58	20.58	20.58	20.58	30.26	30.26	30.26	30.26	73.00	324.00	46.29	45.64	53.00
77	30.06	30.06	30.06	30.06	52.26	52.26	52.26	52.26	109.00	324.00	40.50	33.65	44.00
78	25.69	25.69	25.69	25.69	75.22	75.22	75.22	75.22	250.00	552.00	69.00	65.83	81.00
79	14.66	14.66	14.66	14.66	45.54	45.54	45.54	45.54	141.00	552.00	78.86	38.17	38.00
80	25.22	25.22	25.22	25.22	80.70	80.70	80.70	80.70	172.00	552.00	69.00	57.79	77.00
81	25.58	25.58	25.58	25.58	328.55	328.55	328.55	328.55	1783.00	3686.00	204.78	385.15	384.00
82	12.69	12.69	12.69	12.69	212.59	212.59	212.59	212.59	767.00	3686.00	307.17	573.26	537.00
83	16.95	16.95	16.95	16.95	250.10	250.10	250.10	250.10	959.00	3686.00	245.73	358.06	348.00

TABLE (A.15.A) SUMMARY EVALUATION RESULTS - TEST SERIES 4 (TESTS 69 to 83).

Test No.	BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	WB1	WB2	WT1	WT2	WT3
84	18.87	18.87	18.87	18.87	20.31	20.31	20.31	20.31	27.00	268.00	53.60	66.48	88.00
85	5.71	5.71	5.71	5.71	6.26	6.26	6.26	6.26	19.00	270.00	90.00	20.83	29.00
86	6.29	6.29	6.29	6.29	6.39	6.39	6.39	6.39	12.00	220.00	73.33	55.54	78.00
87	26.11	26.11	26.11	26.11	31.62	31.62	31.62	31.62	33.00	200.00	50.00	40.07	50.00
88	25.42	25.42	25.42	25.42	31.43	31.43	31.43	31.43	26.00	200.00	50.00	42.97	59.00
89	24.72	24.72	24.72	24.72	26.72	26.72	26.72	26.72	23.00	158.00	39.50	26.02	31.00
90	20.65	20.65	20.65	20.65	42.41	42.41	42.41	42.41	54.00	613.00	87.57	87.41	103.00
91	7.35	7.35	7.35	7.35	11.32	11.32	11.32	11.32	36.00	464.00	77.33	37.86	49.00
92	20.06	20.06	20.06	20.06	39.38	39.38	39.38	39.38	47.00	532.00	76.00	91.88	110.00
93	15.07	15.07	15.07	15.07	66.16	66.16	66.16	66.16	17.00	886.00	125.57	146.13	175.00
94	14.66	14.66	14.66	14.66	60.36	60.36	60.36	60.36	44.00	819.00	117.00	111.27	141.00
95	14.53	14.53	14.53	14.53	64.47	64.47	64.47	64.47	31.00	902.00	128.86	156.42	174.00
96	8.07	8.07	8.07	8.07	168.49	168.49	168.49	168.49	157.00	7201.00	720.10	1003.47	1072.00
97	7.55	7.55	7.55	7.55	158.07	158.07	158.07	158.07	176.00	5826.00	529.64	894.53	940.00
98	7.18	7.18	7.18	7.18	167.46	167.46	167.46	167.46	54.00	4435.00	369.58	810.80	885.00

TABLE (A.15.B) SUMMARY EVALUATION RESULTS - TEST SERIES 4 (TESTS 84 to 98).

TEST SERIES 5

THE EFFECT OF MODEL WEIGHTING

MIXED MODEL BALANCING

FINAL ASSIGNMENTS AND RESULTS

TEST PROBLEMS

Tests 99 to 140 16 Element Problem Driscoll-Shafi

EXAMINATION CONDITIONS

No confidence.

Minimum duration = 10% of normal duration.

No line limit.

5 models.

Elements removed at random.

The considered schedule weighting are:

Models		M1	M2	M3	M4	M5
Pattern	P1	1.0	0.0	0.0	0.0	0.0
	P2	0.8	0.05	0.05	0.05	0.05
	P3	0.6	0.1	0.1	0.1	0.1
	P4	0.4	0.15	0.15	0.15	0.15
	P5	0.20	0.20	0.20	0.20	0.20

Single and Multi-Element Assignment.

Test Number 16 Element Problem		Model weights pattern					
Single element assignment	Multiple element assignment	Model	200	201	202	203	204
99	120	P1	1.00	0.00	0.00	0.00	0.00
100	121	P2	0.00	1.00	0.00	0.00	0.00
101	122	P3	0.00	0.00	1.00	0.00	0.00
102	123	P4	0.00	0.00	0.00	1.00	0.00
103	124	P5	0.00	0.00	0.00	0.00	1.00
104	125	P1	0.8	0.05	0.05	0.05	0.05
105	126	P2	0.05	0.8	0.05	0.05	0.05
106	127	P3	0.05	0.05	0.8	0.05	0.05
107	128	P4	0.05	0.05	0.05	0.8	0.05
108	129	P5	0.05	0.05	0.05	0.05	0.8
109	130	P1	0.6	0.1	0.1	0.1	0.1
110	131	P2	0.1	0.6	0.1	0.1	0.1
111	132	P3	0.1	0.1	0.6	0.1	0.1
112	133	P4	0.1	0.1	0.1	0.6	0.1
113	134	P5	0.1	0.1	0.1	0.1	0.6
114	135	P1	0.4	0.15	0.15	0.15	0.15
115	136	P2	0.15	0.4	0.15	0.15	0.15
116	137	P3	0.15	0.15	0.4	0.15	0.15
117	138	P4	0.15	0.15	0.15	0.4	0.15
118	139	P5	0.15	0.15	0.16	0.15	0.4
119	140	P1	0.2	0.2	0.2	0.2	0.2

TABLE (A.16) PROBLEMS INVOLVED IN TEST SERIES 5.

Test No. 99

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	1/2/-/-/5/6	29.00	14.50
		201	1/2/3/-/5/6	38.00	19.00
		202	1/2/3/-/-/6	31.00	15.50
		203	1/-/3/4/5/-	34.00	17.00
		204	-/-/3/4/5/6	38.00	19.00
2	1	200	7	17.00	17.00
		201	-	0.00	0.00
		202	7	17.00	17.00
		203	-	0.00	0.00
		204	7	17.00	17.00
3	1	200	8	15.00	15.00
		201	8	15.00	15.00
		202	8	15.00	15.00
		203	-	0.00	0.00
		204	-	0.00	0.00
4	3	200	9/10/-	53.00	17.67
		201	9/10/11	58.00	19.33
		202	9/10/-	53.00	17.67
		203	9/10/11	58.00	19.33
		204	9/10/-	53.00	17.67
5	1	200	12/13/-	12.00	12.00
		201	12/-/14	14.00	14.00
		202	12/-/14	14.00	14.00
		203	12/13/14	18.00	18.00
		204	12/-/-	8.00	8.00
6	1	200	-/16	6.00	6.00
		201	-/16	6.00	6.00
		202	-/-	0.00	0.00
		203	15/16	15.00	15.00
		204	15/16	15.00	15.00

Test No. 100

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/10	59.00	19.67
		201	1/9/10	59.00	19.67
		202	1/9/10	59.00	19.67
		203	1/9/10	59.00	19.67
		204	-/9/10	53.00	17.67
2	1	200	2/-/-/13	10.00	10.00
		201	2/3/11/-	20.00	20.00
		202	2/3/-/-	15.00	15.00
		203	-/3/11/13	18.00	18.00
		204	-/3/-/-	9.00	9.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
3	2	200	-/5/8/12/-	30.00	15.00
		201	-/5/8/12/14	36.00	18.00
		202	-/-/8/12/14	39.00	14.50
		203	4/5/-/12/14	33.00	16.50
		204	4/5/-/12/-	37.00	13.50
4	1	200	6/-	10.00	10.00
		201	6/-	10.00	10.00
		202	6/-	10.00	10.00
		203	-/15	9.00	9.00
		204	6/15	19.00	19.00
5	1	200	16	6.00	6.00
		201	16	6.00	6.00
		202	-	0.00	0.00
		203	16	6.00	6.00
		204	16	6.00	6.00
6	1	200	7	17.00	17.00
		201	-	0.00	0.00
		202	7	17.00	17.00
		203	-	0.00	0.00
		204	7	17.00	17.00

Test No. 101

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	1/2/-/-/7	29.00	14.50
		201	1/2/3/-/-	21.00	10.50
		202	1/2/3/-/7	38.00	19.00
		203	1/-/3/4/-	27.00	13.50
		204	-/-/3/4/7	38.00	19.00
2	1	200	8	15.00	15.00
		201	8	15.00	15.00
		202	8	15.00	15.00
		203	-	0.00	0.00
		204	-	0.00	0.00
3	3	200	9/10/-	53.00	17.67
		201	9/10/11	58.00	19.33
		202	9/10/-	53.00	17.67
		203	9/10/11	58.00	19.33
		204	9/10/-	53.00	17.67
4	1	200	5/12/13	19.00	19.00
		201	5/12/-	15.00	15.00
		202	-/12/-	8.00	8.00
		203	5/12/13	19.00	19.00
		204	5/12/-	15.00	15.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
5	1	200	6/-/-	10.00	10.00
		201	6/14/-	16.00	16.00
		202	6/14/-	16.00	16.00
		203	-/14/15	15.00	15.00
		204	6/-/15	19.00	19.00
6	1	200	16	6.00	6.00
		201	16	6.00	6.00
		202	-	0.00	0.00
		203	16	6.00	6.00
		204	16	6.00	6.00

Test No. 102

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/10	59.00	19.67
		201	1/9/10	59.00	19.67
		202	1/9/10	59.00	19.67
		203	1/9/10	59.00	19.67
		204	-/9/10	53.00	17.67
2	3	200	2/-/-/8/11/12/13/-/-/16	39.00	13.00
		201	2/3/-/8/11/12/-/14/-/16	55.00	18.33
		202	2/3/-/8/-/12/-/14/-/-	44.00	14.67
		203	-/3/4/-/11/12/13/14/15/16	59.00	19.67
		204	-/3/4/-/-/12/-/-/15/16	44.00	14.67
3	1	200	5/6	17.00	17.00
		201	5/6	17.00	17.00
		202	-/6	10.00	10.00
		203	5/-	7.00	7.00
		204	5/6	17.00	17.00
4	1	200	7	17.00	17.00
		201	-	0.00	0.00
		202	7	17.00	17.00
		203	-	0.00	0.00
		204	7	17.00	17.00

Test No. 103

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	1/2/-/-/5/6	29.00	14.50
		201	1/2/3/-/5/6	38.00	19.00
		202	1/2/3/-/-/6	31.00	15.50
		203	1/-/3/4/5/-	34.00	17.00
		204	-/-/3/4/5/6	38.00	19.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
2	1	200	7	17.00	17.00
		201	-	0.00	0.00
		202	7	17.00	17.00
		203	-	0.00	0.00
		204	7	17.00	17.00
3	3	200	9/10/-	53.00	17.67
		201	9/10/11	58.00	19.33
		202	9/10/-	53.00	17.67
		203	9/10/11	58.00	19.33
		204	9/10/-	53.00	17.67
4	1	200	12/13/-	12.00	12.00
		201	12/-/14	14.00	14.00
		202	12/-/14	14.00	14.00
		203	12/13/14	18.00	18.00
		204	12/-/-	8.00	8.00
5	1	200	-/16	6.00	6.00
		201	-/16	6.00	6.00
		202	-/-	0.00	0.00
		203	15/16	15.00	15.00
		204	15/16	15.00	15.00
6	1	200	8	15.00	15.00
		201	8	15.00	15.00
		202	8	15.00	15.00
		203	-	0.00	0.00
		204	-	0.00	0.00

Test No. 104

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	1/2/-/-/5/6	29.00	14.50
		201	1/2/3/-/5/6	38.00	19.00
		202	1/2/3/-/-/6	31.00	15.50
		203	1/-/3/4/5/-	43.00	17.00
		204	-/-/3/4/5/6	38.00	19.00
2	1	200	7	17.00	17.00
		201	-	0.00	0.00
		202	7	17.00	17.00
		203	-	0.00	0.00
		204	7	17.00	17.00
3	1	200	8	15.00	15.00
		201	8	15.00	15.00
		202	8	15.00	15.00
		203	-	0.00	0.00
		204	-	0.00	0.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
4	3	200	9/10/-	53.00	17.67
		201	9/10/11	58.00	19.33
		202	9/10/-	53.00	17.67
		203	9/10/11	58.00	19.33
		204	9/10/-	53.00	17.67
5	1	200	12/13/-	12.00	12.00
		201	12/-/14	14.00	14.00
		202	12/-/14	14.00	14.00
		203	12/13/14	18.00	18.00
		204	12/-/-	8.00	8.00
6	1	200	-/16	6.00	6.00
		201	-/16	6.00	6.00
		202	-/-	0.00	0.00
		203	15/16	15.00	15.00
		204	15/16	15.00	15.00

Test No. 105

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/10	59.00	19.67
		201	1/9/10	59.00	19.67
		202	1/9/10	59.00	19.67
		203	1/9/10	59.00	19.67
		204	-/9/10	53.00	17.67
2	1	200	2/3/-/13	10.00	10.00
		201	2/3/11/-	20.00	20.00
		202	2/3/-/-	15.00	15.00
		203	-/3/11/13	18.00	18.00
		204	-/3/-/-	9.00	9.00
3	2	200	-/5/8/12/-	30.00	15.00
		201	-/5/8/12/14	36.00	18.00
		202	-/-/8/12/14	29.00	14.50
		203	4/5/-/12/14	33.00	16.50
		204	4/5/-/12/-	27.00	13.50
4	1	200	6/-	10.00	10.00
		201	6/-	10.00	10.00
		202	6/-	10.00	10.00
		203	-/15	9.00	9.00
		204	6/15	19.00	19.00
5	1	200	16	6.00	6.00
		201	16	6.00	6.00
		202	-	0.00	0.00
		203	16	6.00	6.00
		204	16	6.00	6.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
6	1	200	7	17.00	17.00
		201	-	0.00	0.00
		202	7	17.00	17.00
		203	-	0.00	0.00
		204	7	17.00	17.00

Test No. 106

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/-/9	48.00	16.00
		201	1/3/9	57.00	19.00
		202	1/3/9	57.00	19.00
		203	1/3/9	57.00	19.00
		204	-/3/9	51.00	17.00
2	2	200	2/-/7/8/10/-/12	57.00	19.00
		201	2/-/-/8/10/11/12	45.00	15.00
		202	2/-/7/8/10/-/12	57.00	19.00
		203	-/4/-/-/10/11/12	36.00	12.00
		204	-/4/7/-/10/-/12	48.00	16.00
3	1	200	5/6	17.00	17.00
		201	5/6	17.00	17.00
		202	-/6	10.00	10.00
		203	5/-	7.00	7.00
		204	5/6	17.00	17.00
4	1	200	13/-/-	4.00	4.00
		201	-/14/-	6.00	6.00
		202	-/14/-	6.00	6.00
		203	13/14/15	19.00	19.00
		204	-/-/15	9.00	9.00
5	1	200	16	6.00	6.00
		201	16	6.00	6.00
		202	-	0.00	0.00
		203	16	6.00	6.00
		204	16	6.00	6.00

Test No. 107

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/10	59.00	19.67
		201	1/9/10	59.00	19.67
		202	1/9/10	59.00	19.67
		203	1/9/10	59.00	19.67
		204	-/9/10	53.00	17.67

Station Number	Size	Model	Elements	Σt_i	Σte_i
2	1	200	2/-/-/13	10.00	10.00
		201	2/3/11/-	20.00	20.00
		202	2/3/-/-	15.00	15.00
		203	-/3/11/13	18.00	18.00
		204	-/3/-/-	9.00	9.00
3	1	200	-/12	8.00	8.00
		201	-/12	8.00	8.00
		202	-/12	8.00	8.00
		203	4/12	20.00	20.00
		204	4/12	20.00	20.00
4	1	200	-/-	0.00	0.00
		201	14/-	6.00	6.00
		202	14/-	6.00	6.00
		203	14/15	15.00	15.00
		204	-/15	9.00	9.00
5	1	200	5/16	13.00	13.00
		201	5/16	13.00	13.00
		202	-/-	0.00	0.00
		203	5/16	13.00	13.00
		204	5/16	13.00	13.00
6	1	200	7	17.00	17.00
		201	-	0.00	0.00
		202	7	17.00	17.00
		203	-	0.00	0.00
		204	7	17.00	17.00
7	1	200	8	15.00	15.00
		201	8	15.00	15.00
		202	8	15.00	15.00
		203	-	0.00	0.00
		204	-	0.00	0.00
8	1	200	6	10.00	10.00
		201	6	10.00	10.00
		202	6	10.00	10.00
		203	-	0.00	0.00
		204	6	10.00	10.00

Test No. 108

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	1/2/-/-/5/6	29.00	14.50
		201	1/2/3/-/5/6	38.00	19.00
		202	1/2/3/-/-/6	31.00	15.50
		203	1/-/3/4/5/-	34.00	17.00
		204	-/-/3/4/5/6	38.00	19.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
2	1	200	7	17.00	17.00
		201	-	0.00	0.00
		202	7	17.00	17.00
		203	-	0.00	0.00
		204	7	17.00	17.00
3	3	200	9/10/-	53.00	17.67
		201	9/10/11	58.00	19.33
		202	9/10/-	53.00	17.67
		203	9/10/11	58.00	19.33
		204	9/10/-	53.00	17.67
4	1	200	12/13/-	12.00	12.00
		201	12/-/14	14.00	14.00
		202	12/-/14	14.00	14.00
		203	12/13/14	18.00	18.00
		204	12/-/-	8.00	8.00
5	1	200	-/16	6.00	6.00
		201	-/16	6.00	6.00
		202	-	0.00	0.00
		203	15/16	15.00	15.00
		204	15/16	15.00	15.00
6	1	200	8	15.00	15.00
		201	8	15.00	15.00
		202	8	15.00	15.00
		203	-	0.00	0.00
		204	-	0.00	0.00

Test No. 109

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	1/2/-/-/5/6	29.00	14.50
		201	1/2/3/-/5/6	38.00	19.00
		202	1/2/3/-/-/6	31.00	15.50
		203	1/-/3/4/5/-	34.00	17.00
		204	-/-/3/4/5/6	38.00	19.00
2	3	200	9/10/-	53.00	17.67
		201	9/10/11	58.00	19.33
		202	9/10/-	53.00	17.67
		203	9/10/11	58.00	19.33
		204	9/10/-	53.00	17.67
3	2	200	7/8/12	40.00	20.00
		201	-/8/12	23.00	11.50
		202	7/8/12	40.00	20.00
		203	-/-/12	8.00	4.00
		204	7/-/12	25.00	12.50

Station Number	Size	Model	Elements	Σt_i	Σte_i
4	1	200	13/-/-	4.00	4.00
		201	-/14/-	6.00	6.00
		202	-/14/-	6.00	6.00
		203	13/14/15	19.00	19.00
		204	-/-/15	9.00	9.00
5	1	200	16	6.00	6.00
		201	16	6.00	6.00
		202	-	0.00	0.00
		203	16	6.00	6.00
		204	16	6.00	6.00

Test No. 110

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/11	59.00	19.67
		201	1/9/11	59.00	19.67
		202	1/9/11	59.00	19.67
		203	1/9/11	59.00	19.67
		204	-/9/11	53.00	17.67
2	1	200	2/-/-/13	10.00	10.00
		201	2/3/11/-	20.00	20.00
		202	2/3/-/-	15.00	15.00
		203	-/3/11/13	18.00	18.00
		204	-/3/-/-	9.00	9.00
3	2	200	-/5/8/12/-	30.00	15.00
		201	-/5/8/12/14	36.00	18.00
		202	-/-/8/12/14	29.00	14.50
		203	4/5/-/12/14	33.00	16.50
		204	4/5/-/12/-	27.00	13.50
4	1	200	6/-	10.00	10.00
		201	6/-	10.00	10.00
		202	6/-	10.00	10.00
		203	-/15	9.00	9.00
		204	6/15	19.00	19.00
5	1	200	16	6.00	6.00
		201	16	6.00	6.00
		202	-	0.00	0.00
		203	16	6.00	6.00
		204	16	6.00	6.00
6	1	200	7	17.00	17.00
		201	-	0.00	0.00
		202	7	17.00	17.00
		203	-	0.00	0.00
		204	7	17.00	17.00

Test No. 111

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/-/9	48.00	16.00
		201	1/3/9	57.00	19.00
		202	1/3/9	57.00	19.00
		203	1/3/9	57.00	19.00
		204	-/3/9	51.00	17.00
2	1	200	10/-/13	15.00	15.00
		201	10/11/-	16.00	16.00
		202	10/-/-	11.00	11.00
		203	10/11/13	20.00	20.00
		204	10/-/-	11.00	11.00
3	1	200	2/-/12	14.00	14.00
		201	2/-/12	14.00	14.00
		202	2/-/12	14.00	14.00
		203	-/4/12	20.00	20.00
		204	-/4/12	20.00	20.00
4	2	200	5/7/8/-/-	39.00	19.50
		201	5/-/8/14/-	28.00	14.00
		202	-/7/8/14/-	38.00	19.00
		203	5/-/-/14/15	22.00	11.00
		204	5/7/-/-/15	33.00	16.50
5	1	200	6/16	16.00	16.00
		201	6/16	16.00	16.00
		202	6/-	10.00	10.00
		203	-/16	6.00	6.00
		204	6/16	16.00	16.00

Test No. 112

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/10	59.00	19.67
		201	1/9/10	59.00	19.67
		202	1/9/10	59.00	19.67
		203	1/9/10	59.00	19.67
		204	-/9/10	53.00	17.67
2	1	200	2/-/-/13	10.00	10.00
		201	2/3/11/-	20.00	20.00
		202	2/3/-/-	15.00	15.00
		203	-/3/11/13	18.00	18.00
		204	-/3/-/-	9.00	9.00
3	1	200	-/12	8.00	8.00
		201	-/12	8.00	8.00
		202	-/12	8.00	8.00
		203	4/12	20.00	20.00
		204	4/12	20.00	20.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
4	1	200	-/-	0.00	0.00
		201	14/-	6.00	6.00
		202	14/-	6.00	6.00
		203	14/15	15.00	15.00
		204	-/15	9.00	9.00
5	1	200	5/16	13.00	13.00
		201	5/16	13.00	13.00
		202	-/-	0.00	0.00
		203	5/16	13.00	13.00
		204	5/16	13.00	13.00
6	1	200	7	17.00	17.00
		201	-	0.00	0.00
		202	7	17.00	17.00
		203	-	0.00	0.00
		204	7	17.00	17.00
7	1	200	8	15.00	15.00
		201	8	15.00	15.00
		202	8	15.00	15.00
		203	-	0.00	0.00
		204	-	0.00	0.00
8	1	200	6	10.00	10.00
		201	6	10.00	10.00
		202	6	10.00	10.00
		203	-	0.00	0.00
		204	6	10.00	10.00

Test No. 113

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	1/2/-/-/5/6	29.00	14.50
		201	1/2/3/-/5/6	38.00	19.00
		202	1/2/3/-/-/6	31.00	15.50
		203	1/-/3/4/5/-	34.00	17.00
		204	-/-/3/4/5/6	38.00	19.00
2	3	200	9/10/-	53.00	17.67
		201	9/10/11	58.00	19.33
		202	9/10/-	53.00	17.67
		203	9/10/11	58.00	19.33
		204	9/10/-	53.00	17.67
3	2	200	7/12/13/-/-/16	35.00	17.50
		201	-/12/-/14/-/16	20.00	10.00
		202	7/12/-/14/-/-	31.00	15.50
		203	-/12/13/14/15/16	33.00	16.50
		204	7/12/-/-/15/16	40.00	20.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
4	1	200	8	15.00	15.00
		201	8	15.00	15.00
		202	8	15.00	15.00
		203	-	0.00	0.00
		204	-	0.00	0.00

Test No. 114

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	1/2/-/-/5/6	29.00	14.50
		201	1/2/3/-/5/6	38.00	19.00
		202	1/2/3/-/-/6	31.00	15.50
		203	1/-/3/4/5/-	34.00	17.00
		204	-/-/3/4/5/6	38.00	19.00
2	3	200	9/10/-	53.00	17.67
		201	9/10/11	58.00	19.33
		202	9/10/-	53.00	17.67
		203	9/10/11	58.00	19.33
		204	9/10/-	58.00	17.67
3	1	200	12/13/-	12.00	12.00
		201	12/-/14	14.00	14.00
		202	12/-/14	14.00	14.00
		203	12/13/14	18.00	18.00
		204	12/-/-	8.00	8.00
4	1	200	7	17.00	17.00
		201	-	0.00	0.00
		202	7	17.00	17.00
		203	-	0.00	0.00
		204	7	17.00	17.00
5	1	200	8/-	15.00	15.00
		201	8/-	15.00	15.00
		202	8/-	15.00	15.00
		203	-/15	9.00	9.00
		204	-/15	9.00	9.00
6	1	200	16	6.00	6.00
		201	16	6.00	6.00
		202	-	0.00	0.00
		203	16	6.00	6.00
		204	16	6.00	6.00

Test No. 115

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/10	59.00	19.67
		201	1/9/10	59.00	19.67
		202	1/9/10	59.00	19.67
		203	1/9/10	59.00	19.67
		204	-/9/10	53.00	17.67
2	1	200	2/-/-/13	10.00	10.00
		201	2/3/11/-	20.00	20.00
		202	2/3/-/-	15.00	15.00
		203	-/3/11/13	18.00	18.00
		204	-/3/-/-	9.00	9.00
3	2	200	-/5/8/12/-	30.00	15.00
		201	-/5/8/12/14	36.00	18.00
		202	-/-/8/12/14	29.00	14.50
		203	4/5/-/12/14	33.00	16.50
		204	4/5/-/12/-	27.00	13.50
4	1	200	6/-	10.00	10.00
		201	6/-	10.00	10.00
		202	6/-	10.00	10.00
		203	-/15	9.00	9.00
		204	6/15	19.00	19.00
5	1	200	7	17.00	17.00
		201	-	0.00	0.00
		202	7	17.00	17.00
		203	-	0.00	0.00
		204	7	17.00	17.00
6	1	200	16	6.00	6.00
		201	16	6.00	6.00
		202	-	0.00	0.00
		203	16	6.00	6.00
		204	16	6.00	6.00

Test No. 116

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/-/9	48.00	16.00
		201	1/3/9	57.00	19.00
		202	1/3/9	57.00	19.00
		203	1/3/9	57.00	19.00
		204	-/3/9	51.00	17.00
2	1	200	10/-/13	15.00	15.00
		201	10/11/-	16.00	16.00
		202	10/-/-	11.00	11.00
		203	10/11/13	20.00	20.00
		204	10/-/-	11.00	11.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
3	1	200	2/-/12	14.00	14.00
		201	2/-/12	14.00	14.00
		202	2/-/12	14.00	14.00
		203	-/4/12	20.00	20.00
		204	-/4/12	20.00	20.00
4	2	200	5/7/8/-/-	39.00	19.50
		201	5/-/8/14/-	28.00	14.00
		202	-/7/8/14/-	38.00	19.00
		203	5/-/-/14/15	22.00	11.00
		204	5/7/-/-/15	33.00	16.50
5	1	200	6/16	16.00	16.00
		201	6/16	16.00	16.00
		202	6/-	10.00	10.00
		203	-/16	6.00	6.00
		204	6/16	16.00	16.00

Test No. 117

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/10	59.00	19.67
		201	1/9/10	59.00	19.67
		202	1/9/10	59.00	19.67
		203	1/9/10	59.00	19.67
		204	-/9/10	53.00	17.67
2	1	200	2/-/-/13	10.00	10.00
		201	2/3/11/-	20.00	20.00
		202	2/3/-/-	15.00	15.00
		203	-/3/11/13	18.00	18.00
		204	-/3/-/-	9.00	9.00
3	1	200	-/12	8.00	8.00
		201	-/12	8.00	8.00
		202	-/12	8.00	8.00
		203	4/12	20.00	20.00
		204	4/12	20.00	20.00
4	1	200	5/-	7.00	7.00
		201	5/14	13.00	13.00
		202	-/14	6.00	6.00
		203	5/14	13.00	13.00
		204	5/-	7.00	7.00
5	1	200	8/-	15.00	15.00
		201	8/-	15.00	15.00
		202	8/-	15.00	15.00
		203	-/15	9.00	9.00
		204	-/15	9.00	9.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
6	1	200	7	17.00	17.00
		201	-	0.00	0.00
		202	7	17.00	17.00
		203	-	0.00	0.00
		204	7	17.00	17.00
7	1	200	6/16	16.00	16.00
		201	6/16	16.00	16.00
		202	6/-	10.00	10.00
		203	-/16	6.00	6.00
		204	6/16	16.00	16.00

Test No. 118

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	1/2/-/-/5/6	29.00	14.50
		201	1/2/3/-/5/6	38.00	19.00
		202	1/2/3/-/-/6	31.00	15.50
		203	1/-/3/4/5/-	34.00	17.00
		204	-/-/3/4/5/6	38.00	19.00
2	3	200	9/10/-	53.00	17.67
		201	9/10/11	58.00	19.33
		202	9/10/-	53.00	17.67
		203	9/10/11	58.00	19.33
		204	9/10/-	53.00	17.67
3	2	200	7/12/13/-/-/16	35.00	17.50
		201	-/12/-/14/-/16	20.00	10.00
		202	7/12/-/14/-/-	31.00	15.00
		203	-/12/13/14/15/16	33.00	16.50
		204	7/12/-/-/15/16	40.00	20.00
4	1	200	8	15.00	15.00
		201	8	15.00	15.00
		202	8	15.00	15.00
		203	-	0.00	0.00
		204	-	0.00	0.00

Test No. 119

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	1/2/-/-/5/6	29.00	14.50
		201	1/2/3/-/5/6	38.00	19.00
		202	1/2/3/-/-/6	31.00	15.50
		203	1/-/3/4/5/-	34.00	17.00
		204	-/-/3/4/5/6	38.00	19.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
2	3	200	9/10/-	53.00	17.67
		201	9/10/11	58.00	19.33
		202	9/10/-	53.00	17.67
		203	9/10/11	58.00	19.33
		204	9/10/-	53.00	17.67
3	1	200	12/13/-	12.00	12.00
		201	12/-/14	14.00	14.00
		202	12/-/14	14.00	14.00
		203	12/13/14	18.00	18.00
		204	12/-/-	8.00	8.00
4	1	200	7	17.00	17.00
		201	-	0.00	0.00
		202	7	17.00	17.00
		203	-	0.00	0.00
		204	7	17.00	17.00
5	1	200	8/-	15.00	15.00
		201	8/-	15.00	15.00
		202	8/-	15.00	15.00
		203	-/15	9.00	9.00
		204	-/15	9.00	9.00
6	1	200	16	6.00	6.00
		201	16	6.00	6.00
		202	-	0.00	0.00
		203	16	6.00	6.00
		204	16	6.00	6.00

Test No. 120

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	1/2/5	19.00	19.00
		201	1/3	15.00	15.00
		202	1/3	15.00	15.00
		203	1/3	15.00	15.00
		204	3	9.00	9.00
2	1	200	7	17.00	17.00
		201	2/5	13.00	13.00
		202	7	17.00	17.00
		203	4/5	19.00	19.00
		204	4/5	19.00	19.00
3	3	200	9/10/13	57.00	19.00
		201	9/10/11	58.00	19.33
		202	2/9/10	59.00	19.67
		203	9/10/11	58.00	19.33
		204	9/10	53.00	17.67

Station Number	Size	Model	Elements	Σt_i	Σte_i
4	2	200	6/8/12/16	39.00	19.50
		201	6/8/12/14	39.00	19.50
		202	6/8/12/14	39.00	19.50
		203	12/13/14/15/16	33.00	16.50
		204	7/12/15/16	40.00	20.00
5	1	200	-	0.00	0.00
		201	16	6.00	6.00
		202	-	0.00	0.00
		203	-	0.00	0.00
		204	6	10.00	10.00

Test No. 121

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/10	59.00	19.67
		201	1/9/10	59.00	19.67
		202	1/3/9	57.00	19.00
		203	1/9/10	59.00	19.67
		204	3/9	51.00	17.00
2	1	200	2/5/13	17.00	17.00
		201	2/3/11	20.00	20.00
		202	2/10	17.00	17.00
		203	11/12/13	17.00	17.00
		204	4/5	19.00	19.00
3	2	200	7/8/12	40.00	20.00
		201	5/8/12/14	36.00	18.00
		202	7/8/12	40.00	20.00
		203	3/4/14/15	36.00	18.00
		204	7/10/12	36.00	18.00
4	1	200	6/16	16.00	16.00
		201	6/16	16.00	16.00
		202	6/14	16.00	16.00
		203	5/16	13.00	13.00
		204	6/15	19.00	19.00
5	1	200	-	0.00	0.00
		201	-	0.00	0.00
		202	-	0.00	0.00
		203	-	0.00	0.00
		204	16	6.00	6.00

Test No. 122

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	1/2/5/7	36.00	18.00
		201	1/2/3/5/6	38.00	19.00
		202	1/2/3/7	38.00	19.00
		203	1/3/4/5	34.00	17.00
		204	3/4/5/6	38.00	19.00
2	1	200	8	15.00	15.00
		201	8	15.00	15.00
		202	8	15.00	15.00
		203	-	0.00	0.00
		204	7	17.00	17.00
3	3	200	9/10/13	57.00	19.00
		201	9/10/11	58.00	19.33
		202	9/10	53.00	17.67
		203	9/10/11	58.00	19.33
		204	9/10	53.00	17.67
4	1	200	6/12	18.00	18.00
		201	12/14/16	20.00	20.00
		202	6/12	18.00	18.00
		203	12/13/14	18.00	18.00
		204	12/15	17.00	17.00
5	1	200	16	6.00	6.00
		201	-	0.00	0.00
		202	14	6.00	6.00
		203	15/16	15.00	15.00
		204	16	6.00	6.00

Test No. 123

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/10	59.00	19.67
		201	1/9/10	59.00	19.67
		202	1/3/9	57.00	19.00
		203	1/9/10	59.00	19.67
		204	3/9	51.00	17.00
2	3	200	2/5/7/8/12/13	57.00	19.00
		201	2/3/5/8/11/12/14	56.00	18.67
		202	2/7/8/10/12	57.00	19.00
		203	3/4/11/12/13/14/15/16	59.00	19.67
		204	4/5/7/10/12	55.00	18.33
3	1	200	6/16	16.00	16.00
		201	6/16	16.00	16.00
		202	6/14	16.00	16.00
		203	5	7.00	7.00
		204	6/15	19.00	19.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
4	1	200	-	0.00	0.00
		201	-	0.00	0.00
		202	-	0.00	0.00
		203	-	0.00	0.00
		204	16	6.00	6.00

Test No. 124

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	1/2/5/7	36.00	18.00
		201	1/2/3/5/6	38.00	19.00
		202	1/2/3/7	38.00	19.00
		203	1/3/4/5	34.00	17.00
		204	3/4/5/6	38.00	19.00
2	1	200	8	15.00	15.00
		201	8	15.00	15.00
		202	8	15.00	15.00
		203	-	0.00	0.00
		204	7	17.00	17.00
3	3	200	9/10/13	57.00	19.00
		201	9/10/11	38.00	19.33
		202	9/10	53.00	17.67
		203	9/10/11	58.00	19.33
		204	9/10	53.00	17.67
4	1	200	6/12	18.00	18.00
		201	12/14/16	20.00	20.00
		202	6/12	18.00	18.00
		203	12/13/14	18.00	18.00
		204	12/15	17.00	17.00
5	1	200	16	6.00	6.00
		201	-	0.00	0.00
		202	14	6.00	6.00
		203	15/16	15.00	15.00
		204	16	6.00	6.00

Test No. 125

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/10	59.00	19.67
		201	1/9/10	59.00	19.67
		202	1/3/9	57.00	19.00
		203	1/9/10	59.00	19.67
		204	3/9	51.00	17.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
2	2	200	2/5/7/12	38.00	19.00
		201	2/3/5/11/12	35.00	17.00
		202	2/7/10	34.00	17.00
		203	3/11/12/13/14	32.00	16.00
		204	4/5/10/12	38.00	19.00
3	1	200	8/13	19.00	19.00
		201	8	15.00	15.00
		202	8	15.00	15.00
		203	4/5	19.00	19.00
		204	7	17.00	17.00
4	1	200	6/16	16.00	16.00
		201	6/14	16.00	16.00
		202	6/12	18.00	18.00
		203	15/16	15.00	15.00
		204	6/15	19.00	19.00
5	1	200	-	0.00	0.00
		201	16	6.00	6.00
		202	14	6.00	6.00
		203	-	0.00	0.00
		204	16	6.00	6.00

Test No. 126

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/10	59.00	19.67
		201	1/9/10	59.00	19.67
		202	1/3/9	57.00	19.00
		203	1/9/10	59.00	19.67
		204	3/9	51.00	17.00
2	1	200	2/5/13	17.00	17.00
		201	2/3/11	20.00	20.00
		202	2/10	17.00	17.00
		203	11/12/13	17.00	17.00
		204	4/5	19.00	19.00
3	2	200	7/8/12	40.00	20.00
		201	5/8/12/14	36.00	18.00
		202	7/8/12	40.00	20.00
		203	3/4/14/15	36.00	18.00
		204	7/10/12	36.00	18.00
4	1	200	6/16	16.00	16.00
		201	6/16	16.00	16.00
		202	6/14	16.00	16.00
		203	5/16	13.00	13.00
		204	6/15	19.00	19.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
5	1	200	-	0.00	0.00
		201	-	0.00	0.00
		202	-	0.00	0.00
		203	-	0.00	0.00
		204	16	6.00	6.00

Test No. 127

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	1/2/5/7	36.00	18.00
		201	1/2/3/5/6	38.00	19.00
		202	1/2/3/7	38.00	19.00
		203	1/3/4/5	34.00	17.00
		204	3/4/5/6	38.00	19.00
2	1	200	8	15.00	15.00
		201	8	15.00	15.00
		202	8	15.00	15.00
		203	-	0.00	0.00
		204	7	17.00	17.00
3	3	200	9/10/13	57.00	19.00
		201	9/10/11	58.00	19.33
		202	9/10	53.00	17.67
		203	9/10/11	58.00	19.33
		204	9/10	53.00	17.67
4	1	200	6/12	18.00	18.00
		201	12/14/16	20.00	20.00
		202	6/12	18.00	18.00
		203	12/13/14	18.00	18.00
		204	12/15	17.00	17.00
5	1	200	16	6.00	6.00
		201	-	0.00	0.00
		202	14	6.00	6.00
		203	15/16	15.00	15.00
		204	16	6.00	6.00

Test No. 128

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/10	59.00	19.67
		201	1/9/10	59.00	19.67
		202	1/3/9	57.00	19.00
		203	1/9/10	59.00	19.67
		204	3/9	51.00	17.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
2	3	200	2/5/7/8/12/13	57.00	19.00
		201	2/3/5/8/11/12/14	56.00	18.67
		202	2/7/8/10/12	57.00	19.00
		203	3/4/11/12/13/14/15/16	59.00	19.67
		204	4/5/7/10/12	55.00	18.33
3	1	200	6/16	16.00	16.00
		201	6/16	16.00	16.00
		202	6/14	16.00	16.00
		203	5	7.00	7.00
		204	6/15	19.00	19.00
4	1	200	-	0.00	0.00
		201	-	0.00	0.00
		202	-	0.00	0.00
		203	-	0.00	0.00
		204	16	6.00	6.00

Test No. 129

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	1/2/5/7	36.00	18.00
		201	1/2/3/5/6	38.00	19.00
		202	1/2/3/7	38.00	19.00
		203	1/3/4/5	34.00	17.00
		204	3/4/5/6	38.00	19.00
2	1	200	8	15.00	15.00
		201	8	15.00	15.00
		202	8	15.00	15.00
		203	-	0.00	0.00
		204	7	17.00	17.00
3	3	200	9/10/13	57.00	19.00
		201	9/10/11	58.00	19.33
		202	9/10	53.00	17.67
		203	9/10/11	58.00	19.33
		204	9/10	53.00	17.67
4	1	200	6/12	18.00	18.00
		201	12/14/16	20.00	20.00
		202	6/12	18.00	18.00
		203	12/13/14	18.00	18.00
		204	12/15	17.00	17.00
5	1	200	16	6.00	6.00
		201	-	0.00	0.00
		202	14	6.00	6.00
		203	15/16	15.00	15.00
		204	16	6.00	6.00

Test No. 130

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/10	59.00	19.67
		201	1/9/10	59.00	19.67
		202	1/3/9	57.00	19.00
		203	1/9/10	59.00	19.67
		204	3/9	51.00	17.00
2	1	200	2/5/13	17.00	17.00
		201	2/3/11	20.00	20.00
		202	2/10	17.00	17.00
		203	11/12/13	17.00	17.00
		204	4/5	19.00	19.00
3	2	200	7/8/12	40.00	20.00
		201	5/8/12/14	36.00	18.00
		202	7/8/12	40.00	20.00
		203	3/4/14/15	36.00	18.00
		204	7/10/12	36.00	18.00
4	1	200	6/16	16.00	16.00
		201	6/16	16.00	16.00
		202	6/14	16.00	16.00
		203	5/16	13.00	13.00
		204	6/15	19.00	19.00
5	1	200	-	0.00	0.00
		201	-	0.00	0.00
		202	-	0.00	0.00
		203	-	0.00	0.00
		204	16	6.00	6.00

Test No. 131

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/10	59.00	19.67
		201	1/9/10	59.00	19.67
		202	1/3/9	57.00	19.00
		203	1/9/10	59.00	19.67
		204	3/9	51.00	17.00
2	1	200	2/5/13	17.00	17.00
		201	2/3/11	20.00	20.00
		202	2/10	17.00	17.00
		203	11/12/13	17.00	17.00
		204	4/5	19.00	19.00
3	2	200	7/8/12	40.00	20.00
		201	5/8/12/14	36.00	18.00
		202	7/8/12	40.00	20.00
		203	3/4/14/15	36.00	18.00
		204	7/10/12	36.00	18.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
4	1	200	6/16	16.00	16.00
		201	6/16	16.00	16.00
		202	6/14	16.00	16.00
		203	5/16	13.00	13.00
		204	6/15	19.00	19.00
5	1	200	-	0.00	0.00
		201	-	0.00	0.00
		202	-	0.00	0.00
		203	-	0.00	0.00
		204	16	6.00	6.00

Test No. 132

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	1/2/5/7	36.00	18.00
		201	1/2/3/5/6	38.00	19.00
		202	1/2/3/7	38.00	19.00
		203	1/3/4/5	34.00	17.00
		204	3/4/5/6	38.00	19.00
2	3	200	9/10/13	57.00	19.00
		201	9/10/11	58.00	19.33
		202	9/10	53.00	17.67
		203	9/10/11	58.00	19.33
		204	9/10	53.00	17.67
3	2	200	6/8/12/16	39.00	19.50
		201	8/12/14/16	35.00	17.50
		202	8/12/14	39.00	19.50
		203	12/13/14/15/16	33.00	16.50
		204	7/12/15/16	40.00	20.00

Test No. 133

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/10	59.00	19.67
		201	1/9/10	59.00	19.67
		202	1/3/9	57.00	19.00
		203	1/9/10	59.00	19.67
		204	3/9	51.00	17.00
2	3	200	2/5/7/8/12/13	57.00	19.00
		201	2/3/5/8/11/12/14	56.00	18.67
		202	2/7/8/10/12	57.00	19.00
		203	3/4/11/12/13/14/15/16	59.00	19.67
		204	4/5/7/10/12	55.00	18.33

Station Number	Size	Model	Elements	Σt_i	Σte_i
3	1	200	6/16	16.00	16.00
		201	6/16	16.00	16.00
		202	6/14	16.00	16.00
		203	5	7.00	7.00
		204	6/15	19.00	19.00
4	1	200	-	0.00	0.00
		201	-	0.00	0.00
		202	-	0.00	0.00
		203	-	0.00	0.00
		204	16	6.00	6.00

Test No. 134

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	1/2/5/7	36.00	18.00
		201	1/2/3/5/6	38.00	19.00
		202	1/2/3/7	38.00	19.00
		203	1/2/3/4/5	34.00	17.00
		204	3/4/5/6	38.00	19.00
2	1	200	8	15.00	15.00
		201	8	15.00	15.00
		202	8	15.00	15.00
		203	-	0.00	0.00
		204	7	17.00	17.00
3	3	200	9/10/13	57.00	19.00
		201	9/10/11	58.00	19.33
		202	9/10	53.00	17.67
		203	9/10/11	58.00	19.33
		204	9/10	53.00	17.67
4	1	200	6/12	18.00	18.00
		201	12/14/16	20.00	20.00
		202	6/12	18.00	18.00
		203	12/13/14	18.00	18.00
		204	12/15	17.00	17.00
5	1	200	16	6.00	6.00
		201	-	0.00	0.00
		202	14	6.00	6.00
		203	15/16	15.00	15.00
		204	16	6.00	6.00

Test No. 135

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/10	59.00	19.67
		201	1/9/10	59.00	19.67
		202	1/3/9	57.00	19.00
		203	1/9/10	59.00	19.67
		204	3/9	51.00	17.00
2	1	200	2/5/13	17.00	17.00
		201	2/3/11	20.00	20.00
		202	2/10	17.00	17.00
		203	11/12/13	17.00	17.00
		204	4/5	19.00	19.00
3	2	200	7/8/12	40.00	20.00
		201	5/8/12/14	36.00	18.00
		202	7/8/12	40.00	20.00
		203	3/4/14/15	36.00	18.00
		204	7/10/12	36.00	18.00
4	1	200	6/16	16.00	16.00
		201	6/16	16.00	16.00
		202	6/14	16.00	16.00
		203	5/16	13.00	13.00
		204	6/15	19.00	19.00
5	1	200	-	0.00	0.00
		201	-	0.00	0.00
		202	-	0.00	0.00
		203	-	0.00	0.00
		204	16	6.00	6.00

Test No. 136

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/10	59.00	19.67
		201	1/9/10	59.00	19.67
		202	1/3/9	57.00	19.00
		203	1/9/10	59.00	19.67
		204	3/9	51.00	17.00
2	1	200	2/5/13	17.00	17.00
		201	2/3/11	20.00	20.00
		202	2/10	17.00	17.00
		203	11/12/13	17.00	17.00
		204	4/5	19.00	19.00
3	2	200	7/8/12	40.00	20.00
		201	5/8/12/14	36.00	18.00
		202	7/8/12	40.00	20.00
		203	3/4/14/15	36.00	18.00
		204	7/10/12	36.00	18.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
4	1	200	6/16	16.00	16.00
		201	6/16	16.00	16.00
		202	6/14	16.00	16.00
		203	5/16	13.00	13.00
		204	6/15	19.00	19.00
5	1	200	-	0.00	0.00
		201	-	0.00	0.00
		202	-	0.00	0.00
		203	-	0.00	0.00
		204	16	6.00	6.00

Test No. 137

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	1/2/5/7	36.00	18.00
		201	1/2/3/5/6	38.00	19.00
		202	1/2/3/7	38.00	19.00
		203	1/3/4/5	34.00	17.00
		204	3/4/5/6	38.00	19.00
2	3	200	9/10/13	57.00	19.00
		201	9/10/11	58.00	19.33
		202	9/10	53.00	17.67
		203	9/10/11	58.00	19.33
		204	9/10	53.00	17.67
3	2	200	6/8/12/16	39.00	19.50
		201	8/12/14/16	35.00	17.50
		202	6/8/12/14	39.00	19.50
		203	12/13/14/15/16	33.00	16.50
		204	7/12/15/16	40.00	20.00

Test No. 138

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/10	59.00	19.67
		201	1/9/10	59.00	19.67
		202	1/3/9	57.00	19.00
		203	1/9/10	59.00	19.67
		204	3/9	51.00	17.00
2	1	200	2/5/13	17.00	17.00
		201	2/3/11	20.00	20.00
		202	2/10	17.00	17.00
		203	11/12/13	17.00	17.00
		204	4/5	19.00	19.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
3	2	200	7/8/12	40.00	20.00
		201	5/8/12/14	36.00	18.00
		202	7/8/12	40.00	20.00
		203	3/4/14/15	36.00	18.00
		204	7/10/12	36.00	18.00
4	1	200	6/16	16.00	16.00
		201	6/16	16.00	16.00
		202	6/14	16.00	16.00
		203	5/16	13.00	13.00
		204	6/15	19.00	19.00
5	1	200	-	0.00	0.00
		201	-	0.00	0.00
		202	-	0.00	0.00
		203	-	0.00	0.00
		204	16	6.00	6.00

Test No. 139

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	2	200	1/2/5/7	36.00	18.00
		201	1/2/3/5/6	38.00	19.00
		202	1/2/3/7	38.00	19.00
		203	1/3/4/5	34.00	17.00
		204	3/4/5/6	38.00	19.00
2	3	200	9/10/13	57.00	19.00
		201	9/10/11	58.00	19.33
		202	9/10	53.00	17.67
		203	9/10/11	58.00	19.33
		204	9/10	53.00	17.67
3	2	200	6/8/12/16	39.00	19.50
		201	8/12/14/16	35.00	17.50
		202	6/8/12/14	39.00	19.50
		203	12/13/14/15/16	33.00	16.50
		204	7/12/15/16	40.00	20.00

Test No. 140

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9/10	59.00	19.67
		201	1/9/10	59.00	19.67
		202	1/3/9	57.00	19.00
		203	1/9/10	59.00	19.67
		204	3/9	51.00	17.00

Station Number	Size	Model	Elements	Σt_i	Σte_i
2	1	200	2/5/13	17.00	17.00
		201	2/3/11	20.00	20.00
		202	2/10	17.00	17.00
		203	11/12/13	17.00	17.00
		204	4/5	19.00	19.00
3	2	200	7/8/12	40.00	20.00
		201	5/8/12/14	36.00	18.00
		202	7/8/12	40.00	20.00
		203	3/4/14/15	36.00	18.00
		204	7/10/12	36.00	18.00
4	1	200	6/16	16.00	16.00
		201	6/16	16.00	16.00
		202	6/14	16.00	16.00
		203	5/16	13.00	13.00
		204	6/15	19.00	19.00
5	1	200	-	0.00	0.00
		201	-	0.00	0.00
		202	-	0.00	0.00
		203	-	0.00	0.00
		204	16	6.00	6.00

Test No.	BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	WB1	WB2	WT1	WT2	WT3
99	27.89	26.67	27.89	26.67	25.41	21.54	25.41	21.54	71.00	173.00	28.83	44.03	43.00
100	27.89	27.22	27.89	27.22	25.26	26.70	25.26	26.70	59.00	173.00	28.83	45.37	43.00
101	27.89	27.78	27.89	27.78	25.40	25.26	25.40	25.26	63.00	173.00	28.82	46.07	52.00
102	18.78	21.87	18.78	21.87	20.76	23.90	20.76	23.90	53.00	173.00	43.23	54.56	63.00
103	27.89	27.22	27.89	27.22	25.41	25.12	25.41	25.12	71.00	173.00	28.83	44.03	43.00
104	27.89	26.97	27.89	26.97	25.41	22.57	25.41	22.57	71.00	173.00	28.83	44.03	43.00
105	27.89	27.39	27.89	27.39	25.26	26.35	25.26	26.35	59.00	173.00	28.83	45.37	53.00
106	27.89	27.81	27.89	27.81	26.32	26.62	26.32	26.62	61.00	173.00	34.60	58.53	68.00
107	35.10	36.90	35.10	36.90	30.89	34.61	30.89	34.61	99.00	173.00	21.63	41.52	49.00
108	27.89	27.39	27.89	27.39	25.41	25.19	25.41	25.19	71.00	173.00	28.83	44.03	43.00
109	27.89	27.28	27.89	27.28	27.90	26.46	27.90	26.66	67.00	173.00	34.60	43.30	52.00
110	27.89	27.56	27.89	27.56	25.26	25.99	25.26	25.99	59.00	173.00	38.83	45.37	53.00
111	18.87	18.81	18.87	18.81	16.91	16.06	16.91	16.06	51.00	173.00	34.60	38.87	41.00
112	35.10	36.30	35.10	36.30	30.89	33.42	30.89	33.42	99.00	173.00	21.63	41.52	49.00
113	18.87	18.50	18.87	18.50	19.14	20.24	19.14	20.24	49.00	173.00	43.25	33.27	43.00
114	27.89	27.58	27.89	27.58	24.55	23.83	24.55	23.83	53.00	173.00	28.83	45.83	52.00
115	27.89	27.72	27.89	27.72	25.26	25.63	25.26	25.63	59.00	173.00	28.83	45.37	53.00
116	18.87	18.84	18.87	18.84	16.91	16.49	16.91	16.49	51.00	173.00	34.60	38.87	41.00
117	27.89	28.56	27.89	28.56	23.90	24.92	23.90	24.92	69.00	173.00	24.71	38.36	46.00
118	18.87	18.69	18.87	18.69	19.14	19.70	19.14	19.70	49.00	173.00	43.25	33.27	43.00
119	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55	53.00	17.300	28.83	45.83	52.00

TABLE (A.17.A) SUMMARY EVALUATION RESULTS - TEST SERIES 5 (TESTS 99-119).

Test No.	BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	WB1	WB2	WT1	WT2	WT3
120	18.87	17.50	18.87	17.50	19.40	20.49	19.40	20.49	39.00	229.00	45.80	50.64	59.00
121	18.87	18.12	18.87	18.12	20.31	20.81	20.31	20.81	27.00	268.00	53.60	66.43	88.00
122	18.87	18.75	18.87	18.75	18.42	16.67	18.42	16.67	44.00	225.00	45.00	39.01	46.00
123	18.87	21.87	18.87	21.87	20.82	23.90	20.82	23.90	30.00	227.00	56.75	80.29	109.00
124	18.87	18.12	18.87	18.12	18.42	16.34	18.42	16.34	44.00	225.00	45.00	39.01	46.00
125	18.87	17.84	18.87	17.84	18.64	20.08	18.64	20.08	28.00	259.00	51.80	55.88	73.00
126	18.87	18.31	18.87	18.31	20.31	20.69	20.31	20.69	27.00	268.00	53.00	66.48	88.00
127	18.87	18.78	18.87	18.78	18.42	17.13	18.42	17.13	44.00	225.00	45.00	39.01	46.00
128	18.87	21.12	18.87	21.12	20.82	23.16	20.82	23.16	30.00	227.00	56.75	80.29	109.00
129	18.87	18.31	18.87	18.31	18.42	16.88	18.42	16.88	44.00	225.00	45.00	39.01	46.00
130	18.87	18.19	18.87	18.19	20.31	20.48	20.31	20.48	27.00	268.00	53.60	66.48	88.00
131	18.87	18.50	18.87	18.50	20.31	20.56	20.31	20.56	27.00	268.00	53.60	66.48	88.00
132	7.29	7.21	7.29	7.21	7.14	7.25	7.14	7.25	16.00	204.00	86.00	9.27	13.00
133	18.87	20.37	18.87	20.37	20.82	22.41	20.82	22.41	30.00	227.00	56.75	80.29	109.00
134	18.87	18.50	18.87	18.50	18.42	17.41	18.42	17.41	44.00	225.00	45.00	39.01	46.00
135	18.87	18.53	18.87	18.53	20.31	20.39	20.31	20.39	27.00	268.00	53.60	66.48	88.00
136	18.87	18.69	18.87	18.69	20.31	20.44	20.31	20.44	27.00	268.00	53.60	66.48	88.00
137	7.29	7.25	7.29	7.25	7.14	7.19	7.14	7.19	16.00	204.00	68.00	9.27	13.00
138	18.87	19.62	18.87	19.62	20.31	20.69	20.31	20.69	27.00	268.00	53.00	66.48	88.00
139	7.29	7.07	7.29	7.07	7.14	7.18	7.14	7.18	16.00	204.00	68.00	9.27	13.00
140	18.87	18.87	18.87	18.87	20.31	20.31	20.31	20.31	27.00	268.00	53.60	66.48	88.00

TABLE (A.17.B) SUMMARY EVALUATION RESULTS - TEST SERIES 5 (TESTS 120-140).

TEST SERIES 6

GENERAL RESULTS FOR EXAMINED TESTCASES

SINGLE MODEL BALANCING

FINAL ASSIGNMENTS AND RESULTS

TEST PROBLEMS

Tests 141 and 142	16 Element Problem	Driscoll-Shafi
143	21 Element Problem	Wild
144	30 Element Problem	Sawyer
145	45 Element Problem	Kilbridge and Wester
146 and 147	70 Element Problem	Tonge

EXAMINATION CONDITIONS

General

No Confidence Effect
Single Model Production
(Single Element Assignment)
Unlimited Line Length

Test 141

Minimum duration = 10% of normal duration
Cycle time = 16
Maximum station size = 3

Test 142

No compressibility
Cycle time = 59
Maximum station size = 1

Test 143

No compressibility
Cycle time = 37
Maximum station size = 1

Test 144

No compressibility
Cycle time = 43
Maximum station size = 1

Test 145

No compressibility
Cycle time = 71
Maximum station size = 1

Test 146

Minimum duration = 50% of normal duration
Cycle time = 179
Maximum station size = 2

Test 147

No compressibility
Cycle time = 319
Maximum station size = 1.

Test No. 141

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	3	200	1/9	48.00	16.00
2	2	200	3/4/10	32.00	16.00
3	1	200	11/12	13.00	13.00
4	1	200	2/13/14	16.00	16.00
5	1	200	5/15	16.00	16.00
6	2	200	7/8	32.00	16.00
7	1	200	6/16	16.00	16.00

Test No. 142

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	1/3/9	57.00	57.00
2	1	200	2/4/5/10/11/12/13/14	59.00	59.00
3	1	200	6/7/8/15/16	57.00	57.00

Test No. 143

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	1/2/3/4/5/21	37.00	37.00
2	1	200	6/7/8/9/11/12/13	37.00	37.00
3	1	200	10/14/15/16	33.00	33.00
4	1	200	17/18/19/20	36.00	36.00

Test No. 144

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	2/3/12/17	43.00	43.00
2	1	200	1/5/6/13/14/16	43.00	43.00
3	1	200	10/20/21	41.00	41.00
4	1	200	4/7/15/24	40.00	40.00
5	1	200	8/9/22/25	42.00	42.00
6	1	200	18/13/26	35.00	35.00
7	1	200	19/27	43.00	43.00
8	1	200	11/28/29/30	37.00	37.00

Test No. 145

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	1/2/7/11/12/13/15	69.00	69.00
2	1	200	8/14/16/18/19/20	68.00	68.00
3	1	200	17/21/29	71.00	71.00
4	1	200	3/23/24/27	71.00	71.00
5	1	200	4/22/25/26/33	71.00	71.00
6	1	200	5/6/28/36/38	70.00	70.00
7	1	200	9/10/30/31/34/35/39	71.00	71.00
8	1	200	32/37/40/41/42/43/44/45	61.00	61.00

Test No. 146

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	1/2/15	177.00	177.00
2	2	200	3/4/5/6/9/16	358.00	179.00
3	1	200	7/10/11	176.00	176.00
4	2	200	18/24/30/41	358.00	179.00
5	1	200	8/12/57/58	178.00	178.00
6	2	200	13/14/17/19/59	354.00	177.00
7	1	200	20/21/22/70	171.00	171.00
8	2	200	23/25/31/33	358.00	179.00
9	2	200	26/27/28/29/32/34/35/51/62	356.00	178.00
10	1	200	44/45/46/69	179.00	179.00
11	2	200	52/53/54/63	347.00	173.50
12	2	200	36/37/38/39/40/42/43/47 48/49/64/67	355.00	177.50
13	1	200	56/61/68	165.00	165.00
14	1	200	50/55/60/65/66	154.00	154.00

Test No. 147

Station Number	Size	Model	Elements	Σt_i	Σte_i
1	1	200	1/2/3/4/5/7/15	310.00	310.00
2	1	200	6/9/10/16	316.00	316.00
3	1	200	18	319.00	319.00
4	1	200	8/11/12/17/19/24	315.00	315.00
5	1	200	13/14/22	309.00	309.00
6	1	200	20/21/23/30/33/41	306.00	306.00
7	1	200	25/28/31/32	307.00	307.00
8	1	200	26/27/29/34/35/44/45/51/62	305.00	305.00
9	1	200	46/52/53/63	309.00	309.00
10	1	200	36/37/38/39/47/48/54	312.00	312.00
11	1	200	40/42/43/49/56/57/58/64/68	315.00	315.00
12	1	200	50/55/59/60/61/65/66/67/69 70	263.00	263.00

Test No.	BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	WB1	WB2	WT1	WT2	WT3
141	1.70	1.70	1.70	1.70	3.00	3.00	3.00	3.00	0.0	173.00	24.71	31.83	35.00
142	2.26	2.26	2.26	2.26	2.83	2.83	2.83	2.83	0.0	173.00	57.67	1.63	2.00
143	3.38	3.38	3.38	3.38	4.12	4.12	4.12	4.12	0.0	143.00	35.75	3.28	4.00
144	5.81	5.81	5.81	5.81	10.68	10.68	10.68	10.68	0.0	324.00	40.50	8.00	8.00
145	2.84	2.84	2.84	2.84	10.68	10.68	10.68	10.68	0.0	552.00	69.00	9.06	10.00
146	1.94	1.94	1.94	1.94	32.39	32.39	32.39	32.39	0.0	3686.00	263.29	344.56	204.00
147	3.71	3.71	3.71	3.71	63.37	63.37	63.37	63.37	0.0	3686.00	307.17	48.33	56.00

TABLE (A.18) SUMMARY EVALUATION RESULTS - TEST SERIES 6.

SIMULATION

OF LINE OPERATIONS

USEFUL EQUATIONS AND DEFINITIONS

(See Chapters 4 and 5)

$BD2_s(BD1_s)$: Model adjusted balance delay for simulation.

$$BD2_s = \frac{\sum_{y=1}^{Nc} \sum_{k=1}^{P} \{(S_k \times C_s) - T_{ky}\}}{\{\sum_{k=1}^{P} S_k\} \times C_s \times N_c} \times 100 \qquad (5.11)$$

$BD4_s(BD3_s)$: Model adjusted effective balance delay.

$$BD4_s = \frac{\sum_{y=1}^{Nc} \sum_{k=1}^{P} \{S_k \times (C_s - Te_{ky})\}}{\{\sum_{k=1}^{P} S_k\} \times C_s \times N_c} \times 100 \qquad (5.12)$$

$SI2_s(SI1_s)$: Model adjusted smoothness index for simulation.

$$SI2_s = \sqrt{\sum_{y=1}^{Nc} \sum_{k=1}^{P} \{(S_k \times C_s) - T_{ky}\}^2} \qquad (5.13)$$

$SI4_s(SI3_s)$: Model adjusted effective smoothness index.

$$SI4_s = \sqrt{\sum_{y=1}^{Nc} \sum_{k=1}^{P} \{S_k \times (C_s - Te_{ky})\}^2} \qquad (5.14)$$

ARL: Average run length.

$$ARL = \frac{\sum_{i=1}^{Nr} N_x}{N_r} \qquad (5.5)$$

SDRL: Standard deviation of run length.

$$SDRL = \sqrt{\frac{\sum_{x=1}^{Nr} (N_x{}^2) - \{\sum_{x=1}^{Nr} (N_x/N_r)^2\}}{N_r}} \qquad (5.6)$$

APPM: Average production per model.

$$APPM = \frac{\sum_{j=1}^{m} Q_j}{M_s} \qquad (5.7)$$

MDR_s: Model dominance ratio.

$$MDR_s = \frac{Q_{max}}{\{\sum_{j=1}^{m} Q_j\}/M_s} \qquad (5.8)$$

UT	Total upstream working time during simulation.
NT	Total normal working time during simulation.
DT	Total downstream working time during simulation.
LT	Total lost working time during simulation.
TWA	Total work time assigned during simulation.
UUNT	Total unused normal time during simulation.
(f)	Frequency of occurence.

TEST SERIES 7

LINE SPEED EFFECT

FINAL SIMULATION RESULTS

TEST PROBLEMS

Tests 148 to 175	16 Element Problem	Driscoll-Shafi (Test set A)
Tests 176 to 196	16 Element Problem	Driscoll-Shafi (Test set B)

EXAMINATION CONDITIONS

Balancing

16 Element Problem
Single Model Balancing
Minimum duration = 10% normal duration
Confidence levels (50, 75, 95 and 99 per cent)
Cycle time = 20.

Simulation

General

Production schedule for 20 units
Consecutive scheduling
Closed stations
No station overlap

Test set A

50, 75, 95 and 99 per cent balancing confidence
Station variability

Test Set B

75 per cent balancing confidence
No variability, station and element variability cases.

Test Series 7 (Set A)

Test No.	Line Speed *1	Percent Change *2	Theoretical Time Available: Upstream	Normal	Downstream	Total	Unused Normal Time
50% Confidence (Balancing)							
148	15.0	-25.0	0.0	2700.0	0.0	2700.0 *3	10.7
149	18.0	-10.0	0.0	3240.0	0.0	3240.0	57.9
150	19.0	- 5.0	0.0	3420.0	0.0	3420.0	105.8
151	20.0	0.0	0.0	3600.0	0.0	3600.0	204.6
152	21.0	+ 5.0	0.0	3780.0	0.0	3780.0	344.9
153	22.0	+10.0	0.0	3960.0	0.0	3960.0	506.3
154	25.0	+25.0	0.0	4500.0	0.0	4500.0	1037.7
75% Confidence (Balancing)							
155	15.0	-25.0	0.0	3000.0	0.0	3000.0 *4	26.6
156	18.0	-10.0	0.0	3600.0	0.0	3600.0	199.6
157	19.0	- 5.0	0.0	3800.0	0.0	3800.0	351.8
158	20.0	0.0	0.0	4000.0	0.0	4000.0	531.9
159	21.0	+ 5.0	0.0	4200.0	0.0	4200.0	727.8
160	22.0	+10.0	0.0	4400.0	0.0	4400.0	927.4
161	25.0	+25.0	0.0	5000.0	0.0	5000.0	1527.6
95% Confidence (Balancing)							
162	15.0	-25.0	0.0	3300.0	0.0	3300.0 *5	176.4
163	18.0	-10.0	0.0	3960.0	0.0	3960.0	500.4
164	19.0	- 5.0	0.0	4180.0	0.0	4180.0	707.6
165	20.0	0.0	0.0	4400.0	0.0	4400.0	927.6
166	21.0	+ 5.0	0.0	4620.0	0.0	4620.0	1147.6
167	22.0	+10.0	0.0	4840.0	0.0	4840.0	1367.6
168	25.0	+25.0	0.0	5500.0	0.0	5500.0	2027.6
99% Confidence (Balancing)							
169	15.0	-25.0	0.0	3300.0	0.0	3300.0 *6	126.1
170	18.0	-10.0	0.0	3960.0	0.0	3960.0	508.7
171	19.0	- 5.0	0.0	4180.0	0.0	4180.0	717.1
172	20.0	0.0	0.0	4400.0	0.0	4400.0	936.7
173	21.0	+ 5.0	0.0	4620.0	0.0	4620.0	1156.7
174	22.0	+10.0	0.0	4840.0	0.0	4840.0	1376.7
175	25.0	+25.0	0.0	5500.0	0.0	5500.0	2036.7

*1 In equivalent cycle time.
*2 Change from original balancing cycle time.
*3 For 20 units on 4 enlarged stations equivalent to 9 normal stations.
*4 For 20 units on 5 enlarged stations equivalent to 10 normal stations.
*5 For 20 units on 3 enlarged stations equivalent to 11 normal stations.
*6 For 20 units on 4 enlarged stations equivalent to 11 normal stations.

TABLE (A.19.A) PROBLEMS INVOLVED IN TEST SERIES 7 (SET A).

Test Series 7 (Set B)

Test No.	Line Speed *1	Percent Change *2	Theoretical Time Available *3 Upstream	Normal	Downstream	Total	Unused Normal Time
75% Confidence Example (Balancing)							
Deterministic							
176	15.0	-25.0	0.0	3000.0	0.0	3000.0	0.0
177	18.0	-10.0	0.0	3600.0	0.0	3600.0	160.0
178	19.0	- 5.0	0.0	3800.0	0.0	3800.0	340.0
179	20.0	0.0	0.0	4000.0	0.0	4000.0	540.0
180	21.0	+ 5.0	0.0	4200.0	0.0	4200.0	740.0
181	22.0	+10.0	0.0	4400.0	0.0	4400.0	940.0
182	25.0	+25.0	0.0	5000.0	0.0	5000.0	1540.0
Station variability							
183	15.0	-25.0	0.0	3000.0	0.0	3000.0	26.6
184	18.0	-10.0	0.0	3600.0	0.0	3600.0	199.6
185	19.0	- 5.0	0.0	3800.0	0.0	3800.0	351.8
186	20.0	0.0	0.0	4000.0	0.0	4000.0	531.9
187	21.0	+ 5.0	0.0	4200.0	0.0	4200.0	727.8
188	22.0	+10.0	0.0	4400.0	0.0	4400.0	927.4
189	25.0	+25.0	0.0	5000.0	0.0	5000.0	1527.6
Element variability							
190	15.0	-25.0	0.0	3000.0	0.0	3000.0	27.3
191	18.0	-10.0	0.0	3600.0	0.0	3600.0	231.4
192	19.0	- 5.0	0.0	3800.0	0.0	3800.0	354.6
193	20.0	0.0	0.0	4000.0	0.0	4000.0	528.5
194	21.0	+ 5.0	0.0	4200.0	0.0	4200.0	721.8
195	22.0	+10.0	0.0	4400.0	0.0	4400.0	921.1
196	25.0	+25.0	0.0	5000.0	0.0	5000.0	1521.1

*1 In equivalent cycle time.
*2 Change from original balancing cycle time.
*3 For 20 units on 5 enlarged stations equivalent to 10 normal stations.

TABLE (A.19.B) PROBLEMS INVOLVED IN TEST SERIES 7 (SET B).

Test Number		BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	ARL	SDRL	APPM	MDR
148	B	3.89	3.89	3.89	3.89	4.58	4.58	4.58	4.58				
	S	0.40	0.40	0.40	0.40	1.11	1.11	1.11	1.11	20.00	0.00	20.00	1.00
149	B	3.89	3.89	3.89	3.89	4.58	4.58	4.58	4.58				
	S	1.79	1.79	1.79	1.79	3.29	3.29	3.29	3.29	20.00	0.00	20.00	1.00
150	B	3.89	3.89	3.89	3.89	4.58	4.58	4.58	4.58				
	S	3.09	3.09	3.09	3.09	4.76	4.76	4.76	4.76	20.00	0.00	20.00	1.00
151	B	3.89	3.89	3.89	3.89	4.58	4.58	4.58	4.58				
	S	5.68	5.68	5.68	5.68	7.17	7.17	7.17	7.17	20.00	0.00	20.00	1.00
152	B	3.89	3.89	3.89	3.89	4.58	4.58	4.58	4.58				
	S	9.12	9.12	9.12	9.12	10.52	10.52	10.52	10.52	20.00	0.00	20.00	1.00
153	B	3.89	3.89	3.89	3.89	4.58	4.58	4.58	4.58				
	S	12.79	12.79	12.79	12.79	14.44	14.44	14.44	14.44	20.00	0.00	20.00	1.00
154	B	3.89	3.89	3.89	3.89	4.58	4.58	4.58	4.58				
	S	23.06	23.06	23.06	23.06	27.70	27.70	27.70	27.70	20.00	0.00	20.00	1.00

	UT	(f)	(%)	NT	(f)	(%)	DT	(f)	(%)	LT	(f)	(%)	TWA
148	0.0	0	0.00	2689.3	80	77.7	0.0	0	0.00	773.0	73	22.3	3462.3
149	0.0	0	0.00	3182.1	80	91.9	0.0	0	0.00	280.2	57	8.1	3462.3
150	0.0	0	0.00	3314.2	80	95.7	0.0	0	0.00	148.1	45	4.3	3462.3
151	0.0	0	0.00	3395.4	80	98.1	0.0	0	0.00	66.9	21	1.9	3462.3
152	0.0	0	0.00	3435.1	80	99.2	0.0	0	0.00	27.2	9	0.8	3462.3
153	0.0	0	0.00	3453.7	80	99.8	0.0	0	0.00	8.6	5	0.2	3462.3
154	0.0	0	0.00	3462.3	80	100.0	0.0	0	0.00	0.0	0	0.0	3462.3

Test Number		BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	ARL	SDRL	APPM	MDR
155	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02	20.00	0.00	20.00	1.00
	S	0.89	0.89	0.89	0.89	1.79	1.79	1.79	1.79				
156	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02	20.00	0.00	20.00	1.00
	S	5.54	5.54	5.54	5.54	6.34	6.34	6.34	6.34				
157	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02	20.00	0.00	20.00	1.00
	S	9.26	9.26	9.26	0.26	9.64	9.64	9.64	9.64				
158	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02	20.00	0.00	20.00	1.00
	S	13.30	13.30	13.30	13.30	13.86	13.86	13.86	13.86				
159	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02	20.00	0.00	20.00	1.00
	S	17.33	17.33	17.33	17.33	18.54	18.54	18.54	18.54				
160	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02	20.00	0.00	20.00	1.00
	S	21.08	21.08	21.08	21.08	23.47	23.47	23.47	23.47				
161	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02	20.00	0.00	20.00	1.00
	S	30.55	30.55	30.55	30.55	38.85	38.85	38.85	38.85				

	UT	(f)	(%)	NT	(f)	(%)	DT	(f)	(%)	LT	(f)	(%)	TWA
155	0.0	0	0.0	2973.4	100	85.6	0.0	0	0.0	499.1	80	14.4	3472.6
156	0.0	0	0.0	3400.4	100	97.9	0.0	0	0.0	72.1	31	2.1	3472.6
157	0.0	0	0.0	3448.2	100	99.3	0.0	0	0.0	24.4	13	0.7	3472.6
158	0.0	0	0.0	3468.1	100	99.9	0.0	0	0.0	4.5	5	0.1	3472.6
159	0.0	0	0.0	3472.2	100	100.0	0.0	0	0.0	0.4	1	0.0	3472.6
160	0.0	0	0.0	3472.6	100	100.0	0.0	0	0.0	0.0	0	0.0	3472.6
161	0.0	0	0.0	3472.6	100	100.0	0.0	0	0.0	0.0	0	0.0	3472.6

Test Number		BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	ARL	SDRL	APPM	MDR
162	B	7.37	7.37	7.37	7.37	12.99	12.99	12.99	12.99	20.00	0.00	20.00	1.00
	S	5.34	5.34	5.34	5.34	8.80	8.80	8.80	8.80				
163	B	7.37	7.37	7.37	7.37	12.99	12.99	12.99	12.99	20.00	0.00	20.00	1.00
		12.64	12.64	12.64	12.64	16.26	16.26	16.26	16.26				
164	B	7.37	7.37	7.37	7.37	12.99	12.99	12.99	12.99	20.00	0.00	20.00	1.0
		16.93	16.93	16.93	16.93	21.60	21.60	21.60	21.60				
165	B	7.37	7.37	7.37	7.37	12.99	12.99	12.99	12.99	20.00	0.00	20.00	1.0
	S	21.08	21.08	21.08	21.08	27.80	27.80	27.80	27.80				
166	B	7.37	7.37	7.37	7.37	12.99	12.99	12.99	12.99	20.00	0.00	20.00	1.0
	S	24.84	24.84	24.84	24.84	34.42	34.42	34.42	34.42				
167	B	7.37	7.37	7.37	7.37	12.99	12.99	12.99	12.99	20.00	0.00	20.00	1.0
	S	28.26	28.26	28.26	28.26	41.26	41.26	41.26	41.26				
168	B	7.37	7.37	7.37	7.37	12.99	12.99	12.99	12.99	20.00	0.00	20.00	1.0
	S	36.86	36.86	36.86	36.86	62.39	62.39	62.39	62.39				

	UT	(f)	(%)	NT	(f)	(%)	DT	(f)	(%)	LT	(f)	(%)	TWA
162	0.0	0	0.0	3123.6	60	90.0	0.0	0	0.0	348.8	38	10.0	3472.4
163	0.0	0	0.0	3459.6	60	99.6	0.0	0	0.0	12.9	4	0.4	3472.4
164	0.0	0	0.0	3472.4	60	100.0	0.0	0	0.0	0.0	0	0.0	3472.4
165	0.0	0	0.0	3472.4	60	100.0	0.0	0	0.0	0.0	0	0.0	3472.4
166	0.0	0	0.0	3472.4	60	100.0	0.0	0	0.0	0.0	0	0.0	3472.4
167	0.0	0	0.0	3472.4	60	100.0	0.0	0	0.0	0.0	0	0.0	3472.4
168	0.0	0	0.0	3472.4	60	100.0	0.0	0	0.0	0.0	0	0.0	3472.4

Test Number		BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	ARL	SDRL	APPM	MDR
169	B	4.75	4.75	4.75	4.75	7.64	7.64	7.64	7.64	20.00	0.00	20.00	1.00
	S	3.82	3.82	3.82	3.82	5.72	5.72	5.72	5.72				
170	B	4.75	4.75	4.75	4.75	7.64	7.64	7.64	7.64	20.00	0.00	20.00	1.00
		12.85	12.85	12.85	12.85	14.72	14.72	14.72	14.72				
171	B	4.75	4.75	4.75	4.75	7.64	7.64	7.64	7.64	20.00	0.00	20.00	1.00
	S	17.16	17.16	17.16	17.16	20.08	20.08	20.08	20.08				
172	B	4.75	4.75	4.75	4.75	7.64	7.64	7.64	7.64	20.00	0.00	20.00	1.00
	S	21.29	21.29	21.29	21.29	25.96	25.96	25.96	25.96				
173	B	4.75	4.75	4.75	4.75	7.64	7.64	7.64	7.64	20.00	0.00	20.00	1.00
	S	25.04	25.04	25.04	25.04	32.10	32.10	32.10	32.10				
174	B	4.75	4.75	4.75	4.75	7.64	7.64	7.64	7.64	20.00	0.00	20.00	1.00
	S	28.44	28.44	28.44	28.44	38.39	38.39	38.39	38.39				
175	B	4.75	4.75	4.76	4.75	7.64	7.64	7.64	7.64	20.00	0.00	20.00	1.00
	S	37.03	37.03	37.03	37.03	57.60	57.60	57.60	57.60				

	UT	(f)	(%)	NT	(f)	(%)	DT	(f)	(%)	LT	(f)	(%)	TWA
169	0.0	0	0.0	3173.9	80	91.6	0.0	0	0.0	289.4	44	8.4	3463.3
170	0.0	0	0.0	3451.3	80	99.7	0.0	0	0.0	12.0	7	0.3	3463.3
171	0.0	0	0.0	3462.9	80	100.0	0.0	0	0.0	0.4	1	0.0	3463.3
172	0.0	0	0.0	3463.3	80	100.0	0.0	0	0.0	0.0	0	0.0	3463.3
173	0.0	0	0.0	3463.3	80	100.0	0.0	0	0.0	0.0	0	0.0	3463.3
174	0.0	0	0.0	3463.3	80	100.0	0.0	0	0.0	0.0	0	0.0	3463.3
175	0.0	0	0.0	3463.3	80	100.0	0.0	0	0.0	0.0	0	0.0	3463.3

Test Number		BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	ARL	SDRL	APPM	MDR
176	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.00	0.00	20.00	1.00
177	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	4.44	4.44	4.44	4.44	4.24	4.24	4.24	4.24	20.00	0.00	20.00	1.00
178	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	8.95	8.95	8.95	8.95	7.94	7.94	7.94	7.94	20.00	0.00	20.00	1.00
179	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
		13.50	13.50	13.50	13.50	12.77	12.77	12.77	12.77	20.00	0.00	20.00	1.00
180	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	17.62	17.62	17.62	17.62	17.86	17.86	17.86	17.86	20.00	0.00	20.00	1.00
181	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	21.36	21.36	21.36	21.36	23.04	23.04	23.04	23.04	20.00	0.00	20.00	1.00
182	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	30.80	30.80	30.80	30.80	38.77	38.77	38.77	38.77	20.00	0.00	20.00	1.00

	UT	(f)	(%)	NT	(f)	(%)	DT	(f)	(%)	LT	(f)	(%)	TWA
176	0.0	0	0.0	3000.0	100	86.7	0.0	0	0.0	460.0	20	13.3	3460.0
177	0.0	0	0.0	3440.0	100	99.4	0.0	0	0.0	20.0	20	0.6	3460.0
178	0.0	0	0.0	3460.0	100	100.0	0.0	0	0.0	0.0	0	0.0	3460.0
179	0.0	0	0.0	3460.0	100	100.0	0.0	0	0.0	0.0	0	0.0	3460.0
180	0.0	0	0.0	3460.0	100	100.0	0.0	0	0.0	0.0	0	0.0	3460.0
181	0.0	0	0.0	3460.0	100	100.0	0.0	0	0.0	0.0	0	0.0	3460.0
182	0.0	0	0.0	3460.0	100	100.0	0.0	0	0.0	0.0	0	0.0	3460.0

Test Number		BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	ARL	SDRL	APPM	MDR
183	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	0.89	0.89	0.89	0.89	1.79	1.79	1.79	1.79	20.00	0.00	20.00	1.00
184	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	5.54	5.54	5.54	5.54	6.34	6.34	6.34	6.34	20.00	0.00	20.00	1.00
185	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	9.26	9.26	9.26	9.26	9.64	9.64	9.64	9.64	20.00	0.00	20.00	1.00
186	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	13.30	13.30	13.30	13.30	13.86	13.86	13.86	13.86	20.00	0.00	20.00	1.00
187	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	17.33	17.33	17.33	17.33	18.54	18.54	18.54	18.54	20.00	0.00	20.00	1.00
188	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	21.08	21.08	21.08	21.08	23.47	23.47	23.47	23.47	20.00	0.00	20.00	1.00
189	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	30.55	30.55	30.55	30.55	38.85	38.85	38.85	38.85	20.00	0.00	20.00	1.00

	UT	(f)	(%)	NT	(f)	(%)	DT	(f)	(%)	LT	(f)	(%)	TWA
183	0.0	0	0.0	2973.4	100	85.6	0.0	0	0.0	499.1	80	14.4	3472.6
184	0.0	0	0.0	3400.4	100	97.9	0.0	0	0.0	72.1	31	2.1	3472.6
185	0.0	0	0.0	3448.1	100	99.3	0.0	0	0.0	24.4	13	0.7	3472.6
186	0.0	0	0.0	3468.2	100	99.0	0.0	0	0.0	4.5	5	0.1	3472.6
187	0.0	0	0.0	3472.2	100	100.0	0.0	0	0.0	0.4	1	0.0	3472.6
188	0.0	0	0.0	3472.6	100	100.0	0.0	0	0.0	0.0	0	0.0	3472.6
189	0.0	0	0.0	3472.6	100	100.0	0.0	0	0.0	0.0	0	0.0	3472.6

Test Number		BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	ARL	SDRL	APPM	MDR
190	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	0.91	0.91	0.91	0.91	1.59	1.59	1.59	1.59	20.00	0.00	20.00	1.00
191	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	5.93	5.93	5.93	5.93	6.95	6.95	6.95	6.95	20.00	0.00	20.00	1.00
192	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	9.33	9.33	9.33	9.33	10.38	10.38	10.38	10.38	20.00	0.00	20.00	1.00
193	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	13.21	13.21	13.21	13.21	14.47	14.47	14.47	14.47	20.00	0.00	20.00	1.00
194	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	17.18	17.18	17.18	17.18	19.05	19.05	19.05	19.05	20.00	0.00	20.00	1.00
195	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	20.93	20.93	20.93	20.93	23.91	23.91	23.91	23.91	20.00	0.00	20.00	1.00
196	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	30.42	30.42	30.42	30.42	39.16	39.16	39.16	39.16	20.00	0.00	20.00	1.00

	UT	(f)	(%)	NT	(f)	(%)	DT	(f)	(%)	LT	(f)	(%)	TWA
190	0.0	0	0.0	2972.7	100	85.4	0.0	0	0.0	506.3	78	14.6	3478.9
191	0.0	0	0.0	3386.6	100	97.3	0.0	0	0.0	92.3	32	2.7	3478.9
192	0.0	0	0.0	3445.4	100	99.0	0.0	0	0.0	33.5	18	1.0	3478.9
193	0.0	0	0.0	3471.5	100	99.8	0.0	0	0.0	7.5	7	0.2	3478.9
194	0.0	0	0.0	3478.2	100	100.0	0.0	0	0.0	0.7	2	0.0	3478.9
195	0.0	0	0.0	3478.9	100	100.0	0.0	0	0.0	0.0	0	0.0	3478.9
196	0.0	0	0.0	3478.9	100	100.0	0.0	0	0.0	0.0	0	0.0	3478.9

TEST SERIES 8

UPSTREAM AND DOWNSTREAM STATION EXTENSION

FINAL SIMULATION RESULTS

TEST PROBLEMS

Tests 197 to 216	16 Element Problem	Driscoll-Shafi (Test Set A)
Tests 217 to 231	16 Element Problem	Driscoll-Shafi (Test Set B)

EXAMINATION CONDITIONS

Balancing

16 Element Problem
Single model balancing
Minimum duration = 10% of normal duration
Confidence levels (50, 75, 95 and 99 percent)
Cycle time = 20

Simulation

General

Production schedule for 20 units
Consecutive scheduling
Fixed line speed (equivalent to cycle time = 20)
Open stations with station overlap

Test Set A

50, 75, 95 and 99 percent balancing confidence
Station variability

Test Set B

75 percent balancing confidence
No variability, station and element variability cases.

Test Series 8 (Set A)

Test No.	Percent Extension *1	Theoretical Time Available Upstream	Normal	Downstream	Total	Unused Time Normal	Up/Downstream
50% Confidence (Balancing)							
197	0	0.0	3600.0	0.0	3600.0 *2	204.6	0.0
198	5	180.0	3600.0	180.0	3960.0	312.0	209.7
199	10	360.0	3600.0	360.0	4320.0	416.1	449.8
200	20	720.0	3600.0	720.0	4040.0	663.0	917.6
201	50	1800.0	3600.0	1800.0	7200.0	1517.4	2220.3
75% Confidence (Balancing)							
202	0	0.0	4000.0	0.0	4000.0 *3	351.9	0.0
203	5	200.0	4000.0	200.0	4400.0	719.1	208.3
204	10	400.0	4000.0	400.0	4800.0	914.4	413.1
205	20	800.0	4000.0	800.0	5600.0	1291.4	836.0
206	50	2000.0	4000.0	2000.0	8000.0	2372.8	2154.7
95% Confidence (Balancing)							
207	0	0.0	4400.0	0.0	4400.0 *4	927.6	0.0
208	5	220.0	4400.0	220.0	4840.0	1141.6	226.0
209	10	440.0	4400.0	440.0	5280.0	1355.6	452.0
210	20	880.0	4400.0	880.0	6160.0	1777.5	910.0
211	50	2200.0	4400.0	2200.0	8800.0	2905.7	2421.9
99% Confidence (Balancing)							
212	0	0.0	4400.0	0.0	4400.0 *5	936.7	0.0
213	5	220.0	4400.0	220.0	4840.0	1151.7	225.0
214	10	440.0	4400.0	440.0	5280.0	1366.7	450.0
215	20	880.0	4400.0	880.0	6160.0	1792.8	903.9
216	50	2200.0	4400.0	2200.0	8800.0	3002.8	2333.9

*1 Applied equally to up and downstream extension (open station)
*2 For 20 units on 4 enlarged stations equivalent to 9 normal stations
*3 For 20 units on 5 enlarged stations equivalent to 10 normal stations
*4 For 20 units on 3 enlarged stations equivalent to 11 normal stations
*5 For 20 units on 4 enlarged stations equivalent to 11 normal stations

TABLE (A.20.A) PROBLEMS INVOLVED IN TESTS SERIES 8 (SET A).

Test Series 8 (Set B)

75% Confidence (Balancing)

Test No.	Percent Extension *1	Theoretical Time Available *2				Unused Time	
		Upstream	Normal	Downstream	Total	Normal	Up/Downstream
Deterministic							
217	0	0.0	4000.0	0.0	4000.0	540.0	0.0
218	5	200.0	4000.0	200.0	4400.0	736.0	204.0
219	10	400.0	4000.0	400.0	4800.0	931.0	409.0
220	20	800.0	4000.0	800.0	5600.0	1313.0	827.0
221	50	2000.0	4000.0	2000.0	8000.0	2405.0	2135.0
Station variability							
222	0	0.0	4000.0	0.0	4000.0	531.9	0.0
223	5	200.0	4000.0	200.0	4400.0	719.1	208.3
224	10	400.0	4000.0	400.0	4800.0	914.4	413.1
225	20	800.0	4000.0	800.0	5600.0	1291.4	836.0
226	50	2000.0	4000.0	2000.0	8000.0	2372.8	2154.7
Element variability							
227	0	0.0	4000.0	0.0	4000.0	528.5	0.0
228	5	200.0	4000.0	200.0	4400.0	708.6	213.2
229	10	400.0	4000.0	400.0	4800.0	897.9	423.1
230	20	800.0	4000.0	800.0	5600.0	1271.8	849.3
231	50	2000.0	4000.0	2000.0	8000.0	2318.8	2202.3

*1 Applied equally to up and downstream extension (open station)

*2 For 20 units on 5 enlarged stations equivalent to 10 normal stations.

TABLE (A.20.B) PROBLEMS INVOLVED IN TEST SERIES 8 (SET B).

Test Number		BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	ARL	SDRL	APPM	MDR
197	B	3.89	3.89	3.89	3.89	4.58	4.58	4.58	4.58				
	S	5.68	5.68	5.68	5.68	7.17	7.17	7.17	7.17	20.00	0.00	20.00	1.00
198	B	3.89	3.89	3.89	3.89	4.58	4.58	4.58	4.58				
	S	5.68	5.68	5.68	5.68	7.17	7.17	7.17	7.17	20.00	0.00	20.00	1.00
199	B	3.89	3.89	3.89	3.89	4.58	4.58	4.58	4.58				
	S	5.68	5.68	5.68	5.68	7.17	7.17	7.17	7.17	20.00	0.00	20.00	1.00
200	B	3.89	3.89	3.89	3.89	4.58	4.58	4.58	4.58				
	S	5.68	5.68	5.68	5.68	7.17	7.17	7.17	7.17	20.00	0.00	20.00	1.00
201	B	3.89	3.89	3.89	3.89	4.58	4.58	4.58	4.58				
	S	5.68	5.68	5.68	5.68	7.17	7.17	7.17	7.17	20.00	0.00	20.00	1.00

	UT	(f)	(%)	NT	(f)	(%)	DT	(f)	(%)	LT	(f)	(%)	TWA
197	0.0	0	0.0	3395.4	80	98.1	0.0	0	0.0	66.9	21	1.9	3462.3
198	102.7	54	3.0	3288.0	80	95.0	47.6	26	1.4	24.0	11	0.7	3462.3
199	194.5	55	5.6	3183.9	80	92.0	75.8	25	2.2	8.1	5	0.2	3462.3
200	444.5	64	12.8	2937.0	80	84.8	77.9	15	2.2	2.9	2	0.1	3462.3
201	1284.5	64	37.1	2082.6	80	60.2	95.2	16	2.7	0.0	0	0.0	3462.3

Test Number		BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	ARL	SDRL	APPM	MDR
202	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	13.30	13.30	13.30	13.30	13.86	13.86	13.86	13.86	20.00	0.00	20.00	0.00
203	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	13.30	13.30	13.30	13.30	13.86	13.86	13.86	13.86	20.00	0.00	20.00	0.00
204	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	13.30	13.30	13.30	13.30	13.86	13.86	13.86	13.86	20.00	0.00	20.00	0.00
205	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	13.30	13.30	13.30	13.30	13.86	13.86	13.86	13.86	20.00	0.00	20.00	0.00
206	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	13.30	13.30	13.30	13.30	13.86	13.86	13.86	13.86	20.00	0.00	20.00	0.00

	UT	(f)	(%)	NT	(f)	(%)	DT	(f)	(%)	LT	(f)	(%)	TWA
202	0.0	0	0.0	3468.1	100	99.9	0.0	0	0.0	4.5	5	0.1	3472.6
203	191.3	98	5.5	3280.9	100	94.5	0.4	1	0.0	0.0	0	0.0	3472.6
204	386.9	99	11.1	3085.6	100	88.9	0.0	0	0.0	0.0	0	0.0	3472.6
205	764.0	99	22.0	2708.6	100	78.0	0.0	0	0.0	0.0	0	0.0	3472.6
206	1845.3	99	53.1	1627.2	100	46.9	0.0	0	0.0	0.0	0	0.0	3472.6

Test Number		BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	ARL	SDRL	APPM	MDR
207	B	7.37	7.37	7.37	7.37	12.99	12.99	12.99	12.99				
	S	21.08	21.08	21.08	21.08	27.80	27.80	27.80	27.80	20.00	0.00	20.00	1.00
208	B	7.37	7.37	7.37	7.37	12.99	12.99	12.99	12.99				
	S	21.08	21.08	21.08	21.08	27.80	27.80	27.80	27.80	20.00	0.00	20.00	1.00
209	B	7.37	7.37	7.37	7.37	12.99	12.99	12.99	12.99				
	S	21.08	21.08	21.08	21.08	27.80	27.80	27.80	27.80	20.00	0.00	20.00	1.00
210	B	7.37	7.37	7.37	7.37	12.99	12.99	12.99	12.99				
	S	21.08	21.08	21.08	21.08	27.80	27.80	27.80	27.80	20.00	0.00	20.00	1.00
211	B	7.37	7.37	7.37	7.37	12.99	12.99	12.99	12.99				
	S	21.08	21.08	21.08	21.08	27.80	27.80	27.80	27.80	20.00	0.00	20.00	1.00

	UT	(f)	(%)	NT	(f)	(%)	DT	(f)	(%)	LT	(f)	(%)	TWA
207	0.0	0	0.0	3472.4	60	100.0	0.0	0	0.0	0.0	0	0.0	3472.4
208	214.0	59	6.2	3258.4	60	95.8	0.0	0	0.0	0.0	0	0.0	3472.4
209	428.0	59	12.3	3044.4	60	87.7	0.0	0	0.0	0.0	0	0.0	3472.4
210	850.0	59	24.5	2622.5	59	75.5	0.0	0	0.0	0.0	0	0.0	3472.4
211	1978.1	59	57.0	1494.3	40	43.0	0.0	0	0.0	0.0	0	0.0	3472.4

Test Number		BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	ARL	SDRL	APPM	MDR
212	B	4.75	4.75	4.75	4.75	7.64	7.64	7.64	7.64				
	S	21.29	21.29	21.29	21.29	25.96	25.96	25.96	25.96	20.00	0.00	20.00	0.00
213	B	4.75	4.75	4.75	4.75	7.64	7.64	7.64	7.64				
	S	21.29	21.29	21.29	21.29	25.96	25.96	25.96	25.96	20.00	0.00	20.00	0.00
214	B	4.75	4.75	4.75	4.75	7.64	7.64	7.64	7.64				
	S	21.29	21.29	21.29	21.29	25.96	25.96	25.96	25.96	20.00	0.00	20.00	0.00
215	B	4.75	4.75	4.75	4.75	7.64	7.64	7.64	7.64				
	S	21.29	21.29	21.29	21.29	25.96	25.96	25.96	25.96	20.00	0.00	20.00	0.00
216	B	4.75	4.75	4.75	4.75	7.64	7.64	7.64	7.64				
	S	21.29	21.29	21.29	21.29	25.96	25.96	25.96	25.96	20.00	0.00	20.00	0.00

	UT	(f)	(%)	NT	(f)	(%)	DT	(f)	(%)	LT	(f)	(%)	TWA
212	0.0	0	0.0	3463.3	80	100.0	0.0	0	0.0	0.0	0	0.0	3463.3
213	215.0	79	6.2	3248.3	80	93.8	0.0	0	0.0	0.0	0	0.0	3463.3
214	430.0	79	12.4	3033.3	80	87.6	0.0	0	0.0	0.0	0	0.0	3463.3
215	856.1	79	24.7	2607.2	80	75.3	0.0	0	0.0	0.0	0	0.0	3463.3
216	2066.1	79	59.7	1397.2	69	40.3	0.0	0	0.0	0.0	0	0.0	3463.3

Test Number		BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	ARL	SDRL	APPM	MDR
217	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	13.50	13.50	13.50	13.50	12.77	12.77	12.77	12.77	20.00	0.00	20.00	1.00
218	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	13.50	13.50	13.50	13.50	12.77	12.77	12.77	12.77	20.00	0.00	20.00	1.00
219	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	13.50	13.50	13.50	13.50	12.77	12.77	12.77	12.77	20.00	0.00	20.00	1.00
220	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	13.50	13.50	13.50	13.50	12.77	12.77	12.77	12.77	20.00	0.00	20.00	1.00
221	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	13.50	13.50	13.50	13.50	12.77	12.77	12.77	12.77	20.00	0.00	20.00	1.00

	UT	(f)	(%)	NT	(f)	(%)	DT	(f)	(%)	LT	(f)	(%)	TWA
217	0.0	0	0.0	3460.0	100	100.0	0.0	0	0.0	0.0	0	0.0	3460.0
218	196.0	99	5.7	3264.0	100	94.3	0.0	0	0.0	0.0	0	0.0	3460.0
219	391.0	99	11.3	3069.0	100	88.7	0.0	0	0.0	0.0	0	0.0	3460.0
220	773.0	99	22.3	2687.0	100	77.7	0.0	0	0.0	0.0	0	0.0	3460.0
221	1865.0	99	53.9	1595.0	100	46.1	0.0	0	0.0	0.0	0	0.0	3460.0

Test Number		BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	ARL	SDRL	APPM	MDR
222	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	13.30	13.30	13.30	13.30	13.86	13.86	13.86	13.86	20.00	0.00	20.00	1.00
223	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	13.30	13.30	13.30	13.30	13.86	13.86	13.86	13.86	20.00	0.00	20.00	1.00
224	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	13.30	13.30	13.30	13.30	13.86	13.86	13.86	13.86	20.00	0.00	20.00	1.00
225	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	13.30	13.30	13.30	13.30	13.86	13.86	13.86	13.86	20.00	0.00	20.00	1.00
226	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	13.30	13.30	13.30	13.30	13.86	13.86	13.86	13.86	20.00	0.00	20.00	1.00

	UT	(f)	(%)	NT	(f)	(%)	DT	(f)	(%)	LT	(f)	(%)	TWA
222	0.0	0	0.0	3468.1	100	99.9	0.00	0	0.0	4.5	5	0.1	3472.6
223	191.3	98	5.5	3280.9	100	94.5	0.40	1	0.0	0.0	0	0.0	3472.6
224	386.9	99	11.1	3085.6	100	88.9	0.00	0	0.0	0.0	0	0.0	3472.6
225	764.0	99	22.0	2708.6	100	78.0	0.00	0	0.0	0.0	0	0.0	3472.6
226	1845.3	99	53.1	1627.2	100	46.9	0.00	0	0.0	0.0	0	0.0	3472.6

Test Number		BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	ARL	SDRL	APPM	MDR
227	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	13.21	13.21	13.21	13.21	14.47	14.47	14.47	14.47	20.00	0.00	20.00	1.00
228	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	13.21	13.21	13.21	13.21	14.47	14.47	14.47	14.47	20.00	0.00	20.00	1.00
229	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	13.21	13.21	13.21	13.21	14.47	14.47	14.47	14.47	20.00	0.00	20.00	1.00
230	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	13.21	13.21	13.21	13.21	14.47	14.47	14.47	14.47	20.00	0.00	20.00	1.00
231	B	3.65	3.65	3.65	3.65	4.02	4.02	4.02	4.02				
	S	13.21	13.21	13.21	13.21	14.47	14.47	14.47	14.47	20.00	0.00	20.00	1.00

	UT	(f)	(%)	NT	(f)	(%)	DT	(f)	(%)	LT	(f)	(%)	TWA
227	0.0	0	0.0	3471.5	100	99.8	0.00	0	0.00	7.5	7	0.2	3478.9
228	185.5	97	5.3	3291.4	100	94.6	1.30	2	0.00	0.7	1	0.0	3478.9
229	376.2	98	10.8	3102.1	100	89.2	0.7	1	0.00	0.0	0	0.0	3478.9
230	750.7	99	21.6	2728.2	100	78.4	0.00	0	0.00	0.0	0	0.0	3478.9
231	1797.7	99	51.7	1681.2	100	48.3	0.00	0	0.00	0.0	0	0.0	3478.9

TEST SERIES 9

VARIATION IN PRODUCTION MIX

FINAL SIMULATION RESULTS

TEST PROBLEMS

Tests 232 to 252	16 Element Problem	Driscoll-Shafi	(Test Set A)
Tests 253 to 273	30 Element Problem	Sawyer	(Test Set B)

EXAMINATION CONDITIONS

Balancing

Mixed model balancing
Single Element Assignment
Minimum duration = 10% of normal duration
Deterministic balancing (50% confidence)
Equal schedule weighting
Random removal of elements (Tables (A.1) and (A.3) part 1)

Cycle time = 20 (16 element problem)
= 44 (30 element problem)

Simulation

General

Production schedule for 20 units
Consecutive scheduling
Closed stations
Station variability
Line speed equivalent = 20 (16 element problem)
= 44 (30 element problem)

Variable product mix.

Test Number: 16 Element Problem	Test Number: 30 Element Problem	Model weights pattern — Model: 200	201	202	203	204
232	253	1.0	0.0	0.0	0.0	0.0
233	254	0.0	1.0	0.0	0.0	0.0
234	255	0.0	0.0	1.0	0.0	0.0
235	256	0.0	0.0	0.0	1.0	0.0
236	257	0.0	0.0	0.0	0.0	1.0
237	258	0.8	0.05	0.05	0.05	0.05
238	259	0.05	0.8	0.05	0.05	0.05
239	260	0.05	0.05	0.8	0.05	0.05
240	261	0.05	0.05	0.05	0.8	0.05
241	262	0.05	0.05	0.05	0.05	0.8
242	263	0.6	0.1	0.1	0.1	0.1
243	264	0.1	0.6	0.1	0.1	0.1
244	265	0.1	0.1	0.6	0.1	0.1
245	266	0.1	0.1	0.1	0.6	0.1
246	257	0.1	0.1	0.1	0.1	0.6
247	268	0.4	0.15	0.15	0.15	0.15
248	269	0.15	0.4	0.15	0.15	0.15
249	270	0.15	0.15	0.4	0.15	0.15
250	271	0.15	0.15	0.15	0.4	0.15
251	272	0.15	0.15	0.15	0.15	0.4
252	273	0.20	0.20	0.20	0.20	0.20

Theoretical Time Available

	Upstream	Normal	Downstream	Total
16 Element	0.0	3600.00	0.0	3600.00
30 Element	0.0	7040.00	0.0	7040.00

TABLE (A.21) PROBLEMS INVOLVED IN TEST SERIES 9.

Test Number		BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	ARL	SDRL	APPM	MDR
232	B	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55	20.00	0.00	20.00	5.00
	S	26.32	26.32	26.32	26.32	22.12	22.12	22.12	22.12				
233	B	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55	20.00	0.00	20.00	5.00
	S	27.63	27.63	27.63	27.63	26.31	26.31	26.31	26.31				
234	B	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55	20.00	0.00	20.00	5.00
	S	27.33	27.33	27.33	27.33	24.89	24.89	24.89	24.89				
235	B	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55	20.00	0.00	20.00	5.00
	S	30.92	30.92	30.92	30.92	28.08	28.08	28.08	28.08				
236	B	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55	20.00	0.00	20.00	5.00
	S	26.98	26.98	26.98	26.98	23.34	23.34	23.34	23.34				

	UT	(f)	(%)	NT	(f)	(%)	DT	(f)	(%)	LT	(f)	(%)	TWA	UUNT
232	0.00	0	0.00	2652.60	120	99.9	0.00	0	0.00	3.8	4	0.1	2656.4	947.4
233	0.00	0	0.00	2605.4	100	99.1	0.00	0	0.00	22.6	11	0.9	2628.0	994.6
234	0.00	0	0.00	2616.0	100	99.9	0.00	0	0.00	3.8	4	0.1	2619.9	984.0
235	0.00	0	0.00	2486.8	100	99.1	0.00	0	0.00	22.2	11	0.9	2509.6	1113.2
236	0.00	0	0.00	2628.7	120	99.7	0.00	0	0.00	8.2	8	0.3	2636.9	971.3

Test Number		BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	ARL	SDRL	APPM	MDR
237	B	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55				
	S	26.75	26.75	26.75	26.75	22.92	22.99	22.92	22.99	4.00	6.99	4.00	4.00
238	B	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55				
	S	27.79	27.79	27.79	27.79	25.93	25.93	25.93	25.93	4.00	6.99	4.00	4.00
239	B	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55				
	S	27.49	27.49	27.49	27.49	24.85	24.85	24.85	24.85	4.00	6.99	4.00	4.00
240	B	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55				
	S	30.33	30.33	30.33	30.33	27.52	27.52	27.55	27.55	4.00	6.99	4.00	4.00
241	B	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55				
	S	27.23	27.23	27.23	27.23	23.82	23.82	23.82	23.82	4.00	6.99	4.00	4.00

	UT	(f)	(%)	NT	(f)	(%)	DT	(f)	(%)	LT	(f)	(%)	TWA	UUNT
237	0.00	0	0.00	2637.0	117	99.8	0.00	0	0.00	5.2	7	0.2	2642.2	963.0
238	0.00	0	0.00	2599.7	102	99.3	0.00	0	0.00	17.8	9	0.7	2617.5	1000.3
239	0.00	0	0.00	2610.4	102	99.7	0.00	0	0.00	7.0	6	0.3	2617.3	989.6
240	0.00	0	0.00	2508.0	102	99.1	0.00	0	0.00	48.4	17	1.9	2531.3	1092.0
241	0.00	0	0.00	2619.7	117	99.7	0.00	0	0.00	8.2	8	0.3	2627.9	980.3

Test Number		BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	ARL	SDRL	APPM	MDR
242	B	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55				
	S	27.22	27.22	27.22	27.22	23.63	23.63	23.63	23.63	4.00	5.37	4.00	3.00
243	B	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55				
	S	27.21	27.21	27.21	27.21	25.63	23.63	25.63	23.63	4.00	5.37	4.00	3.00
244	B	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55				
	S	27.32	27.21	27.32	27.21	24.84	24.84	24.84	24.84	4.00	5.37	4.00	3.00
245	B	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55				
	S	29.37	29.37	29.37	29.37	26.60	26.60	26.60	26.60	4.00	5.37	4.00	3.00
246	B	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55				
	S	27.29	27.29	27.29	27.29	24.27	24.27	24.27	24.27	4.00	5.37	4.00	3.00

	UT	(f)	(%)	NT	(f)	(%)	DT	(f)	(%)	LT	(f)	(%)	TWA	UUNT
242	0.00	0	0.0	2620.2	114	99.6	0.00	0	0.00	10.7	7	0.4	2630.6	979.8
243	0.00	0	0.0	2602.4	104	99.3	0.00	0	0.00	17.3	7	0.7	2619.6	997.6
244	0.00	0	0.0	2616.4	104	99.8	0.00	0	0.00	6.5	6	0.2	2622.9	983.6
245	0.00	0	0.0	2542.7	104	99.3	0.00	0	0.00	17.6	8	0.7	2560.3	1057.3
246	0.00	0	0.0	2617.5	114	99.7	0.00	0	0.00	8.3	8	0.3	2625.8	982.5

Test Number		BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	ARL	SDRL	APPM	MDR
247	B	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55				
	S	27.42	27.42	27.42	27.42	24.25	24.25	24.25	24.25	4.00	4.10	4.00	2.00
248	B	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55				
	S	27.75	27.75	27.75	27.75	25.27	25.27	25.27	25.27	4.00	4.10	4.00	2.00
249	B	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55				
	S	27.51	27.51	27.51	27.51	24.78	24.78	24.78	24.78	4.00	4.10	4.00	2.00
250	B	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55				
	S	28.37	28.37	28.37	28.37	25.62	25.62	25.62	25.62	4.00	4.10	4.00	2.00
251	B	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55				
	S	27.26	27.26	27.26	27.26	24.49	24.49	24.49	24.49	4.00	4.10	4.00	2.00
252	B	27.89	27.89	27.89	27.89	24.55	24.55	24.55	24.55				
	S	28.02	28.02	28.02	28.02	24.92	24.92	24.92	24.92	4.00	3.58	4.00	1.00

	UT	(f)	(%)	NT	(f)	(%)	DT	(f)	(%)	LT	(f)	(%)	TWA	UUNT
247	0.00	0	0.00	2610.8	111	99.7	0.00	0	0.00	8.9	5	0.3	2619.7	989.2
248	0.00	0	0.00	2601.0	106	99.6	0.00	0	0.00	9.9	4	0.4	2610.9	999.0
249	0.00	0	0.00	2609.8	106	99.9	0.00	0	0.00	2.2	3	0.1	2612.1	990.2
250	0.00	0	0.00	2578.7	106	99.8	0.00	0	0.00	6.1	4	0.2	2584.8	1021.3
251	0.00	0	0.00	2618.6	111	99.8	0.00	0	0.00	4.0	5	0.2	2622.6	981.4
252	0.00	0	0.00	2591.3	108	99.7	0.00	0	0.00	8.2	4	0.3	2599.5	1008.7

Test Number		BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	ARL	SDRL	APPM	MDR
253	B	30.57	30.57	30.57	30.57	47.13	47.13	47.13	47.13				
	S	31.93	31.93	31.93	31.93	49.94	49.94	49.94	49.94	20.00	0.00	20.00	5.00
254	B	30.57	30.57	30.57	30.57	47.13	47.13	47.13	47.13				
	S	29.83	29.83	29.83	29.83	42.59	42.59	42.59	42.59	20.00	0.00	20.00	5.00
255	B	30.57	30.57	30.57	30.57	47.13	47.13	47.13	47.13				
	S	30.54	30.54	30.54	30.54	47.36	47.36	47.36	47.36	20.00	0.00	20.00	5.00
256	B	30.57	30.57	30.57	30.57	47.13	47.13	47.13	47.13				
	S	28.16	28.16	28.16	28.16	47.17	47.17	47.17	47.17	20.00	0.00	20.00	5.00
257	B	30.57	30.57	30.57	30.57	47.13	47.13	47.13	47.13				
	S	30.37	30.37	30.37	30.37	47.02	47.02	47.02	47.02	20.00	0.00	20.00	5.00

	UT	(f)	(%)	NT	(f)	(%)	DT	(f)	(%)	LT	(f)	(%)	TWA	UUNT
253	0.00	0	0.00	4792.2	160	99.5	0.00	0	0.00	24.2	11	0.5	4816.4	2247.8
254	0.00	0	0.00	4939.8	160	99.7	0.00	0	0.00	17.1	8	0.3	4956.8	2100.2
255	0.00	0	0.00	4890.2	160	99.6	0.00	0	0.00	21.7	12	0.4	4911.9	2149.8
256	0.00	0	0.00	5057.6	160	99.6	0.00	0	0.00	20.7	14	0.4	5078.4	1982.4
257	0.00	0	0.00	4901.9	160	99.6	0.00	0	0.00	21.5	10	0.4	4923.3	4923.3

Test Number		BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	ARL	SDRL	APPM	MDR
258	B	30.57	30.57	30.57	30.57	47.13	47.13	47.13	47.13				
	S	31.44	31.44	31.44	31.44	49.39	49.39	49.39	49.39	4.00	6.99	4.00	4.0
259	B	30.57	30.57	30.57	30.57	47.13	47.13	47.13	47.13				
	S	29.86	29.86	29.86	29.86	43.66	43.66	43.66	43.66	4.00	6.99	4.00	4.0
260	B	30.57	30.57	30.57	30.57	47.13	47.13	47.13	47.13				
	S	30.39	30.39	30.39	30.39	47.16	47.16	47.16	47.16	4.00	6.99	4.00	4.0
261	B	30.57	30.57	30.57	30.57	47.13	47.13	47.13	47.13				
	S	28.61	28.61	28.61	28.61	47.01	47.01	47.01	47.01	4.00	6.99	4.00	4.0
262	B	30.57	30.57	30.57	30.57	47.13	47.13	47.13	47.13				
	S	30.28	30.28	30.28	30.28	46.77	46.77	46.77	46.77	4.00	6.99	4.00	4.0

	UT	(f)	(%)	NT	(f)	(%)	DT	(f)	(%)	LT	(f)	(%)	TWA	UUNT
258	0.0	0	0.0	4826.9	160	99.5	0.0	0	0.0	24.2	11	0.5	4851.1	2213.1
259	0.0	0	0.0	4937.6	160	99.7	0.0	0	0.0	14.3	7	0.3	4951.9	2102.4
260	0.0	0	0.0	4900.4	160	99.6	0.0	0	0.0	18.3	10	0.4	4918.7	2139.6
261	0.0	0	0.0	5025.6	160	99.7	0.0	0	0.0	15.8	11	0.3	5041.4	2014.4
262	0.0	0	0.0	4908.5	160	99.7	0.0	0	0.0	15.7	9	0.3	4924.2	2131.5

Test Number		BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	ARL	SDRL	APFM	MDR
263	B	30.57	30.57	30.57	30.57	47.13	47.13	47.13	47.13				
	S	31.00	31.00	31.00	31.00	48.70	48.70	48.70	48.70	4.00	5.37	4.00	3.00
264	B	30.57	30.57	30.57	30.57	47.13	47.13	47.13	47.13				
	S	29.96	29.96	29.96	29.96	45.08	45.08	45.08	45.08	4.00	5.37	4.00	3.00
265	B	30.57	30.57	30.57	30.57	47.13	47.13	47.13	47.13				
	S	30.30	30.30	30.30	30.30	47.35	47.35	47.35	47.35	4.00	5.37	4.00	3.00
266	B	30.57	30.57	30.57	30.57	47.13	47.13	47.13	47.13				
	S	29.13	29.13	29.13	29.13	47.36	47.36	47.36	47.36	4.00	5.37	4.00	3.00
267	B	30.57	30.57	30.57	30.57	47.13	47.13	47.13	47.13				
	S	30.25	30.25	30.25	30.25	47.20	47.20	47.20	47.20	4.00	5.37	4.00	3.00

	UT	(f)	(%)	NT	(f)	(%)	DT	(f)	(%)	LT	(f)	(%)	TWA	UUNT
263	0.0	0	0.0	4857.8	160	99.6	0.0	0	0.0	21.2	12	0.4	4879.0	2182.2
264	0.0	0	0.0	4931.0	160	99.7	0.0	0	0.0	16.4	10	0.3	4947.4	2109.0
265	0.0	0	0.0	4906.7	160	99.6	0.0	0	0.0	20.4	13	0.4	4927.1	2133.3
266	0.0	0	0.0	4989.0	160	99.5	0.0	0	0.0	22.6	15	0.5	5011.6	2051.0
267	0.0	0	0.0	4910.7	160	99.5	0.0	0	0.0	23.9	14	0.5	4934.6	2129.3

Test Number		BD1	BD2	BD3	BD4	SI1	SI2	SI3	SI4	ARL	SDRL	APPM	MDR
268	B	30.57	30.57	30.57	30.57	47.13	47.13	47.13	47.13				
	S	30.58	30.58	30.58	30.58	48.08	48.08	48.08	48.08	4.00	4.10	4.00	2.0
269	B	30.57	30.57	30.57	30.57	47.13	47.13	47.13	47.13				
	S	30.03	30.03	30.03	30.03	46.06	46.06	46.06	46.06	4.00	4.10	4.00	2.0
270	B	30.57	30.57	30.57	30.57	47.13	47.13	47.13	47.13				
	S	30.21	30.21	30.21	30.21	47.09	47.09	47.09	47.09	4.00	4.10	4.00	2.0
271	B	30.57	30.57	30.57	30.57	47.13	47.13	47.13	47.13				
	S	29.69	29.67	29.67	29.67	46.91	46.91	46.91	46.91	4.00	4.10	4.00	2.0
272	B	30.57	30.57	30.57	30.57	47.13	47.13	47.13	47.13				
	S	30.22	30.22	30.22	30.22	46.85	46.85	46.85	46.85	4.00	4.10	4.00	2.0
273	B	30.57	30.57	30.57	30.57	47.13	47.13	47.13	47.13				
	S	30.13	30.13	30.13	30.13	47.01	47.01	47.01	47.01	4.00	3.58	4.00	1.0

	UT	(f)	(%)	NT	(f)	(%)	DT	(f)	(%)	LT	(f)	(%)	TWA	UUNT
268	0.0	0	0.0	4887.3	160	99.5	0.0	0	0.0	26.7	15	0.5	4914.0	2152.7
269	0.0	0	0.0	4926.0	160	99.6	0.0	0	0.0	21.0	13	0.4	4946.9	2114.0
270	0.0	0	0.0	4913.3	160	99.6	0.0	0	0.0	21.0	13	0.4	4934.2	2126.7
271	0.0	0	0.0	4951.2	160	99.6	0.0	0	0.0	20.3	12	0.4	4971.5	2088.8
272	0.0	0	0.0	4912.9	160	99.6	0.0	0	0.0	19.4	11	0.4	4932.3	2127.1
273	0.0	0	0.0	4918.8	160	99.5	0.0	0	0.0	23.5	13	0.5	4942.3	2121.2

APPENDIX B

USERS' GUIDE TO

ALB PROGRAMS

USERS GUIDE TO ALB PROGRAMS

B.1. Introduction

The ALB programs suite has been written to enable the balancing of single and mixed model assembly lines under a variety of conditions and then to subsequently simulate the operation of the assembly line for various production programs. The program suite operates therefore in two distinct phases, balancing and simulation, and as a general rule simulation will follow balancing. The following notes describe the procedure required to create the necessary data files, to operate the necessary programs and to obtain the associated results.

The number of work elements, the number of assembly line stations and many other major parameters are limited only by the size of programs developed. Table (B.1) identifies the major variables associated with the ALB suite and indicates their present limits.

Throughout the users guide the sixteen elements mixed model balancing problem used in the thesis text will again be used to demonstrate the various file and output structures.

B.2. The Computer System in Use

The files and programs described here were designed for use on an ICL 1906S computer providing FORTRAN 4 language compilers. The computer actually used was at the University of Liverpool over the period 1978 to 1981.

B.3. Assembly Line Balancing Using ALB Programs

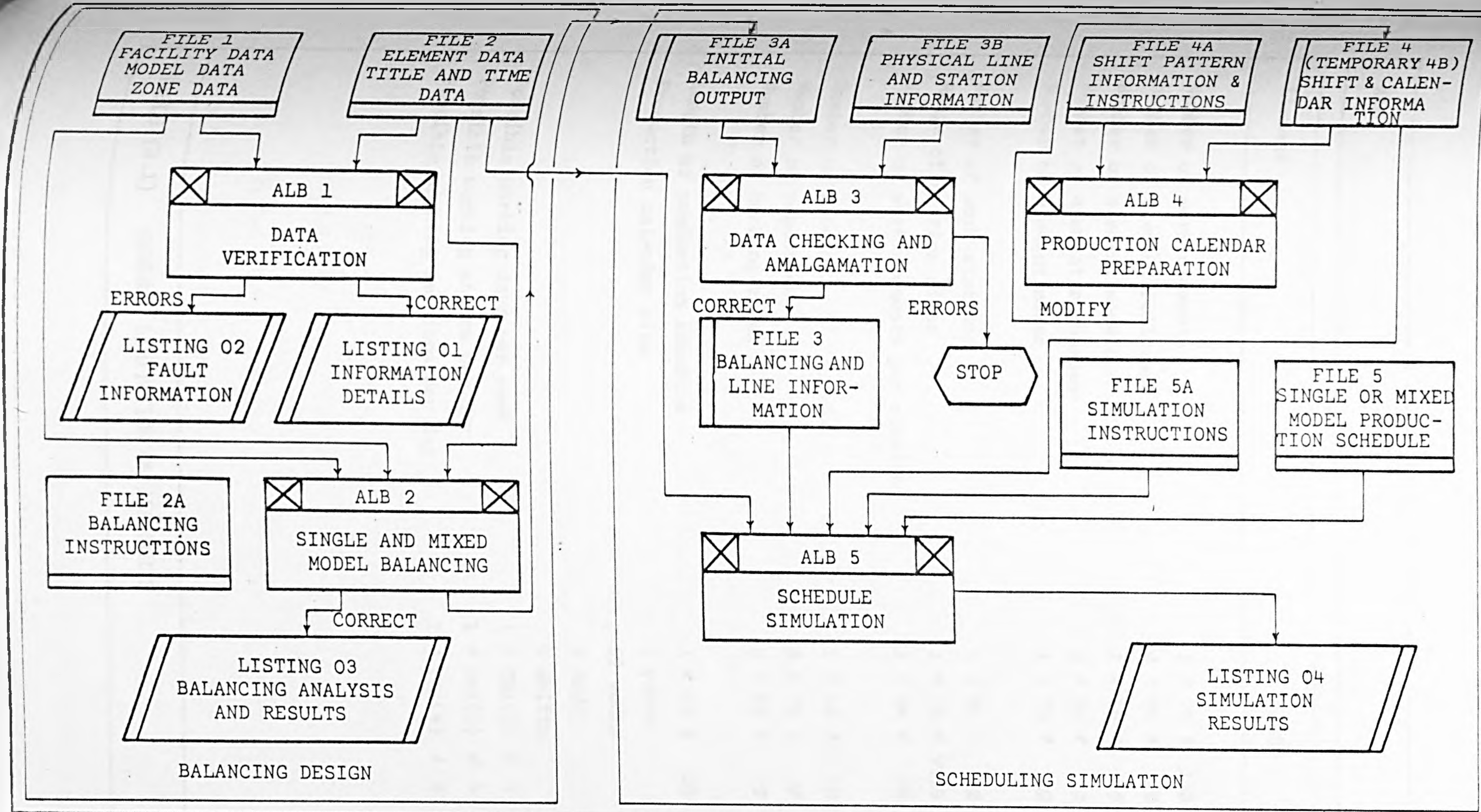


FIG. (B.1.) PROGRAM AND FILE ARRANGEMENT.

ALB

Element	Range
Number of work elements	1 ≤ T5 ≤ 100
Number of element followers	0 ≤ F4 ≤ 10
Number of element models	1 ≤ F6 ≤ 10
Number of element resources	0 ≤ F5 ≤ 10
Number of element zones	1 ≤ F9 ≤ 10
Number of work stations	1 ≤ T4 ≤ 40
Range of station sizes	1 ≤ IZ ≤ 9999
Number of work elements per station	1 ≤ S4 ≤ 20
Number of models	1 ≤ T6 ≤ 10
Number of resources	0 ≤ T3 ≤ 30
Number of working zones	0 ≤ T8 ≤ 10
Length of production schedule	1 ≤ T7 ≤ 30
Production calendar size	5 years 52 weeks 7 days 4 shifts
Possible working days per week	1 ≤ TM1(1) ≤ 7
Possible working shifts per day	1 ≤ TM1(2) ≤ 4
Possible working sessions per day	1 ≤ TM1(4) ≤ 8

TABLE (B.1) GENERAL LIMITATION ON ALB SUITE

The first stage of the ALB program suite is the balancing of the required assembly line under the problem conditions in question. The sequence of events involved in this is shown in figure (B.1) and consists of firstly preparing two major data files FILE 1 and FILE 2, verifying the data in these files using the program ALB1 and where the verification is satisfactory the balancing is subsequently carried out by the balancing program ALB2 in conjunction with the instruction file FILE 2A.

B.3.1. FILE 1: Resource, Model and Zone Data

Associated with each balancing problem will be a variety of resources available at each station, a number of zones into which each station is defined and a number of models which will pass down the assembly line. This file contains all the relevant information for defining these three groups and the detailed information on how to construct this file is given in table (B.2).

Resources play an important part in the balancing of assembly lines although at present apart from the manpower resource, which has been designated resource number 1ØØ, resources do not take part in the balancing procedure but are printed for information and analysis purposes. Figure (B.2) shows a typical layout for FILE 1 and contains six types of resources, when using the ALB programs the minimum is to specify resource number 1ØØ.

This file also contains a brief description of the various models to be produced on the assembly line. There will be at least one model in this list (single model balancing) and the model identity numbers specified play an important part in data verification, balancing and simulation. The illustrating problem shows five model alternatives for mixed model balancing case.

FILE 1: Manual Input

Card Set	Number of Cards	Format	Contents & Descriptions
1	One	I4	Number of resources T3. This card contains the total number of different types of resources involved in the problem being examined. The size of the resource list must be in the range 1 - 3Ø inclusive.
2	T3 each containing	I4	Resource identity number D1 ( ) Each resource is referred to by an unique identity number specified at this point. Common practice at present is to use the identity number 1ØØ for operators. The range of possible values for resource identity numbers is 1 - 9999 inclusive.
		8A8	Resource description D11 ( ) Each resource can be described at this point by the use of an alphanumeric description of up to 32 characters. Descriptions are not compulsory and may be left blank.
3	One	I4	Number of models T6 This card contains the total number of different types of models involved in the problem being examined. The size of the model list must be in the range 1 - 1Ø inclusive.
4	T6 each containing	I4	Model identity number E1 ( ) Each model is referred to by a unique identity number specified at this point. The range of possible values for model identity numbers is 1 - 9999 inclusive.
		8A8	Model description E11 ( ) Each model can be described at this point by the use of an alphanumeric description of up to 64 characters. Descriptions are not compulsory and may be left blank.

TABLE (B.2) CONTENTS OF RESOURCE, MODEL, WORKING ZONE DATA FILE.

FILE 1: Manual Input (Continuation)

Card Set	Number of Cards	Format	Contents & Descriptions
5	One	I4	Number of working zones T8. This card contains the total number of different types of working zones involved in the problem being examined. The size of the working zone list must be in the range 1 - 1Ø inclusive.
6	T8 each containing	I4	Working zone identity number Z1 ( ) Each working zone is referred to by a unique identity number specified at this point. The range of possible values for working zone identity numbers is 1 - 9999 inclusive.
		8A8	Working zone description Z11 ( ) Each working zone can be described at this point by the use of an alphanumeric description of up to 64 characters inclusive. Descriptions are not compulsory and may be left blank.
			Note: When compiling this file remember that any resource, model or working zone not specified here cannot be used in the problem under investigation.

TABLE (B.2) CONTENTS OF RESOURCE, MODEL, WORKING ZONE DATA FILE.

FILE 1: Illustrating Example

```
   6
 100 OPERATOR
  21 SPOT WELDER
  22 SPRAY GUN
  23 AIR CONDITION
  24 SPECIAL LIFTING M/C
  25 SPECIAL ELECTRICAL M/C
   5
 200 2 DOOR           1100 CC
 201 2 DOOR DELUXE    1100 CC
 202 4 DOOR           1300 CC
 203 4 DOOR DELUXE    1300 CC
 204 4 DOOR ESTATE    1750 CC
   5
   1 ALL AREAS
   2 LEFT HAND SIDE
   3 RIGHT HAND SIDE
   4 TOP WORKING
   5 UNDER SIDE WORKING
****
```

FIG. (B.2) RESOURCE, MODEL AND WORKING ZONES.

Five working zones have also been included in the illustrating problem to demonstrate the possibility of their inclusion although at present no account is taken of working zones in the balancing procedure, the list of zones being used for information purposes only.

The inputing of this file is achieved by using the following cards:

INPUT FILE 1, T////
Cards as described in table (B.2)
and illustrated in figure (B.2)
////

B.3.2. FILE 2: Contents Element Data File

The major parameters associated with balancing problems are those related to the work elements involved in the problem information in the job task and which have to be assigned and balanced on the assembly line. The detailed information required on each element and other information contained in this file is given in table (B.3) and the illustrating example file for the sixteen elements is shown in figure (B.3).

This file should contain as a minimum the problem title, at least one element and time information relevant to the problem, and is input using the following card image:

INPUT FILE 2, T///
Cards as described in table (B.3)
and illustrated in figure (B.3)
///

FILE 2: Manual Input

Card Set	Number of Cards	Format	Contents & Descriptions
1	One	8A8	Problem title T1 ( ). This is the identification for each simulation exercise in alphanumeric characters. The title does not affect the balancing and may be blank or up to 64 characters.
2	One	I4	The number of work element T5. This is the number of elements involved in the balancing and simulation exercises. Range of possible values 1 - 1ØØ inclusive.
3	T5 groups containing 6 cards		FOR EACH ELEMENT
	Card 1	I4	Element identity number F1 ( ). Each identity number is unique, integer and within the range 1 - 9999 inclusive.
		F6.2	Element average time F2 ( ). This represents the average duration of the work element performed by a practical worker at normal pace. Values are real and in the range Ø.Ø < < 1ØØØ.Ø
		F6.2	Element minimum duration F8 ( ). This represents the shortest possible time in which the work element can be completed by any size of work group. Values are real and in the range Ø.Ø < < 1ØØØ.Ø.
		F6.2	Element variance F3 ( ). This represents the normal variance of work element durations recorded when determining the average durations performed by a practiced worker. Values are real and in the range Ø.Ø < < 1ØØØ.Ø.

TABLE (B.3) CONTENTS OF ELEMENT DATA FILE.

FILE 2: Manual Input (Continuation)

Card Set	Number of Cards	Format	Contents & Descriptions
		7A8	Element description F7 ( ). This is an alphanumeric description of the work element which contains information when required but does not take part in balancing or simulation stages. Range of number of characters Ø - 56 inclusive. Descriptions are not compulsory and may be left blank.
	Card 2	1ØI4	Element followers F4 ( ). This list contains the immediate followers for the element under consideration. Up to ten followers can be specified by listing follower element numbers in any order, unused locations must be to the right of the follower list. Element with more than ten followers cannot be simulated, elements with no followers have this card blank. Follwers are integer and must appear as elements in this set of cards, in the range 1 - 9999 inclusive.
	Card 3	1ØI4	Element resources F5 ( ). This contains the specific resources needed by the element under consideration. Every element will normally use at least resource 1ØØ (manpower) and up to nine addition resources specified by listing resource numbers in any order. Element with more than ten resources cannot be simulated. Resource numbers are integer, must come from the list of resources in FILE 1 and be in the range 1 - 9999 inclusive. Unused locations must be to the right of the resource list.

TABLE (B.3) CONTENTS OF ELEMENT DATA FILE.

FILE 2: Manual Input (Continuation)

Card Set	Number of Cards	Format	Contents & Descriptions
	Card 4	1ØI4	Element resource levels F51 ( ). This list contains the number of units of each resource required by the element under consideration. This list should be as long as the resource list (F5( )) and should place individual resource levels in the same matrix location as the position of the resource identity number. Resource levels are integer and be in the range 1 - 9999 inclusive.
	Card 5	1ØI4	Element models F6 ( ). This list contains the product models that include the element under consideration as part of their total work content. Up to ten models can be specified by listing model numbers in any order. Elements involved in more than ten models can not be simulated and at least one model must be specified. Model numbers are integer, must come from the list of models in FILE 1 and be in the range 1 - 9999 inclusive.
	Card 6	1ØI4	Element working zones F9 ( ). This list contains the working zones associated with the element under consideration. Up to ten zones can be included and each element will normally be associated with at least one zone, zone being specified by the inclusion of zone number. At present zones are specified only for information purpose and will not influence balancing and simulation. Elements involving more than ten zones cannot be simulated. Zone numbers are integer, must come from the list of zones in FILE 1 and be in the range 1 - 9999 inclusive.

TABLE (B.3) CONTENTS OF ELEMENT DATA FILE.

FILE 2: Manual Input (Continuation)

Card Set	Number of Cards	Format	Contents & Descriptions
4	One	A8	Time units TØ. This specifies the time units in use and will be used for information and printing only. Range of the number of characters Ø - 8 inclusive.
		F1Ø.2	Shift time available T9. The number of time units available per shift, specified in the time units given on this card.
		F1Ø.2	Number of time units per hour T1Ø. The number of time units available per hour, specified in the time units given on this card.
			Note: Where any given card contains only blanks when compiling this file the blank card must still be included.

TABLE (B.3) CONTENTS OF ELEMENT DATA FILE.

FILE 2: Illustrating Example.

```
16 ELEMENT PROBLEM - MIXED MODEL - RANDOM REMOVAL ELEMENTS
 16
  1  6.0   2.0   1.5  ELEMENT NUMBER 1
  2   3    9
100  22   23
  1   1    1
200 201  202 203
  1
  2  6.0   3.0   1.5  ELEMENT NUMBER 2
  5
100  21
  1   1
200 201  202
  2
  3  9.0   4.0   2.0  ELEMENT NUMBER 3
  4
100
  1
201 202  203 204
  2
  4 12.0   3.0   3.0  ELEMENT NUMBER 4
  5   7
100
  1
203 204
  3
  5  7.0   2.0   2.0  ELEMENT NUMBER 5
  6
100  21
  1   1
200 201  203 204
  1
  6 10.0   4.0   3.0  ELEMENT NUMBER 6
  0
100
  1
200 201  202 204
  1
  7 17.0   5.0   4.0  ELEMENT NUMBER 7
  0
100
  1
200 202  204
  1
  8 15.0   4.0   4.0  ELEMENT NUMBER 8
  0
100  22   23
  1   1    1
200 201  202
  2
```

FIG. (B.3) CONTENTS OF ELEMENT DATA FILE.

FILE 2: Illustrating Example (Continuation)

```
   9 42.0   11.0    8.0   ELEMENT NUMBER 9
  10
 100
   1
 200 201  202  203  204
   3
  10 11.0    3.0    2.0   ELEMENT NUMBER 10
  11
 100  21   22
   1   1    1
 200 201  202  203  204
   1
  11  5.0    2.0    1.0   ELEMENT NUMBER 11
  12  13
 100  22   23
   1   1    1
 201 203
   1
  12  8.0    8.0    2.0   ELEMENT NUMBER 12
  14
 100
   1
 200 201  202  203  204
   2
  13  4.0    4.0    1.0   ELEMENT NUMBER 13
  14
 100
   1
 200 203
   2
  14  6.0    3.0    1.0   ELEMENT NUMBER 14
  15
 100  25
   1   1
 201 202  203
   3
  15  9.0    4.0    2.0   ELEMENT NUMBER 15
  16
 100  23   25
   1   1    1
 203 204
   4
  16  6.0    3.0    1.5   ELEMENT NUMBER 16
   0
 100
   1
 200 201  203  204
   5
MINUTES
****         480.00      60.00
```

FIG. (B.3) CONTENTS OF ELEMENT DATA FILE (Continuation).

B.3.3. Running Program ALB1

Before proceeding to the balancing program the information contained in FILE 1 and FILE 2 is verified against a list of possible errors. The error checks carried out by program ALB1 are listed in table (B.4). If the two files are satisfactory then a listing of the information useful to the assembly line designer is printed as shown in Appendix B.1 (listing 01), where there are errors in data, an indication of the source of the faults, along with a statement that errors have been found is produced in a simple second listing (listing 02). The card image format for running the program ALB1 is as follows:

CLEM EXECUTE = BALB1, *CRØ = FILE 2, *CR1 = FILE 1,

*LPØ = OUTPUT

where:

BALB1 = The binary version of the program ALB1.

CRØ = The input channel for file FILE 2.

CR1 = The input channel for file FILE 1.

LPØ = The output channel for 01 or 02.

B.3.4. FILE 2A Balancing Instructions

With the element, resource, zone and model information verified, FILE 2A must be completed before ALB2, the balancing program, can be run. This file is normally small enough to be directly input as cards along with the ALB2 execution instructions. However for the purpose of consistency the information required for ALB2 is set out in detail in table (B.5) and can be input as a separate file using the instruction:

ALB1

A. Resources

1. Check that the number of resources (T3) lies within the range 1 to 3Ø.
2. Check that each resource identity number is unique.
3. Check that all identity numbers are positive.

B. Models

1. Check that the number of models (T6) lies within the range 1 to 1Ø.
2. Check that each model identity number is unique.
3. Check that all identity numbers are positive.

C. Working zones

1. Check that the number of working zones (T8) lies within the range 1 to 1Ø.
2. Check that each zone identity number is unique.
3. Check that all identity numbers are positive.

D. Elements

1. Check that number of elements is within the range 1 to 1ØØ.
2. Check that every element identity number is positive and unique.
3. Check that every element time is positive.
4. Check that every element variance is zero or positive.
5. Check that every element minimum duration is positive and less or equal to the element time.
6. Check that all element followers are in the list of elements.
7. Check that every element requires at least one resource.
8. Check that all element resources are in the list of resources.
9. Check that the level of resource for each specified resource is at least one.
10. Check that every element has at least one working zone.
11. Check that all element working zones are in the list of working zones.
12. Check that every element has at least one model.
13. Check that all element models are in the list of models.

E. Time

1. Check that the number of time units per shift is positive.
2. Check that the number of time units per hour is positive.

Note: Errors of omission (data left out), or errors of incorrect formating will be detected by the normal FORTRAN diagnostics and execution errors will be produced.

TABLE (B.4) LIST OF ERROR CHECKS CARRIED OUT BY ALB1.

FILE 2A: Manual Input

Card Set	Number of Cards	Format	Contents & Descriptions
1	One	I4	Time control parameter L1. This variable specifies whether deterministic (L1 = Ø) or variable times (L1 = 1) are to be used when calculating element duration throughout balancing.
		F6.2	Percentage confidence required C1. Where variable element times are to be used, this variable specifies the degree of confidence that must be allowed for each time. For example: element average time = 1Ø.Ø element variance = 4.Ø percentage confidence = 99.9% (C1) then using the normal distribution +3.Ø9 standard deviation covers 99.9% of distribution therefore element time = $1Ø.Ø + \sqrt{4.Ø} \times 3.Ø9$ = 16.18.
2	One	I4	Line control parameter L3. Two types of assembly line length can be balanced using the ALB programs. Either no line length limit can be specified (L3 = Ø) or a definite line length can be accommodated (L3 = 1).
		I4	Line length L4. Where a line length limit is included this limit is specified in terms of the maximum number of stations possible (L4). Possible ranges of values 1 to 9999 inclusive but may be left at zero if L4 is not in use.
		I4	Weighting control parameter L12. When dealing with mixed model balancing the station size selected is selected on a basis of the least lost time.

TABLE (B.5) CONTENTS OF BALANCING INSTRUCTION FILE.

FILE 2A: Manual Input (Continuation)

Card Set	Number of Cards	Format	Contents & Descriptions
			The estimated least lost time is calculated using the equation: (Time available for all models - estimated work content.) When equal number of each model are to be produced the estimated work content is the sum of the assigned element times for each model. When substantially unequal numbers of each model are to be produced, the estimated work content should be modified to give account for the different proportions of models produced. To achieve this set L12 = Ø for no relative weighting and set L12 = 1 for the inclusion of model weighting.
		I4	Writing parameter L7 When L7 = Ø only the final balance results are printed. When L7 = 1 individual element assignment and results are also printed.
		I4	Manual maximum station size L25 When balancing, two alternative maximum station sizes can be considered, a computer generated maximum station size L11 and a manually input maximum station size L25. The greater of the two is selected. Range of manual maximum station sizes 1 - 9999 inclusive.
3	One	I4	Balancing control parameter L5 Three balancing models exist, each being selected by the value of L5, where: L5 = 1 Single model balancing L5 = 2 Mixed model, single element assignment L5 = 3 Mixed model, multiple element assignment.

TABLE (B.5) CONTENTS OF BALANCING INSTRUCTION FILE.

FILE 2A: Manual Input (Continuation)

Card Set	Number of Cards	Format	Contents & Descriptions
			Remember to check the consistency between the problem data and the value of L5 selected.
		F6.2	Cycle time C. This is the required cycle time for the balancing problem. Range of possible values Ø.Ø < C ≤ 1ØØØ.Ø.
4	One	1ØF6.2	Relative model ratios ADJ ( ) Where mixed model balancing is to take place the estimated production of each model is input at this point in order to enable the calculation of relative model ratios. The possible range of estimated production is Ø.Ø < < 1ØØØ.Ø. Ratios are used in the ranking process for mixed model balancing and may be used in the selection of station size. For single model balancing it is still necessary to enter one value.

TABLE (B.5) CONTENTS OF BALANCING INSTRUCTION FILE.

```
INPUT FILE 2A, T////
Cards as described in table (B.5)
and illustrated in figure (B.4)
////
```

In the illustrating example two possible balancing strategies have been shown in figure (B.4). In both cases variable element times are being allowed for with the desire to cover 90% of all normal variation in time. Furthermore both examples must be balanced with a limited line length of ten stations, taking into account the relative importance of each model and giving both a full and abre-viated print out of balancing information. No maximum station size has been specified by the designer and a cycle time of 20 minutes has been selected for both cases. In the first version of those illustrating examples mixed model, single element assignment is being demonstrated and in the second version of the example mixed model, multiple element assignment is under review, both cases being applied to a varying number of models under production.

B.3.5. Running Program ALB2

Having specified the balancing instructions and prepared the necessary data files the next task is to run the heuristic program ALB2. This is achieved by entering the following card image instructions:

```
CLEM EXECUTE = BALB2, *CRØ = FILE 2, *CR1 = FILE 1, *CP1 =
FILE 3A, *LPØ = OUTPUT
```

where:

BALB2 = The binary version of the program ALB2.

FILE 2A: Illustrating example.

```
  1 90.00
  1  10    1    1    0
  3 20.00
100.00900.00200.00500.00700.00
```

```
  1 90.00
  1  10    1    0    0
  2 20.00
100.00900.00200.00500.00700.00
```

FIG. (B.4) CONTENTS OF BALANCING INSTRUCTION FILE.

CRØ = The input channel for file FILE 2.

CR1 = The input channel for file FILE 1.

CR7 = The input channel for file FILE 2A.

CP1 = The output channel for file FILE 3A.

LPØ = The output channel for listing 03.

Two outputs are obtained from the ALB2 program on completion of balancing. Firstly the balancing results in a compacted form are output to FILE 3A for use in the simulation stage (further details on this file are given in section (B.4)). Secondly, a listing of results is output on the line printer for the balancing engineer (listing 03).

The listing from the two versions of the illustrating example are given in Appendix B1, one showing the full listing that can be obtained for mixed model single element assignment and the other showing the abbreviated listing of results for a multiple element assignment version of the problem.

In addition to printing the balancing results a detailed and useful analysis of elements, resources, models and precedence is also given as well as information on potential balance delay figures. At the end of balancing four versions of balance delay and smoothness index as explained in Chapter 4 are calculated and printed along with a summary of assignments and work distribution.

<u>Note 1</u>: The cycle time is checked against the elements involved in the problem to ensure an answer is feasible before balancing commences.

<u>Note 2</u>: As file ALB2 is quite brief an alternative is to simply place the cards after the CLEM card and remove reference to FILE 2A. An example of this alternative approach would be:

CLEM EXECUTE = BALB2, *CRØ = FILE 2, *CR1 = FILE 1, *CP1 = FILE 3A, *LPØ = OUTPUT.

Cards as described in table (B.5)
and illustrated in figure (B.4)

Note 3: Variables as defined before.

B.4. Simulation of Assembly Line Operation

Once constructed, assembly lines quite often have to operate under conditions different from those at the balancing stage. To discover the effects of this variation a simulation program has also been included in the ALB suite. The necessary files and preparation programs are also shown in figure (B.1), the remainder of this part of the user's guide gives the instructions necessary to undertake a simulation study.

B.4.1. FILE 3A: Initial Balancing Output File

This file is constructed by the balancing programs and is not normally interferred with by the balancing engineer, the contents of this file are described in table (B.6), and illustrated in figure (B.5), the multiple element assignment version of the problem having been selected for illustration.

B.4.2. FILE 3B: Physical Line and Station Information File

Before the balancing information is fed through to the simulation program, additional information on the physical position of the stations on the assembly line must be added. The instructions on the physical data is contained in FILE 3B and is as detailed in table (B.7) and illustrated in figure (B.6).

FILE 3A: Computer Generated File

Card Set	Number of Cards	Format	Contents & Descriptions
1	One	I4	Number of work stations T4 or IS. This is the number of work stations resulting from the balancing program ALB2. Range of possible values 1 - 4Ø inclusive.
		I4	Number of models T6. This is the number of models that were involved in the balancing exercise. Range of possible values 1 - 1Ø inclusive.
		I4	Number of work elements T5. This is the number of work elements that were involved in the balancing exercise. Range of possible values 1 - 1ØØ inclusive.
2	One	F6.2	Cycle time C. This is the cycle time used in the balancing exercise. Range of possible values is Ø.Ø < < 1ØØØ.Ø.
3	One	1ØI4	Model list El ( ). This list contains the model identity numbers that were involved in the balancing exercise. Up to ten model identities can be in the list. Model identity number are integer and in the range 1 - 9999 inclusive.
4	One	1ØI4	Model adjustments ADJ ( ). This is the relative model ratios calculated and used in the balancing program. This list must be as long as the model list, and model ratios occupy the same matrix locations as the models to which they apply. The range of possible values is Ø.Ø < <1.Ø.

TABLE (B.6) CONTENTS OF INITIAL BALANCING OUTPUT.

FILE 3A: Computer Generated File (Continuation)

Card Set	Number of Cards	Format	Contents & Descriptions
5	IS Groups		FOR EACH WORK STATION.
	Card 1	I4	Work station identity number I. Each identity number is unique, integer, consecutive and within the range 1 - 4∅ inclusive.
		I4	Work station capacity IZ. This represents the size of work group of the station under consideration and is in the range 1 - 9999 inclusive.
		F6.2	Station time available. This is the work time available in the station and depends on the station size. Range of possible values is ∅.∅ < < 1∅∅∅.∅.
	Card 2	2∅I4	Element identity numbers IC ( ). This list contains the identity numbers of elements assigned to the station under consideration. Between 1 and 2∅ inclusive, elements may appear in the list. Element identity numbers are integer and in the range 1 - 9999 inclusive.
6	T5		FOR EACH ELEMENT
		10I4	Element station assignment IAS ( ). This is the station allocation of each element, model by model, with matrix positions corresponding to the model list. Up to ten values in the range 1 to 4∅ inclusive may appear.
7	One	8F6.2	Balancing delay and smoothness index. BD1 to BD4 & SI1 to SI4 This card contains four versions of balance delay and four versions of smoothness index calculated during the balancing stage.

TABLE (B.6) CONTENTS OF INITIAL BALANCING OUTPUT.

FILE 3A: Computer Generated File (Continuation)

Card Set	Number of Cards	Format	Contents & Descriptions
			Range of possible values for each balance delay or smoothness index Ø.Ø ≤ < 1ØØØ.Ø.

TABLE (B.6) CONTENTS OF INITIAL BALANCING OUTPUT.

```
   7    5   16
20.00
  200    201    202    203    204
0.04   0.38   0.08   0.21   0.29
  1    1  20.00
  1    2    3   13    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  2    3  60.00
  4    9   10    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  3    1  20.00
  2    5    7   10   11   12    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  4    1  20.00
  2    5    7   12   13   14    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  5    1  20.00
  4    7    8    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  6    1  20.00
  5    6   14   15   16    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  7    1  20.00
  6   16    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  1    1    1    1    0
  1    3    4    0    0
  0    1    1    1    1
  0    0    0    5    2
  3    4    0    6    4
  6    6    6    0    7
  4    0    3    0    5
  5    5    5    0    0
  2    2    2    2    2
  2    2    2    2    3
  0    3    0    3    0
  3    4    4    3    4
  1    0    0    4    0
  0    6    6    4    0
  0    0    0    6    6
  6    7    0    7    6
17.16 17.16 17.13 17.13 17.69 17.69 16.06 16.06
****
```

FIG. (B.5) INITIAL BALANCING OUTPUT FILE (MIXED MODEL, MULTIPLE ELEMENT ASSIGNMENT) (ILLUSTRATION EXAMPLE).

FILE 3B: Manual Input

Card Set	Number of Cards	Format	Contents & Descriptions
1	One	F6.2	Line Speed V. This is the line speed associated with the balancing cycle time and therefore enables the calculation of station and line length. Range of possible values Ø.Ø < < 1ØØØ.Ø. The line speed is defined as a number of length units (TTØ) per time unit (TØ).
		A8	Length units (TTØ). This alphanumeric variable contains the basic length units in use. Range of number of characters Ø - 8 inclusive.
2	One	F6.2	Line length (SLL). This is the total line length specified in length units. Range of possible values Ø.Ø < < 1ØØØ.Ø.
		F6.2	Line start position (ST). This is the location of the start of the first assembly line station. Range of possible values Ø.Ø < < 1ØØØ.Ø.
3	One	I4	Manual or computer preparation L2Ø. The location of each station and the amount of upstream and downstream excess can be calculated by the computer (L2Ø = 1), or can be input for each individual station manually (L2Ø = 2).
EITHER COMPUTER GENERATION			
4.A	One	F6.2	Station upstream excess length UE. This is the upstream excess length to be allocated to each station. Range of possible values Ø.Ø < < 1ØØØ.Ø.

TABLE (B.7) CONTENTS OF PHYSICAL LINE AND STATION INFORMATION.

FILE 3B: Manual Input (Continuation)

Card Set	Number of Cards	Format	Contents & Descriptions
		F6.2	Station downstream excess length DE. This is the downstream excess length to be allocated to each station. Range of possible values Ø.Ø < < 1ØØØ.Ø.
OR MANUAL	INPUT		
4.B	T4 (Number of Stations)	F6.2	Station start position S3 (, 1). This is the station start position expressed in length units. Range of possible values Ø.Ø < < 1ØØØ.Ø.
		F6.2	Station upstream excess length S3 (,3) This is the upstream excess length to be allocated to the station. Range of possible values Ø.Ø < < 1ØØØ.Ø.
		F6.2	Station downstream excess length S3 (, 4). This is the downstream excess length to be allocated to the station. Range of possible values Ø.Ø < < 1ØØØ.Ø. inclusive.

TABLE (B.7) CONTENTS OF PHYSICAL LINE AND STATION INFORMATION.

FILE 3B (Two different illustration examples)

```
  0.50 METER
100.00  5.00
  2
  5.00  0.00  3.00
 15.00  1.00  2.00
 25.00  2.00  1.00
 35.00  3.00  3.00
 45.00  0.00  0.00
 55.00  2.00  0.00
 65.00  3.00  1.00
```

```
  0.50 METER
100.00  5.00
  1
  2.00  3.00
```

FIG. (B.6) PHYSICAL LINE AND STATION INFORMATION FILES (ILLUSTRATION EXAMPLE).

Two examples of FILE 3B are shown, a manually entered arrangement of work stations and the information necessary for the computer to generate work station positions, of the examples shown the manually input example will be used to illustrate the simulation program. The information is input to FILE 3B using the following card image:

INPUT FILE 3B, T////

Cards as described in table (B.7)

and illustrated in figure (B.6)

////

B.4.3. Running Program ALB3

Program ALB3 is a simple program for creating all the information on the work station positions and the assembly line length by merging FILE 3A and FILE 3B to produce FILE 3. The program also verifying that the data in FILE 3B is satisfactory by checking that the given line length is enough to accommodate all the work stations. The card image format for running the program ALB3 is as follows:

CLEM EXECUTE = BALB3, *CRØ = FILE 3B, *CR1 = FILE 3A, *CP1 = FILE 3.

where:

BALB3 = The binary version of the program ALB3.

CRØ = The input channel for file FILE 3B.

CR1 = The input channel for file FILE 3A.

CP1 = The output channel for file FILE 3.

B.4.4. FILE 3: Balancing and Line Information

This file is constructed by the Data Checking and Amalgamation

Program ALB3 and is not normally interferred with by the balancing engineer, the contents of this file are described in table (B.8), and illustrated in figure (B.7). This file will be picked up later by the simulation program ALB5.

B.4.5. FILE 4 (4B): Shift and Calendar Information

Throughout the simulation of the production schedule reference will be made to a five years calendar to check whether the relevant shift is working or not. Thus a more realistic simulation can be obtained for the production program. This calendar is contained in FILE 4 and amendments to it will be made by FILE 4A and program ALB4. The contents of FILE 4 are given in detail in table (B.9) and an abbreviated listing of the file is shown in figure (B.8). The abbreviated listing shows the first half year of the five year calendar, the remainder of the calendar consisting of all working shifts (1). The calendar appears as 2ØI4 card image and simply continues from the last point shown.

B.4.6. FILE 4A: Shift Pattern Information and Instructions

Amendments to the master file (File 4) are achieved through the instructions given in FILE 4A and the execution of program ALB4. The program operates on a sectional basis with six sections available as shown following:

Section 1: Creating a new calendar.

Section 2: Updating the existing calendar.

Section 3: Adding holiday shut-downs.

Section 4: Adding internal cause shut-downs.

Section 5: Adding external cause shut-downs.

FILE 3: Computer Generated File

Card Set	Number of Cards	Format	Contents & Descriptions
1	One	I4	Number of work stations T4. This is the number of work stations resulting from the balancing program ALB2. Range of possible values 1 - 4Ø inclusive.
		I4	Number of models T6. This is the number of models that were involved in the balancing exercise. Range of possible values 1 - 1Ø inclusive.
		I4	Number of work elements T5. This is the number of work elements that were involved in the balancing exercise. Range of possible values 1 - 1ØØ inclusive.
2	One	F6.2	Cycle time T2. This is the cycle time used in the balancing exercise. Range of possible values Ø.Ø < < 1ØØØ.Ø.
		F6.2	Work station basic length SL. This is the station length specified in length units and is calculated according to the given line speed and the cycle time used in the balancing exercise. Range of possible values Ø.Ø < < 1ØØØ.Ø.
		F6.2	Line length SLL. This is the total line length specified in length units. Range of possible values Ø.Ø < < 1ØØØ.Ø.
		F6.2	Line speed TL3. This is the line speed associated with the balancing cycle time.

TABLE (B.8) CONTENTS OF BALANCING AND LINE INFORMATION.

FILE 3: Computer Generated File (Continuation)

Card Set	Number of Cards	Format	Contents & Descriptions
			Range of possible values Ø.Ø < < 1ØØØ.Ø. The line speed is defined as a number of length units (TTØ) per time unit (TØ).
		A8	Length units (TTØ). This alphanumeric variable contains the basic length units in use. Range of number of characters is Ø - 8 inclusive.
3	One	1ØI4	Relative model ratios ADJ ( ). This is the relative model ratios calculated and used in the balancing program. This list must be as long as the model list, and model ratios occupy the same matrix locations as the models to which they apply. The range of possible values is Ø < ≤ 1.Ø.
5	T5 Groups		For each station.
	Card 1	I4	Work station identity number S1 (, 1). Each identity number is unique, integer, consecutive and within the range 1 - 1Ø inclusive.
		I4	Work station capacity S1 (, 2). This represents the size of work group of the station under consideration and in the range 1 - 9999 inclusive.
		F6.2	Work station start position S3 (, 1). This is the equivalent closed station start position specified in length units. Range of possible values is Ø.Ø ≤ < 1ØØØ.Ø.

TABLE (B.8) CONTENTS OF BALANCING AND LINE INFORMATION.

FILE 3: Computer Generated File (Continuation)

Card Set	Number of Cards	Format	Contents & Descriptions
		F6.2	Station time available S3 (, 2). This is the work time available in the station and depends on the station size. Range of possible values is Ø.Ø < < 1ØØØ.Ø.
		F6.2	Station upstream excess length S3 (,3) This is the station upstream excess length expressed in length units. Range of possible values in Ø.Ø < < 1ØØØ.Ø.
		F6.2	Station downstream excess length S3 (, 4). This is the downstream excess length expressed in length units. Range of possible values Ø.Ø < < 1ØØØ.Ø.
	Card 2	2ØI4	Element identity numbers S4 ( ). This list contains the element identity numbers of elements assigned to the station under consideration (S1 (, 1)). Between 1 and 2Ø inclusive, elements may appear in the list. Element identity numbers are integer, and in the range 1 - 9999 inclusive.
6	T5		For each element.
		1ØI4	Element station assignment IAS (,). This is the station allocation of each element, model by model, with matrix positions corresponding to the model list. Up to ten values in the range 1 to 4Ø inclusive may appear.
7	One	8F6.2	Balance delay and smoothness index BD1 ___ BD4 & SI1 ___ SI4

TABLE (B.8) CONTENTS OF BALANCING AND LINE INFORMATION.

FILE 3: Computer Generated File (Continuation)

Card Set	Number of Cards	Format	Contents & Descriptions
			This card contains four versions of balance delay and four versions of smoothness index calculated during the balancing stage. Range of possible values for each balance delay or smoothness index is Ø.Ø ≤ < 1ØØØ.Ø.

TABLE (B.8) CONTENTS OF BALANCING AND LINE INFORMATION.

```
    7     5    16
20,00 10,00100,00  0,50 METER
  200   201   202   203   204
0,04  0,38  0,08  0,21  0,29
   1     1  5,00 20,00  0,00  3,00
   1     2     5    13     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
   2     3 15,00 60,00  1,00  2,00
   4     9    10     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
   3     1 25,00 20,00  2,00  1,00
   2     5     7    10    11    12     0     0     0     0     0     0     0     0     0     0     0     0     0     0
   4     1 35,00 20,00  3,00  3,00
   2     5     7    12    13    14     0     0     0     0     0     0     0     0     0     0     0     0     0     0
   5     1 45,00 20,00  0,00  0,00
   4     7     8     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
   6     1 55,00 20,00  2,00  0,00
   5     6    14    15    16     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
   7     1 65,00 20,00  3,00  1,00
   6    16     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0     0
   1     1     1     1     0
   1     3     4     0     0
   0     1     1     1     1
   0     0     0     5     2
   3     4     0     6     4
   6     6     6     0     7
   4     0     3     0     5
   5     5     5     0     0
   2     2     2     2     2
   2     2     2     2     3
   0     3     0     3     0
   3     4     4     3     4
   1     0     0     4     0
   0     6     6     4     0
   0     0     0     6     6
   6     7     0     7     6
 17,16 17,16 17,13 17,13 17,69 16,06 17,69 16,06
****
```

FIG. (B.7) BALANCING AND LINE INFORMATION FILE (MIXED MODEL, MULTIPLE ELEMENT ASSIGNMENT) (ILLUSTRATION EXAMPLE).

FILE 4 (FILE 4B): Computer Generated File

Card Set	Number of Cards	Format	Contents & Descriptions
1	One	I4	Standard working days per week TM1 (1). This is the number of working days per week up to 7 days represent Monday to Sunday. Range of possible values is 1 ≤ ≤ 7.
		I4	Maximum number of shifts per day TM1(2). This is the maximum number of shifts in which the calendar is designed to work with up to 4 shifts per day permitted. Range of possible values 1 ≤ ≤ 4.
		I4	Starting year TM1 (3). This is the calendar starting year e.g. 1980. Range of possible values 1 ≤ ≤ 9999.
		I4	Number of sessions TM1 (4). This is the number of working sessions per day in which the calendar is designed to work with, up to 8 sessions per day permitted. Range of possible values is 1 ≤ ≤ 8.
		I4	Timetable identity number TM1 (5). This is a <u>unique</u> identifier for the calendar. Range of possible values 1 ≤ ≤ 9999.
2	4 Card 1	7I4	First shift status TM2 (, 1). This indicates whether the first shift is normally in use (value = 1) throughout the seven days of the working week. If not in use (value = Ø).
	Card 2	7I4	Second shift status TM2 (, 2). This indicates whether the second shift is normally in use (value = 1) throughout the seven days of the working week. If not in use (value = Ø).

TABLE (B.9) CONTENTS OF SHIFT AND CALENDAR INFORMATION.

FILE 4 (FILE 4B): Computer Generated File (Continuation)

Card Set	Number of Cards	Format	Contents & Descriptions
	Card 3	7I4	Third Shift Status TM2 (, 3) This indicates whether the third shift is normally in use (value = 1) throughout the seven days of the working week. If not in use (value = Ø).
	Card 4	7I4	Fourth Shift Status TM2 (, 4) This indicates whether the fourth shift is normally in use (value = 1) throughout the seven days of the working week. If not in use (value = Ø).
3	One	8I4	Session identity numbers TM3 ( ). This card contains the identity numbers associated with every working session, the value of the identity signifying the shift associated with the session in question. Range of possible values is 0 - 4 inclusive.
4	One	8F5.2	Session start times TM4 (, 1). This card contains the session starting times for all the working sessions in use per day. This list should be as long as the list of session identity numbers and should be in the same order. Range of possible values is Ø.Ø ≤ < 24.Ø.
5	One	8F5.2	Session durations TM4 (, 2). This card contains the session durations for all the working sessions in use per day. This list should be as long as the list of session identity numbers and should be in the same order. Range of possible values is Ø.Ø < ≤ 24.Ø.
6	364	2ØI4	Shift status for the five years, each year contains 52 weeks, each week contains seven days at maximum and each day contains four shifts TM5 (, , ,).

TABLE (B.9) CONTENTS OF SHIFT AND CALENDAR INFORMATION.

FILE 4 (FILE 4B): Computer Generated File (Continuation)

Card Set	Number of Cards	Format	Contents & Descriptions
			Range of possible values is Ø - 4 inclusive. Where: Ø = normal not working shift. 1 = working shift. 3 = holiday break - not working shift. 4 = internal cause - not working shift. 5 = external cause - not working shift.

TABLE (B.9) CONTENTS OF SHIFT AND CALENDAR INFORMATION.

FILE 4: *Illustrating Example*

```
   5   31980    4    1    0    0    0    0    0
   1    1    1    1    1    1    1
   1    1    1    1    1    1    1
   1    1    1    1    1    1    1
   1    1    1    1    1    1    1
   1    2    2    3    0    0    0    0
0.00 8.0013.0018.00 0.00 0.00 0.00 0.00
8.00 4.00 4.00 4.00 0.00 0.00 0.00 0.00
   1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    3    1
   1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
   1    1    1    1    1    1    1    1    1    1    1    1    4    4    4    4    4    4    4    4
   4    4    4    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1    1
```

FIG. (B.8) SHIFT AND CALENDAR INFORMATION.

FILE 4: *Illustrating Example (Continuation)*

1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	5	5	5	5	5	5	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1												

FIG. (B.8) SHIFT AND CALENDAR INFORMATION.

Section 1 when used is used on its own and is terminated automatically. Sections 2 to 5 can be used repeatedly in any order any number of times and all terminated by entering section 6 into the data file. The inputing of this file is achieved by using the following cards:

```
INPUT FILE 4A, T////
Cards as described in table (B.1Ø)
and illustrated in figure (B.9)
////
```

B.4.7. Running Program ALB4

Program ALB4 is responsible for creating and maintaining the five years production calendar, the program is sectioned into six parts, the relevant part being selected from the information held in FILE 4A. The card image format for running the program ALB4 is as follows:

```
CLEM EXECUTE = BALB4, *CRØ = FILE 4A, *CR1 = FILE 4, *CP1 =
FILE 4B, EXIT = 1LAB.
1LAB
IF NOT DISP (OK), EJ
LF FILE 4B
IF REPLY (FILE EMPTY), EJ
CY FILE 4B, FILE 4
ER FILE 4B
EJ
****
```

where:

FILE 4A: Manual Input

Card Set	Number of Cards	Format	Contents & Descriptions
1	One	I4	Switch parameter (I4). This is the parameter which switches the program process the the required section according to I4 value. There are 6 sections possible and the file may be made up of a combination of sections (but section 1 must be run alone). Possible range of values of I4 are: 1 = Creating a new timetable (FILE 4). 2 = Updating file FILE 4. 3 = Adding holiday shut-down to file FILE 4. 4 = Adding internal cause shut-down to file FILE 4. 5 = Adding external cause shut-down to file FILE 4. 6 = Stop the program. Section 1 is run on its own and automatically proceeds to end the process. Sections 2 to 5 can be blocked together for any number of combinations and section 6 is used to end the process. Section 6 is the terminator and no further cards are needed.
2	Section 1 1	I4	Standard working days per week TM1 (1). This is the number of working days per week, up to seven days, representing Monday to Sunday. Range of possible values 1 - 7 inclusive.
		I4	Maximum number of shifts per day TM1 (2). This is the maximum number of shifts in which the calendar is desired to work with.. Up to four shifts per day permitted. Range of possible values is 1 - 4 inclusive.

TABLE (B.10) CONTENTS OF SHIFT PATTERN INFORMATION & INSTRUCTIONS.

FILE 4A: Manual Input (Continuation)

Card Set	Number of Cards	Format	Contents & Descriptions
		I4	Starting year TM1 (3). This is the calendar starting year e.g. 1981. Range of possible values is 1 ≤ ≤ 9999.
		I4	Number of sessions TM1 (4). This is the number of working sessions per day with which the calendar is desired to work. Range of possible values is 1 - 8 inclusive.
		I4	Timetable identity number TM1 (5). This is a unique identifier for the calendar required to be prepared. Range of possible values is 1 - 9999 inclusive.
2	4 Card 1	7I4	First shift status TM2 (, 1). This indicates whether the first shift normally in use (value = 1) throughout the seven days of the working week. If not in use (value = Ø).
	Card 2	7I4	Second shift status TM2 (, 2). This indicates whether the second shift is normally in use (value = 1) throughout the seven days of the working week. If not in use (value = Ø).
	Card 3	7I4	Third shift status TM2 (, 3). This indicates whether the third shift is normally in use (value = 1) throughout the seven days of the working week. If not in use (value = Ø).
	Card 4	7I4	Fourth shift status TM4 (,4). This indicates whether the fourth shift is normally in use (value = 1) throughout the seven days of the working week. If not in use (value = Ø).

TABLE (B.1Ø) CONTENTS OF SHIFT PATTERN INFORMATION & INSTRUCTIONS.

FILE 4A: Manual Input (Continuation)

Card Set	Number of Cards	Format	Contents & Descriptions
3	One	8I4	Session identity numbers TM3 ( ). This card contains the identity numbers associated with every working session, the value of the identity signifying the shift associated with the session in question. Range of possible values is 1 - 4 inclusive.
4	One	8F5.2	Session start times TM4 (, 1). This card contains the session starting times for all the working sessions in use per day. This list should be as long as the list of session identity numbers and should be in the same order. Range of possible values is Ø.Ø ≤ < 24.Ø.
5	One	8F5.2	Session durations TM4 (, 2). This card contains the session duration for all the working sessions in use per day. This list should be as long as the list of session identity numbers and should be in the same order. Range of possible values is Ø.Ø < ≤ 24.Ø.
6	<u>Section 2</u> One	I4	Number of years in the existing calendar required to be kept and moved forward to the beginning of the five year I5 calendar. Range of possible values 1 ≤ < 5.
7	<u>Sections 3, 4 and 5</u> Card 1	4I4	(Sections 3, 4 and 5 may be repeated) Start shift, day, week and year I1, J1, K1, L1.

TABLE (B.1Ø) CONTENTS OF SHIFT PATTERN INFORMATION & INSTRUCTIONS.

FILE 4A: Manual Input (Continuation)

Card Set	Number of Cards	Format	Contents & Descriptions
			This card contains the start time of the new shut-down interval being added to the existing calendar. Range of possible values: $1 \leq I1 \leq 4$ $1 \leq J1 \leq 7$ $1 \leq K1 \leq 52$ $1 \leq 1L \leq 9999$ Dates out of range of the calendar will be rejected.
	Card 2	4I4	End shift, day, week and year I2, J2, K2, L2. This card contains the finishing time of the new shut-down interval being added to the existing calendar. Range of possible values: $1 \leq I2 \leq 4$ $1 \leq J2 \leq 7$ $1 \leq K2 \leq 52$ $1 \leq L2 \leq 9999$ Dates out of range of the calendar will be rejected.
	Card 3	A8	Alphanumeric block data B. This card answers the question of whether there are more entries in this section (section being processed). A "YES" answer allows another card set from the same section. A "NO" will send the program to the original switch parameter. Range of possible number of characters 1 - 8 inclusive.

TABLE (B.1Ø) CONTENTS OF SHIFT PATTERN INFORMATION & INSTRUCTIONS.

FILE 4A: Illustrating Example

```
 1
 5    31976    4    1
 1    1    1    1    1    1    1
 1    1    1    1    1    1    1
 1    1    1    1    1    1    1
 1    1    1    1    1    1    1
 1    2    2    3
0.00 8.0013.0018.00
8.00 4.00 4.00 4.00
****
```

A. Sample Section 1.
Creating a new timetable five year shift calendar.
Automatically terminated after completing section 1.

```
   2                        Section 2
   1
   3
   1    1    61980
   3    5    61980          Section 3
 YES
   1    1   201980
   3    5   221980
  NO
   4
   1    1   101980
   3    3   101980          Section 4
  NO
   5
   2    4   121980
   3    5   121980          Section 5
  NO
   6                        Section 6
****
```

B. Sample Sections 2 - 5.
Updating and adding different types of shut-down periods.

FIG. (B.9) SHIFT PATTERN INFORMATION AND INSTRUCTIONS.

BALB4 = The binary version of ALB4 program.

CRØ = The input channel for FILE 4A.

CR1 = The input channel for FILE 4.

CP1 = The output channel for FILE 4B.

Note 1: Lines 2 to 7 in the running instructions places the temporary file FILE 4B into file FILE 4 then erases the temporary file FILE 4B.

Note 2: In case of running section 1 the part of "CR1 = FILE 4" must not be included in the clem card.

B.4.8. FILE 5: Single or Mixed Model Production Schedule

The major piece of information required when simulating assembly line production through a given timetable is the production schedule to be produced. Creating the production schedule FILE 5 involves two different cases. For single model production a simple one cycle production program is produced which includes the total output required.

For mixed model production the production program is more complicated and may involve any number of cycles each containing a variety of models along with a variety of production quantitites, and cycles may be repeated a number of times, the main limitation on the complexity of the production program is the limit on the number of entries that may be made, which is 3Ø at present. Details on constructing a production program is given in table (B.11) and figure (B.10) demonstrates a simple single model production program along with a more complete mixed model program. The mixed model program is the one used to demonstrate the illustrating problem. The file FILE 5 is input to the computer using the following instructions:

FILE 5: Manual Input

Card Set	Number of Cards	Format	Contents & Descriptions
1	One	I4	Length of production schedule T7. This states the number of entries in the production schedule. Possible range of integer values 0 < ≮ 3∅.
		I4	Schedule identity number T11. This is a unique identifier for the simulation taking place. Range of possible values 0 ≮ ≮ 9999.
2	T7 each containing	I4	Cycle group S6 (, 1) A production program is made up of a number of cycles, each of which may be repeated, where each cycle must be completely finished before the next cycle starts. The cycle group number identifies the cycle to which this entry refers. Entries need not therefore be in cycle order and cycle identities not need be in order themselves. Range of possible cycle group values 1 ≮ ≮ 9999.
		I4	Model identity number S6 (, 2). This is the model to be produced. This value must be consistent with the list of models in (FILE 1).
		I4	Model quantity S6 (, 3). This is the number of units of model specified that are required at this stage. These units will be launched in sequence onto the assembly line before the next entry in the cycle group. Range of possible values 1 ≮ ≮9999.

TABLE (B.11) CONTENTS OF SINGLE OR MIXED MODEL PRODUCTION SCHEDULE.

FILE 5: Manual Input (Continuation)

Card Set	Number of Cards	Format	Contents & Descriptions
		I4	Number of repeat cycles required S6 (, 4). Each cycle may be repeated several times before moving on to the next program cycle. The number of repeat cycles (including the first cycle) should be specified with the <u>first</u> entry for each cycle. The remaining entries for the same cycle group have a zero entry. Range of possible values for the first entry 1 ≤ ≤ 9999.

TABLE (B.11) CONTENTS OF SINGLE OR MIXED MODEL PRODUCTION SCHEDULE.

FILE 5: Illustrating Example

```
   1   1
   1  2004000    1
****
```

```
10    2
 1  200   60   3
 1  201   30   0
 1  203   50   0
 2  200  600   1
 3  204   70   4
 1  202   40   0
 3  203   30   0
 3  202  110   0
 4  201  140   2
 4  203   70   0
****
```

Program in sorted sequence

Sequence	Model	Quantity	Cycles	Total production
1	200	60	3	
1	201	30	3	
1	203	50	3	
1	202	40	3	540
2	200	600	1	600
3	204	70	4	
3	203	30	4	
3	202	110	4	840
4	201	140	2	
4	203	70	2	420
				2400

A. Single model production schedule to produce 4000 products of model 200 in one cycle.

B. Mixed model production schedule to produce 2400 products in 4 different cycles, 5 models are involved in the production program.

FIG. (B.10) SINGLE AND MIXED MODEL PRODUCTION SCHEDULE.

INPUT FILE 5, T////

Cards as shown in table (B.11)

and illustrated in figure (B.10)

////

B.4.9. FILE 5A: Simulation Instructions

When simulating production on the assembly line a number of different permutations of simulation approaches and information required in a particular simulation run are possible. The contents of FILE 5A is specified in detail in table (B.12) and a number of examples are included in figure (B.11), the first two examples being the ones used in the illustrating problem.

Amongst the most important points worth noting are:

(a) Either deterministic or variable times can be assumed for each element.

(b) Either element or station variability can be considered, i.e. either each element time can vary normally or the total element times at a station can vary normally.

(c) Continuous or independent scheduling can be obtained, where the new program is either sequenced onto unused assembly line or is assumed to be sequenced immediately after another program.

(d) The line speed expressed in terms of the line cycle time can be specified for each program and is not necessarily the same as the balancing cycle time.

The file FILE 5A is input to the computer using the following instructions:

INPUT FILE 5A, T////

FILE 5A: Manual Input

Card Set	Number of Cards	Format	Contents & Descriptions
1	One	I4	Optional station information LA1. Throughout the simulation of the production program, intermediate printouts of station information may be useful. This may be required by setting LA1 equal to the desired frequency of output e.g. LA1 = Ø no intermediate output required. LA1 = 1Ø one printout every ten cycles required. Range of possible values Ø ≤ < 1ØØØØ Values must be integer.
		I4	Deterministic or variable times LA2. When determining the time taken at each station for the work elements involved, three choices exist: LA2 = Ø Take the average deterministic time. LA2 = 1 Take either station or element variability into account as specified by LA5.
		I4	Partial or full print of work station information LA4. When an intermediate printout of station information is taking place under control parameter LA1, either a full printout (LA4 = 1) giving 22 pieces of information per station, or an abbreviated printout (LA4 = Ø) giving fourteen pieces of information per station.
		I4	Element or station variability LA5. When dealing with variable element times (LA2 = 1), two cases can be considered. LA5 = Ø Individual variation on each work element. LA5 = 1 Variation on total element time at the station. Note: LA5 = 1 is considered the more normal case.

TABLE (B.12) CONTENTS OF SIMULATION INSTRUCTIONS.

FILE 5A: Manual Input (Continuation)

Card Set	Number of Cards	Format	Contents & Descriptions
		I4	Continuous or Independent Schedule LA6. When simulating a production program, the efficiency and balance results are affected by the way in which the lead in and phase out periods are treated. Two alternatives exist: LA6 = Ø Continuous scheduling, where the production program follows immediately behind an existing program and will be in turn immediately followed, leaving no station awaiting work. LA6 = 1 Independent scheduling, where no other program is remotely involved and idle stations will exist during the start and finish sequences.
2	One	F6.2	Line cycle time TL2. Once in operation the line cycle time for a given production program may differ from the original balancing cycle time. The actual line cycle time is therefore input within the range Ø.Ø < < 1ØØØ.Ø.
3	One	F8.2	Schedule start time TM(1) Range of possible values Ø.Ø ≤ < 24.Ø.
		F8.2	Schedule starting day TM(2). Starting day in values 1 - 7 inclusive, to represent Monday to Sunday. Range of possible values 1.Ø ≤ ≤ 7.Ø. Real whole numbers only permitted.
		F8.2	Schedule start week TM(3). Starting week values are based on a 52 week year. Range of possible values 1.Ø ≤ ≤ 52.Ø. Real whole numbers only permitted.

TABLE (B.12) CONTENTS OF SIMULATION INSTRUCTIONS.

FILE 5A: Manual Input (Continuation)

Card Set	Number of Cards	Format	Contents & Descriptions
		F8.2	Schedule start year TM(4). Starting year value based on possible five year calendar. Range of possible values (only when the calendar five years). Real whole numbers only permitted. Note: An error will arise if the production program starting information is inconsistent with the five year calendar (FILE 4) and with the weekly working pattern.

TABLE (B.12) CONTENTS OF SIMULATION INSTRUCTIONS.

FILE 5A: Illustrating Example

(A)

```
800    1    1    1    0
18.00
    8.00     5.00     5.00 1980.00
```

Station information every 800 cycles.
Variable time is considered.
Full print output of station information.
Variation on total element time at the station.
Continuous schedule.
Cycle time = 18.ØØ minutes.
Starting time = 8.ØØ a.m., day 5, week 5, 1980.

(B)

```
800    1    0    1    1
18.00
    8.00     5.00     5.00 1980.00
```

Station information every 800 cycles.
Variable time is considered.
Partial print output of station information.
Variation on total element time at the station.
Independent schedule.
Cycle time = 18.ØØ minutes.
Starting time = 8.ØØ a.m., day 5, week 5, 1980.

(C)

```
  1    0    1    0    1
15.00
    8.00     1.00     1.00 1980.00
```

Station information every cycle.
Deterministic time is considered.
Full print output of station information.
No consideration for the time variability.
Independent schedule.
Cycle time = 15.ØØ minutes.
Starting time = 8.ØØ a.m., day 1, week 1, 1980.

(D)

```
  1    1    0    0    0
22.00
    8.00     1.00     1.00 1980.00
```

Station information every cycle.
Variable time is considered.
Partial print output of station information.
Variation on total element time at the station.
Continuous schedule.
Cycle time = 22.ØØ minutes.
Starting time = 8.ØØ a.m., day 1, week 1, 1980.

FIG. (B.11) SIMULATION INSTRUCTIONS.

Cards as shown in table (B.12)

and illustrated in figure (B.11)

////

B.4.10: Running the Program ALB5

The actual simulation of assembly lines is carried out by the program ALB5 which produces an information listing, which for the illustrating cases have been included in Appendix B1. As specified in FILE 5A two examples of this listing (listing 04) are shown in Appendix B-1, one listing being a full extended listing and the second an abbreviated listing, each based on one of the first two examples shown in figure (B.11). The instruction for running the program ALB5 is as follows:

CLEM EXECUTE = BALB5, *CRØ = FILE 2, *CR1 = FILE 3, *CR2 = FILE 5, *CR8 = FILE 4, LIB = *NAGF

where:

BALB5 = The binary version of the program ALB5.

CRØ = The input channel for FILE 2.

CR1 = The input channel for FILE 3.

CR2 = The input channel for FILE 5.

CR8 = The input channel for FILE 4.

and LIB = *NAGF is the instruction which generates random numbers from the computer library when required.

The use of program ALB5 completes the ALB program suite.

PROGRAM OUTPUT

ALB1

(LISTING 01)

```
*********************     WRITE OUT DATA   - NO ERROR FOUND -   DATA SATISFACTORY   *********************
                    ****************************************************************
                    ****************************************************************
                    ***
                    *** 16 ELEMENT PROBLEM - MIXED MODEL - RANDOM REMOVAL ELEMENTS      ***
                    ***                                                                 ***
                    ****************************************************************   ***
                    ****************************************************************
                    ****************************************************************
                    ***    NUMBER OF ELEMENTS =    16
                    ****************************************************************   ***
**********************************************************************************************************
*                       *
* ELEMENT NUMBER :    1 * DESCRIPTION : ELEMENT NUMBER 1                                                 *
*                       *                                                                                *
-------------------------                                                                                *
*                                                                                                        *
* ELEMENT TIME :   6.00        ELEMENT VARIANCE :   1.50       ELEMENT MINIMUM DURATION :  2.00          *
*                                                                                                        *
* LIST OF FOLLOWERS           :   2   3   9                                                              *
* LIST OF RESOURCES           : 100  22  23                                                              *
* LEVEL OF RESOURCES          :   1   1   1                                                              *
* LIST OF WORKING ZONES       :   1                                                                      *
* LIST OF MODELS              : 200 201 202 203                                                          *
**********************************************************************************************************
**********************************************************************************************************
*                       *
* ELEMENT NUMBER :    2 * DESCRIPTION : ELEMENT NUMBER 2                                                 *
*                       *                                                                                *
-------------------------                                                                                *
*                                                                                                        *
* ELEMENT TIME :   6.00        ELEMENT VARIANCE :   1.50       ELEMENT MINIMUM DURATION :  3.00          *
*                                                                                                        *
* LIST OF FOLLOWERS           :   5                                                                      *
* LIST OF RESOURCES           : 100  21                                                                  *
* LEVEL OF RESOURCES          :   1   1                                                                  *
* LIST OF WORKING ZONES       :   2                                                                      *
* LIST OF MODELS              : 200 201 202                                                              *
**********************************************************************************************************
```

```
* ELEMENT NUMBER :    3 * DESCRIPTION : ELEMENT NUMBER 3
*                       *
-------------------------
*
* ELEMENT TIME :    9.00        ELEMENT VARIANCE :    2.00        ELEMENT MINIMUM DURATION :  4.00
*
* LIST OF FOLLOWERS             :   4
* LIST OF RESOURCES             : 100
* LEVEL OF RESOURCES            :   1
* LIST OF WORKING ZONES         :   2
* LIST OF MODELS                : 201 202 203 204
*******************************************************************************************
*******************************************************************************************
*                       *
* ELEMENT NUMBER :    4 * DESCRIPTION : ELEMENT NUMBER 4
*                       *
-------------------------
*
* ELEMENT TIME :   12.00        ELEMENT VARIANCE :    3.00        ELEMENT MINIMUM DURATION :  3.00
*
* LIST OF FOLLOWERS             :   5   7
* LIST OF RESOURCES             : 100
* LEVEL OF RESOURCES            :   1
* LIST OF WORKING ZONES         :   3
* LIST OF MODELS                : 203 204
*******************************************************************************************
*******************************************************************************************
*                       *
* ELEMENT NUMBER :    5 * DESCRIPTION : ELEMENT NUMBER 5
*                       *
-------------------------
*
* ELEMENT TIME :    7.00        ELEMENT VARIANCE :    2.00        ELEMENT MINIMUM DURATION :  2.00
*
* LIST OF FOLLOWERS             :   6
* LIST OF RESOURCES             : 100  21
* LEVEL OF RESOURCES            :   1   1
* LIST OF WORKING ZONES         :   1
* LIST OF MODELS                : 200 201 203 204
*******************************************************************************************
```

```
ELEMENT NUMBER :    6 * DESCRIPTION : ELEMENT NUMBER 6
-----------------------

ELEMENT TIME :  10.00      ELEMENT VARIANCE :   3.00      ELEMENT MINIMUM DURATION :  4.00

LIST OF FOLLOWERS          : NONE
LIST OF RESOURCES          : 100
LEVEL OF RESOURCES         :   1
LIST OF WORKING ZONES      :   1
LIST OF MODELS             : 200 201 202 204

ELEMENT NUMBER :    7 * DESCRIPTION : ELEMENT NUMBER 7
-----------------------

ELEMENT TIME :  17.00      ELEMENT VARIANCE :   4.00      ELEMENT MINIMUM DURATION :  5.00

LIST OF FOLLOWERS          : NONE
LIST OF RESOURCES          : 100
LEVEL OF RESOURCES         :   1
LIST OF WORKING ZONES      :   1
LIST OF MODELS             : 200 202 204

ELEMENT NUMBER :    8 * DESCRIPTION : ELEMENT NUMBER 8
-----------------------

ELEMENT TIME :  15.00      ELEMENT VARIANCE :   4.00      ELEMENT MINIMUM DURATION :  4.00

LIST OF FOLLOWERS          : NONE
LIST OF RESOURCES          : 100  22  23
LEVEL OF RESOURCES         :   1   1   1
LIST OF WORKING ZONES      :   2
LIST OF MODELS             : 200 201 202
```

```
* ELEMENT NUMBER :   9 * DESCRIPTION : ELEMENT NUMBER 9
*                      *
------------------------
*
* ELEMENT TIME :  42.00       ELEMENT VARIANCE :    8.00       ELEMENT MINIMUM DURATION : 11.00
*
* LIST OF FOLLOWERS            :  10
* LIST OF RESOURCES            : 100
* LEVEL OF RESOURCES           :   1
* LIST OF WORKING ZONES        :   3
* LIST OF MODELS               : 200 201 202 203 204
**********************************************************************************************
**********************************************************************************************
*                      *
* ELEMENT NUMBER :  10 * DESCRIPTION : ELEMENT NUMBER 10
*                      *
------------------------
*
* ELEMENT TIME :  11.00       ELEMENT VARIANCE :    2.00       ELEMENT MINIMUM DURATION :  3.00
*
* LIST OF FOLLOWERS            :  11
* LIST OF RESOURCES            : 100  21  22
* LEVEL OF RESOURCES           :   1   1   1
* LIST OF WORKING ZONES        :   1
* LIST OF MODELS               : 200 201 202 203 204
**********************************************************************************************
**********************************************************************************************
*                      *
* ELEMENT NUMBER :  11 * DESCRIPTION : ELEMENT NUMBER 11
*                      *
------------------------
*
* ELEMENT TIME :   5.00       ELEMENT VARIANCE :    1.00       ELEMENT MINIMUM DURATION :  2.00
*
* LIST OF FOLLOWERS            :  12  13
* LIST OF RESOURCES            : 100  22  23
* LEVEL OF RESOURCES           :   1   1   1
* LIST OF WORKING ZONES        :   1
* LIST OF MODELS               : 201 203
**********************************************************************************************
```

```
* ELEMENT NUMBER :  12 * DESCRIPTION : ELEMENT NUMBER 12
-------------------------
*
* ELEMENT TIME :    8.00         ELEMENT VARIANCE :    2.00         ELEMENT MINIMUM DURATION :  8.00
*
* LIST OF FOLLOWERS          :  14
* LIST OF RESOURCES          : 100
* LEVEL OF RESOURCES         :   1
* LIST OF WORKING ZONES      :   2
* LIST OF MODELS             : 200 201 202 203 204
****************************************************************************************************
****************************************************************************************************
*                          *
* ELEMENT NUMBER :  13 * DESCRIPTION : ELEMENT NUMBER 13
*                          *
-------------------------
*
* ELEMENT TIME :    4.00         ELEMENT VARIANCE :    1.00         ELEMENT MINIMUM DURATION :  4.02
*
* LIST OF FOLLOWERS          :  14
* LIST OF RESOURCES          : 100
* LEVEL OF RESOURCES         :   1
* LIST OF WORKING ZONES      :   2
* LIST OF MODELS             : 200 203
****************************************************************************************************
****************************************************************************************************
*                          *
* ELEMENT NUMBER :  14 * DESCRIPTION : ELEMENT NUMBER 14
*                          *
-------------------------
*
* ELEMENT TIME :    6.00         ELEMENT VARIANCE :    1.00         ELEMENT MINIMUM DURATION :  3.00
*
* LIST OF FOLLOWERS          :  15
* LIST OF RESOURCES          : 100  25
* LEVEL OF RESOURCES         :   1   1
* LIST OF WORKING ZONES      :   3
* LIST OF MODELS             : 201 202 203
****************************************************************************************************
```

```
*************************************************************************************************
*                         *
* ELEMENT NUMBER :  15 * DESCRIPTION : ELEMENT NUMBER 15
*                         *
-------------------------
*
* ELEMENT TIME :   9.00       ELEMENT VARIANCE :   2.00       ELEMENT MINIMUM DURATION :  4.00
*
* LIST OF FOLLOWERS          :  16
* LIST OF RESOURCES          : 100  23  25
* LEVEL OF RESOURCES         :   1   1   1
* LIST OF WORKING ZONES      :   4
* LIST OF MODELS             : 203 204
*************************************************************************************************
*************************************************************************************************
*                         *
* ELEMENT NUMBER :  16 * DESCRIPTION : ELEMENT NUMBER 16
*                         *
-------------------------
*
* ELEMENT TIME :   6.00       ELEMENT VARIANCE :   1.50       ELEMENT MINIMUM DURATION :  3.00
*
* LIST OF FOLLOWERS          : NONE
* LIST OF RESOURCES          : 100
* LEVEL OF RESOURCES         :   1
* LIST OF WORKING ZONES      :   5
* LIST OF MODELS             : 200 201 203 204
*************************************************************************************************
**************************************************
* TIME INFORMATION :-                            *
**************************************************
*                                                *
* TIME UNITS = MINUTES                           *
* NUMBER OF TIME UNITS PER HOUR =       60.00    *
* SHIFT TIME AVAILABLE =      480.00             *
*                                                *
**************************************************
```

```
NUMBER OF SPECIAL FACILITIES =     6

FACILITIES AVAILABLE :-

100 =   OPERATOR
 21 =   SPOT WELDER
 22 =   SPRAY GUN
 23 =   AIR CONDITION
 24 =   SPECIAL LIFTING M/C
 25 =   SPECIAL ELECTRICAL M/C

NUMBER OF WORKING ZONES =    5

WORKING ZONES DESCRIPTIONS :-

    1 =  ALL AREAS
    2 =  LEFT HAND SIDE
    3 =  RIGHT HAND SIDE
    4 =  TOP WORKING
    5 =  UNDER SIDE WORKING

NUMBER OF MODELS =    5

MODELS SPECIFICATIONS :-

 200 =  2 DOOR            1100 CC
 201 =  2 DOOR DELUXE     1100 CC
 202 =  4 DOOR            1300 CC
 203 =  4 DOOR DELUXE     1300 CC
 204 =  4 DOOR ESTATE     1750 CC
```

PROGRAM OUTPUT

ALB2

(LISTING 03)

FULL LISTING

```
**  16 ELEMENT PROBLEM - MIXED MODEL - RANDOM REMOVAL ELEMENTS  **

* INFORMATION ANALYSIS *

                    TIME UNITS =   MINUTES
         NORMAL SHIFT DURATION =   480.00

* ELEMENTS *

ELEMENT LISTING :

ELEMENT   1        WORK CONTENT =  6.00      MINIMUM DURATION =  2.00      WORK VARIANCE =  1.50
      ----

              LIST OF MODELS :   200 201 202 203
           LIST OF FOLLOWERS :     2   3   9
       LIST OF WORKING ZONES :     1
           LIST OF RESOURCES :   100  22  23
            MINIMUM QUANTITY :     1   1   1
```

```
ELEMENT   2        WORK CONTENT =  6.00        MINIMUM DURATION =  3.00        WORK VARIANCE =  1.50
-----
                  LIST OF MODELS :   200 201 202
               LIST OF FOLLOWERS :     5
           LIST OF WORKING ZONES :     2
               LIST OF RESOURCES :   100   21
                MINIMUM QUANTITY :     1    1

ELEMENT   3        WORK CONTENT =  9.00        MINIMUM DURATION =  4.00        WORK VARIANCE =  2.00
-----
                  LIST OF MODELS :   201 202 203 204
               LIST OF FOLLOWERS :     4
           LIST OF WORKING ZONES :     2
               LIST OF RESOURCES :   100
                MINIMUM QUANTITY :     1

ELEMENT   4        WORK CONTENT = 12.00        MINIMUM DURATION =  3.00        WORK VARIANCE =  3.00
-----
                  LIST OF MODELS :   203 204
               LIST OF FOLLOWERS :     5    7
           LIST OF WORKING ZONES :     3
               LIST OF RESOURCES :   100
                MINIMUM QUANTITY :     1

ELEMENT   5        WORK CONTENT =  7.00        MINIMUM DURATION =  2.00        WORK VARIANCE =  2.00
-----
                  LIST OF MODELS :   200 201 203 204
               LIST OF FOLLOWERS :     6
           LIST OF WORKING ZONES :     1
               LIST OF RESOURCES :   100   21
                MINIMUM QUANTITY :     1    1
```

```
ELEMENT   6        WORK CONTENT = 10.00        MINIMUM DURATION =  4.00        WORK VARIANCE =  3.00
-----
                LIST OF MODELS :   200 201 202 204
             LIST OF FOLLOWERS :     0
         LIST OF WORKING ZONES :     1
             LIST OF RESOURCES :   100
              MINIMUM QUANTITY :     1

ELEMENT   7        WORK CONTENT = 17.00        MINIMUM DURATION =  5.00        WORK VARIANCE =  4.00
-----
                LIST OF MODELS :   200 202 204
             LIST OF FOLLOWERS :     0
         LIST OF WORKING ZONES :     1
             LIST OF RESOURCES :   100
              MINIMUM QUANTITY :     1

ELEMENT   8        WORK CONTENT = 15.00        MINIMUM DURATION =  4.00        WORK VARIANCE =  4.00
-----
                LIST OF MODELS :   200 201 202
             LIST OF FOLLOWERS :     0
         LIST OF WORKING ZONES :     2
             LIST OF RESOURCES :   100   22   23
              MINIMUM QUANTITY :     1    1    1

ELEMENT   9        WORK CONTENT = 42.00        MINIMUM DURATION = 11.00        WORK VARIANCE =  8.00
-----
                LIST OF MODELS :   200 201 202 203 204
             LIST OF FOLLOWERS :    10
         LIST OF WORKING ZONES :     3
             LIST OF RESOURCES :   100
              MINIMUM QUANTITY :     1
```

```
ELEMENT 10        WORK CONTENT = 11.00        MINIMUM DURATION =  3.00        WORK VARIANCE =  2.00
-----

             LIST OF MODELS :   200 201 202 203 204
          LIST OF FOLLOWERS :    11
      LIST OF WORKING ZONES :     1
          LIST OF RESOURCES :   100   21   22
           MINIMUM QUANTITY :     1    1    1

ELEMENT 11        WORK CONTENT =  5.00        MINIMUM DURATION =  2.00        WORK VARIANCE =  1.00
-----

             LIST OF MODELS :   201 203
          LIST OF FOLLOWERS :    12  13
      LIST OF WORKING ZONES :     1
          LIST OF RESOURCES :   100   22   23
           MINIMUM QUANTITY :     1    1    1

ELEMENT 12        WORK CONTENT =  8.00        MINIMUM DURATION =  8.00        WORK VARIANCE =  2.00
-----

             LIST OF MODELS :   200 201 202 203 204
          LIST OF FOLLOWERS :    14
      LIST OF WORKING ZONES :     2
          LIST OF RESOURCES :   100
           MINIMUM QUANTITY :     1

ELEMENT 13        WORK CONTENT =  4.00        MINIMUM DURATION =  4.00        WORK VARIANCE =  1.00
-----

             LIST OF MODELS :   200 203
          LIST OF FOLLOWERS :    14
      LIST OF WORKING ZONES :     2
          LIST OF RESOURCES :   100
           MINIMUM QUANTITY :     1
```

```
ELEMENT 14          WORK CONTENT =  6.00        MINIMUM DURATION = 3.00        WORK VARIANCE =  1.00
    ----

                        LIST OF MODELS :   201 202 203
                     LIST OF FOLLOWERS :    15
                  LIST OF WORKING ZONES :    3
                     LIST OF RESOURCES :   100   25
                      MINIMUM QUANTITY :     1    1

ELEMENT 15          WORK CONTENT =  9.00        MINIMUM DURATION =  4.00       WORK VARIANCE =  2.00
    ----

                        LIST OF MODELS :   203 204
                     LIST OF FOLLOWERS :    16
                  LIST OF WORKING ZONES :    4
                     LIST OF RESOURCES :   100   23   25
                      MINIMUM QUANTITY :     1    1    1

ELEMENT 16          WORK CONTENT =  6.00        MINIMUM DURATION =  3.00       WORK VARIANCE =  1.50
    ----

                        LIST OF MODELS :   200 201 203 204
                     LIST OF FOLLOWERS :     0
                  LIST OF WORKING ZONES :    5
                     LIST OF RESOURCES :   100
                      MINIMUM QUANTITY :     1
```

ANALYSIS OF ELEMENTS :

SUMMARY
****

TOTAL NUMBER OF ELEMENTS = 16
NUMBER OF REDUCIBLE DURATION ELEMENTS = 14
NUMBER OF ELEMENTS REQUIRING MORE THAN ONE WORKER = 0

	WORK CONTENT	MINIMUM DURATION
MAXIMUM ELEMENT TIME =	42.00	11.00
MINIMUM ELEMENT TIME =	4.00	2.00
MEAN ELEMENT TIME =	10.81	4.06
MEAN STANDARD DEVIATION =	1.20	0.27
RANGE OF ELEMENT TIMES FROM :	4.00	2.00
TO :	42.00	11.00
TOTAL ELEMENT TIMES =	173.00	65.00
AVERAGE MINIMUM DURATION / WORK CONTENT =	0.38	

ELEMENT TIMES DISTRIBUTION
****

NORMAL TIME RANGE FROM :	TO	ELEMENT NUMBERS
4.00 -	7.80	1 2 5 11 13 14 16
7.80 -	11.60	3 6 10 12 15
11.60 -	15.40	4 8
15.40 -	19.20	7
19.20 -	23.00	
23.00 -	26.80	
26.80 -	30.60	
30.60 -	34.40	
34.40 -	38.20	
38.20 -	42.00	
42.00 -	45.80	9

RESOURCES

RESOURCE IDENTITY	ELEMENTS UTILISING RESOURCE = MINIMUM QUANTITY									
100	1	2	3	4	5	6	7	8	9	10
	11	12	13	14	15	16				
21	2	5	10							
22	1	8	10	11						
23	1	8	11	15						
25	14	15								

MODELS

NUMBER OF MODELS = 5

MODEL	NUMBER OF ELEMENTS	TOTAL WORK CONTENT
200	11	132.00
201	12	131.00
202	10	130.00
203	12	125.00
204	10	131.00

PRECEDENCE

NUMBER OF ELEMENTS = 16
NUMBER OF PRECEDENCE COLUMNS = 8
MINIMUM PRECEDENCE COLUMN SIZE = 1
MAXIMUM PRECEDENCE COLUMN SIZE = 3
PRECEDENCE DIFFICULTY = 2.00

COLUMN NUMBER	WORK CONTENT	ELEMENTS INCLUDED
1	21.00	1 8
2	57.00	2 3 9
3	23.00	4 10
4	29.00	5 7 11
5	22.00	6 12 13
6	6.00	14
7	9.00	15
8	6.00	16

POSSIBLE BALANCE STRATEGY

BALANCE GUIDE

BALANCE DELAY & OUTPUT INFORMATION

CYCLE TIME	STATION CAPACITY REQUIRED	AVERAGE SHIFT OUTPUT	% BALANCE DELAY
173.00	1	2.77	0.00
172.99	2	2.77	50.00
86.50	2	5.55	0.00
86.49	3	5.55	33.33
57.67	3	8.32	0.00
57.66	4	8.33	24.99
43.25	4	11.10	0.00
43.24	5	11.10	19.98
34.60	5	13.87	0.00
34.59	6	13.88	16.64
28.83	6	16.65	0.00
28.82	7	16.65	14.26
24.71	7	19.42	0.00

24.70 21.63	8 8	19.43 22.20	12.46 0.00
21.61 19.22	9 9	22.21 24.97	11.07 0.00
19.21 17.30	10 10	24.98 27.75	9.95 0.00
17.29 15.73	11 11	27.76 30.52	9.04 0.00
15.72 14.42	12 12	30.54 33.29	8.28 0.00
14.41 13.31	13 13	33.32 36.07	7.63 0.00
13.30 12.36	14 14	36.10 38.84	7.07 0.00
12.35 11.53	15 15	38.88 41.62	6.59 0.00
11.52 11.00	16 16	41.65 43.64	6.17 1.70

CYCLE TIME INFORMATION

	NORMAL TIME	97.5% CONFIDENCE	99.9% CONFIDENCE
MAXIMUM CYCLE TIME	173.00	220.11	247.28
MINIMUM CYCLE TIME	11.00	11.00	11.00

```
MIXED MODEL BALANCING
*********************

SELECTED CYCLE TIME = 20.00MINUTES        SELECTED PROCEDURE ; MIXED MODEL - SINGLE ELEMENT ASSIGNMENT
INITIAL BASIC STATION SIZE  =  1          INITIAL MAXIMUM STATION SIZE =   3
LIMITED LINE LENGTH = 10   STATION
VARIABLE ELEMENT TIMES INCLUDED WITH 90.00 % CONFIDENCE ( EQUIVALENT  1.28 STANDARD DEVIATIONS )

NOMINAL SCHEDULE USED

   . MODEL ; 200     SCHEDULE QUANTITY : 100        ADJUSTMENT :  0.04
             201                         900                      0.38
             202                         200                      0.08
             203                         500                      0.21
             204                         700                      0.29

NOMINAL SCHEDULE VALUES INPUT BY DESIGNER AS DATA
SCHEDULE WEIGHTING ADJUSTMENT INCLUDED IN SELECTING THE BEST STATION SIZE
```

```
STATION NUMBER :   1   STATION SIZE :  1  CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT    1  TIME =  6.00  EFFECTIVE TIME =  7.39  EFFECTIVE STATION TIME REMAINING = 12.61
ELEMENT    3  TIME =  9.00  EFFECTIVE TIME = 10.60  EFFECTIVE STATION TIME REMAINING =  2.01

                                   CYCLE TIME =     20.00   MAXIMUM WORK DURATION =     17.99
                  TIME AVAILABLE ALL MODELS =    100.00   ESTIMATED WORK CONTENT =    76.96
                        ESTIMATED LOST TIME =     23.04          ( SCHEDULE ADJUSTED )


STATION NUMBER :   1   STATION SIZE :  2  CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT    1  TIME =  6.00  EFFECTIVE TIME =  3.69  EFFECTIVE STATION TIME REMAINING = 16.31
ELEMENT    3  TIME =  9.00  EFFECTIVE TIME =  5.30  EFFECTIVE STATION TIME REMAINING = 11.01
ELEMENT    4  TIME = 12.00  EFFECTIVE TIME =  6.98  EFFECTIVE STATION TIME REMAINING =  4.03
ELEMENT    2  TIME =  6.00  EFFECTIVE TIME =  3.69  EFFECTIVE STATION TIME REMAINING =  7.31

                                   CYCLE TIME =     20.00   MAXIMUM WORK DURATION =     15.97
                  TIME AVAILABLE ALL MODELS =    200.00   ESTIMATED WORK CONTENT =   130.32
                        ESTIMATED LOST TIME =     69.68          ( SCHEDULE ADJUSTED )


STATION NUMBER :   1   STATION SIZE :  3  CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT    1  TIME =  6.00  EFFECTIVE TIME =  2.46  EFFECTIVE STATION TIME REMAINING = 17.54
ELEMENT    9  TIME = 42.00  EFFECTIVE TIME = 15.07  EFFECTIVE STATION TIME REMAINING =  2.47

                                   CYCLE TIME =     20.00   MAXIMUM WORK DURATION =     17.53
                  TIME AVAILABLE ALL MODELS =    300.00   ESTIMATED WORK CONTENT =   252.17
                        ESTIMATED LOST TIME =     47.83          ( SCHEDULE ADJUSTED )

                                                            ***********************
                                                            *                     *
                                                            *  STATION BALANCED   *
                                                            *  SIZE = 1 ACCEPTED  *
                                                            *                     *
                                                            ***********************
```

```
STATION NUMBER :   2   STATION SIZE :  1   CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT    4   TIME = 12.00   EFFECTIVE TIME = 13.96   EFFECTIVE STATION TIME REMAINING =  6.04
ELEMENT    2   TIME =  6.00   EFFECTIVE TIME =  7.39   EFFECTIVE STATION TIME REMAINING = 12.61

                              CYCLE TIME =     20.00    MAXIMUM WORK DURATION =     13.96
                    TIME AVAILABLE ALL MODELS =    100.00   ESTIMATED WORK CONTENT =     53.37
                          ESTIMATED LOST TIME =     46.63        ( SCHEDULE ADJUSTED )

STATION NUMBER :   2   STATION SIZE :  2   CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT    4   TIME = 12.00   EFFECTIVE TIME =  6.98   EFFECTIVE STATION TIME REMAINING = 13.02
ELEMENT    2   TIME =  6.00   EFFECTIVE TIME =  3.69   EFFECTIVE STATION TIME REMAINING = 16.31
ELEMENT    5   TIME =  7.00   EFFECTIVE TIME =  4.30   EFFECTIVE STATION TIME REMAINING =  8.72
ELEMENT    6   TIME = 10.00   EFFECTIVE TIME =  5.98   EFFECTIVE STATION TIME REMAINING =  2.74

                              CYCLE TIME =     20.00    MAXIMUM WORK DURATION =     17.26
                    TIME AVAILABLE ALL MODELS =    200.00   ESTIMATED WORK CONTENT =    140.13
                          ESTIMATED LOST TIME =     59.87        ( SCHEDULE ADJUSTED )

STATION NUMBER :   2   STATION SIZE :  3   CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT    9   TIME = 42.00   EFFECTIVE TIME = 15.07   EFFECTIVE STATION TIME REMAINING =  4.93
ELEMENT   10   TIME = 11.00   EFFECTIVE TIME =  4.20   EFFECTIVE STATION TIME REMAINING =  0.73

                              CYCLE TIME =     20.00    MAXIMUM WORK DURATION =     19.27
                    TIME AVAILABLE ALL MODELS =    300.00   ESTIMATED WORK CONTENT =    289.01
                          ESTIMATED LOST TIME =     10.99        ( SCHEDULE ADJUSTED )

                                                             ***********************
                                                             *                     *
                                                             *  STATION BALANCED   *
                                                             *  SIZE = 3 ACCEPTED  *
                                                             *                     *
                                                             ***********************
```

```
STATION NUMBER :    3   STATION SIZE :   1   CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT    4  TIME = 12.00  EFFECTIVE TIME = 13.96  EFFECTIVE STATION TIME REMAINING =  6.04
ELEMENT    2  TIME =  6.00  EFFECTIVE TIME =  7.39  EFFECTIVE STATION TIME REMAINING = 12.61

                              CYCLE TIME =      20.00    MAXIMUM WORK DURATION =     13.96
                  TIME AVAILABLE ALL MODELS =  100.00    ESTIMATED WORK CONTENT =    53.37
                        ESTIMATED LOST TIME =   46.63         ( SCHEDULE ADJUSTED )


STATION NUMBER :    3   STATION SIZE :   2   CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT    4  TIME = 12.00  EFFECTIVE TIME =  6.98  EFFECTIVE STATION TIME REMAINING = 13.02
ELEMENT   11  TIME =  5.00  EFFECTIVE TIME =  3.07  EFFECTIVE STATION TIME REMAINING =  9.95
ELEMENT   12  TIME =  8.00  EFFECTIVE TIME =  8.00  EFFECTIVE STATION TIME REMAINING =  1.95
ELEMENT    2  TIME =  6.00  EFFECTIVE TIME =  3.69  EFFECTIVE STATION TIME REMAINING =  5.24

                              CYCLE TIME =      20.00    MAXIMUM WORK DURATION =     18.05
                  TIME AVAILABLE ALL MODELS =  200.00    ESTIMATED WORK CONTENT =   119.26
                        ESTIMATED LOST TIME =   80.74         ( SCHEDULE ADJUSTED )


STATION NUMBER :    3   STATION SIZE :   3   CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT    4  TIME = 12.00  EFFECTIVE TIME =  4.65  EFFECTIVE STATION TIME REMAINING = 15.35
ELEMENT   11  TIME =  5.00  EFFECTIVE TIME =  2.04  EFFECTIVE STATION TIME REMAINING = 13.30
ELEMENT   12  TIME =  8.00  EFFECTIVE TIME =  8.00  EFFECTIVE STATION TIME REMAINING =  5.30
ELEMENT    2  TIME =  6.00  EFFECTIVE TIME =  3.00  EFFECTIVE STATION TIME REMAINING =  6.96
ELEMENT   13  TIME =  4.00  EFFECTIVE TIME =  4.00  EFFECTIVE STATION TIME REMAINING =  1.30

                              CYCLE TIME =      20.00    MAXIMUM WORK DURATION =     18.70
                  TIME AVAILABLE ALL MODELS =  300.00    ESTIMATED WORK CONTENT =   125.67
                        ESTIMATED LOST TIME =  174.33         ( SCHEDULE ADJUSTED )

                                                          ***********************
                                                          *                     *
                                                          *  STATION BALANCED   *
                                                          *  SIZE = 1 ACCEPTED  *
                                                          *                     *
                                                          ***********************
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```
STATION NUMBER :   4   STATION SIZE :  1  CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT  11  TIME =  5.00  EFFECTIVE TIME =  6.13  EFFECTIVE STATION TIME REMAINING = 13.87
ELEMENT  12  TIME =  8.00  EFFECTIVE TIME =  9.60  EFFECTIVE STATION TIME REMAINING =  4.27

                                    CYCLE TIME =     20.00   MAXIMUM WORK DURATION =    15.73
                        TIME AVAILABLE ALL MODELS =    100.00   ESTIMATED WORK CONTENT =    65.89
                            ESTIMATED LOST TIME =     34.11         ( SCHEDULE ADJUSTED )


STATION NUMBER :   4   STATION SIZE :  2  CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT  11  TIME =  5.00  EFFECTIVE TIME =  3.07  EFFECTIVE STATION TIME REMAINING = 16.93
ELEMENT  12  TIME =  8.00  EFFECTIVE TIME =  8.00  EFFECTIVE STATION TIME REMAINING =  8.93
ELEMENT  13  TIME =  4.00  EFFECTIVE TIME =  4.00  EFFECTIVE STATION TIME REMAINING =  4.93
ELEMENT   5  TIME =  7.00  EFFECTIVE TIME =  4.30  EFFECTIVE STATION TIME REMAINING =  0.63

                                    CYCLE TIME =     20.00   MAXIMUM WORK DURATION =    19.37
                        TIME AVAILABLE ALL MODELS =    200.00   ESTIMATED WORK CONTENT =   111.72
                            ESTIMATED LOST TIME =     88.28         ( SCHEDULE ADJUSTED )


STATION NUMBER :   4   STATION SIZE :  3  CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT  11  TIME =  5.00  EFFECTIVE TIME =  2.04  EFFECTIVE STATION TIME REMAINING = 17.96
ELEMENT  12  TIME =  8.00  EFFECTIVE TIME =  8.00  EFFECTIVE STATION TIME REMAINING =  9.96
ELEMENT  13  TIME =  4.00  EFFECTIVE TIME =  4.00  EFFECTIVE STATION TIME REMAINING =  5.96
ELEMENT   5  TIME =  7.00  EFFECTIVE TIME =  2.87  EFFECTIVE STATION TIME REMAINING =  3.09
ELEMENT  14  TIME =  6.00  EFFECTIVE TIME =  3.00  EFFECTIVE STATION TIME REMAINING =  0.09
ELEMENT   6  TIME = 10.00  EFFECTIVE TIME =  4.00  EFFECTIVE STATION TIME REMAINING =  0.09

                                    CYCLE TIME =     20.00   MAXIMUM WORK DURATION =    19.91
                        TIME AVAILABLE ALL MODELS =    300.00   ESTIMATED WORK CONTENT =   182.84
                            ESTIMATED LOST TIME =    117.16         ( SCHEDULE ADJUSTED )

                                                                  ***********************
                                                                  *                     *
                                                                  *  STATION BALANCED   *
                                                                  *  SIZE = 1 ACCEPTED  *
                                                                  *                     *
                                                                  ***********************
```

```
STATION NUMBER :   5   STATION SIZE :  1  CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT  13  TIME =  4.00  EFFECTIVE TIME =  5.13  EFFECTIVE STATION TIME REMAINING = 14.87
ELEMENT   5  TIME =  7.00  EFFECTIVE TIME =  8.60  EFFECTIVE STATION TIME REMAINING =  6.27

                              CYCLE TIME =    20.00   MAXIMUM WORK DURATION =     13.73
               TIME AVAILABLE ALL MODELS =   100.00   ESTIMATED WORK CONTENT =    45.84
                     ESTIMATED LOST TIME =    54.16        ( SCHEDULE ADJUSTED )

STATION NUMBER :   5   STATION SIZE :  2  CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT  13  TIME =  4.00  EFFECTIVE TIME =  4.00  EFFECTIVE STATION TIME REMAINING = 16.00
ELEMENT   5  TIME =  7.00  EFFECTIVE TIME =  4.30  EFFECTIVE STATION TIME REMAINING = 11.70
ELEMENT  14  TIME =  6.00  EFFECTIVE TIME =  3.57  EFFECTIVE STATION TIME REMAINING =  8.13
ELEMENT  15  TIME =  9.00  EFFECTIVE TIME =  5.30  EFFECTIVE STATION TIME REMAINING =  2.83
ELEMENT   6  TIME = 10.00  EFFECTIVE TIME =  5.98  EFFECTIVE STATION TIME REMAINING =  4.42

                              CYCLE TIME =    20.00   MAXIMUM WORK DURATION =     17.17
               TIME AVAILABLE ALL MODELS =   200.00   ESTIMATED WORK CONTENT =   143.45
                     ESTIMATED LOST TIME =    56.55        ( SCHEDULE ADJUSTED )

STATION NUMBER :   5   STATION SIZE :  3  CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT  13  TIME =  4.00  EFFECTIVE TIME =  4.00  EFFECTIVE STATION TIME REMAINING = 16.00
ELEMENT   5  TIME =  7.00  EFFECTIVE TIME =  2.87  EFFECTIVE STATION TIME REMAINING = 13.13
ELEMENT  14  TIME =  6.00  EFFECTIVE TIME =  3.00  EFFECTIVE STATION TIME REMAINING = 10.13
ELEMENT  15  TIME =  9.00  EFFECTIVE TIME =  4.00  EFFECTIVE STATION TIME REMAINING =  6.13
ELEMENT   6  TIME = 10.00  EFFECTIVE TIME =  4.00  EFFECTIVE STATION TIME REMAINING =  9.13
ELEMENT   8  TIME = 15.00  EFFECTIVE TIME =  5.75  EFFECTIVE STATION TIME REMAINING =  3.38
ELEMENT  16  TIME =  6.00  EFFECTIVE TIME =  3.00  EFFECTIVE STATION TIME REMAINING =  0.38

                              CYCLE TIME =    20.00   MAXIMUM WORK DURATION =     19.62
               TIME AVAILABLE ALL MODELS =   300.00   ESTIMATED WORK CONTENT =   220.47
                     ESTIMATED LOST TIME =    79.53        ( SCHEDULE ADJUSTED )

                                                        ***********************
                                                        *                     *
                                                        *  STATION BALANCED   *
                                                        *  SIZE = 1 ACCEPTED  *
                                                        *                     *
                                                        ***********************
```

```
STATION NUMBER :   6   STATION SIZE :  1   CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT  14  TIME =  6.00  EFFECTIVE TIME =  7.13  EFFECTIVE STATION TIME REMAINING = 12.87
ELEMENT  15  TIME =  9.00  EFFECTIVE TIME = 10.60  EFFECTIVE STATION TIME REMAINING =  2.27

                        CYCLE TIME =   20.00   MAXIMUM WORK DURATION =    17.73
          TIME AVAILABLE ALL MODELS =  100.00   ESTIMATED WORK CONTENT =    50.28
               ESTIMATED LOST TIME =   49.72        ( SCHEDULE ADJUSTED )


STATION NUMBER :   6   STATION SIZE :  2   CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT  14  TIME =  6.00  EFFECTIVE TIME =  3.57  EFFECTIVE STATION TIME REMAINING = 16.43
ELEMENT  15  TIME =  9.00  EFFECTIVE TIME =  5.30  EFFECTIVE STATION TIME REMAINING = 11.13
ELEMENT   6  TIME = 10.00  EFFECTIVE TIME =  5.98  EFFECTIVE STATION TIME REMAINING =  8.72
ELEMENT   8  TIME = 15.00  EFFECTIVE TIME =  8.63  EFFECTIVE STATION TIME REMAINING =  1.82

                        CYCLE TIME =   20.00   MAXIMUM WORK DURATION =    18.18
          TIME AVAILABLE ALL MODELS =  200.00   ESTIMATED WORK CONTENT =   140.78
               ESTIMATED LOST TIME =   59.22        ( SCHEDULE ADJUSTED )


STATION NUMBER :   6   STATION SIZE :  3   CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT  14  TIME =  6.00  EFFECTIVE TIME =  3.00  EFFECTIVE STATION TIME REMAINING = 17.00
ELEMENT  15  TIME =  9.00  EFFECTIVE TIME =  4.00  EFFECTIVE STATION TIME REMAINING = 13.00
ELEMENT   6  TIME = 10.00  EFFECTIVE TIME =  4.00  EFFECTIVE STATION TIME REMAINING = 12.00
ELEMENT   8  TIME = 15.00  EFFECTIVE TIME =  5.75  EFFECTIVE STATION TIME REMAINING =  7.25
ELEMENT   7  TIME = 17.00  EFFECTIVE TIME =  6.42  EFFECTIVE STATION TIME REMAINING =  0.82
ELEMENT  16  TIME =  6.00  EFFECTIVE TIME =  3.00  EFFECTIVE STATION TIME REMAINING =  0.82

                        CYCLE TIME =   20.00   MAXIMUM WORK DURATION =    19.18
          TIME AVAILABLE ALL MODELS =  300.00   ESTIMATED WORK CONTENT =   214.77
               ESTIMATED LOST TIME =   85.23        ( SCHEDULE ADJUSTED )

                                                 ***********************
                                                 *                     *
                                                 *  STATION BALANCED   *
                                                 *  SIZE = 1 ACCEPTED  *
                                                 *                     *
                                                 ***********************
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STATION NUMBER :    7   STATION SIZE :  1   CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT   6  TIME = 10.00  EFFECTIVE TIME = 11.96  EFFECTIVE STATION TIME REMAINING =  8.04
ELEMENT  16  TIME =  6.00  EFFECTIVE TIME =  7.39  EFFECTIVE STATION TIME REMAINING =  0.65

                              CYCLE TIME =     20.00   MAXIMUM WORK DURATION =     19.35
                   TIME AVAILABLE ALL MODELS =    100.00   ESTIMATED WORK CONTENT =     81.20
                         ESTIMATED LOST TIME =     18.80           ( SCHEDULE ADJUSTED )


STATION NUMBER :    7   STATION SIZE :  2   CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT   6  TIME = 10.00  EFFECTIVE TIME =  5.98  EFFECTIVE STATION TIME REMAINING = 14.02
ELEMENT   8  TIME = 15.00  EFFECTIVE TIME =  8.63  EFFECTIVE STATION TIME REMAINING =  5.39
ELEMENT  16  TIME =  6.00  EFFECTIVE TIME =  3.69  EFFECTIVE STATION TIME REMAINING =  1.69

                              CYCLE TIME =     20.00   MAXIMUM WORK DURATION =     18.31
                   TIME AVAILABLE ALL MODELS =    200.00   ESTIMATED WORK CONTENT =    124.36
                         ESTIMATED LOST TIME =     75.64           ( SCHEDULE ADJUSTED )


STATION NUMBER :    7   STATION SIZE :  3   CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT   6  TIME = 10.00  EFFECTIVE TIME =  4.00  EFFECTIVE STATION TIME REMAINING = 16.00
ELEMENT   8  TIME = 15.00  EFFECTIVE TIME =  5.75  EFFECTIVE STATION TIME REMAINING = 10.25
ELEMENT   7  TIME = 17.00  EFFECTIVE TIME =  6.42  EFFECTIVE STATION TIME REMAINING =  3.82
ELEMENT  16  TIME =  6.00  EFFECTIVE TIME =  3.00  EFFECTIVE STATION TIME REMAINING =  0.82

                              CYCLE TIME =     20.00   MAXIMUM WORK DURATION =     19.18
                   TIME AVAILABLE ALL MODELS =    300.00   ESTIMATED WORK CONTENT =    164.49
                         ESTIMATED LOST TIME =    135.51           ( SCHEDULE ADJUSTED )

                                                                *********************
                                                                *                   *
                                                                *  STATION BALANCED *
                                                                *  SIZE = 1 ACCEPTED*
                                                                *                   *
                                                                *********************
```

```
STATION NUMBER :   8   STATION SIZE :  1  CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT    8  TIME = 15.00  EFFECTIVE TIME = 17.26  EFFECTIVE STATION TIME REMAINING =  2.74

                                    CYCLE TIME =     20.00   MAXIMUM WORK DURATION =     17.26
                         TIME AVAILABLE ALL MODELS =    100.00  ESTIMATED WORK CONTENT =     43.16
                            ESTIMATED LOST TIME =     56.84            ( SCHEDULE ADJUSTED )

STATION NUMBER :   8   STATION SIZE :  2  CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT    8  TIME = 15.00  EFFECTIVE TIME =  8.63  EFFECTIVE STATION TIME REMAINING = 11.37
ELEMENT    7  TIME = 17.00  EFFECTIVE TIME =  9.63  EFFECTIVE STATION TIME REMAINING =  1.74

                                    CYCLE TIME =     20.00   MAXIMUM WORK DURATION =     18.26
                         TIME AVAILABLE ALL MODELS =    200.00  ESTIMATED WORK CONTENT =     83.29
                            ESTIMATED LOST TIME =    116.71            ( SCHEDULE ADJUSTED )

STATION NUMBER :   8   STATION SIZE :  3  CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT    8  TIME = 15.00  EFFECTIVE TIME =  5.75  EFFECTIVE STATION TIME REMAINING = 14.25
ELEMENT    7  TIME = 17.00  EFFECTIVE TIME =  6.42  EFFECTIVE STATION TIME REMAINING =  7.82

                                    CYCLE TIME =     20.00   MAXIMUM WORK DURATION =     12.18
                         TIME AVAILABLE ALL MODELS =    300.00  ESTIMATED WORK CONTENT =     83.29
                            ESTIMATED LOST TIME =    216.71            ( SCHEDULE ADJUSTED )

                                                                   ***********************
                                                                   *                     *
                                                                   *  STATION BALANCED   *
                                                                   *  SIZE = 1 ACCEPTED  *
                                                                   *                     *
                                                                   ***********************
```

```
STATION NUMBER :   9   STATION SIZE :  1  CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT    7  TIME = 17.00  EFFECTIVE TIME = 19.26  EFFECTIVE STATION TIME REMAINING =  0.74

                                CYCLE TIME =     20.00   MAXIMUM WORK DURATION =     19.26
                     TIME AVAILABLE ALL MODELS =    100.00  ESTIMATED WORK CONTENT =     40.13
                           ESTIMATED LOST TIME =     59.87          ( SCHEDULE ADJUSTED )

STATION NUMBER :   9   STATION SIZE :  2  CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT    7  TIME = 17.00  EFFECTIVE TIME =  9.63  EFFECTIVE STATION TIME REMAINING = 10.37

                                CYCLE TIME =     20.00   MAXIMUM WORK DURATION =      9.63
                     TIME AVAILABLE ALL MODELS =    200.00  ESTIMATED WORK CONTENT =     40.13
                           ESTIMATED LOST TIME =    159.87          ( SCHEDULE ADJUSTED )

STATION NUMBER :   9   STATION SIZE :  3  CYCLE TIME : 20.00

ACCEPTED ELEMENTS
ELEMENT    7  TIME = 17.00  EFFECTIVE TIME =  6.42  EFFECTIVE STATION TIME REMAINING = 13.58

                                CYCLE TIME =     20.00   MAXIMUM WORK DURATION =      6.42
                     TIME AVAILABLE ALL MODELS =    300.00  ESTIMATED WORK CONTENT =     40.13
                           ESTIMATED LOST TIME =    259.87          ( SCHEDULE ADJUSTED )

                                                              ************************
                                                              *                      *
                                                              *   STATION BALANCED   *
                                                              *   SIZE = 1 ACCEPTED  *
                                                              *                      *
                                                              ************************
```

BALANCE RESULTS

STATION NUMBER : 1 STATION SIZE : 1 MIXED MODEL PRODUCTION / SINGLE-ELEMENT ASSIGNMENT

ELEMENTS	MODELS 200	201	202	203	204
1	7.39	7.39	7.39	7.39	0.00
3	0.00	10.60	10.60	10.60	10.60
WORK CONTENT :	7.39	17.99	17.99	17.99	10.60
WORK DURATION :	7.39	17.99	17.99	17.99	10.60
COMPRESSED TIME :	2.00	6.00	6.00	6.00	4.00

STATION NUMBER : 2 STATION SIZE : 3 MIXED MODEL PRODUCTION / SINGLE-ELEMENT ASSIGNMENT

ELEMENTS	MODELS 200	201	202	203	204
9	45.20	45.20	45.20	45.20	45.20
10	12.60	12.60	12.60	12.60	12.60
WORK CONTENT :	57.80	57.80	57.80	57.80	57.80
WORK DURATION :	19.27	19.27	19.27	19.27	19.27
COMPRESSED TIME :	14.00	14.00	14.00	14.00	14.00

STATION NUMBER : 3 STATION SIZE : 1 MIXED MODEL PRODUCTION / SINGLE-ELEMENT ASSIGNMENT

ELEMENTS	MODELS 200	201	202	203	204
2	7.39	7.39	7.39	0.00	0.00
4	0.00	0.00	0.00	13.96	13.96
WORK CONTENT :	7.39	7.39	7.39	13.96	13.96
WORK DURATION :	7.39	7.39	7.39	13.96	13.96
COMPRESSED TIME :	3.00	3.00	3.00	3.00	3.00

STATION NUMBER : 4 STATION SIZE : 1 MIXED MODEL PRODUCTION / SINGLE-ELEMENT ASSIGNMENT

ELEMENTS	MODELS 200	201	202	203	204
11	0.00	6.13	0.00	6.13	0.00
12	9.60	9.60	9.60	9.60	9.60
WORK CONTENT :	9.60	15.73	9.60	15.73	9.60
WORK DURATION :	9.60	15.73	9.60	15.73	9.60
COMPRESSED TIME :	8.00	10.00	8.00	10.00	8.00

STATION NUMBER : 5 STATION SIZE : 1 MIXED MODEL PRODUCTION / SINGLE-ELEMENT ASSIGNMENT

ELEMENTS	MODELS 200	201	202	203	204
5	8.60	8.60	0.00	8.60	8.60
13	5.13	0.00	0.00	5.13	0.00
WORK CONTENT :	13.73	8.60	0.00	13.73	8.60
WORK DURATION :	13.73	8.60	0.00	13.73	8.60
COMPRESSED TIME :	6.00	2.00	0.00	6.00	2.00

STATION NUMBER : 6 STATION SIZE : 1 MIXED MODEL PRODUCTION / SINGLE-ELEMENT ASSIGNMENT

ELEMENTS	MODELS 200	201	202	203	204
14	0.00	7.13	7.13	7.13	0.00
15	0.00	0.00	0.00	10.60	10.60
WORK CONTENT :	0.00	7.13	7.13	17.73	10.60
WORK DURATION :	0.00	7.13	7.13	17.73	10.60
COMPRESSED TIME :	0.00	3.00	3.00	7.00	4.00

STATION NUMBER : 7 STATION SIZE : 1 MIXED MODEL PRODUCTION / SINGLE-ELEMENT ASSIGNMENT

ELEMENTS	MODELS 200	201	202	203	204
6	11.96	11.96	11.96	0.00	11.96
16	7.39	7.39	0.00	7.39	7.39
WORK CONTENT :	19.35	19.35	11.96	7.39	19.35
WORK DURATION :	19.35	19.35	11.96	7.39	19.35
COMPRESSED TIME :	7.00	7.00	4.00	3.00	7.00

STATION NUMBER : 8 STATION SIZE : 1 MIXED MODEL PRODUCTION / SINGLE-ELEMENT ASSIGNMENT

ELEMENTS	MODELS 200	201	202	203	204
8	17.26	17.26	17.26	0.00	0.00
WORK CONTENT :	17.26	17.26	17.26	0.00	0.00
WORK DURATION :	17.26	17.26	17.26	0.00	0.00
COMPRESSED TIME :	4.00	4.00	4.00	0.00	0.00

STATION NUMBER : 9 STATION SIZE : 1 MIXED MODEL PRODUCTION / SINGLE-ELEMENT ASSIGNMENT

ELEMENTS	MODELS 200	201	202	203	204
7	19.26	0.00	19.26	0.00	19.26
WORK CONTENT :	19.26	0.00	19.26	0.00	19.26
WORK DURATION :	19.26	0.00	19.26	0.00	19.26
COMPRESSED TIME :	5.00	0.00	5.00	0.00	5.00

BALANCE EFFICIENCY

BD1 = 32,22 BD3 = 32,22 SI1 = 30,35 SI3 = 30,35

BD2 = 32,20 BD4 = 32,20 SI2 = 30,31 SI4 = 30,31

WORK DISTRIBUTION EFFICIENCY

STATION NUMBER	STATION SIZE	TIME AVAILABLE	MAXIMUM WORK	MINIMUM WORK	STATION RANGE	NORMAL AVERAGE	NORMAL ST. DV.	WEIGHTED AVERAGE	WEIGHTED ST. DV.	WORK VARIETY
1	1	20,00	18,38	7,57	10,81	14,39	10,11	15,39	10,36	18,38
2	3	60,00	58,44	58,44	0,00	57,80	0,00	57,80	0,00	58,44
3	1	20,00	14,22	7,57	6,65	10,02	7,20	10,67	7,35	21,79
4	1	20,00	16,09	9,81	6,28	12,05	6,72	13,18	7,17	16,09
5	1	20,00	14,09	0,00	14,09	8,93	11,23	9,17	11,24	14,09
6	1	20,00	18,09	0,00	18,09	8,52	12,87	10,06	13,32	18,09
7	1	20,00	19,79	7,57	12,22	15,48	11,08	16,24	11,21	19,79
8	1	20,00	17,56	0,00	17,56	10,36	18,91	8,63	19,30	17,56
9	1	20,00	19,56	0,00	19,56	11,56	21,10	8,03	22,53	19,56
					105,27					203,80

WB1 = 105,27 WT1 = 22,64 WT3 = 44,00

WB2 = 203,80 WT2 = 38,47

PROGRAM OUTPUT

ALB2

(LISTING 03)

ABBREVIATED OUTPUT

```
                         MIXED MODEL BALANCING
                         *********************

SELECTED CYCLE TIME = 20.00 MINUTES      SELECTED PROCEDURE : MIXED MODEL = MULTI-ELEMENT ASSIGNMENT
INITIAL BASIC STATION SIZE  =  1         INITIAL MAXIMUM STATION SIZE =   3
LIMITED LINE LENGTH = 10   STATION
VARIABLE ELEMENT TIMES INCLUDED WITH 90.00 % CONFIDENCE ( EQUIVALENT  1.28 STANDARD DEVIATIONS )

NOMINAL SCHEDULE USED

    MODEL : 200     SCHEDULE QUANTITY : 100       ADJUSTMENT :  0.04
            201                         900                     0.38
            202                         200                     0.08
            203                         500                     0.21
            204                         700                     0.29

SCHEDULE WEIGHTING ADJUSTMENT VALUES IGNORED FOR MULTI-ELEMENT ASSIGNMENT
SCHEDULE WEIGHTING ADJUSTMENT INCLUDED IN SELECTING THE BEST STATION SIZE
```

BALANCE RESULTS

STATION NUMBER : 1 STATION SIZE : 1 MIXED MODEL PRODUCTION / MULTI-ELEMENT ASSIGNMENT

ELEMENTS	MODELS 200	201	202	203	204
1	7,39	7,39	7,39	7,39	0,00
2	7,39	0,00	0,00	0,00	0,00
3	0,00	10,60	10,60	10,60	10,60
WORK CONTENT :	14.77	17.99	17.99	17.99	10.60
WORK DURATION :	14.77	17.99	17.99	17.99	10.60
COMPRESSED TIME :	5,00	6,00	6,00	6.00	4,00

STATION NUMBER : 2 STATION SIZE : 3 MIXED MODEL PRODUCTION / MULTI-ELEMENT ASSIGNMENT

ELEMENTS	MODELS 200	201	202	203	204
4	0,00	0,00	0,00	0,00	13,96
9	45,20	45,20	45.20	45.20	45,20
10	12,60	12.60	12,60	12,60	0.00
WORK CONTENT :	57,80	57,80	57,80	57,80	59.16
WORK DURATION :	19.27	19.27	19.27	19.27	19.72
COMPRESSED TIME :	14.00	14.00	14.00	14.00	14.00

STATION NUMBER : 3 STATION SIZE : 1 MIXED MODEL PRODUCTION / MULTI-ELEMENT ASSIGNMENT

ELEMENTS	MODELS 200	201	202	203	204
2	0.00	7.39	0.00	0.00	0.00
5	8.60	0.00	0.00	0.00	0.00
7	0.00	0.00	19.26	0.00	0.00
10	0.00	0.00	0.00	0.00	12.60
11	0.00	6.13	0.00	6.13	0.00
12	9.60	0.00	0.00	9.60	0.00
WORK CONTENT :	18.20	13.52	19.26	15.73	12.60
WORK DURATION :	18.20	13.52	19.26	15.73	12.60
COMPRESSED TIME :	10.00	5.00	5.00	10.00	3.00

STATION NUMBER : 4 STATION SIZE : 1 MIXED MODEL PRODUCTION / MULTI-ELEMENT ASSIGNMENT

ELEMENTS	MODELS 200	201	202	203	204
2	0.00	0.00	7.39	0.00	0.00
5	0.00	8.60	0.00	0.00	8.60
7	19.26	0.00	0.00	0.00	0.00
12	0.00	9.60	9.60	0.00	9.60
13	0.00	0.00	0.00	5.13	0.00
14	0.00	0.00	0.00	7.13	0.00
WORK CONTENT :	19.26	18.20	16.99	12.26	18.20
WORK DURATION :	19.26	18.20	16.99	12.26	18.20
COMPRESSED TIME :	5.00	10.00	11.00	7.00	10.00

STATION NUMBER : 5 STATION SIZE : 1 MIXED MODEL PRODUCTION / MULTI-ELEMENT ASSIGNMENT

ELEMENTS	MODELS 200	201	202	203	204
4	0.00	0.00	0.00	13.96	0.00
7	0.00	0.00	0.00	0.00	19.26
8	17.26	17.26	17.26	0.00	0.00
WORK CONTENT :	17.26	17.26	17.26	13.96	19.26
WORK DURATION :	17.26	17.26	17.26	13.96	19.26
COMPRESSED TIME :	4.00	4.00	4.00	3.00	5.00

STATION NUMBER : 6 STATION SIZE : 1 MIXED MODEL PRODUCTION / MULTI-ELEMENT ASSIGNMENT

ELEMENTS	MODELS 200	201	202	203	204
5	0.00	0.00	0.00	8.60	0.00
6	11.96	11.96	11.96	0.00	0.00
13	5.13	0.00	0.00	0.00	0.00
14	0.00	7.13	7.13	0.00	0.00
15	0.00	0.00	0.00	10.60	10.60
16	0.00	0.00	0.00	0.00	7.39
WORK CONTENT :	17.09	19.09	19.09	19.20	17.99
WORK DURATION :	17.09	19.09	19.09	19.20	17.99
COMPRESSED TIME :	8.00	7.00	7.00	6.00	7.00

STATION NUMBER : 7 STATION SIZE : 1 MIXED MODEL PRODUCTION / MULTI-ELEMENT ASSIGNMENT

ELEMENTS	MODELS 200	201	202	203	204
6	0.00	0.00	0.00	0.00	11.96
16	7.39	7.39	0.00	7.39	0.00
WORK CONTENT :	7.39	7.39	0.00	7.39	11.96
WORK DURATION :	7.39	7.39	0.00	7.39	11.96
COMPRESSED TIME :	3.00	3.00	0.00	3.00	4.00

BALANCE EFFICIENCY

BD1 = 17.16　　BD3 = 17.16　　SI1 = 16.48　　SI3 = 16.48

BD2 = 17.13　　BD4 = 17.13　　SI2 = 15.80　　SI4 = 15.80

WORK DISTRIBUTION EFFICIENCY

STATION NUMBER	STATION SIZE	TIME AVAILABLE	MAXIMUM WORK	MINIMUM WORK	STATION RANGE	NORMAL AVERAGE	NORMAL ST. DV.	WEIGHTED AVERAGE	WEIGHTED ST. DV.	WORK VARIETY
1	1	20.00	18.38	10.81	7.57	15.87	6.51	15.70	6.52	25.95
2	3	60.00	59.84	58.44	1.41	58.07	1.22	58.20	1.25	72.66
3	1	20.00	19.56	12.81	6.75	15.86	5.76	14.39	6.64	64.85
4	1	20.00	19.56	12.56	7.00	16.98	5.52	16.91	5.52	58.32
5	1	20.00	19.56	14.22	5.34	17.00	3.82	17.16	3.83	51.34
6	1	20.00	19.62	17.50	2.12	18.49	1.85	18.71	1.92	51.97
7	1	20.00	12.22	0.00	12.22	6.82	8.60	8.10	9.06	19.79
					42.41					344.88

WB1 = 42.41　　WT1 = 49.27　　WT3 = 53.00

WB2 = 344.88　　WT2 = 47.92

PROGRAM OUTPUT

ALB5

(LISTING 04)

(FULL LISTING)

TITLE : 16 ELEMENT PROBLEM - MIXED MODEL - RANDOM REMOVAL ELEMENTS

PRODUCTION SCHEDULE NUMBER : 2   TIMETABLE NUMBER : 1

PRODUCTION TIMETABLE :

PROGRAM START : 8.00		ESTIMATED FINISH TIME : 1.80	
DAY :	FRIDAY	DAY :	MONDAY
WEEK :	5	WEEK :	15
YEAR :	1980	YEAR :	1980

PROGRAM DISRUPTION :

FROM	TO	CAUSE
SHIFT 1 DAY:MONDAY WEEK: 6 YEAR:1980	SHIFT 3 DAY:FRIDAY WEEK: 6 YEAR:1980	HOLIDAY
SHIFT 1 DAY:MONDAY WEEK: 10 YEAR:1980	SHIFT 3 DAY:WEDNSDAY WEEK: 10 YEAR:1980	INTERNAL
SHIFT 2 DAY:THURSDAY WEEK: 12 YEAR:1980	SHIFT 3 DAY:FRIDAY WEEK: 12 YEAR:1980	EXTERNAL

```
WEEKLY TIMETABLE :

STANDARD DAYS IN WEEK  :   5
MAXIMUM SHIFTS PER DAY :   3

              DAY : MONDAY   TUESDAY  WEDNSDAY THURSDAY FRIDAY

        SHIFT   1 : WORKING  WORKING  WORKING  WORKING  WORKING
        SHIFT   2 : WORKING  WORKING  WORKING  WORKING  WORKING
        SHIFT   3 : WORKING  WORKING  WORKING  WORKING  WORKING
```

```
TIMES OF WORKING SHIFTS :

( 24 HOUR CLOCK )

        SHIFT : 1     START AT :  0.00    DURATION :  8.00
        SHIFT : 2     START AT :  8.00    DURATION :  4.00
        SHIFT : 2     START AT : 13.00    DURATION :  4.00
        SHIFT : 3     START AT : 18.00    DURATION :  4.00
```

PRODUCT SCHEDULE SUMMARY :

TOTAL NUMBER OF MODELS REQUIRED = 5
TOTAL NUMBER OF UNITS REQUIRED =2400
MODEL DOMINANCE RATIO = 1.62

MODEL RATIOS :

MODEL = 200	UNITS REQUIRED = 780	MODEL RATIO =0.33	ORIGINAL BALANCING ADJUSTMENT =0.04
MODEL = 201	UNITS REQUIRED = 370	MODEL RATIO =0.15	ORIGINAL BALANCING ADJUSTMENT =0.38
MODEL = 203	UNITS REQUIRED = 410	MODEL RATIO =0.17	ORIGINAL BALANCING ADJUSTMENT =0.21
MODEL = 204	UNITS REQUIRED = 280	MODEL RATIO =0.12	ORIGINAL BALANCING ADJUSTMENT =0.29
MODEL = 202	UNITS REQUIRED = 560	MODEL RATIO =0.23	ORIGINAL BALANCING ADJUSTMENT =0.08

ALL MODELS ARE INCLUDED IN THIS SCHEDULE PROGRAM

ACTUAL SCHEDULE :

CYCLE GROUP	MODEL	QUANTITY	NO. CYCLES
1	200	60	3
1	201	30	
1	203	50	
1	202	40	
2	200	600	1
3	204	70	4
3	203	30	
3	202	110	
4	201.	140	2
4	203	70	

```
SIMULATION RUN INFORMATION :

SCHEDULE NUMBER :   2                TIMETABLE NUMBER :   1

ORIGINAL BALANCING INFORMATION :
     MIXED MODEL LINE
     VARIABLE TIME LINE
     BALANCING CYCLE TIME : 20.00  MINUTES
     BALANCING LINE SPEED :  0.50   METER   PER MINUTES

SIMULATION INFORMATION :
     FREQUENCY OF WORKSTATION PRINTOUT : 800 CYCLES
     FULL PRINT OF WORK STATION DATA
     STATION VARIABILITY USED WHEN REQUIRED
     CONTINUOUS SCHEDULING
```

```
*  LINE PARAMETERS :
*********************
      LINE CYCLE TIME : 18.00  MINUTES
      LINE SPEED :  0.56   METER   PER MINUTES

      STATION NUMBER :   1     STATION SIZE :   1     TIME AVAILABLE : 20.00
                               NO BASIC TIME FOR ANY MODEL EXCEEDS THE LINE CYCLE TIME
      STATION NUMBER :   2     STATION SIZE :   3     TIME AVAILABLE : 60.00
                               NO BASIC TIME FOR ANY MODEL EXCEEDS THE LINE CYCLE TIME
      STATION NUMBER :   3     STATION SIZE :   1     TIME AVAILABLE : 20.00
                               NO BASIC TIME FOR ANY MODEL EXCEEDS THE LINE CYCLE TIME
      STATION NUMBER :   4     STATION SIZE :   1     TIME AVAILABLE : 20.00
                               NO BASIC TIME FOR ANY MODEL EXCEEDS THE LINE CYCLE TIME
      STATION NUMBER :   5     STATION SIZE :   1     TIME AVAILABLE : 20.00
                               NO BASIC TIME FOR ANY MODEL EXCEEDS THE LINE CYCLE TIME
      STATION NUMBER :   6     STATION SIZE :   1     TIME AVAILABLE : 20.00
                               NO BASIC TIME FOR ANY MODEL EXCEEDS THE LINE CYCLE TIME
      STATION NUMBER :   7     STATION SIZE :   1     TIME AVAILABLE : 20.00
                               NO BASIC TIME FOR ANY MODEL EXCEEDS THE LINE CYCLE TIME

      BASIC TIME FOR ALL MODELS AT ALL STATIONS BELOW OR EQUAL TO THE LINE CYCLE TIME
```

```
LINE CHARACTERISTICS  (DIMENSION IN METRE)
*******************************************

             TOTAL UPSTREAM EXCESS = 11,00
           TOTAL DOWNSTREAM EXCESS = 10,00
                                     ------
                             TOTAL = 21,00

                      LESS OVERLAP = 20,00
                                     ------
                             TOTAL =  1,00
                                                                     LINE LENGTH =100,00
             UNUSED TRANSIT LENGTH = 29,00                  TOTAL STATION LENGTH = 70,00
                                     ------                                        ------
                             TOTAL = 30,00                                 TOTAL = 30,00

           TOTAL NUMBER OF STATIONS =   7
          NUMBER OF SIMPLE STATIONS =   6
NUMBER OF INCREASED CAPACITY STATIONS = 1

           MAXIMUM STATION CAPACITY = 60,00
           MINIMUM STATION CAPACITY = 20,00
           AVERAGE STATION CAPACITY = 25,71

 NUMBER OF OPERATORS IN GROUP WORKING ;  1  2  3  4  5  6  7  8  9
                 FREQUENCY OF OCCURNCE ;  6  0  1  0  0  0  0  0  0
```

LINE DETAILS ;

	START POSITION	END POSITION	LENGTH	UPSTREAM LENGTH	D-STREAM LENGTH	TRANSIT LENGTH	POSSIBLE OVERLAP LENGTH	POSSIBLE EXCESS LENGTH
RELATION BETWEEN START & 1						5.00	0.00	5.00
STATION NUMBER 1	5.00	15.00	10.00	0.00	3.00			
RELATION BETWEEN 1 & 2						0.00	4.00	0.00
STATION NUMBER 2	15.00	25.00	10.00	1.00	2.00			
RELATION BETWEEN 2 & 3						0.00	4.00	0.00
STATION NUMBER 3	25.00	35.00	10.00	2.00	1.00			
RELATION BETWEEN 3 & 4						0.00	4.00	0.00
STATION NUMBER 4	35.00	45.00	10.00	3.00	3.00			
RELATION BETWEEN 4 & 5						0.00	3.00	0.00
STATION NUMBER 5	45.00	55.00	10.00	0.00	0.00			
RELATION BETWEEN 5 & 6						0.00	2.00	0.00
STATION NUMBER 6	55.00	65.00	10.00	2.00	0.00			
RELATION BETWEEN 6 & 7						0.00	3.00	0.00
STATION NUMBER 7	65.00	75.00	10.00	3.00	1.00			
RELATION BETWEEN 7 & END						25.00	0.00	24.00
TOTALS			70.00	11.00	10.00	30.00	20.00	29.00

STATIONS INFORMATION ;

SCHEDULE NUMBER = 2 TIMETABLE NUMBER = 1

PROGRAM LENGTH =2406 CYCLE NUMBER = 800

TIME = 8.00 SHIFT = 1 DAY =TUESDAY WEEK = 9 YEAR = 1980

STATION NUMBER :	1	2	3	4	5	6	7
STATION SIZE :	1	3	1	1	1	1	1
MODEL NUMBER :	200	200	200	200	200	200	200
STATION CONDITION :	WORKING	WORKING	WORKING	WORKING	WORKING	WORKING	WORKING
NOMINAL M. OUTPUT :	800	799	798	797	796	795	794
ACTUAL M. OUTPUT :	800	799	798	797	796	795	240
STATION WORK TIME :	14.9	45.5	17.1	14.6	21.8	15.5	0.0
MAXIMUM WORK TIME :	22.3	62.7	24.0	22.9	21.8	23.0	8.7
MINIMUM WORK TIME :	8.9	43.2	8.3	7.1	7.8	10.4	0.0
WORK ASSIGNED :	12494.7	42363.1	11590.1	12001.8	11411.0	12773.5	1434.2
TIME AVAILABLE :	14400.0	43146.0	14364.0	14346.0	14328.0	14310.0	14292.0
DOWNSTREAM WORKING:	154.3	692.2	3.8	11.4	0.0	0.0	0.0
FREQUENCY :	120	180	3	11	0	0	0
UPSTREAM WORKING :	0.0	2555.6	2778.8	3820.7	0.0	2600.3	1238.0
FREQUENCY :	0	619	795	786	0	778	240
NORMAL WORKING :	12340.5	39099.9	8813.9	8169.7	11378.5	10162.9	196.2
FREQUENCY :	800	799	798	797	796	795	167
OVERLAP WORK TIME :	340.8	2270.6	2215.1	296.7	607.4	790.1	194.1
FREQUENCY :	231	976	916	182	371	470	110
NEXT START POS'N :	5.0	14.0	23.0	32.3	45.0	53.0	62.0
TOTAL LOST WORK :	0.0	15.3	2.6	0.0	32.4	10.3	0.0
FREQUENCY :	0	7	1	0	37	17	0

STATIONS INFORMATION ;

SCHEDULE NUMBER = 2 TIMETABLE NUMBER = 1

PROGRAM LENGTH =2406 CYCLE NUMBER =1600

TIME = 8,00 SHIFT = 1 DAY =TUESDAY WEEK = 12 YEAR = 1980

STATION NUMBER :	1	2	3	4	5	6	7
STATION SIZE :	1	3	1	1	1	1	1
MODEL NUMBER :	204	204	204	204	204	204	204
STATION CONDITION :	WORKING	WORKING	WORKING	WORKING	WORKING	WORKING	WORKING
NOMINAL M. OUTPUT :	1600	1599	1598	1597	1596	1595	1594
ACTUAL M. OUTPUT :	1600	1599	1598	1597	1596	1595	474
STATION WORK TIME :	10.7	52.2	13.5	14.7	17.6	16.1	10.5
MAXIMUM WORK TIME :	22.3	63.0	24.0	24.0	21.9	23.0	14.3
MINIMUM WORK TIME :	4.7	43.2	7.4	7.1	7.8	8.6	0.0
WORK ASSIGNED :	23651.3	85037.3	23154.3	24071.2	23437.4	25388.5	3544.8
TIME AVAILABLE :	28800.0	86346.0	28764.0	28746.0	28728.0	28710.0	28692.0
DOWNSTREAM WORKING:	242.5	2235.2	24.9	28.2	0.0	0.0	0.0
FREQUENCY :	202	477	24	22	0	0	0
UPSTREAM WORKING :	0.0	4567.2	5434.6	7827.5	0.0	5297.0	2491.5
FREQUENCY :	0	1122	1574	1575	0	1570	474
NORMAL WORKING :	23408.8	78168.3	17687.5	16215.5	23349.4	20077.7	1053.3
FREQUENCY :	1600	1599	1598	1597	1596	1595	386
OVERLAP WORK TIME :	540.7	4843.1	5127.5	859.3	1471.1	1776.2	333.3
FREQUENCY :	370	1853	1880	419	845	1021	198
NEXT START POS'N :	5.0	14.0	23.0	32.0	45.0	53.0	62.0
TOTAL LOST WORK :	0.0	66.5	7.3	0.0	107.9	13.7	0.0
FREQUENCY :	0	35	6	0	104	25	0

STATIONS INFORMATION :

SCHEDULE NUMBER = 2 TIMETABLE NUMBER = 1

PROGRAM LENGTH =2406 CYCLE NUMBER =2400

TIME = 22,00 SHIFT = 3 DAY =FRIDAY WEEK = 14 YEAR = 1980

STATION NUMBER :	1	2	3	4	5	6	7
STATION SIZE :	1	3	1	1	1	1	1
MODEL NUMBER :	203	203	203	203	203	203	203
STATION CONDITION :	WORKING	WORKING	WORKING	WORKING	WORKING	WORKING	WORKING
NOMINAL M. OUTPUT :	2400	2399	2398	2397	2396	2395	2394
ACTUAL M. OUTPUT :	2400	2399	2398	2397	2396	2395	1054
STATION WORK TIME :	13.0	50.6	13.1	11.6	11.6	12.8	7.0
MAXIMUM WORK TIME :	22.3	63.0	24.0	24.0	21.9	23.0	14.6
MINIMUM WORK TIME :	4.7	42.4	6.2	7.0	6.3	8.6	0.0
WORK ASSIGNED :	34968.9	127466.0	33623.2	34777.9	35048.8	38093.2	7429.6
TIME AVAILABLE :	43200.0	129546.0	43164.0	43146.0	43128.0	43110.0	43092.0
DOWNSTREAM WORKING:	269.7	3186.2	36.7	28.2	0.0	0.0	0.0
FREQUENCY :	237	672	34	22	0	0	0
UPSTREAM WORKING :	0.0	7036.3	8211.0	12125.3	0.0	8005.8	5513.7
FREQUENCY :	0	1727	2364	2375	0	2363	1054
NORMAL WORKING :	34699.2	117154.6	25366.1	22624.4	34859.4	30068.8	1915.9
FREQUENCY :	2400	2399	2398	2397	2396	2395	818
OVERLAP WORK TIME :	656.8	6998.4	7504.3	1190.8	2230.2	2960.6	758.6
FREQUENCY :	477	2701	2787	585	1232	1672	462
NEXT START POSIN :	5.0	14.0	23.0	32.0	45.0	53.0	62.0
TOTAL LOST WORK :	0.0	88.9	9.5	0.0	189.4	18.6	0.0
FREQUENCY :	0	46	10	0	174	32	0

```
FINAL ANALYSIS ;

SCHEDULE AS SHOWN COMPLETED
SCHEDULE NUMBER =    2                         TIMETABLE NUMBER =    1
FINISH TIME =  1,80  SHIFT = 1  DAY =MONDAY   WEEK =15 YEAR = 1980

PRODUCTION |

                                                    TOTAL PRODUCTION CYCLES =2406
                                                 LESS START & FINISH CYCLES =   6
      NUMBER OF FINISHED UNITS =  2400                                      ----
         NUMBER OF MODEL RUNS =    29                NUMBER OF FINISHED UNITS =2400
                                 ----
          AVERAGE RUN LENGTH = 82,76                        NUMBER OF MODELS =    5
STANDARD DEVIATION RUN LENGTH =131,25           AVERAGE PRODUCTION PER MODEL =480.00
                                                       MODEL DOMINANCE RATIO =  1,62

EFFICIENCY MEASURES ;

              BALANCING                           SIMULATION
              ---------                           ----------

              BD1 = 17,16                         BD1 = 20,76

              BD3 = 17,16                         BD3 = 20,75

              BD2 = 17,13                         BD2 = 20,76

              BD4 = 17,13                         BD4 = 20,75
```

SI1 = 17,69	SI1 = 18,28
SI3 = 17,69	SI3 = 18,27
SI2 = 16,06	SI2 = 18,28
SI4 = 16,06	SI4 = 18,27

	USED	PERCENT	FREQUENCY	AVAILABLE
TOTAL UPSTREAM TIME =	40964.2	(13.1 %)	9899	56160,0
TOTAL DOWNSTREAM TIME =	3520.8	(1.1 %)	965	60480,0
TOTAL NORMAL TIME =	266880.7	(85.6 %)	15221	388800,0

THEORETICAL TIME AVAILABLE =	505440,0
LESS	
UNUSED UP/DOWN TIME =	72155,1
UNUSED NORMAL TIME =	121919,3
TOTAL WORK OUTPUT =	311365,7

TOTAL WORK OUTPUT =	311365.7	(99.9 %)
TOTAL LOST TIME =	306.4	(0.1 %)
FREQUENCY =	263	
TOTAL WORK ASSIGNED =	311672.1	(100.0 %)

PROGRAM OUTPUT

ALB5

(LISTING 04)

(ABBREVIATED LISTING)

```
TITLE : 16 ELEMENT PROBLEM - MIXED MODEL - RANDOM REMOVAL ELEMENTS
PRODUCTION SCHEDULE NUMBER :  2                    TIMETABLE NUMBER :  1

PRODUCTION TIMETABLE :

    PROGRAM START :  8.00                ESTIMATED FINISH TIME :  1.80
              DAY :  FRIDAY                               DAY :  MONDAY
             WEEK :   5                                  WEEK :  15
             YEAR :  1980                                YEAR :  1980

PROGRAM DISRUPTION :

              FROM                                   TO                    CAUSE
SHIFT 1 DAY,MONDAY   WEEK,  6 YEAR,1980   SHIFT 3 DAY,FRIDAY   WEEK,  6 YEAR,1980   HOLIDAY

SHIFT 1 DAY,MONDAY   WEEK, 10 YEAR,1980   SHIFT 3 DAY,WEDNSDAY WEEK, 10 YEAR,1980   INTERNAL

SHIFT 2 DAY,THURSDAY WEEK, 12 YEAR,1980   SHIFT 3 DAY,FRIDAY   WEEK, 12 YEAR,1980   EXTERNAL
```

```
WEEKLY TIMETABLE :

STANDARD DAYS IN WEEK  :   5
MAXIMUM SHIFTS PER DAY :   3

            DAY : MONDAY   TUESDAY  WEDNSDAY THURSDAY FRIDAY

      SHIFT  1 : WORKING  WORKING  WORKING  WORKING  WORKING
      SHIFT  2 : WORKING  WORKING  WORKING  WORKING  WORKING
      SHIFT  3 : WORKING  WORKING  WORKING  WORKING  WORKING
```

```
TIMES OF WORKING SHIFTS :

( 24 HOUR CLOCK )

        SHIFT : 1    START AT :  0.00   DURATION :  8.00
        SHIFT : 2    START AT :  8.00   DURATION :  4.00
        SHIFT : 2    START AT : 13.00   DURATION :  4.00
        SHIFT : 3    START AT : 18.00   DURATION :  4.00
```

PRODUCT SCHEDULE SUMMARY :

TOTAL NUMBER OF MODELS REQUIRED = 5
TOTAL NUMBER OF UNITS REQUIRED =2400
MODEL DOMINANCE RATIO = 1.62

MODEL RATIOS :

MODEL = 200	UNITS REQUIRED = 780	MODEL RATIO =0.33	ORIGINAL BALANCING ADJUSTMENT =0.04
MODEL = 201	UNITS REQUIRED = 370	MODEL RATIO =0.15	ORIGINAL BALANCING ADJUSTMENT =0.38
MODEL = 203	UNITS REQUIRED = 410	MODEL RATIO =0.17	ORIGINAL BALANCING ADJUSTMENT =0.21
MODEL = 204	UNITS REQUIRED = 280	MODEL RATIO =0.12	ORIGINAL BALANCING ADJUSTMENT =0.29
MODEL = 202	UNITS REQUIRED = 560	MODEL RATIO =0.23	ORIGINAL BALANCING ADJUSTMENT =0.08

ALL MODELS ARE INCLUDED IN THIS SCHEDULE PROGRAM

ACTUAL SCHEDULE :

CYCLE GROUP	MODEL	QUANTITY	NO. CYCLES
1	200	60	3
1	201	30	
1	203	50	
1	202	40	
2	200	600	1
3	204	70	4
3	203	30	
3	202	110	
4	201	140	2
4	203	70	

```
SIMULATION RUN INFORMATION :

     SCHEDULE NUMBER :   2              TIMETABLE NUMBER :   1

ORIGINAL BALANCING INFORMATION :
     MIXED MODEL LINE
     VARIABLE TIME LINE
     BALANCING CYCLE TIME : 20.00  MINUTES
     BALANCING LINE SPEED :  0.50   METER   PER MINUTES

SIMULATION INFORMATION :
     FREQUENCY OF WORKSTATION PRINTOUT : 800 CYCLES
     PARTIAL PRINT OF WORK STATION DATA
     STATION VARIABILITY USED WHEN REQUIRED
     INDEPENDANT SCHEDULING
```

```
LINE PARAMETERS :

    LINE CYCLE TIME : 18.00  MINUTES
    LINE SPEED :  0.56   METER   PER MINUTES

    STATION NUMBER :   1     STATION SIZE :   1     TIME AVAILABLE : 20.00
                             NO BASIC TIME FOR ANY MODEL EXCEEDS THE LINE CYCLE TIME

    STATION NUMBER :   2     STATION SIZE :   3     TIME AVAILABLE : 60.00
                             NO BASIC TIME FOR ANY MODEL EXCEEDS THE LINE CYCLE TIME

    STATION NUMBER :   3     STATION SIZE :   1     TIME AVAILABLE : 20.00
                             NO BASIC TIME FOR ANY MODEL EXCEEDS THE LINE CYCLE TIME

    STATION NUMBER :   4     STATION SIZE :   1     TIME AVAILABLE : 20.00
                             NO BASIC TIME FOR ANY MODEL EXCEEDS THE LINE CYCLE TIME

    STATION NUMBER :   5     STATION SIZE :   1     TIME AVAILABLE : 20.00
                             NO BASIC TIME FOR ANY MODEL EXCEEDS THE LINE CYCLE TIME

    STATION NUMBER :   6     STATION SIZE :   1     TIME AVAILABLE : 20.00
                             NO BASIC TIME FOR ANY MODEL EXCEEDS THE LINE CYCLE TIME

    STATION NUMBER :   7     STATION SIZE :   1     TIME AVAILABLE : 20.00
                             NO BASIC TIME FOR ANY MODEL EXCEEDS THE LINE CYCLE TIME

    BASIC TIME FOR ALL MODELS AT ALL STATIONS BELOW OR EQUAL TO THE LINE CYCLE TIME
```

```
LINE CHARACTERISTICS  (DIMENSION IN METRE)

         TOTAL UPSTREAM EXCESS = 11,00
       TOTAL DOWNSTREAM EXCESS = 10,00
                                ------
                         TOTAL = 21,00

                  LESS OVERLAP = 20,00
                                ------
                         TOTAL =  1,00

         UNUSED TRANSIT LENGTH = 29,00                  LINE LENGTH =100,00
                                ------         TOTAL STATION LENGTH = 70,00
                         TOTAL = 30,00                               ------
                                                              TOTAL = 30,00

      TOTAL NUMBER OF STATIONS =  7
     NUMBER OF SIMPLE STATIONS =  6
NUMBER OF.INCREASED CAPACITY STATIONS =  1

      MAXIMUM STATION CAPACITY = 60,00
      MINIMUM STATION CAPACITY = 20,00
      AVERAGE STATION CAPACITY = 25,71

 NUMBER OF OPERATORS IN GROUP WORKING ;  1  2  3  4  5  6  7  8  9
               FREQUENCY OF OCCURNCE ;  6  0  1  0  0  0  0  0  0
```

LINE DETAILS :

	START POSITION	END POSITION	LENGTH	UPSTREAM LENGTH	D-STREAM LENGTH	TRANSIT LENGTH	POSSIBLE OVERLAP LENGTH	POSSIBLE EXCESS LENGTH
RELATION BETWEEN START & 1						5.00	0.00	5.00
STATION NUMBER 1	5.00	15.00	10.00	0.00	3.00			
RELATION BETWEEN 1 & 2						0.00	4.00	0.00
STATION NUMBER 2	15.00	25.00	10.00	1.00	2.00			
RELATION BETWEEN 2 & 3						0.00	4.00	0.00
STATION NUMBER 3	25.00	35.00	10.00	2.00	1.00			
RELATION BETWEEN 3 & 4						0.00	4.00	0.00
STATION NUMBER 4	35.00	45.00	10.00	3.00	3.00			
RELATION BETWEEN 4 & 5						0.00	3.00	0.00
STATION NUMBER 5	45.00	55.00	10.00	0.00	0.00			
RELATION BETWEEN 5 & 6						0.00	2.00	0.00
STATION NUMBER 6	55.00	65.00	10.00	2.00	0.00			
RELATION BETWEEN 6 & 7						0.00	3.00	0.00
STATION NUMBER 7	65.00	75.00	10.00	3.00	1.00			
RELATION BETWEEN 7 & END						25.00	0.00	24.00
TOTALS			70.00	11.00	10.00	30.00	20.00	29.00

STATIONS INFORMATION :

SCHEDULE NUMBER = 2 TIMETABLE NUMBER = 1

PROGRAM LENGTH =2406 CYCLE NUMBER = 800

TIME = 8,00 SHIFT = 1 DAY =TUESDAY WEEK = 9 YEAR = 1980

STATION NUMBER	:	1	2	3	4	5	6	7
STATION SIZE	:	1	3	1	1	1	1	1
MODEL NUMBER	:	200	200	200	200	200	200	200
STATION CONDITION	:	WORKING	WORKING	WORKING	WORKING	WORKING	WORKING	WORKING
NOMINAL M. OUTPUT	:	800	800	800	800	800	800	800
ACTUAL M. OUTPUT	:	800	799	798	797	796	795	240
STATION WORK TIME	:	14,9	45,5	17,1	14,6	21,8	15.5	0.0
MAXIMUM WORK TIME	:	22,3	62,7	24,0	22,9	21,8	23.0	8,7
MINIMUM WORK TIME	:	8,9	0,0	0,0	0,0	0,0	0.0	0,0
WORK ASSIGNED	:	12494,7	42363,1	11599,1	12001,8	11411,0	12773.5	1434,2
TIME AVAILABLE	:	14400,0	43200,0	14400,0	14400,0	14400,0	14400.0	14400,0
NEXT START POS'N	:	5,0	14,0	23,0	32,3	45,0	53.0	62,0
TOTAL LOST WORK	:	0,0	15,3	2,6	0,0	32,4	10,3	0,0
FREQUENCY	:	0	7	1	0	37	17	0

STATIONS INFORMATION :

SCHEDULE NUMBER = 2 TIMETABLE NUMBER = 1

PROGRAM LENGTH =2406 CYCLE NUMBER =1600

TIME = 8,00 SHIFT = 1 DAY =TUESDAY WEEK = 12 YEAR = 1980

STATION NUMBER	:	1	2	3	4	5	6	7
STATION SIZE	:	1	3	1	1	1	1	1
MODEL NUMBER	:	204	204	204	204	204	204	204
STATION CONDITION	:	WORKING	WORKING	WORKING	WORKING	WORKING	WORKING	WORKING
NOMINAL M. OUTPUT	:	1600	1600	1600	1600	1600	1600	1600
ACTUAL M. OUTPUT	:	1600	1599	1598	1597	1596	1595	474
STATION WORK TIME	:	10.7	52.2	13.5	14.7	17.6	16.1	10.5
MAXIMUM WORK TIME	:	24.3	63.0	24.0	24.0	21.9	23.0	14.3
MINIMUM WORK TIME	:	4.7	0.0	0.0	0.0	0.0	0.0	0.0
WORK ASSIGNED	:	23651.3	85037.3	23154.3	24071.2	23437.4	25388.5	3544.8
TIME AVAILABLE	:	28800.0	86400.0	28800.0	28800.0	28800.0	28800.0	28800.0
NEXT START POS'N	:	5.0	14.0	23.0	32.0	45.0	53.0	62.0
TOTAL LOST WORK	:	0.0	66.5	7.3	0.0	107.9	13.7	0.0
FREQUENCY	:	0	35	6	0	104	25	0

STATIONS INFORMATION :

SCHEDULE NUMBER = 2 TIMETABLE NUMBER = 1

PROGRAM LENGTH =2406 CYCLE NUMBER =2400

TIME = 22.00 SHIFT = 3 DAY =FRIDAY WEEK = 14 YEAR = 1980

STATION NUMBER :	1	2	3	4	5	6	7
STATION SIZE :	1	3	1	1	1	1	1
MODEL NUMBER :	203	203	203	203	203	203	203
STATION CONDITION :	WORKING	WORKING	WORKING	WORKING	WORKING	WORKING	WORKING
NOMINAL M. OUTPUT :	2400	2400	2400	2400	2400	2400	2400
ACTUAL M. OUTPUT :	2400	2399	2398	2397	2396	2395	1054
STATION WORK TIME :	13.0	50.6	13.1	11.6	11.6	12.8	7.0
MAXIMUM WORK TIME :	24.3	63.0	24.0	24.0	21.9	23.0	14.6
MINIMUM WORK TIME :	4.7	0.0	0.0	0.0	0.0	0.0	0.0
WORK ASSIGNED :	34968.9	127466.0	33623.2	34777.9	35048.8	38093.2	7429.6
TIME AVAILABLE :	43200.0	129600.0	43200.0	43200.0	43200.0	43200.0	43200.0
NEXT START POS'N :	9.0	14.0	23.0	32.0	45.0	53.0	62.0
TOTAL LOST WORK :	0.0	88.9	9.5	0.0	189.4	18.6	0.0
FREQUENCY :	0	46	10	0	174	32	0

```
FINAL ANALYSIS :

    SCHEDULE AS SHOWN COMPLETED

    SCHEDULE NUMBER =   2                          TIMETABLE NUMBER =   1

    FINISH TIME =  1.80  SHIFT = 1  DAY =MONDAY   WEEK =15 YEAR = 1980

PRODUCTION :

                                                  TOTAL PRODUCTION CYCLES =2406
                                               LESS START & FINISH CYCLES =    6
      NUMBER OF FINISHED UNITS =  2400                                    ----
          NUMBER OF MODEL RUNS =    29          NUMBER OF FINISHED UNITS =2400
                                  ----
            AVERAGE RUN LENGTH = 82.76                  NUMBER OF MODELS =    5
 STANDARD DEVIATION RUN LENGTH =151.25     AVERAGE PRODUCTION PER MODEL =480.00
                                                  MODEL DOMINANCE RATIO =  1.62

EFFICIENCY MEASURES :

              BALANCING                       SIMULATION
              ---------                       ----------

              BD1 = 17,16                     BD1 = 20,96

              BD3 = 17,16                     BD3 = 20,95

              BD2 = 17,13                     BD2 = 20,96

              BD4 = 17,13                     BD4 = 20,95
```

```
                 SI1 = 17,69                                   SI1 = 18,58
                 SI3 = 17,69                                   SI3 = 18,58
                 SI2 = 16,06                                   SI2 = 18,58
                 SI4 = 16,06                                   SI4 = 18,58

                          USED          PERCENT           FREQUENCY        AVAILABLE
                          ----          -------           ---------        ---------
   TOTAL UPSTREAM TIME =   40964.2      (  13,1 % )          9899           56300,4
 TOTAL DOWNSTREAM TIME =    3520.8      (   1.1 % )           965           60631,2
     TOTAL NORMAL TIME =  266880.7      (  85,6 % )         15221          389772,0
                        ----------                                       ----------
                                                THEORETICAL TIME AVAILABLE =  506703,6
                                                        LESS
                                                    UNUSED UP/DOWN TIME =   72446,7
                                                     UNUSED NORMAL TIME =  122891,3
                                                                          ----------
     TOTAL WORK OUTPUT =  311365.7      (  99,9 % )          TOTAL WORK OUTPUT =  311365,7

       TOTAL LOST TIME =     306.4      (   0,1 % )
             FREQUENCY =     263
                        ----------
   TOTAL WORK ASSIGNED =  311672.1      ( 100,0 % )
```

APPENDIX C

COMPUTER PROGRAMS

THE ALB PROGRAM SUITE

GLOSSARY OF MAJOR PROGRAM TERMS

GENERAL:

ADJ ( )	Relative model ratios (relative quantities).
BD1 [BBD1/SBD1]	Balance delay (actual time basis).
BD2 [BBD2/SBD2]	Balance delay (weighted actual time basis).
BD3 [BBD3/SBD3]	Balance delay (effective time basis).
BD4 [BBD4/SBD4]	Balance delay (weighted effective time basis).
D1 ( )	Identity numbers for special facilities.
D11 ( )	Description of special facilities.
E1 ( )	Model identify numbers.
E11 ( )	Description of models.
F1 ( )	Work element identity numbers.
F2 ( )	Element work content (average time).
F3 ( )	Element work content (variance).
F4 ( )	Element followers.
F5 ( )	Type of resources required by each element.
F6 ( )	Element models.
F7 ( )	Element descriptions.
F8 ( )	Element work content (minimum duration time).
F9 ( )	Element working zones.
F51 ( )	Level of resources required by each element.
IAS ( )	Initially specifies element involvement for each model and finally contains station assignment for each element.
S1 ( )	Two part matrix containing (for each work station):

	a - The station identity number.
	b - The station capacity (size).
S3 ( )	Four part matrix containing (for each work station):
	a - Maximum work content.
	b - Minimum work content.
	c - Upstream excess length.
	d - Downstream excess length.
S4 ( )	Matrix containing the element assignments for the station.
SI1 [BSI1/SSI1]	Smoothness index (actual time basis).
SI2 [BSI2/SSI2]	Smoothness index (weighted actual time basis).
SI3 [BSI3/SSI3]	Smoothness index (effective time basis).
SI4 [BSI4/SSI4]	Smoothness index (weighted effective time basis).
TØ	Alphanumeric time units.
T1	The problem title.
T2	Balancing cycle time.
T3	Number of special facilities.
T4	Number of work stations.
T5	Number of work elements.
T6	Number of models included in the balance phase.
T7	Number of entries of the production schedule.
T8	Number of working zones.
T9	Shift time available.
T1Ø	Number of time units per hour.
T11	Identity number used to indicate particular production schedule being simulated.

TM ( )	Four part matrix containing: a - The schedule start time (hours). b - The schedule start day number. c - The schedule start week number. d - The schedule start year number.
TM1 ( )	Five part matrix containing: a - Number of working days per week. b - Maximum number of shifts per day. c - Calendar starting year. d - Number of shift sessions per day. e - Identity number used to indicate particular timetable in use.
TM2 ( )	Matrix containing status of each session i.e. working or not.
TM3 ( )	Shift identify number for each session.
TM4 ( )	Two part matrix containing: a - the session starting times. b - the session durations.
TM5 ( )	Matrix containing the shift status for five years, each year containing 52 weeks, each week containing 7 days, and each day containing 4 shifts.
Z1 ( )	Working zone identity numbers.
Z11 ( )	Working zone descriptions.

<u>ALB2</u>

A ( )	Station information containing: the station number, model number, and four parts of the station work conditions.

a - the minimum duration of work so far assigned to the station.

b - the total time of work so far assigned divided by the station size.

c - the sum of the effective time of elements so far assigned to the station.

d - the total effective time of the best solution so far achieved.

AV	Average work content assigned to the work station.
AV1	Weighted average work content assigned to the work station.
AR	Ratio of total minimum duration to the total work content.
C	Cycle time used in balancing procedure.
C1	Percentage confidence ratio.
C2	Standard deviation equivalent to the given confidence ratio (C1).
CT1	The cycle time which gives the minimum balance delay for a known number of work stations.
CT2	The cycle time which gives the maximum balance delay for a known number of work stations.
CMIN	The minimum compressed element time.
CMAX	The maximum compressed element time.
CMEAN	The mean compressed element time.
EM ( )	Total work content at each station for each model.
I2	The selected work element for the current assignment.

I99	Control parameter generated during the procedure to stop the program if the balance cannot be achieved with the existed conditions.
IAS1 ( )	Current elements assigned for all models.
IAS2 ( )	Elements assigned giving the best solution, so far.
IC ( )	Initially contains the location of elements, and secondly used to store a list of work elements at a given station.
IEM ( )	Number of predecessors existing for each element.
IEM1 ( )	Free or not free precedence status for each element.
IFW ( )	Copy of F4 element follower matrix.
IL ( )	List of elements requiring a given resource.
IS	Number of work station calculated by the balancing procedure.
IS2	The total number of assignments so far achieved.
IS3	The total number of assignments required to complete the balance.
ITR ( )	List of elements within a given time range.
IZ ( )	Station sizes produced by the balancing procedure.
J1	Highest ranked element assigned to work station.
J3	Highest ranked element tested for assignment.
J1Ø	The current work station for assigning work elements.
JK	Number of work elements in the present precedence diagram column.
L [L4]	Specified restricted line length.

L1	Time control parameter (deterministic/variable element times).
L3	Line control parameter (limited line length problem or not).
L5	Balancing control parameter. 1. Single model problem. 2. Mixed model problem: single element assignment. 3. Mixed model problem: multi-element assignment.
L7	Output control parameter for detailed assignment information.
L1Ø [L1ØØ, L1Ø1]	The initial minimum station size.
L11	The initial maximum station size.
L12	Weighting control parameter selecting the use of normal or weighted assigned time as the station size selection criteria.
L25	Manually input initial maximum station size.
LR ( )	Work element ranks.
N	Number of time reducible elements.
N2	Number of work elements required more than one operator to be performed.
RG	Element time range.
S1	Theoretical shift output.
S2	Theoretical balance delay.
SD	Total standard deviation for elements assigned to a given station.
SD1	Total weighted standard deviation for elements assigned to a given station.

SDC	Standard deviation of the range of minimum duration times.
SDN	Standard deviation of the range of normal element times.
ST ( )	Station information containing: a - maximum work assigned to the station. b - minimum work assigned to the station. c - range of work assigned. d - total work variety assigned.
SUMN	Grand total of normal work element durations.
SUMP1	Grand total of normal work element durations allowing for 97.5% confidence.
SUMP2	Grand total of normal work element durations allowing for 99.5% confidence.
TADJ	Total number of units in nominal balance schedule.
TC	Total number work content in each precedence column.
TM1	Element work content including 97.5% confidence increase.
TM2	Element work content including 99.5% confidence increase.
TMAX	Maximum element time.
TMIN	Minimum element time.
TMEAN	Mean element time.
TR1	The starting point of a time range.
TR2	The ending point of a time range.
TT1	Grand total of normal work element durations.
TT2	Total of minimum duration times for unassigned work elements.

TT3	Total of normal work contents for unassigned work elements.
TT [WB2]	Training index.
TWV [WB1]	Total of assigned work.
V1	The equivalent number of standard deviations to the given confidence ratio.
WT1	Average station range.
WT2	Standard deviation of station range.
WT3	Range of work variety over the entire line.

ALB3

DE	Station downstream excess length.
L2Ø	Manual or computer data preparation.
SL	Work station basic length.
SLL	Line length in length units.
ST	Line start position.
TTØ	Length units.
UE	Station upstream excess length.
V	Line speed.

ALB4

I4	Control parameter to select the appropriate program section.
I5	Number of years in the shift calendar required to be kept without any change.
II	Type of production shut-down.
IT1	Number of shifts from the start of calendar to the start of shut-down.
IT2	Number of shifts from the start of calendar to the end of shut-down.

ITS — Number of shifts from the start of the calendar to the period requiring updating.

ITE — Number of shifts from the start of the calendar to the end of the period requiring updating.

I1 — Starting shift for a given shut-down.

I2 — Finishing shift for a given shut-down.

J1 — Starting day for a given shut-down.

J2 — Finishing day for a given shut-down.

K1 — Starting week for a given shut-down.

K2 — Finishing week for a given shut-down.

L1 — Starting year for a given shut-down.

L2 — Finishing year for a given shut-down.

ALB5

A1 — Station current upstream working length.

A2 — Station current normal working length.

A3 — Station current downstream working length.

A4 — Lost work effort at current station (in length units).

ADJ ( ) — Two part matrix containing:

a - the model ratios used in the balancing procedure.

b - The model ratios in the simulation run.

AV — Average batch size.

AV1 — Percentage of the total downstream time used.

AV2 — Percentage of the total upstream time used.

AV3 — Percentage of the total normal time used.

AV4 — Percentage of the total time lost.

AA1 [AA2]	Line location for start of work.
AB1 [AB2]	Line location for finish of work.
AVE	Average station size.
D	Alphanumeric list of days.
D2	Alphanumeric list of shift status.
D3	Alphanumeric station status.
DN	Total downstream time available.
E	The station end location.
EP	Final location after completing work tasks.
ITM1	Starting time (hours) for simulation.
ITM2	Starting day for simulation.
ITM3	Starting week for simulation.
ITM4	Starting year for simulation.
IX8	Current time from beginning of calendar in number of shifts.
IX9	Estimated finish time from beginning of calendar in number of shifts.
II1	Shift status in calendar.
IE	Ending shift of production break.
IS	Starting shift of production break.
IA2	Shift session number.
IA3	Day number.
IA4	Week number.
IR ( )	Frequencies distribution of station sizes.
JE	Ending day of production break.
JJ	Number of cycles in start upsequence.
JJ1	Total number of cycles in product sequence.
JS	Starting day of production break.
KE	Ending week of production break.

KS	Starting week of production break.
L1	Number of occurrences of downstream working.
L2	Number of occurrences of upstream working.
L3	Number of occurrences of normal working.
L4	Number of occurrences of working lost time.
LA1	Control parameter (optional station information).
LA2	Control parameter (deterministic or variable element times).
LA4	Control parameter (partial or full print of work station information).
LA5	Control parameter (element or station variability).
LA6	Control parameter (continuous or independent schedule).
LE	Ending year of production break.
LS	Starting year of production break.
M	Largest number of units required for any model.
M1	Smallest number of units required for any model.
ML	Number of units produced.
ML1	Number of batch runs.
ML2	Size of batch sizes.
ML3	Sum of squared batch sizes.
N	Actual number of models in the simulation run.
N1	The current cycle number.
N2	Total number of launches in the production schedule.
N3	Number of finished units.

N4	Station status.
N5	Identity of model currently in the station.
N88	Control parameter to end program with faulty data.
N99	Frequency of printed station information.
OO	Status parameter indicating existence of shut-downs.
PE	Distance between limit positions of consecutive work stations.
PO	Possible overlap length between two consecutive work stations.
PEE	Additional line length after final station in the line.
PES	Additional line length before the first station in the line.
POE	Possible overlap length between last station and end.
POS	Possible overlap length between the start and the first station.
RN	Total time available for normal working.
S2 ( )	Station information matrix containing: a - total downstream work time b - total upstream work time c - total normal work time d - total lost work time e - station work time f - total overlap work time g - maximum work time h - minimum work time

i - total work output

j - total station time available

k - station next start position.

S5 ( )	Station work content.
S6 ( )	Production schedule information.
S7 ( )	Two part matrix containing (for each station): a - the identity number of the model in the station b - the station status.
S8 ( )	Matrix containing the station upstream time working, downstream time working, normal time working, and storing all the updated calculations for balance delay and smoothness index.
S6Ø ( )	Three part production schedule matrix containing: a - model identity number b - number of cycles required c - total number of units required of the model in question.
S81 ( )	Matrix containing total lost time for each station.
SI2 ( )	Matrix containing the frequency of occurrence work achievement at each station, e.g. upstream, downstream, and lost work.
SC ( )	Alphanumeric block matrix containing list of work station conditions.
SC1	Identifying number to specify the station condition.
SL	Work station basic length.

SLL	Line length.
SS	Average size of uninterrupted model runs.
SSS	Standard deviation of the uninterrupted model runs.
SUM1	Total downstream time used in the line.
SUM2	Total upstream time used in the line.
SUM3	Total normal time used in the line.
SUM4	Total lost time in the line.
SUM5	Total work output in the line.
T61	Actual number of model in.
TA4	Expected time (hours) of schedule completed as either: a - initial estimate b - estimate during simulation.
TDN	Total downstream excess length.
TL1	Line speed.
TL2	Line cycle time.
TL3	Line speed associated with balancing cycle time.
TOT	Total work during the entire production program.
TOT1	Total work output during the entire production program.
TOT2	Total time available (normal + upstream + downstream time) during the entire production program.
TPE	Total unused length in the line.
TPO	Total overlap length in the line.
TR	Transit length between each pair of consecutive stations (including upstream and downstream excess length).

TRE	Transit length for last station.
TSL	Total normal length of all work stations.
TTR	Total transit length for entire line.
TTR1	Equivalent line length.
TUD	Total up and downstream excess length for entire line.
TUP	Total upstream excess length for entire line.
UN	Total unused normal time during the entire production program.
UP	Total upstream time available during the entire production program.
UTUD	Total unused transit length for entire line.
X1	Original model ratio used in balancing by the model in question.
X11	Actual model ratio used in the simulation run by the model in question.
XD	Model dominance ratio.
Y	Maximum station capacity (multiple of basic station size).
YY	Minimum station capacity (multiple of basic station size).

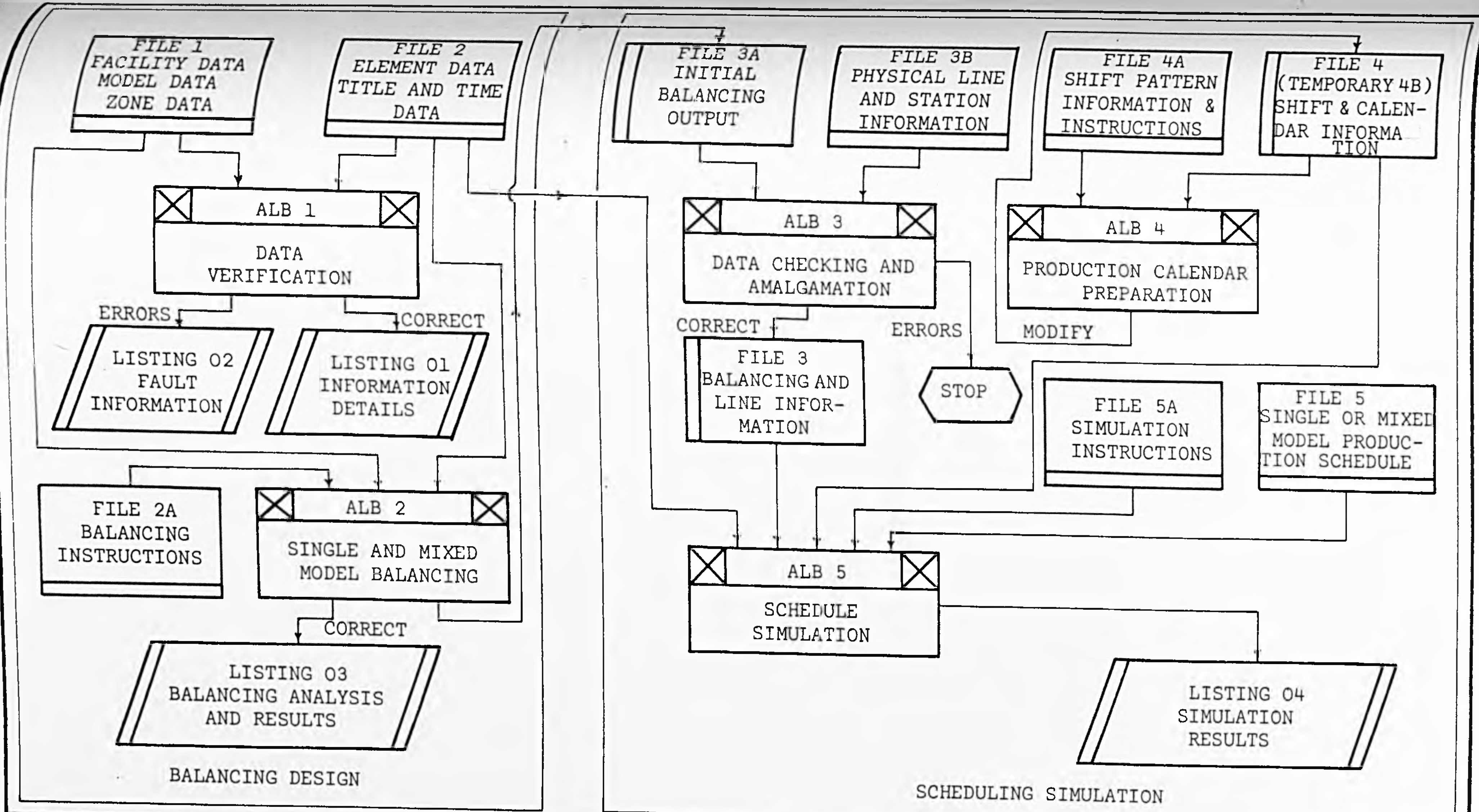
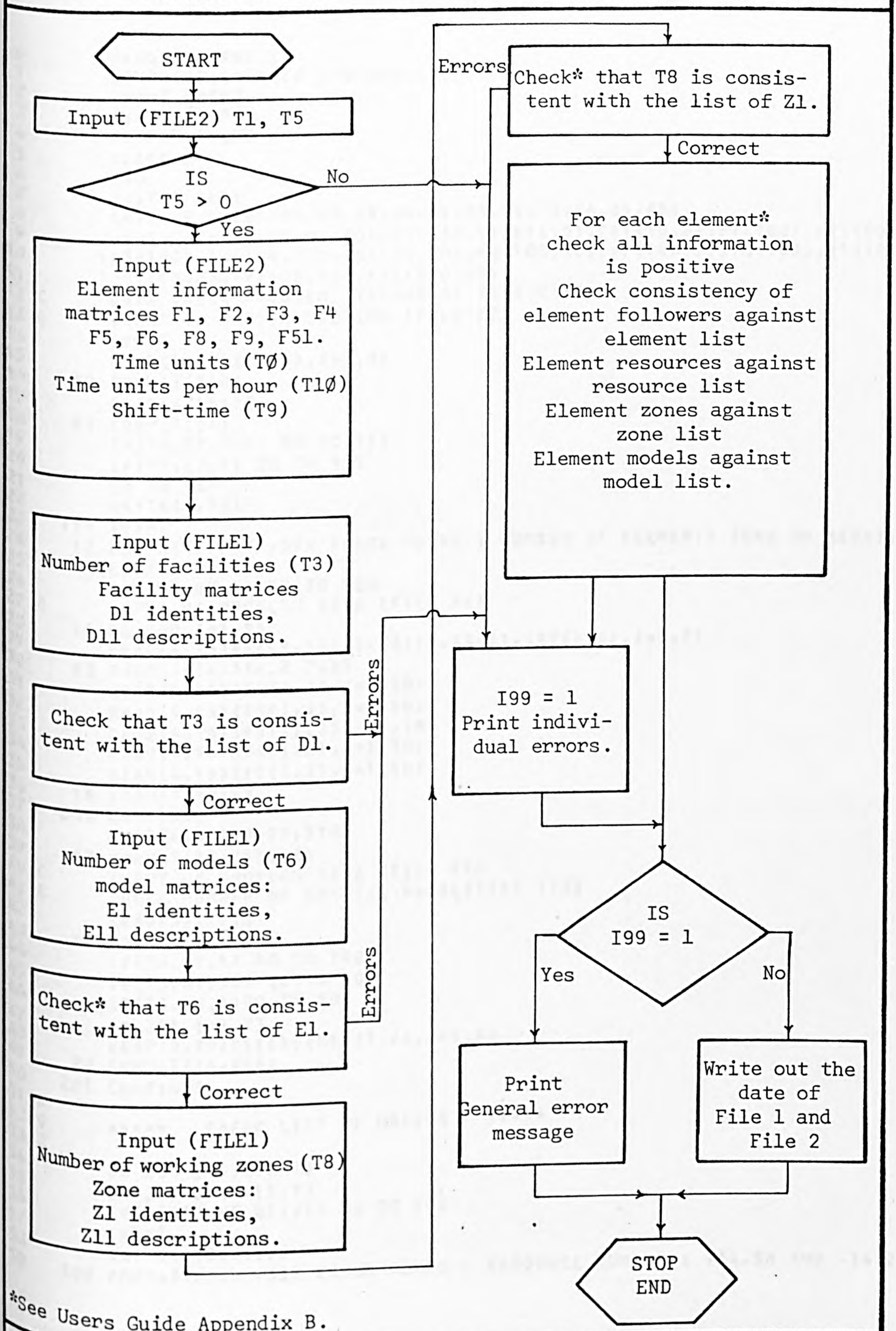


FIG. (C.1.) PROGRAM AND FILE ARRANGEMENT.

ALB 1

DATA VERIFICATION PROGRAM

ALB 1: DATA VERIFICATION PROGRAM



*See Users Guide Appendix B.

FIG. (C2) GENERAL FLOW CHART FOR ALB1.

ALB1 PROGRAM

```
      PROGRAM (FXXXX)
      COMPRESS INTEGER AND LOGICAL
      INPUT 4=CR0
      INPUT 5=CR1
      OUTPUT 6=LP0
      TRACE 2
      END
      MASTER ALB1
      INTEGER D1,E1,F1,F4,F5,F6,F9,T3,T5,T8,T6,Z1,F51
      DIMENSION T1(8),D1(30),D11(30,4),E1(10),E11(10,8),F1(100).F2(100),
     1F3(100),F4(100,10),F5(100,10),F6(100,10),F7(100,7),F8(100),Z1(10),
     2Z11(10,8),F9(100,10),F51(100,10)
C     DATA CHECK PROBLEM  (START OF TEST CASE)
C     INPUT OF MASTER SECTION (FILE F2)
      I99=0
      READ(4,10)(T1(I),I=1,8)
   10 FORMAT(8A8)
      READ(4,11)T5
   11 FORMAT(I4)
      IF(T5.GT.100) GO TO 111
      IF(T5.LT.1) GO TO 111
      GO TO 14
      WRITE(6,12)
  111 I99=1
   12 FORMAT(///1H ,50H ERROR FOUND : NUMBER OF ELEMENTS ZERO OR NEGATIV
     1E///)
      IF(I99.EQ.1) GO TO 900
C     INPUT OF PROBLEM DATA (FILE F2)
   14 DO 200 I=1,T5
      READ(4,15)F1(I),F2(I),F8(I),F3(I),(F7(I,J),J=1,7)
   15 FORMAT(I4,3F6.2,7A8)
      READ(4,16)(F4(I,J),J=1,10)
      READ(4,16)(F5(I,J),J=1,10)
      READ(4,16)(F51(I,J),J=1,10)
      READ(4,16)(F6(I,J),J=1,10)
      READ(4,16)(F9(I,J),J=1,10)
   16 FORMAT(10I4)
  200 CONTINUE
      READ(4,87)T0,T9,T10
   87 FORMAT(A8,2F10.2)
C     INPUT OF PROBLEM DATA (FILE F1)
C     CHECK NUMBER OF SPECIAL FACILITIES (T3)
      READ(5,17)T3
   17 FORMAT(I4)
      IF(T3.LT.1) GO TO 100
      IF(T3.GT.30) GO TO 100
      IF(T3.EQ.1)GO TO 101
      DO 201 I=1,T3
      READ(5,20)D1(I),(D11(I,J),J=1,4)
   20 FORMAT(I4,8A8)
  201 CONTINUE
C
C     *****   CHECK LIST OF MODELS   *****
C
      DO 203 I=1,(T3-1)
      DO 202 J=(I+1),T3
      IF(D1(I).NE.D1(J)) GO TO 202
      I99=1
      WRITE(6,300)I,J
  300 FORMAT(//1H ,33H ERROR FOUND : RESOURCE NUMBER : ,I4,5H AND ,I4,23
```

```
     +H HAVE THE SAME IDENTITY)
 202 CONTINUE
 203 CONTINUE
     DO 204 I=1,T3
     IF(D1(I).GT.0) GO TO 204
     I99=1
     WRITE(6,301)I
 301 FORMAT(//1H ,33H ERROR FOUND : RESOURCE NUMBER : ,I4,30H HAS NEGAT
     +IVE OR ZERO IDENTITY)
 204 CONTINUE
     GO TO 101
 100 I99=1
     WRITE(6,302)T3
 302 FORMAT(//1H ,27H ERROR FOUND : T3 VALUE OF ,I4,23H IS OUT OF RANGE
     + 1 - 30)
     GO TO 900
 101 READ(5,17)T6
     IF(T6.LT.1) GO TO 102
     IF(T6.GT.10) GO TO 102
     IF(T6.EQ.1) GO TO 103
     DO 205 I=1,T6
     READ(5,20)E1(I),(E11(I,J),J=1,8)
 205 CONTINUE
C
C    *****     CHECK LIST OF MODELS    *****
C
     DO 207 I=1,(T6-1)
     DO 206 J=(I+1),T6
     IF(E1(I).NE.E1(J)) GO TO 206
     I99=1
     WRITE(6,303)I,J
 303 FORMAT(//1H ,29H ERROR FOUND : MODEL NUMBER : ,I4,5H AND ,I4,23H H
     +AVE THE SAME IDENTITY)
 206 CONTINUE
 207 CONTINUE
     DO 208 I=1,T6
     IF(E1(I).GT.0) GO TO 208
     I99=1
     WRITE(6,304)I
 304 FORMAT(//1H ,30H ERROR FOUND : MODEL NUMBER : ,I4,30H HAS NEGATIVE
     + OR ZERO IDENTITY)
 208 CONTINUE
     GO TO 103
 102 I99=1
     WRITE(6,305)T6
 305 FORMAT(//1H ,27H ERROR FOUND : T6 VALUE OF ,I4,23H IS OUT OF RANGE
     + 1 - 10)
     GO TO 900
 103 READ(5,17)T8
     IF(T8.LT.1) GO TO 104
     IF(T8.GT.10) GO TO 104
     IF(T8.EQ.1) GO TO 105
     DO 209 I=1,T8
     READ(5,20)Z1(I),(Z11(I,J),J=1,8)
 209 CONTINUE
C
C    *****    CHECK LIST OF WORKING ZONES    *****
C
     DO 211 I=1,(T8-1)
     DO 210 J=(I+1),T8
```

```
      IF(Z1(I).NE.Z1(J)) GO TO 210
      I99=1
      WRITE(6,306)I,J
  306 FORMAT(//1H ,29H ERROR FOUND : ZONE NUMBER : ,I4,5H AND ,I4,23H HA
     +VE THE SAME IDENTITY)
  210 CONTINUE
  211 CONTINUE
      DO 212 I=1,T8
      IF(Z1(I).GT.0) GO TO 212
      I99=1
      WRITE(6,307)I
  307 FORMAT(//1H ,29H ERROR FOUND : ZONE NUMBER : ,I4,30H HAS NEGATIVE
     +OR ZERO IDENTITY)
  212 CONTINUE
      GO TO 105
  104 I99=1
      WRITE(6,308)T8
  308 FORMAT(//1H ,27H ERROR FOUND : T8 VALUE OF ,I4,23H IS OUT OF RANGE
     + 1 - 10)
      GO TO 900
C
C     ******    ELEMENT CHECKS     *******
C
  105 DO 2201 I=1,T5
      IF(F1(I).GT.0) GO TO 350
      I99=1
      WRITE(6,309)I
  309 FORMAT(//1H ,32H ERROR FOUND : ELEMENT NUMBER : ,I4,30H HAS NEGATI
     +VE OR ZERO IDENTITY)
  350 IF(I.EQ.T5) GO TO 351
      DO 221 J=(I+1),T5
      IF(F1(I).NE.F1(J)) GO TO 221
      I99=1
      WRITE(6,310)I,J
  310 FORMAT(//1H ,32H ERROR FOUND : ELEMENT NUMBER : ,I4,5H AND ,I4,31H
     + IN LIST HAVE THE SAME IDENTITY)
  221 CONTINUE
  351 IF(F2(I).GT.0.0) GO TO 352
      I99=1
      WRITE(6,311)I
  311 FORMAT(//1H ,32H ERROR FOUND : ELEMENT NUMBER : ,I4,35H IN LIST HA
     +S INCORRECT ELEMENT TIME)
  352 IF(F3(I).GE.0.0) GO TO 353
      I99=1
      WRITE(6,312)I
  312 FORMAT(//,1H ,32H ERROR FOUND : ELEMENT NUMBER : ,I4,30H INLIST HA
     +S INCORRECT VARIANCE)
  353 IF(F8(I).GT.0.0.AND.F8(I).LE.F2(I)) GO TO 354
      I99=1
      WRITE(6,313)I
  313 FORMAT(//1H ,32H ERROR FOUND : ELEMENT NUMBER : ,I4,39H IN LIST HA
     +S INCORRECT MINIMUM DURATION)
  354 DO 223 J=1,10
      IF(F4(I,J).EQ.0) GO TO 223
      DO 222 K=1,T5
      IF(F4(I,J).NE.F1(K)) GO TO 222
      GO TO 223
  222 CONTINUE
      I99=1
      WRITE(6,314)I,J
```

```
  314 FORMAT(//1H ,32H ERROR FOUND : ELEMENT NUMBER : ,I4,19H FOLLOWER N
     +UMBER : ,I4,35H IN LIST IS NOT AN ACCEPTED ELEMENT)
  223 CONTINUE
C
C     *****    ELEMENT RESOURCES CHECKS     *****
C
      KK=0
      DO 224 J=1,10
      IF(F5(I,J).EQ.0) GO TO 224
      KK=KK+1
      DO 2231 K=1,T3
      IF(F5(I,J).NE.D1(K)) GO TO 2231
      GO TO 224
 2231 CONTINUE
      I99=1
      WRITE(6,315)I,J
  315 FORMAT(//1H ,32H ERROR FOUND : ELEMENT NUMBER : ,I4,19H RESOURCE N
     +UMBER : ,I4,36H IN LIST IS NOT AN ACCEPTED RESOURCE)
  224 CONTINUE
      IF(KK.GT.0) GO TO 355
      I99=1
      WRITE(6,316)I
  316 FORMAT(//1H ,14H ERROR FOUND :,45H NO RESOURCES SPECIFIED FOR ELEM
     +ENT NUMBER : ,I4,8H IN LIST)
C
C     *****    RESOURCE LEVELS CHECK    *****
C
  355 DO 225 J=1,10
      IF(F5(I,J).EQ.0) GO TO 225
      IF(F51(I,J).GT.0) GO TO 225
      I99=1
      WRITE(6,317)I,J
  317 FORMAT(//1H ,32H ERROR FOUND : ELEMENT NUMBER : ,I4,19H RESOURCE N
     +UMBER : ,I4,37H IN LIST HAS INCORRECT RESOURCE LEVEL)
  225 CONTINUE
C
C     *****    ELEMENT MODELS CHECKS    *****
C
      KK=0
      DO 227 J=1,10
      IF(F6(I,J).EQ.0) GO TO 227
      KK=KK+1
      DO 226 K=1,T6
      IF(F6(I,J).NE.E1(K)) GO TO 226
      GO TO 227
  226 CONTINUE
      I99=1
      WRITE(6,318)I,J
  318 FORMAT(//1H ,32H ERROR FOUND : ELEMENT NUMBER : ,I4,16H MODEL NUMB
     +ER : ,I4,30H IN LIST IS NOT ACCEPTED MODEL)
  227 CONTINUE
      IF(KK.GT.0) GO TO 356
      I99=1
      WRITE(6,319)I
  319 FORMAT(//1H ,14H ERROR FOUND :,42H NO MODELS SPECIFIED FOR ELEMENT
     + NUMBER : ,I4,8H IN LIST)
C
C     *****    ELEMENT WORKING ZONES CHECKS    *****
C
  356 KK=0
```

```
      DO 229 J=1,10
      IF(F9(I,J).EQ.0) GO TO 229
      KK=KK+1
      DO 228 K=1,T8
      IF(F9(I,J).NE.Z1(K)) GO TO 228
      GO TO 229
  228 CONTINUE
      I99=1
      WRITE(6,320)I,J
  320 FORMAT(//1H ,32H ERROR FOUND : ELEMENT NUMBER : ,I4/15H ZONE NUMBE
     +R : ,I4,29H IN LIST IS NOT ACCEPTED ZONE)
  229 CONTINUE
      IF(KK.GT.0) GO TO 357
      I99=1
      WRITE(6,321)I
  321 FORMAT(//1H ,14H ERROR FOUND :,41H NO ZONES SPECIFIED FOR ELEMENT
     +NUMBER : ,I4,8H IN LIST)
 2201 CONTINUE
C
C
C     *****    TIME CHECKS    *****
C
  357 IF(T9.GT.0.0) GO TO 358
      I99=1
      WRITE(6,322)
  322 FORMAT(//1H ,14H ERROR FOUND :,41H NUMBER OF TIME UNITS PER SHIFT
     +INCORRECT)
  358 IF(T10.GT.0.0) GO TO 9999
      I99=1
      WRITE(6,323)
  323 FORMAT(//1H ,40H NUMBER OF TIME UNITS PER HOUR INCORRECT)
C
C             ********************************************
C             ********************************************
C             ****                                    ****
C             ****          WRITING THE DATA          ****
C             ****                                    ****
C             ********************************************
C             ********************************************
C
 9999 IF(I99.EQ.1) GO TO 40
      WRITE(6,39)
   39 FORMAT(//1H ,103H*********************   WRITE OUT DATA  - NO ERR
     1OR FOUND -  DATA SATISFACTORY   *********************)
      GO TO 42
   40 WRITE(6,41)
   41 FORMAT(//1H ,99H       ***********************        ERROR FOUND
     1JOB FINISHED       ******************************)
   42 WRITE(6,43)
   43 FORMAT(1H ,16X,70H**********************************************
     1***********************)
      WRITE(6,44)
   44 FORMAT(1H ,16X,70H**********************************************
     1***********************)
      WRITE(6,45)
   45 FORMAT(1H ,16X,3H***,64X,3H***)
      WRITE(6,46)(T1(I),I=1,8)
   46 FORMAT(1H ,16X,3H***,8A8,3H***)
      WRITE(6,47)
   47 FORMAT(1H ,16X,3H***,64X,3H***)
      WRITE(6,48)
```

```
   48 FORMAT(1H ,16X,70H************************************************
     1**********************)
      WRITE(6,49)
   49 FORMAT(1H ,16X,70H************************************************
     1**********************)
      WRITE(6,50)
   50 FORMAT(1H ,16X,70H************************************************
     1**********************)
      WRITE(6,51)T5
   51 FORMAT(1H ,16X,27H***   NUMBER OF ELEMENTS = ,I4,36X,3H***)
      WRITE(6,52)
   52 FORMAT(1H ,16X,70H************************************************
     1**********************)
      DO 243 I=1,T5
      WRITE(6,53)
   53 FORMAT(1H ,103H***************************************************
     1****************************************************)
      WRITE(6,54)
   54 FORMAT(1H ,103H*                                  *
     1                                                  *)
      WRITE(6,55)F1(I),(F7(I,J),J=1,7)
   55 FORMAT(1H ,18H* ELEMENT NUMBER :,I4,16H * DESCRIPTION :,7A8,7X,2H
     1*)
      WRITE(6,56)
   56 FORMAT(1H ,103H*                                  *
     1                                                  *)
      WRITE(6,57)
   57 FORMAT(1H ,24H------------------------,77X,2H *)
      WRITE(6,58)
   58 FORMAT(1H ,2H* ,99X,2H *)
      WRITE(6,59)F2(I),F3(I),F8(I)
   59 FORMAT(1H ,17H* ELEMENT TIME :_,F6.2,5X,21H  ELEMENT VARIANCE : ,F
     16.2,5X,28H  ELEMENT MINIMUM DURATION :,F6.2,7X,2H *)
      WRITE(6,60)
   60 FORMAT(1H ,2H* ,99X,2H *)
      J10=0
      DO 240 J=1,10
      IF(F4(I,J).GT.0) J10=J
  240 CONTINUE
      IF(J10.EQ.0) GO TO 62
      WRITE(6,61)(F4(I,J),J=1,J10)
   61 FORMAT(1H ,30H* LIST OF FOLLOWERS           :,10I4)
   62 IF(J10.EQ.0) WRITE(6,63)
   63 FORMAT(1H ,35H* LIST OF FOLLOWERS           : NONE)
      WRITE(6,631)
  631 FORMAT(1H+,101X,2H *)
      J10=0
      DO 241 J=1,10
      IF(F5(I,J).GT.0) J10=J
  241 CONTINUE
      IF(J10.EQ.0) GO TO 65
      WRITE(6,64)(F5(I,J),J=1,J10)
   64 FORMAT(1H ,30H* LIST OF RESOURCES           :,10I4)
   65 IF(J10.EQ.0) WRITE(6,66)
   66 FORMAT(1H ,35H* LIST OF RESOURCES           : NONE)
      WRITE(6,661)
  661 FORMAT(1H+,101X,2H *)
      J10=0
      DO 820 J=1,10
      IF(F51(I,J).GT.0)J10=J
```

```
820 CONTINUE
    IF(J10.EQ.0)GOTO 811
    WRITE(6,810)(F51(I,J),J=1,J10)
810 FORMAT(1H ,30H* LEVEL OF RESOURCES          :,10I4)
811 IF(J10.EQ.0)WRITE(6,812)
812 FORMAT(1H ,35H* LEVEL OF RESOURCES          : NONE)
    WRITE(6,661)
    J10=0
    DO 410 J=1,10
    IF(F9(I,J).GT.0) J10=J
410 CONTINUE
    IF(J10.EQ.0) GO TO 412
    WRITE(6,411)(F9(I,J),J=1,J10)
411 FORMAT(1H ,30H* LIST OF WORKING ZONES       :,10I4)
412 IF(J10.EQ.0) WRITE(6,413)
413 FORMAT(1H ,35H* LIST OF WORKING ZONES       : NONE)
    WRITE(6,661)
    J10=0
    DO 242 J=1,10
    IF(F6(I,J).GT.0) J10=J
242 CONTINUE
    IF(J10.EQ.0) GO TO 68
    WRITE(6,67)(F6(I,J),J=1,J10)
 67 FORMAT(1H ,30H* LIST OF MODELS              :,10I4)
 68 IF(J10.EQ.0) WRITE(6,69)
 69 FORMAT(1H ,35H* LIST OF MODELS              : NONE)
    WRITE(6,691)
691 FORMAT(1H*,101X,2H *)
    WRITE(6,70)
 70 FORMAT(1H ,103H****************************************************
   1***************************************************)
243 CONTINUE
    WRITE(6,79)
    WRITE(6,324)
324 FORMAT(1H ,21H* TIME INFORMATION :-,27X,1H*)
    WRITE(6,79)
    WRITE(6,78)
    WRITE(6,325)T0
325 FORMAT(1H ,1H*,14H TIME UNITS = ,A8,25X,1H*)
    WRITE(6,326)T10
326 FORMAT(1H ,1H*,33H NUMBER OF TIME UNITS PER HOUR = ,F10.2,4X,1H*)
    WRITE(6,327)T9
327 FORMAT(1H ,1H*,24H SHIFT TIME AVAILABLE = ,F10.2,13X,1H*)
    WRITE(6,78)
    WRITE(6,79)
    WRITE(6,71)
 71 FORMAT(1H ,49H*************************************************)
    WRITE(6,72)T3
 72 FORMAT(1H ,33H* NUMBER OF SPECIAL FACILITIES = ,I4,10X,2H *)
    WRITE(6,73)
 73 FORMAT(1H ,49H*************************************************)
    WRITE(6,74)
 74 FORMAT(1H ,49H* FACILITIES AVAILABLE :-                       *)
    WRITE(6,75)
 75 FORMAT(1H ,49H*************************************************)
    WRITE(6,76)
 76 FORMAT(1H ,2H* ,45X,2H *)
    DO 244 I=1,T3
    WRITE(6,77)D1(I),(D11(I,J),J=1,4)
 77 FORMAT(1H ,1H*,I4,3H = ,4A8,7X,2H *).
```

```
  244 CONTINUE
      WRITE(6,78)
   78 FORMAT(1H ,2H* ,45X,2H *)
      WRITE(6,79)
   79 FORMAT(1H ,49H*************************************************)
      WRITE(6,80)
      WRITE(6,801)T8
  801 FORMAT(1H ,27H* NUMBER OF WORKING ZONES =,I4,43X,2H* )
      WRITE(6,82)
      WRITE(6,802)
  802 FORMAT(1H ,31H* WORKING ZONES DESCRIPTIONS :-,42X,2H *)
      WRITE(6,84)
      WRITE(6,85)
      DO 420 I=1,T8
      WRITE(6,803)Z1(I),(Z11(I,J),J=1,8)
  803 FORMAT(1H ,2H* ,I4,3H = ,8A8,2H *)
  420 CONTINUE
      WRITE(6,85)
      WRITE(6,84)
      WRITE(6,80)
   80 FORMAT(1H ,75H****************************************************
     1***********************)
      WRITE(6,81)T6
   81 FORMAT(1H ,21H* NUMBER OF MODELS = ,I4,48X,2H *)
      WRITE(6,82)
   82 FORMAT(1H ,75H****************************************************
     1***********************)
      WRITE(6,83)
   83 FORMAT(1H ,26H* MODELS SPECIFICATIONS :-,47X,2H *)
      WRITE(6,84)
   84 FORMAT(1H ,75H****************************************************
     1***********************)
      WRITE(6,85)
   85 FORMAT(1H ,2H* ,71X,2H *)
      DO 245 I=1,T6
      WRITE(6,86)E1(I),(E11(I,J),J=1,8)
   86 FORMAT(1H ,2H* ,I4,3H = ,8A8,2H *)
  245 CONTINUE
      WRITE(6,85)
      WRITE(6,84)
  900 STOP
      END
      FINISH
EJ
****
```

<u>ALB 2</u>

<u>ASSEMBLY LINE BALANCING PROGRAM</u>

ALB 2 : ASSEMBLY LINE BALANCING PROGRAM

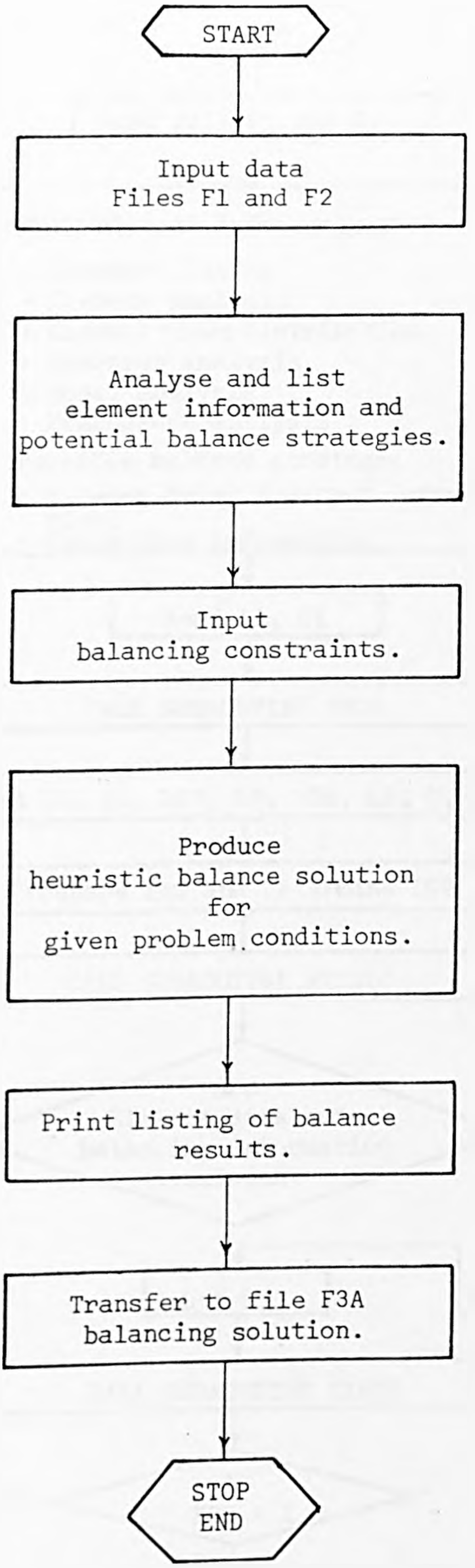


FIG. (C.3) GENERAL FLOW CHART ALB 2.

ALB 2 : ASSEMBLY LINE BALANCING PROGRAM.

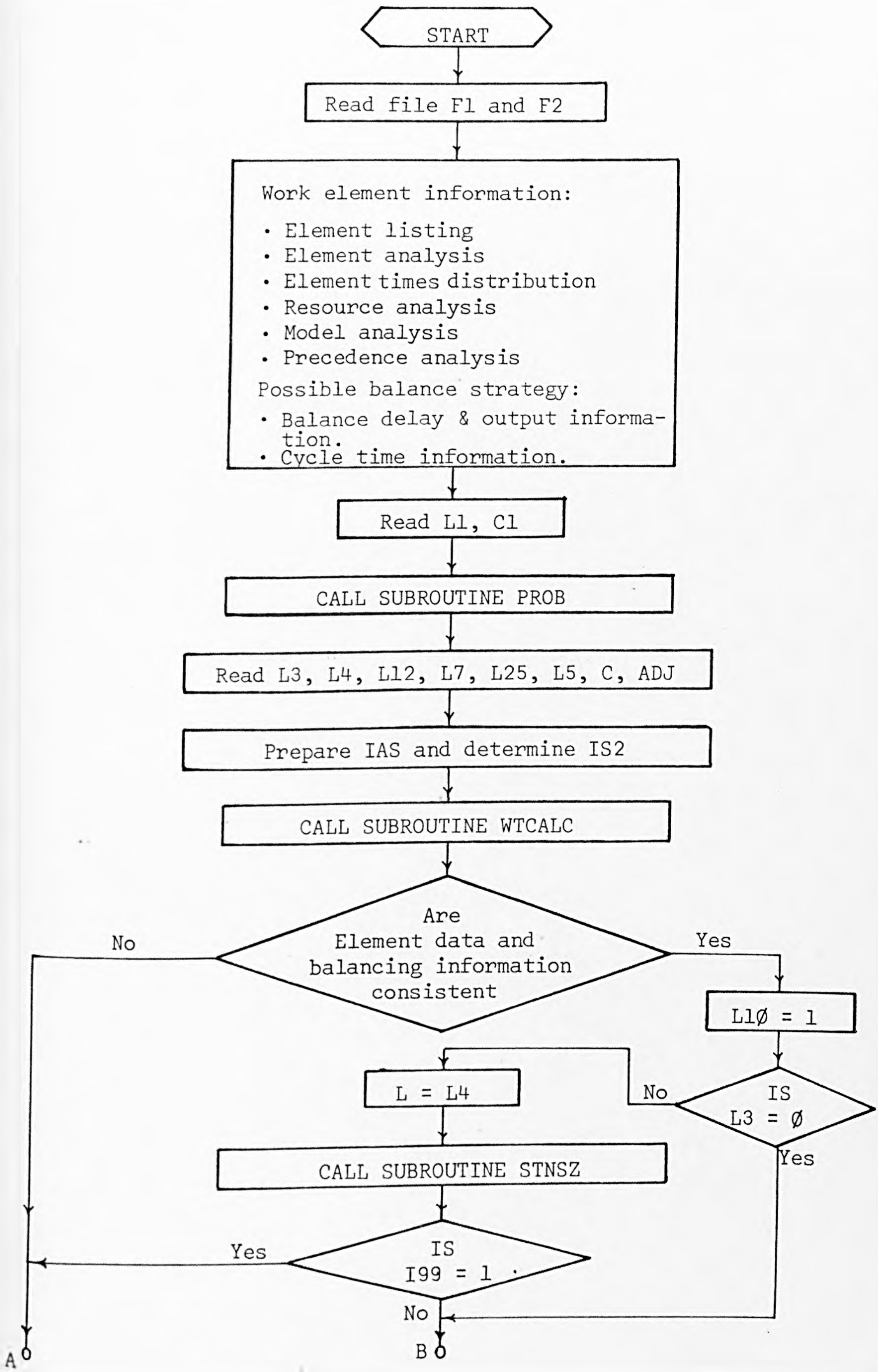


FIG. (C.3.A) DETAILED FLOW CHART ALB 2.

ALB 2 : ASSEMBLY LINE BALANCING PROGRAM.

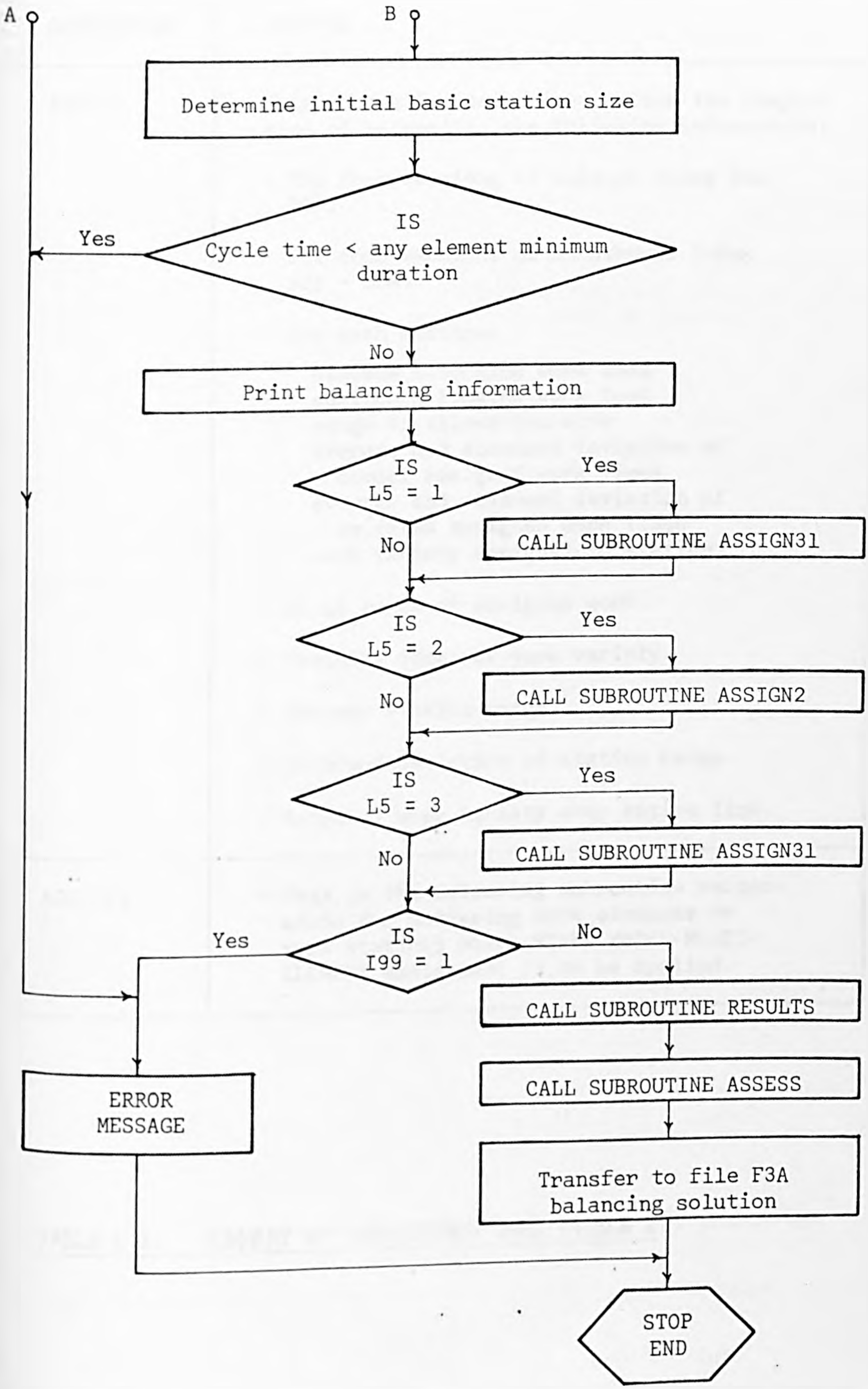


FIG. (C.3.B)   DETAILED FLOW CHART ALB 2 (Continuation).

SUBROUTINE	PURPOSE
ASSESS	This subroutine determines, after the completion of balancing, the following information: - The four versions of Balance Delay BD1-BD4. - The four versions of Smoothness Index SD1 - SD4. - For each station: minimum allocated work load maximum allocated work load range of allocation work average and standard deviation of normal assigned work times average and standard deviation of weighted assigned work times work variety assigned to station. - Total range of assigned work. - Training index of work variety. - Average station range. - Standard deviation of station range. - Range of work variety over entire line.
ASSIGN2	- This is the balancing subroutine responsible for assigning work elements to work stations where MIXED MODEL-MULTI-ELEMENT assignment is to be applied.

TABLE C.1. SUMMARY OF SUBROUTINES USED IN ALB 2.

ASSIGN31	This is the balancing subroutine responsible for assigning work elements to work stations where either 1 - SINGLE MODEL BALANCING or 2 - MIXED MODEL SINGLE ELEMENT assignment is to be applied.
PREC	This subroutine determines at any point the precedence availability for assignment of any work element on a basis of precedence restrictions.
PROB	This subroutine determines the number of normal distribution standard deviations equivalent to a given percentage confidence level.
RESULTS	This subroutine prints the balance results which includes for each station: - station number - station size - assigned elements model by model - work content model by model - work duration model by model - compressed time model by model.
STNSZ	Determines the estimated basic station size required to complete a viable balance assignment where a limit on line length applies.
WTCALC	This subroutine calculates the weight associated with each element and the ranks elements in order of highest weight first. For single model and mixed model multi element assignment, element weights are based on element time plus element times of all followers. For mixed model single element assignment the weights are modified by relative model ratios.

TABLE C.1. SUMMARY OF SUBROUTINES USED IN ALB 2 (Continuation)

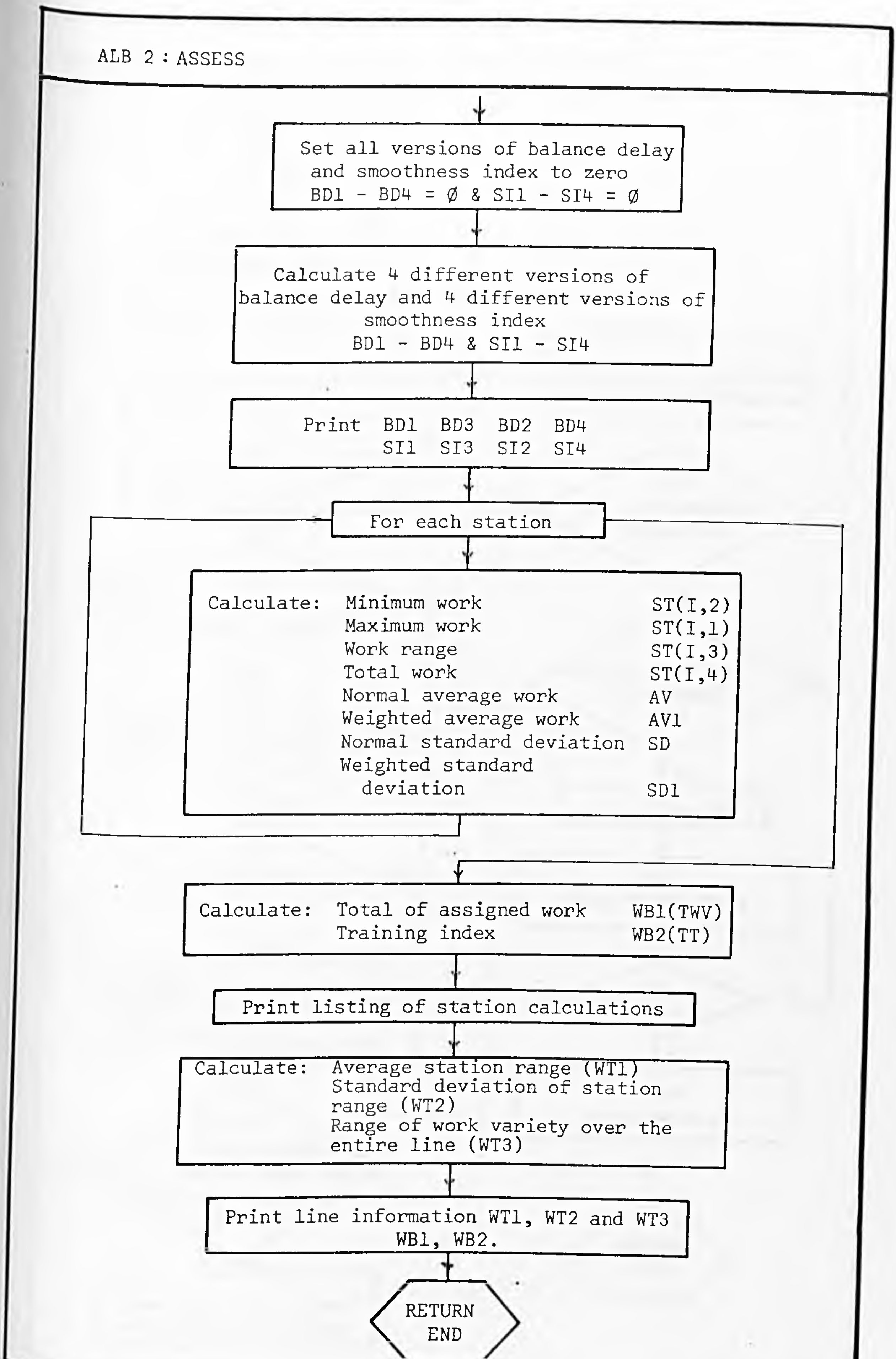


FIG. (C.4) FLOW CHART FOR SUBROUTINE ASSESS

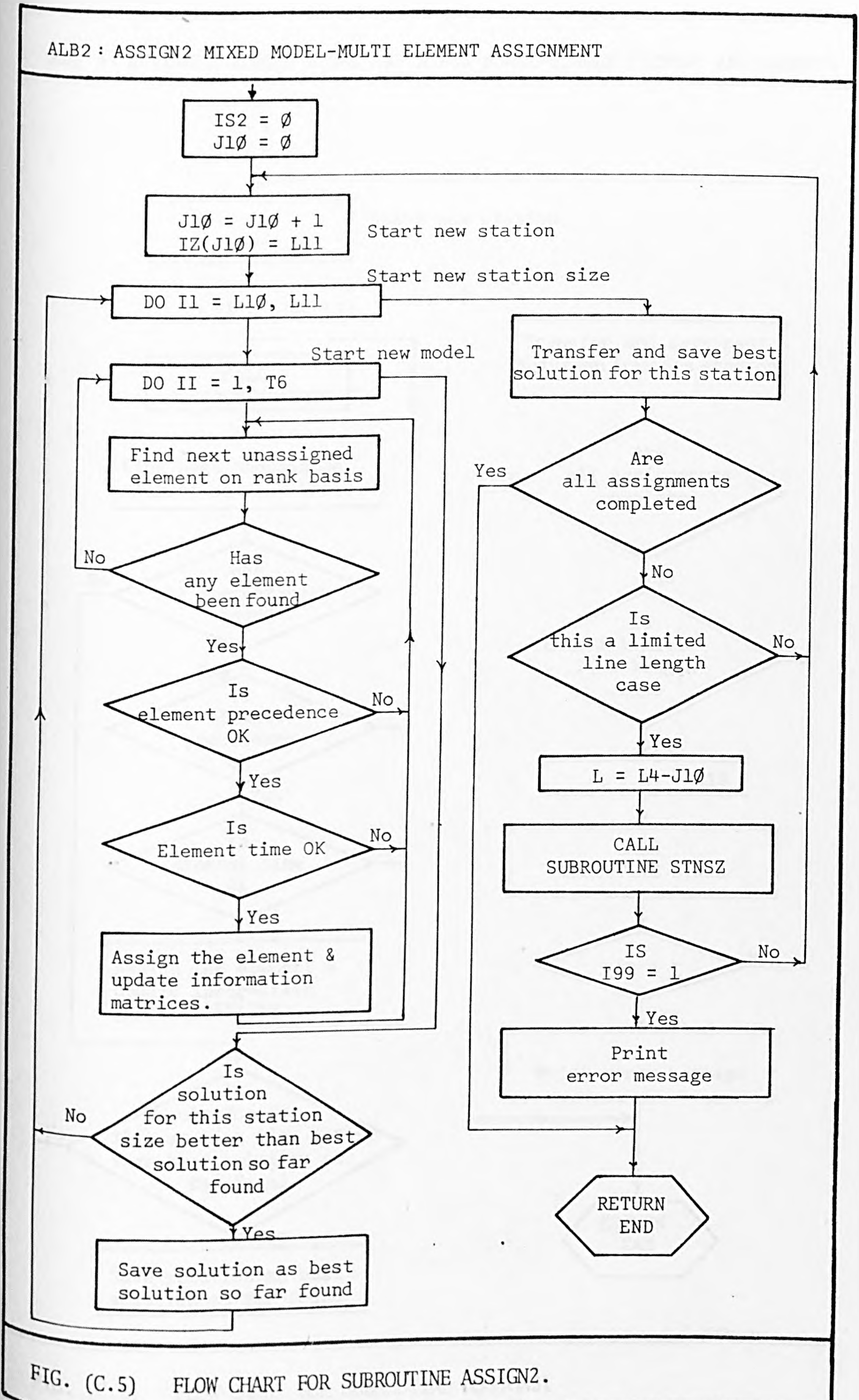


FIG. (C.5) FLOW CHART FOR SUBROUTINE ASSIGN2.

ALB 2 : ASSIGN31 SINGLE MODEL AND MIXED MODEL-SINGLE ELEMENT ASSIGNMENT.

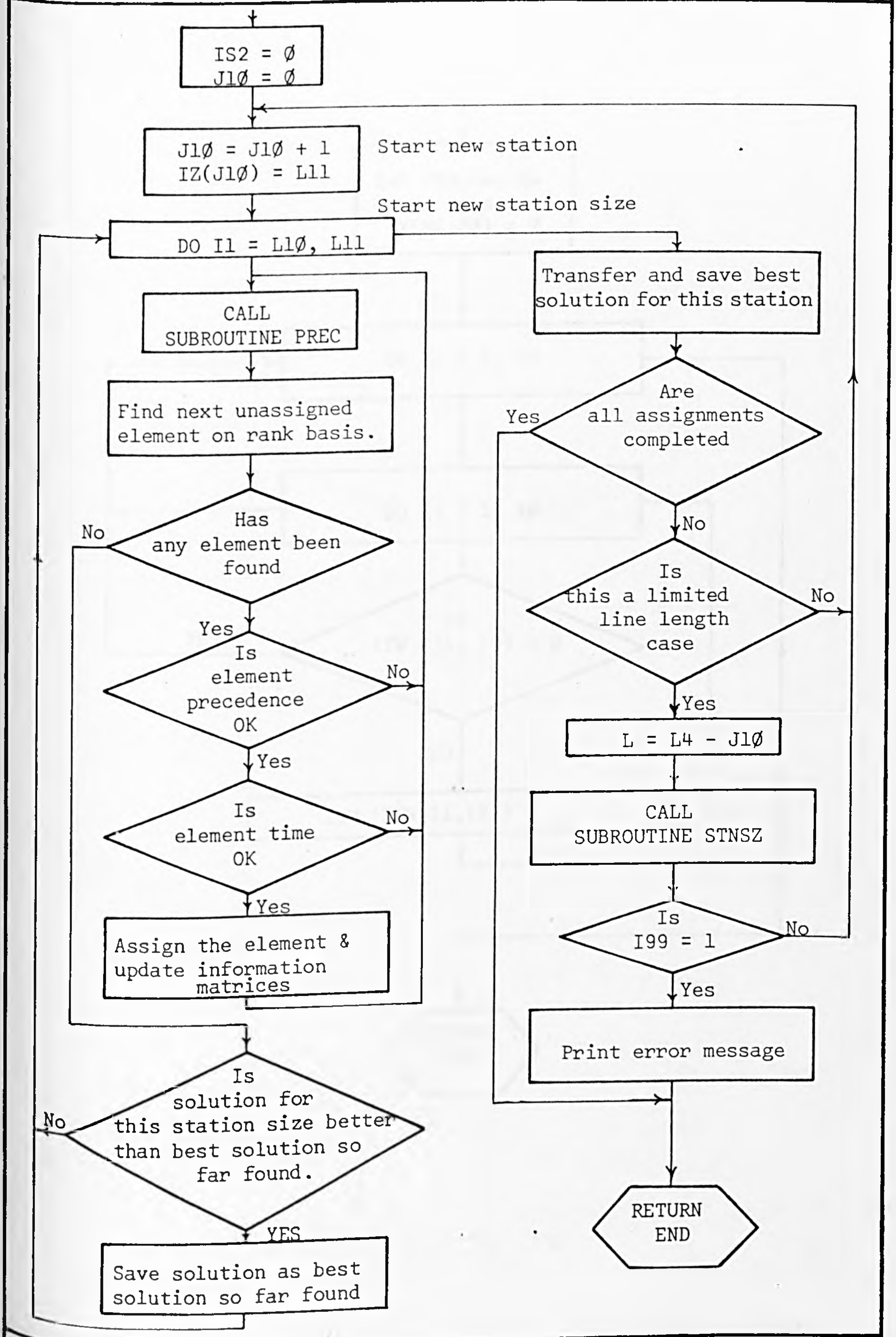


FIG. (C.6) FLOW CHART FOR SUBROUTINE ASSIGN31

ALB2: PREC

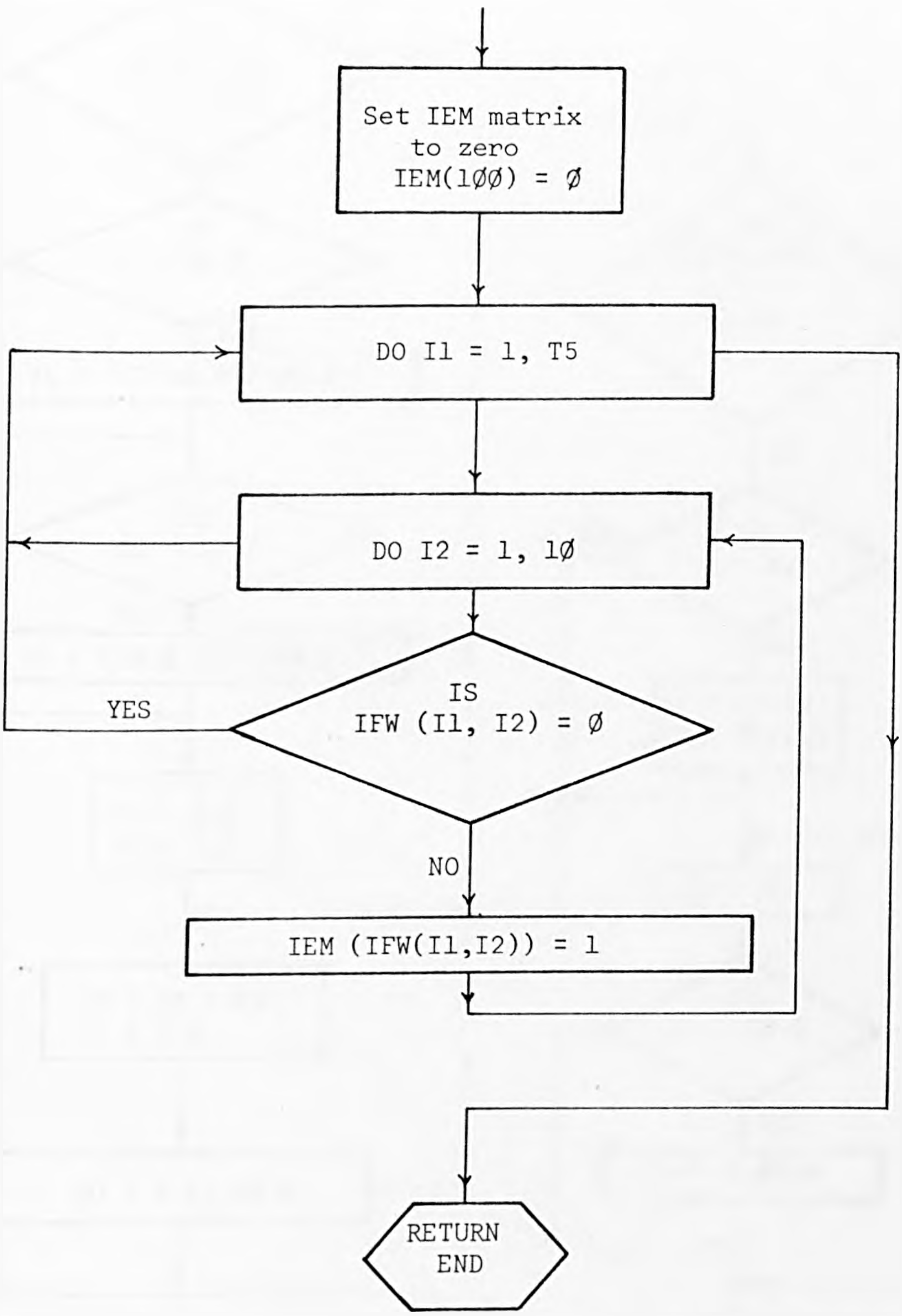


FIG. (C.7) FLOW CHART FOR SUBROUTINE PREC.

ALB2: PROB

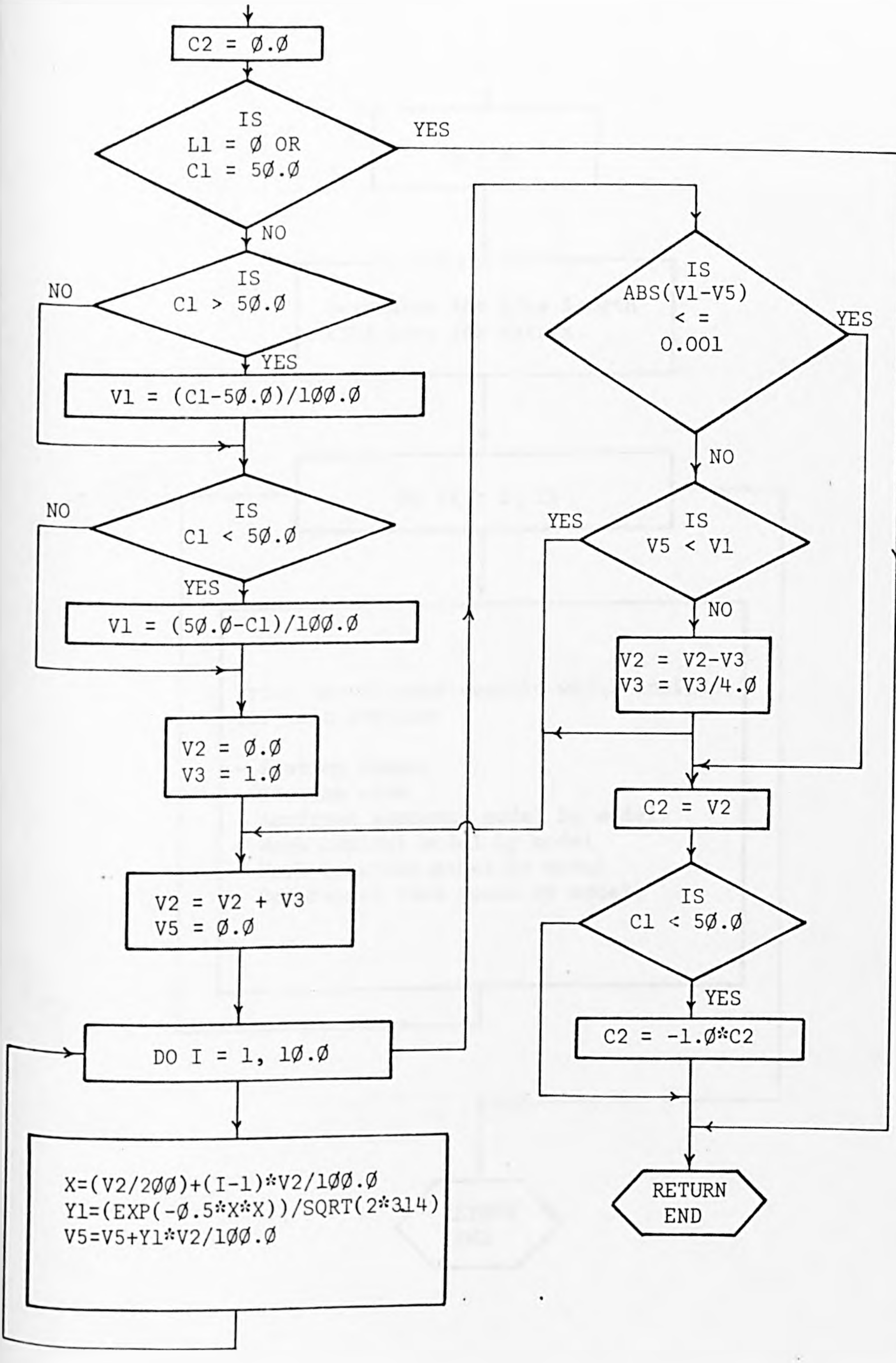


FIG. (C.8) DETAILED FLOW CHART FOR SUBROUTINE PROB.

ALB2: RESULTS

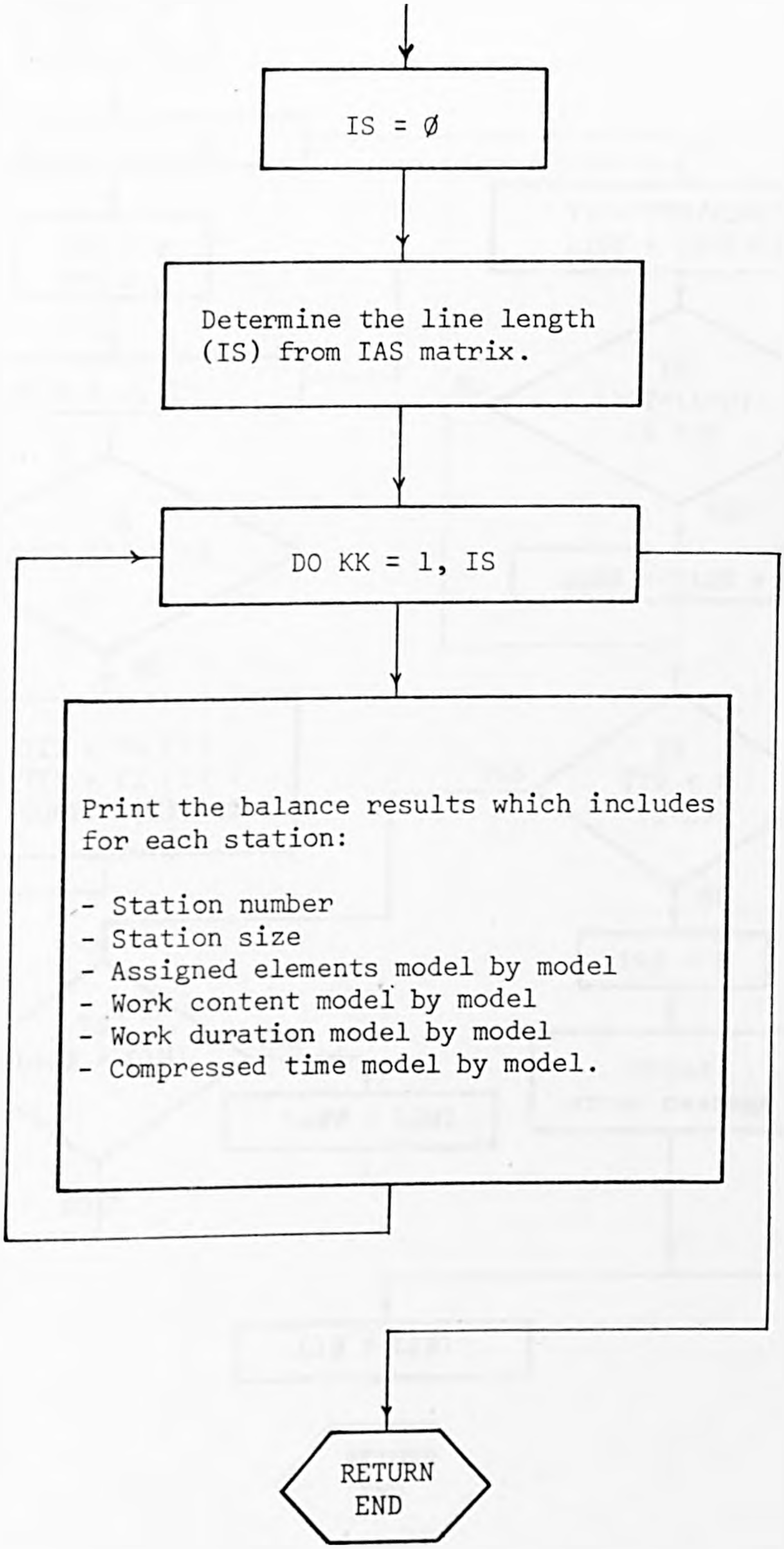


FIG. (C.9) FLOW CHART FOR SUBROUTINE RESULTS.

ALB2: STNSZ

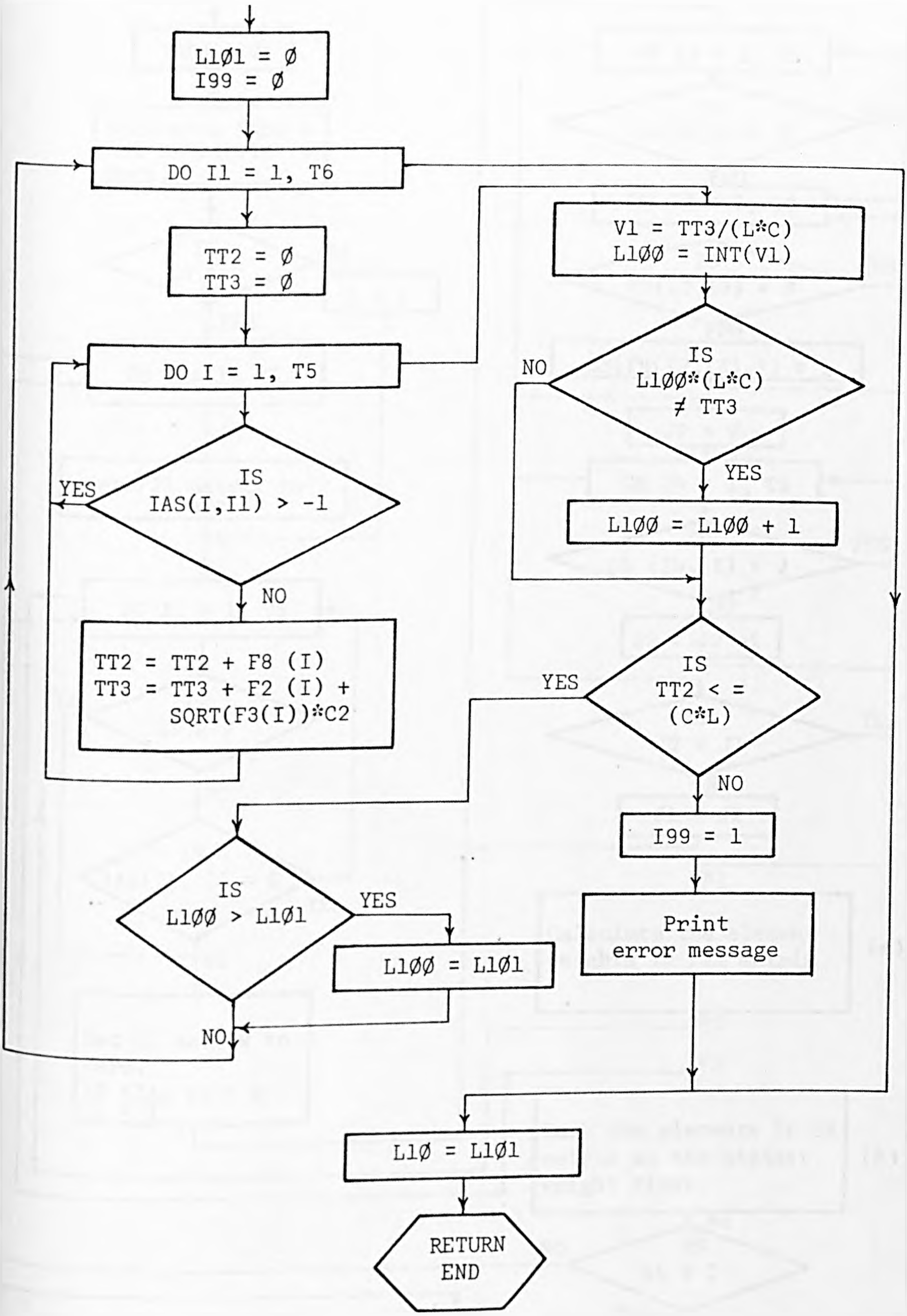


FIG. (C.10) DETAILED FLOW CHART FOR SUBROUTINE STNSZ.

ALB2: WTCALC (Part 1)

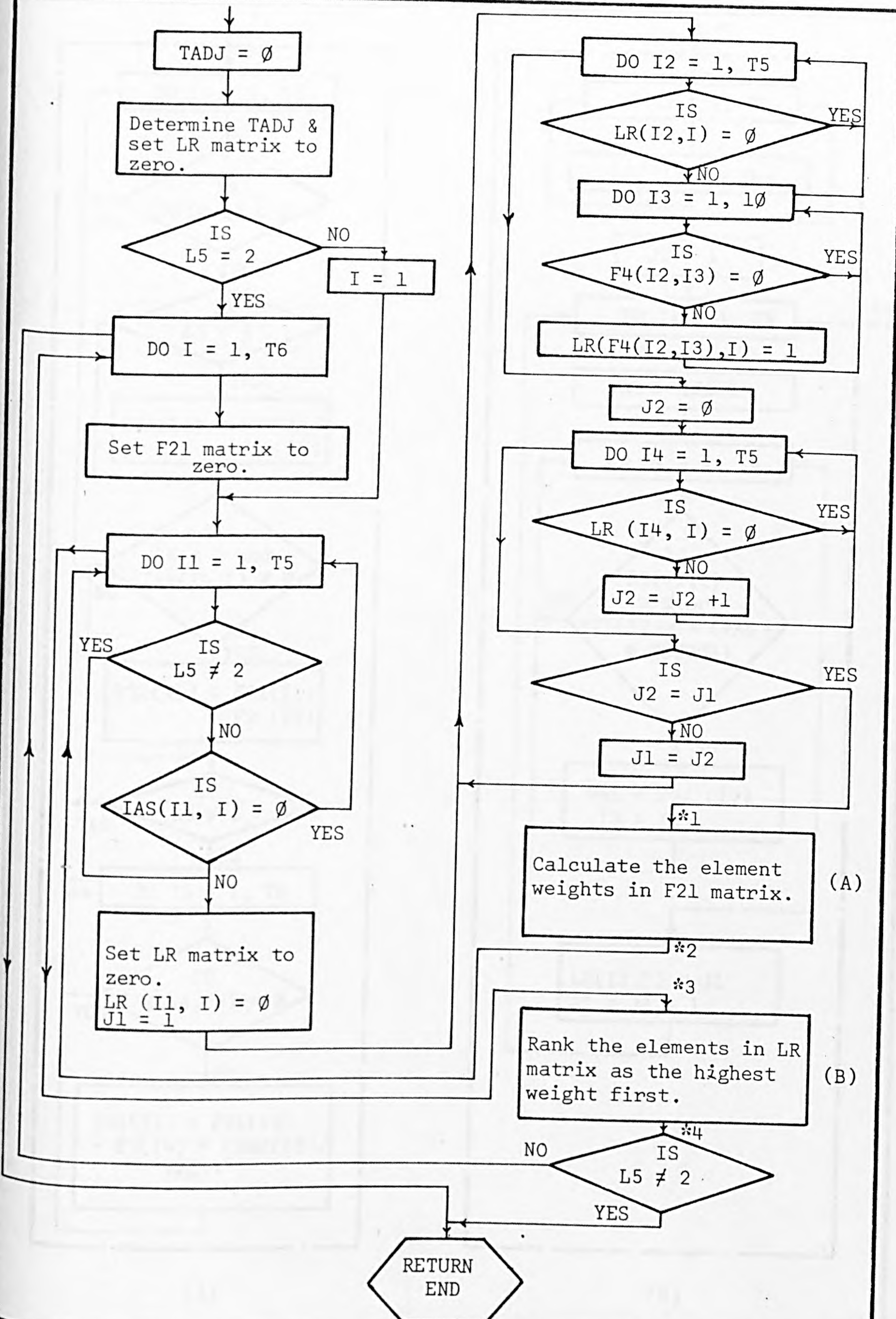


FIG. (C.11.A) DETAILED FLOW CHART FOR SUBROUTINE WTCALC.

ALB2: WTCALC (Part 2)

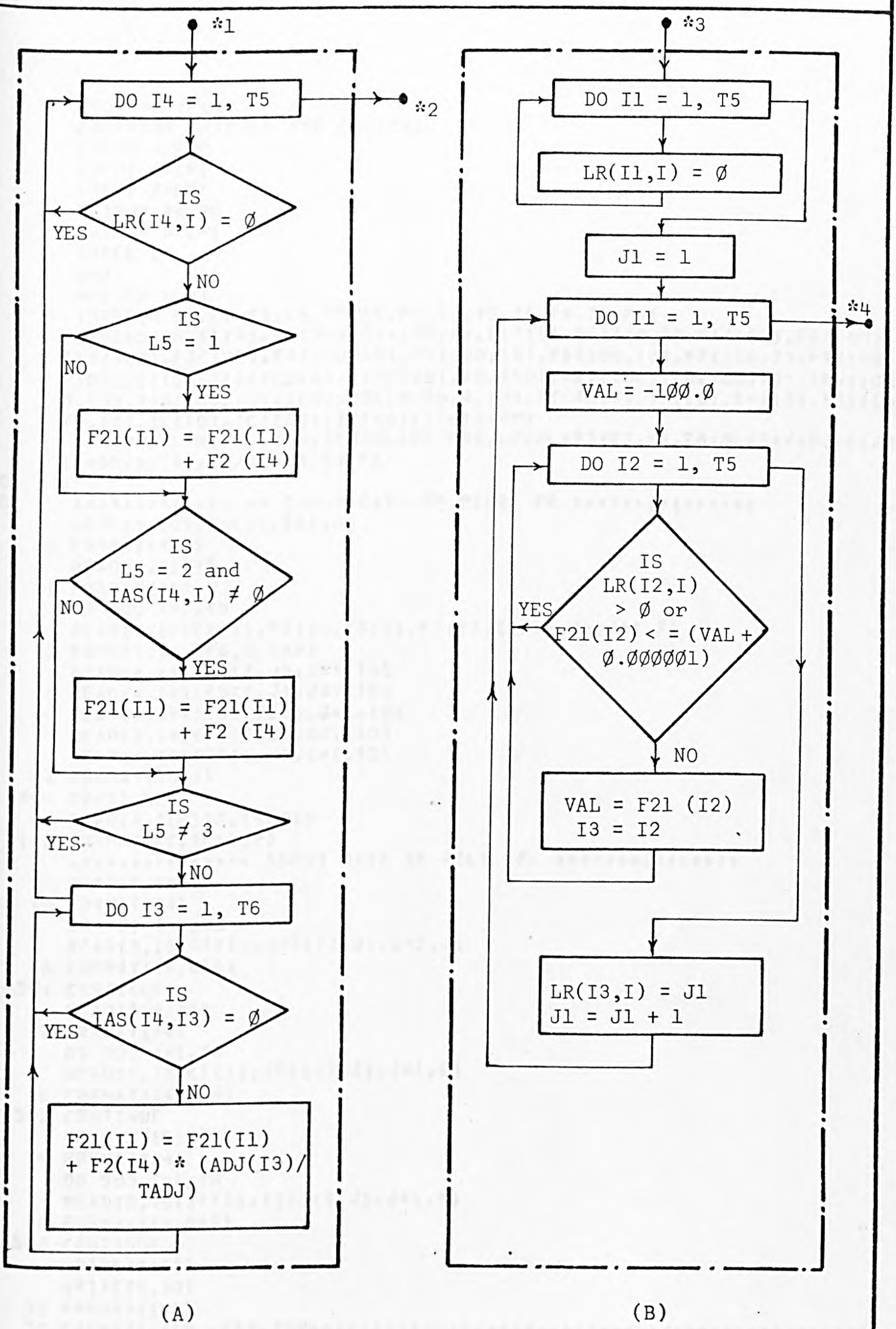


FIG. (C.11.B) WEIGHT AND RANKING SECTION OF SUBROUTINE WTCALC.

ALB2 PROGRAM

```
      PRØGRAM (FXXX)
      CØMPRESS INTEGER AND LØGICAL
      INPUT 4=CR0
      INPUT 5=CR1
      INPUT 7=CR7
      OUTPUT 6=LP0
      OUTPUT 8=CP1
      TRACE 2
      END
      MASTER ALB2
      INTEGER D1,E1,F1,F4,F5,F6,F9,T3,T5,T6,T8,Z1,F51
      DIMENSIØN T1(8),D1(30),D11(30,4),E1(10),E11(10,8),F1(100),F2(100),
     1F8(100),F3(100),F4(100,10),F5(100,10),F6(100,10),F7(100,7),F9(100,
     210),Z1(10),Z11(100,8),ITR(120),ADJ(10),F21(100),LR(100,10),IFW(100
     3,10),IAS(100,10),IEM(100),A(40,4,10),ST(40,4),TM(10),EM(10),F51(10
     40,10),IL(10),IC(100),IZ(40),IEM1(100)
      CØMMØN/SLAB1/F1,IFW,IEM/SLAB2/F21,LR/SLAB3/F2,F4,F6/SLAB4/ADJ,E1/S
     1LAB5/A,IAS,IZ/SLAB6/F3,F8
C
C     **************** INPUT DATA ØF FILE  F2 ***************
      READ(4,10)(T1(I),I=1,8)
   10 FØRMAT(8A8)
      READ(4,11)T5
   11 FØRMAT(I4)
      DØ 500 I=1,T5
      READ(4,12)F1(I),F2(I),F8(I),F3(I),(F7(I,J),J=1,7)
   12 FØRMAT(I4,3F6.2,7A8)
      READ(4,14)(F4(I,J),J=1,10)
      READ(4,14)(F5(I,J),J=1,10)
      READ(4,14)(F51(I,J),J=1,10)
      READ(4,14)(F6(I,J),J=1,10)
      READ(4,14)(F9(I,J),J=1,10)
   14 FØRMAT(10I4)
  500 CØNTINUE
      READ(4,118)T0,T9,T10
  118 FØRMAT(A8,2F10.2)
C     *************** INPUT DATA ØF FILE  F1 ***************
      READ(5,15)T3
   15 FØRMAT(I4)
      DØ 501 I=1,T3
      READ(5,16)D1(I),(D11(I,J),J=1,4)
   16 FØRMAT(I4,8A8)
  501 CØNTINUE
      READ(5,17)T6
   17 FØRMAT(I4)
      DØ 502 I=1,T6
      READ(5,18)E1(I),(E11(I,J),J=1,8)
   18 FØRMAT(I4,8A8)
  502 CØNTINUE
      READ(5,19)T8
   19 FØRMAT(I4)
      DØ 503 I=1,T8
      READ(5,20)Z1(I),(Z11(I,J),J=1,8)
   20 FØRMAT(I4,8A8)
  503 CØNTINUE
      WRITE(6,52)
      WRITE(6,30)
   52 FØRMAT(1H1)
   30 FØRMAT(//1H ,25X,70H*********************************************
     1*************************)
```

```
      WRITE(6,31)
   31 FØRMAT(1H ,25X,70H***********************************************
     1***********************)
      WRITE(6,32)
   32 FØRMAT(1H ,25X,2H**,66X,2H**)
      WRITE(6,33)T1
   33 FØRMAT(1H ,25X,2H**,1X,8A8,1X,2H**)
      WRITE(6,32)
      WRITE(6,31)
      WRITE(6,31)
      WRITE(6,96)
      WRITE(6,810)
  810 FØRMAT(1H ,1H*,118X,1H*)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,34)
   34 FØRMAT(1H ,1H*,5X,24H************************,89X,1H*)
      WRITE(6,35)
   35 FØRMAT(1H ,1H*,5X,1H*,22X,1H*,89X,1H*)
      WRITE(6,36)T0
   36 FØRMAT(1H ,1H*,5X,1H*,21H INFØRMATIØN ANALYSIS,2H *,21X,14H  TIME
     1UNITS =,3X,A8,43X,1H*)
      WRITE(6,37)T9
   37 FØRMAT(1H ,1H*,5X,1H*,22X,1H*,12X,24HNØRMAL SHIFT DURATIØN * ,F8.2
     1,45X,1H*)
      WRITE(6,34)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,39)
   39 FØRMAT(1H ,1H*,5X,14H**************,99X,1H*)
      WRITE(6,40)
   40 FØRMAT(1H ,1H*,5X,1H*,12X,1H*,99X,1H*)
      WRITE(6,41)
   41 FØRMAT(1H ,1H*,5X,14H*  ELEMENTS  *,99X,1H*)
      WRITE(6,40)
      WRITE(6,39)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,810)
C     ************** ELEMENT LISTING & ELEMENT REDUCTIØN RATIØ *********
      WRITE(6,50)
   50 FØRMAT(1H ,1H*,5X,18H ELEMENT LISTING ;,95X,1H*)
      WRITE(6,38)
   38 FØRMAT(1H ,1H*,24H************************,94X,1H*)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,810)
      DØ 510 I=1,T5
      J1=0
      J2=0
      J3=0
      J4=0
      DØ 509 I9=1,10
      IF(F6(I,I9).GT.0)J1=I9
      IF(F4(I,I9).GT.0)J2=I9
      IF(F9(I,I9).GT.0)J3=I9
      IF(F5(I,I9).GT.0)J4=I9
  509 CØNTINUE
```

```
      WRITE(6,810)
      WRITE(6,54)F1(I),F2(I),F8(I),F3(I)
   54 FØRMAT(1H ,1H*,5X,7HELEMENT,I4,8X,14HWØRK CONTENT =,F6.2,8X,18HMIN
     1IMUM DURATIØN =,F6.2,8X,15HWØRK VARIANCE =,F6.2,13X,1H*)
      WRITE(6,53)
   53 FØRMAT(1H ,1H*,12X,4H----,102X,1H*)
      WRITE(6,810)
      WRITE(6,51)(F6(I,J),J=1,J1)
   51 FØRMAT(1H ,1H*,32X,16HLIST ØF MØDELS :,2X,(10I4,1X))
      WRITE(6,811)
  811 FØRMAT(1H+,119X,1H*)
      WRITE(6,55)(F4(I,J),J=1,J2)
   55 FØRMAT(1H ,1H*,5X,20X,23H    LIST ØF FØLLØWERS :,2X,10(I4,1X))
      WRITE(6,811)
      WRITE(6,56)(F9(I,J),J=1,J3)
   56 FØRMAT(1H ,1H*,5X,20X,23HLIST ØF WØRKING ZØNES :,2X,10(I4,1X))
      WRITE(6,811)
      WRITE(6,57)(F5(I,J),J=1,J4)
   57 FØRMAT(1H ,1H*,5X,20X,23H    LIST ØF RESØURCES :,2X,10(I4,1X))
      WRITE(6,811)
      WRITE(6,58)(F51(I,J),J=1,J4)
   58 FØRMAT(1H ,1H*,5X,20X,23H     MINIMUM QUANTITY :,2X,10(I4,1X))
      WRITE(6,811)
      WRITE(6,810)
      WRITE(6,810)
  510 CONTINUE
C     ************** ANALYSIS CALCULATIØN **************
C     *** CONVERT F4 MATRIX FRØM NUMBERS TØ LØCATIØNS ***
      DØ 5012 I=1,T5
      DØ 5011 I1=1,10
      IF(F4(I,I1).EQ.0)GØTØ 5011
      DØ 5010 I2=1,T5
      IF(F1(I2).NE.F4(I,I1))GØTØ 5010
      F4(I,I1)=I2
      GØTØ 5011
 5010 CØNTINUE
 5011 CØNTINUE
 5012 CØNTINUE
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,96)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,810)
      N2=0
      N=0
      TT1=0.0
      TT2=0.0
      TMAX=0.0
      CMAX=0.0
      TMIN=1000.0
      CMIN=1000.0
      SUMN=0.0
      SUMP1=0.0
      SUMP2=0.0
      DØ 512 I=1,T5
      IF(F2(I).NE.F8(I)) N=N+1
      IF(F51(I,1).GT.1) N2=N2+1
      IF(F8(I).LT.CMIN) CMIN=F8(I)
```

```
      IF(F2(I).LT.TMIN) TMIN=F2(I)
      IF(F8(I).GT.CMAX) CMAX=F8(I)
      IF(F2(I).GT.TMAX) TMAX=F2(I)
      SUMN=SUMN+F2(I)
      TIM1=F2(I)+1.96*SQRT(F3(I))
      TIM2=F2(I)+3.09*SQRT(F3(I))
      SUMP1=SUMP1+TIM1
      SUMP2=SUMP2+TIM2
      TT1=TT1+F2(I)
      TT2=TT2+F8(I)
  512 CØNTINUE
      N1=T5-N
      TMEAN=TT1/FLØAT(T5)
      CMEAN=TT2/FLØAT(T5)
      SDN=0.0
      SDC=0.0
      DØ 513 I=1,T5
      SDN=(F2(I)-TMEAN)*(F2(I)-TMEAN)
      SDC=(F8(I)-CMEAN)*(F8(I)-CMEAN)
  513 CØNTINUE
      SDN=(SDN/FLØAT(T5))**0.5
      SDC=(SDC/FLØAT(T5))**0.5
C     ************* ELEMENT SUMMARY ***************
      WRITE(6,60)
   60 FØRMAT(1H ,1H*,5X,24H  ANALYSIS ØF ELEMENTS :,89X,1H*)
      WRITE(6,61)
   61 FØRMAT(1H ,1H*,29H*****************************,89X,1H*)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,62)
   62 FØRMAT(1H ,1H*,5X,9H  SUMMARY,104X,1H*)
      WRITE(6,63)
   63 FØRMAT(1H ,1H*,5X,9H  *******,104X,1H*)
      WRITE(6,810)
      WRITE(6,64)T5
   64 FØRMAT(1H ,1H*,5X,29H   TØTAL NUMBER ØF ELEMENTS =,I4,80X,1H*)
      WRITE(6,65)N
   65 FØRMAT(1H ,1H*,5X,41H  NUMBER ØF REDUCIBLE DURATIØN ELEMENTS =,I4,
     168X,1H*)
      WRITE(6,66)N2
   66 FØRMAT(1H ,1H*,5X,53H  NUMBER ØF ELEMENTS REQUIRING MØRE THAN ØNE
     1WØRKER =,I4,56X,1H*)
      IF(N2.GT.0) WRITE(6,67)
   67 FØRMAT(1H ,1H*,25X,34HTHIS MAY BEFØRE MØDIFIED BALANCING,59X,1H*)
      WRITE(6,810)
      WRITE(6,68)
   68 FØRMAT(1H ,1H*,48X,6H WØRK ,6X,12H  MINIMUM   ,46X,1H*)
      WRITE(6,69)
   69 FØRMAT(1H ,1H*,5X,42X,7HCØNTENT,5X,12H   DURATIØN   ,47X,1H*)
      WRITE(6,120)
  120 FØRMAT(1H ,1H*,5X,42X,7H-------,6X,12H ---------- ,46X,1H*)
      WRITE(6,810)
      WRITE(6,121)TMAX,CMAX
  121 FØRMAT(1H ,1H*,5X,38H                   MAXIMUM ELEMENT TIME =,5X,F6.
     12,9X,F6.2,49X,1H*)
      WRITE(6,122)TMIN,CMIN
  122 FØRMAT(1H ,1H*,5X,38H                   MINIMUM ELEMENT TIME =,5X,F6.
     12,9X,F6.2,49X,1H*)
      WRITE(6,123)TMEAN,CMEAN
  123 FØRMAT(1H ,1H*,5X,38H                      MEAN ELEMENT TIME =,5X,F6.
```

```
     12,9X,F6.2,49X,1H*)
      WRITE(6,124)SDN,SDC
  124 FØRMAT(1H ,1H*,5X,38H                  MEAN STANDARD DEVIATIØN =,5X,F6.
     12,9X,F6.2,49X,1H*)
      WRITE(6,125)TMIN,CMIN
  125 FØRMAT(1H ,1H*,5X,38H        RANGE ØF ELEMENT TIMES    FRØM :,5X,F6.
     12,9X,F6.2,49X,1H*)
      WRITE(6,126)TMAX,CMAX
  126 FØRMAT(1H ,1H*,5X,38H                                    TØ :,5X,F6.
     12,9X,F6.2,49X,1H*)
      WRITE(6,127)TT1,TT2
  127 FØRMAT(1H ,1H*,5X,38H                 TØTAL ELEMENT TIMES =,1X,F10
     1.2,9X,F6.2,49X,1H*)
      AR=TT2/TT1
      WRITE(6,900)AR
  900 FØRMAT(1H ,1H*,2X,41HAVERAGE MINIMUM DURATIØN / WØRK CØNTENT =,5X,
     1F6.2,64X,1H*)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,96)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,810)
C     *************** ELEMENT TIMES RANGE **************
      WRITE(6,70)
   70 FØRMAT(1H ,1H*,5X,30H  ELEMENT TIMES DISTRIBUTIØN  ,83X,1H*)
      WRITE(6,71)
   71 FØRMAT(1H ,1H*,35H***********************************,83X,1H*)
      WRITE(6,810)
      WRITE(6,73)
   73 FØRMAT(1H ,1H*,5X,25H    NØRMAL TIME RANGE    ,17H ELEMENT NUMBERS
     1 ,71X,1H*)
      WRITE(6,74)
   74 FØRMAT(1H ,1H*,5X,25H      FRØM :   TØ        ,88X,1H*)
      WRITE(6,810)
      RG=(TMAX-TMIN)/10.0
      DØ 520 I=1,11
      TR1=(TMIN-0.0001)+(I-1)*RG
      TR2=TR1+RG
      J1=1
      DØ 517 I1=1,30
      ITR(I1)=0
  517 CØNTINUE
      DØ 518 J=1,T5
      IF(F2(J).LT.TR1.ØR.F2(J).GT.TR2) GØ TØ 518
      ITR(J1)=F1(J)
      J1=J1+1
      IF(J1.LE.120) GØ TØ 518
      WRITE(6,75)
   75 FØRMAT(///1H ,35H***  ERRØR MATRIX ITR EXCEEDED  ***///)
      GØ TØ 9999
  518 CØNTINUE
      J2=1
      J3=J1-1
      IF(J3.EQ.0) WRITE(6,76)TR1,TR2
   76 FØRMAT(1H ,1H*,9X,F6.2,3H - ,F6.2,94X,1H*)
      IF(J3.EQ.0) GØ TØ 604
```

```
      IF((J1-1).GT.30) J3=30
      WRITE(6,77)TR1,TR2,(ITR(K),K=J2,J3)
   77 FØRMAT(1H ,1H*,9X,F6.2,3H - ,F6.2,3X,30I3)
      WRITE(6,811)
  604 DØ 519 L=1,3
      IF(J3.GE.(J1-1)) GØ TØ 520
      J2=J2+(30*L)
      J3=(J1-1)
      IF((J1-1).GT.(30+(30*L))) J3=(30+(3*L))
      WRITE(6,78)(ITR(K),K=J2,J3)
   78 FØRMAT(1H ,1H*,30X,30I3)
      WRITE(6,811)
  519 CØNTINUE
  520 CØNTINUE
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,96)
   96 FØRMAT(1H ,120H****************************************************
     1*****************************************************************
     2***)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,810)
C     *************** RESØURCES ***************
      WRITE(6,97)
   97 FØRMAT(1H ,1H*,5X,15H***************,98X,1H*)
      WRITE(6,98)
   98 FØRMAT(1H ,1H*,5X,1H*,13X,1H*,98X,1H*)
      WRITE(6,99)
   99 FØRMAT(1H ,1H*,5X,1H*,13H  RESØURCES  ,1H*,98X,1H*)
      WRITE(6,98)
      WRITE(6,97)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,100)
  100 FØRMAT(1H ,1H*,5X,10H RESØURCE ,5X,48H  ELEMENTS UTILISING RESØURC
     1E - MINIMUM QUANTITY,50X,1H*)
      WRITE(6,101)
  101 FØRMAT(1H ,1H*,5X,10H IDENTITY ,103X,1H*)
      WRITE(6,810)
C     *************** ALL RESØURCES ***************
      DØ 526 I=1,I3
      JJ=1
      XX=0.0
      DØ 525 J=1,I5
      DØ 524 K=1,10
      IF(F5(J,K).NE.D1(I)) GØ TØ 524
      IL(JJ)=F1(J)
      JJ=JJ+1
      IF(JJ.LT.11) GØ TØ 524
      IF(XX.EQ.1.0)GØ TØ 607
      WRITE(6,102)D1(I),(IL(JX),JX=1,(JJ-1))
  102 FØRMAT(1H ,1H*,5X,2X,I4,9X,10(I4,1X))
      WRITE(6,811)
      JJ=1
      XX=1.0
      GØ TØ 524
  607 WRITE(6,103)(IL(JX),JX=1,(JJ-1))
  103 FØRMAT(1H ,1H*,5X,15X,10(I4,1X))
```

```
      WRITE(6,811)
      JJ=1
  524 CONTINUE
  525 CONTINUE
      IF(JJ.EQ.1) GO TO 526
      IF(XX.EQ.1.0)GOTO 608
      WRITE(6,102)D1(I),(IL(JX),JX=1,(JJ-1))
      WRITE(6,811)
      GO TO 526
  608 WRITE(6,103)(IL(JX),JX=1,(JJ-1))
      WRITE(6,811)
  526 CONTINUE
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,96)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,104)
C     *************** MODELS CALCULATION ***************
  104 FORMAT(1H ,1H*,5X,12H************,101X,1H*)
      WRITE(6,105)
  105 FORMAT(1H ,1H*,5X,1H*,10X,1H*,101X,1H*)
      WRITE(6,106)
  106 FORMAT(1H ,1H*,5X,12H*  MODELS  *,101X,1H*)
      WRITE(6,105)
      WRITE(6,107)
  107 FORMAT(1H ,1H*,5X,12H************,101X,1H*)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,108)T6
  108 FORMAT(1H ,1H*,5X,3X,20H  NUMBER OF MODELS =,I2,88X,1H*)
      WRITE(6,810)
      WRITE(6,109)
  109 FORMAT(1H ,1H*,5X,3X,7H  MODEL,5X,18HNUMBER OF ELEMENTS,5X,18HTOTA
     1L WORK CONTENT,57X,1H*)
      WRITE(6,135)
  135 FORMAT(1H ,1H*,5X,5X,5H-----,5X,18H------------------,5X,18H------
     1------------,57X,1H*)
      WRITE(6,810)
      DO 529 I=1,T6
      N=0
      TW=0.0
      DO 528 J=1,T5
      DO 527 K=1,10
      IF(F6(J,K).NE.E1(I)) GO TO 527
      N=N+1
      TW=TW+F2(J)
      GO TO 528
  527 CONTINUE
  528 CONTINUE
      WRITE(6,110)E1(I),N,TW
  110 FORMAT(1H ,1H*,10X,I4,10X,I4,18X,F10.2,62X,1H*)
  529 CONTINUE
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,96)
```

```
C      *************** PRECEDENCE CALCULATIØNS ***************
       WRITE(6,810)
       WRITE(6,810)
       WRITE(6,810)
       WRITE(6,111)
  111 FØRMAT(1H ,1H*,5X,16H****************,97X,1H*)
       WRITE(6,112)
  112 FØRMAT(1H ,1H*,5X,1H*,14X,1H*,97X,1H*)
       WRITE(6,113)
  113 FØRMAT(1H ,1H*,5X,16H*  PRECEDENCE   *,97X,1H*)
       WRITE(6,112)
       WRITE(6,111)
C      *************** CØLUMNS CALCULATIØNS ***************
       DØ 531 I=1,T5
       DØ 531 J=1,10
  531 IFW(I,J)=F4(I,J)
       I1=0
  610 I1=I1+1
       DØ 532 I=1,T5
       IF(IC(I).GT.0)GØ TØ 532
       IC(I)=-1
  532 CØNTINUE
       DØ 534 I=1,T5
       DØ 534 J=1,10
       IF(IFW(I,J).EQ.0)GØ TØ 534
       IC(IFW(I,J))=0
  534 CØNTINUE
       I2=0
       DØ 536 I=1,T5
       IF(IC(I).NE.-1)GØ TØ 536
       IF(IC(I).GT.0)GØ TØ 536
       IC(I)=I1
       I2=1
       DØ 535 K=1,10
  535 IFW(I,K)=0
  536 CØNTINUE
       IF(I2.EQ.1)GØ TØ 610
       MIN11=1000
       MAX11=0
       DØ 538 I=1,(I1-1)
       ITØT=0
       DØ 537 J=1,T5
       IF(IC(J).NE.I)GØ TØ 537
       ITØT=ITØT+1
  537 CØNTINUE
       IF(ITØT.GT.MAX11)MAX11=ITØT
       IF(ITØT.LT.MIN11)MIN11=ITØT
  538 CØNTINUE
       WRITE(6,810)
       WRITE(6,810)
  611 WRITE(6,114)T5
  114 FØRMAT(1H ,1H*,5X,12X,22H  NUMBER ØF ELEMENTS =,I3,76X,1H*)
       JK=I1-1
       WRITE(6,115)JK
  115 FØRMAT(1H ,1H*,7X,32H  NUMBER ØF PRECEDENCE CØLUMNS =,I3,76X,1H*)
       WRITE(6,116)MIN11
  116 FØRMAT(1H ,1H*,5X,34H  MINIMUM PRECEDENCE CØLUMN SIZE =,I3,76X,1H*
     1)
       WRITE(6,117)MAX11
  117 FØRMAT(1H ,1H*,5X,34H  MAXIMUM PRECEDENCE CØLUMN SIZE =,I3,76X,1H*
```

```
     1)
      PD=FLØAT(T5)/FLØAT(JK)
      WRITE(6,130)PD
  130 FØRMAT(1H ,1H*,5X,9X,25H  PRECEDENCE DIFFICULTY =,F6.2,73X,1H*)
      WRITE(6,810)
      WRITE(6,132)
  132 FØRMAT(1H ,1H*,5X,8H  CØLUMN,5X,5H WØRK,7X,8HELEMENTS,80X,1H*)
      WRITE(6,812)
  812 FØRMAT(1H ,1H*,5X,8H  NUMBER,5X,7HCØNTENT,5X,8HINCLUDED,80X,1H*)
      WRITE(6,136)
  136 FØRMAT(1H ,1H*,5X,8H  ------,5X,7H-------,5X,8H--------,80X,1H*)
      WRITE(6,810)
      DØ 542 I=1,JK
      DØ 540 II=1,T5
      LR(II,1)=0
  540 CONTINUE
      JJ=0
      TC=0.0
      DØ 541 J=1,T5
      IF(IC(J).NE.I)GØTØ 541
      JJ=JJ+1
      TC=TC+F2(J)
      LR(JJ,1)=F1(J)
  541 CØNTINUE
      WRITE(6,133)I,TC,(LR(K,1),K=1,JJ)
  133 FØRMAT(1H ,1H*,5X,3X,I3,6X,F6.2,8X,20I4)
      WRITE(6,811)
  542 CØNTINUE
C     *************** BALANCE DELAY  &  ØUTPUT  INFØRMATIØN   *********
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,810)
      WRITE(6,96)
      WRITE(6,52)
      WRITE(6,230)
  230 FØRMAT(1H ,10X,100H****************************************************
     1************************************************)
      WRITE(6,231)
  231 FØRMAT(1H ,10X,1H*,98X,1H*)
      WRITE(6,231)
      WRITE(6,231)
      WRITE(6,42)
   42 FØRMAT(1H ,10X,1H*,5X,31H*******************************,62X,1H*)
      WRITE(6,43)
   43 FØRMAT(1H ,10X,1H*,5X,1H*,29X,1H*,62X,1H*)
      WRITE(6,44)
   44 FØRMAT(1H ,10X,1H*,5X,31H*  PØSSIBLE BALANCE STRATEGY  *,62X,1H*)
      WRITE(6,43)
      WRITE(6,42)
      WRITE(6,231)
      WRITE(6,231)
      WRITE(6,45)
   45 FØRMAT(1H ,10X,1H*,5X,19H*******************,74X,1H*)
      WRITE(6,46)
   46 FØRMAT(1H ,10X,1H*,5X,1H*,17X,1H*,74X,1H*)
      WRITE(6,47)
   47 FØRMAT(1H ,10X,1H*,5X,19H*  BALANCE GUIDE  *,74X,1H*)
      WRITE(6,46)
      WRITE(6,48)
   48 FØRMAT(1H ,10X,1H*,5X,19H*******************,74X,1H*)
```

```
      WRITE(6,231)
      WRITE(6,231)
      WRITE(6,232)
  232 FØRMAT(1H ,10X,1H*,5X,40H****************************************,
     153X,1H*)
      WRITE(6,233)
  233 FØRMAT(1H ,10X,1H*,5X,1H*,38X,1H*,53X,1H*)
      WRITE(6,92)
   92 FØRMAT(1H ,10X,1H*,5X,1H*,36H  BALANCE DELAY & ØUTPUT INFØRMATIØN,
     13H  *,53X,1H*)
      WRITE(6,233)
      WRITE(6,232)
      WRITE(6,231)
      WRITE(6,231)
      WRITE(6,901)
  901 FØRMAT(1H ,10X,1H*,36X,7HSTATIØN,15X,8H AVERAGE,32X,1H*)
      I1=INT(SUMN/CMAX)
      IF((FLØAT(I1)*CMAX).LT.SUMN)I1=I1+1
      WRITE(6,94)
   94 FØRMAT(1H ,10X,1H*,12X,10HCYCLE TIME,4X,1H ,4X,18HCAPACITY REQUIRE
     1D ,8X,12HSHIFT ØUTPUT,10X,16H % BALANCE DELAY,3X,1H*)
      WRITE(6,231)
      I1=INT(SUMN/CMAX)
      IF((FLØAT(I1)*CMAX).LT.SUMN)I1=I1+1
      S1=T9/SUMN
      WRITE(6,906)SUMN,S1
  906 FØRMAT(1H ,10X,1H*,10X,F10.2,18X,4H 1  ,14X,F10.2,18X,6H  0.00,8X,
     11H*)
      DØ 910 I=2,I1
      WRITE(6,231)
      CT1=(SUMN/FLØAT(I-1))-0.01
      IF(CT1.LT.CMAX)CT1=CMAX
      S1=T9/CT1
      S2=(CT1*FLØAT(I)-SUMN)*100.00/(CT1*FLØAT(I))
      WRITE(6,907)CT1,I,S1,S2
  907 FØRMAT(1H ,10X,1H*,10X,F10.2,16X,I4,16X,F10.2,18X,F6.2,8X,1H*)
      IF(CT1.EQ.CMAX)GØTØ 909
      CT2=SUMN/FLØAT(I)
      IF(CT2.LT.CMAX)CT2=CMAX
      S1=T9/CT2
      S2=(CT2*FLØAT(I)-SUMN)*100.00/(CT2*FLØAT(I))
      IF(S2.LT.0.0)S2=0.0
      WRITE(6,907)CT2,I,S1,S2
      IF(CT2.EQ.CMAX)GØTØ 909
  910 CØNTINUE
C     ********    CYCLE TIME INFØRMATIØN    *********
  909 WRITE(6,231)
      WRITE(6,231)
      WRITE(6,231)
      WRITE(6,230)
      WRITE(6,231)
      WRITE(6,231)
      WRITE(6,231)
      WRITE(6,234)
  234 FØRMAT(1H ,10X,1H*,5X,28H****************************,65X,1H*)
      WRITE(6,235)
  235 FØRMAT(1H ,10X,1H*,5X,1H*,26X,1H*,65X,1H*)
      WRITE(6,80)
   80 FØRMAT(1H ,10X,1H*,5X,1H*,27H  CYCLE TIME INFØRMATIØN  *,65X,1H*)
      WRITE(6,235)
```

```
      WRITE(6,234)
      WRITE(6,231)
      WRITE(6,231)
      WRITE(6,83)
   83 FØRMAT(1H ,10X,1H*,30X,11HNØRMAL TIME,3X,16H97.5% CØNFIDENCE,3X,16
     1H99.9% CØNFIDENCE,10X,1H*)
      WRITE(6,128)
  128 FØRMAT(1H ,10X,1H*,30X,11H-----------,3X,16H----------------,3X,16
     1H----------------,10X,1H*)
      WRITE(6,84)SUMN,SUMP1,SUMP2
   84 FØRMAT(1H ,10X,1H*,5X,20H  MAXIMUM CYCLE TIME,5X,F10.2,7X,F10.2,9X
     1,F10.2,22X,1H*)
      WRITE(6,85)CMAX,CMAX,CMAX
   85 FØRMAT(1H ,10X,1H*,5X,20H  MINIMUM CYCLE TIME,5X,F10.2,7X,F10.2,9X
     1,F10.2,22X,1H*)
      WRITE(6,231)
      WRITE(6,231)
      WRITE(6,231)
      WRITE(6,230)
C     *************** INPUT ØF DATA ***************
      READ(7,201)L1,C1
      CALL PRØB (L1,C1,C2)
      READ(7,200)L3,L4,L12,L7,L25
  200 FØRMAT(20I4)
      READ(7,201)L5,C
  201 FØRMAT(I4,F6.2)
      DØ 700 I=1,T6
      ADJ(I)=1.0
  700 CØNTINUE
      READ(7,202)(ADJ(I),I=1,T6)
  202 FØRMAT(10F6.2)
C     *************** PREPARE IAS( ) ***************
      DØ 712 I1=1,T5
      DØ 712 I2=1,T6
  712 IAS(I1,I2)=0
      IS3=0
      DØ 715 I1=1,T5
      DØ 714 I2=1,10
      IF(F6(I1,I2).EQ.0)GØTØ 714
      IS3=IS3+1
      DØ 713 I3=1,T6
      IF(E1(I3).EQ.F6(I1,I2))IAS(I1,I3)=-1
  713 CØNTINUE
  714 CØNTINUE
  715 CØNTINUE
C     *************** PREPARING THE RANK ***************
      CALL WTCALC (T5,L5,T6)
      IF(T6.EQ.1.AND.L5.EQ.1)GØTØ 1000
      IF(T6.GT.1.AND.L5.GT.1)GØTØ 1000
      WRITE(6,203)L5,T6
  203 FØRMAT(//1H ,26H  INCØRRECT SØLUTIØN MØDEL,I4,20H SELECTED FØR PRØ
     1BLEM WITH,I4,7H MØDELS//)
      GØ TØ 9999
C     *************** LIMITED LINE LENGTH PRØBLEM ***************
 1000 L10=1
      IF(L3.EQ.0)GØTØ 1001
      L=L4
      CALL STNSZ (T5,T6,C2,C,L,L10,I99)
      IF(I99.EQ.1)GØTØ 9999
C     *************** ØVERSIZE ELEMENT SECTIØN ***************
```

```
 1001 L11=L10
      J1=0
      DØ 702 I=1,I5
      IF((F2(I)+SQRT(F3(I))*C2).LE.(L11*C))GØTØ 1002
      V1=(F2(I)+SQRT(F3(I))*C2)/C
      J=INT(V1)
      IF((J*C).NE.F2(I))J=J+1
      L11=J
 1002 IF(F8(I).LE.C)GØTØ 702
      J1=1
      WRITE(6,205)F1(I),C,F8(I)
  205 FØRMAT(/1H ,9H  ELEMENT,I4,41H  CAN NØT BE ALLØCATED IN A CYCLE TI
     1ME ØF,F6.2,28H  WITH A MINIMUM DURATIØN ØF,F6.2/)
  702 CØNTINUE
      IF(L11.LT.L25)L11=L25
      IF(J1.EQ.0)GØTØ 1003
      WRITE(6,206)
  206 FØRMAT(//1H ,75H  PRØBLEMS WITH CYCLE TIME AND ELEMENT MINIMUM DUR
     1ATIØN - BALANCING STØPPED//)
      GØ TØ 9999
 1003 WRITE(6,52)
      WRITE(6,207)
  207 FØRMAT(////1H ,10X,110H***********************************************
     1**************************************************************
     2*)
      WRITE(6,208)
  208 FØRMAT(1H ,10X,1H*,108X,1H*)
      IF(L5.EQ.1)WRITE(6,209)
  209 FØRMAT(1H ,10X,1H*,43X,22HSINGLE MØDEL BALANCING,43X,1H*/1H ,10X,1
     1H*,43X,22H**********************,43X,1H*)
      WRITE(6,208)
      IF(L5.EQ.1)WRITE(6,210)C,T0
  210 FØRMAT(1H ,10X,1H*,23H  SELECTED CYCLE TIME =,F6.2,A8,5X,43HSELECT
     1ED PRØCEDURE : SINGLE MØDEL BALANCING,23X,1H*)
      IF(L5.GT.1)WRITE(6,211)
  211 FØRMAT(1H ,10X,1H*,43X,21HMIXED MØDEL BALANCING,44X,1H*/1H ,10X,1H
     1*,43X,21H*********************,44X,1H*)
      WRITE(6,208)
      IF(L5.EQ.2)WRITE(6,212)C,T0
  212 FØRMAT(1H ,10X,1H*,23H  SELECTED CYCLE TIME =,F6.2,1X,A8,5X,59HSEL
     1ECTED PRØCEDURE : MIXED MØDEL - MULTI-ELEMENT ASSIGNMENT,6X,1H*)
      IF(L5.EQ.3)WRITE(6,213)C,T0
  213 FØRMAT(1H ,10X,1H*,23H  SELECTED CYCLE TIME =,F6.2,A8,1X,5X,60HSEL
     1ECTED PRØCEDURE : MIXED MØDEL - SINGLE ELEMENT ASSIGNMENT,5X,1H*)
      WRITE(6,214)L10,L11
  214 FØRMAT(1H ,10X,1H*,31H  INITIAL BASIC STATIØN SIZE  =,I3,2X,6X,31H
     1 INITIAL MAXIMUM STATIØN SIZE =,I4,31X,1H*)
      IF(L3.EQ.1)WRITE(6,215)L4
  215 FØRMAT(1H ,10X,1H*,23H  LIMITED LINE LENGTH =,I3,2X,8H STATIØN,72X
     1,1H*)
      IF(L3.EQ.0)WRITE(6,216)
  216 FØRMAT(1H ,10X,1H*,20H  NØ LIMIT ØN LENGTH,88X,1H*)
      IF(L1.EQ.0)WRITE(6,217)
  217 FØRMAT(1H ,10X,1H*,30H  DETERMINISTIC TIMES INCLUDED,78X,1H*)
      IF(L1.EQ.1)WRITE(6,218)C1,C2
  218 FØRMAT(1H ,10X,1H*,38H  VARIABLE ELEMENT TIMES INCLUDED WITH,F6.2,
     126H % CØNFIDENCE ( EQUIVALENT,F6.2,22H STANDARD DEVIATIØNS ),10X,1
     2H*)
      WRITE(6,208)
      WRITE(6,219)
```

```
  219 FORMAT(1H ,10X,1H*,23H  NOMINAL SCHEDULE USED,85X,1H*)
      WRITE(6,208)
      TADJ=0.0
      DO 711 I=1,T6
  711 TADJ=TADJ+ADJ(I)
      DO 703 I=1,T6
      IF(I.GT.1)GOTO 1004
      X=ADJ(1)
      ADJ(I)=X/TADJ
      IX=X
      WRITE(6,220)E1(I),IX,ADJ(I)
  220 FORMAT(1H ,10X,1H*,5X,9H  MODEL :,I4,5X,19HSCHEDULE QUANTITY :,I4,
     15X,14H  ADJUSTMENT :,F6.2,37X,1H*)
      GOTO 703
 1004 X=ADJ(I)
      ADJ(I)=X/TADJ
      IX=X
      WRITE(6,221)E1(I),IX,ADJ(I)
  221 FORMAT(1H ,10X,1H*,14X,I4,24X,I4,19X,F6.2,37X,1H*)
  703 CONTINUE
 1005 WRITE(6,208)
      IF(L5.EQ.3)WRITE(6,222)
      IF(L5.EQ.1)WRITE(6,223)
      IF(L5.EQ.2)WRITE(6,224)
  222 FORMAT(1H ,10X,1H*,51H  NOMINAL SCHEDULE VALUES INPUT BY DESIGNER
     1AS DATA,57X,1H*)
  223 FORMAT(1H ,10X,1H*,64H  NO SCHEDULE WEIGHTING ADJUSTMENT VALUES IN
     1PUT FOR SINGLE MODEL,44X,1H*)
  224 FORMAT(1H ,10X,1H*,75H  SCHEDULE WEIGHTING ADJUSTMENT VALUES IGNOR
     1ED FOR MULTI-ELEMENT ASSIGNMENT,33X,1H*)
      IF(L12.EQ.1.AND.L5.NE.1)WRITE(6,307)
      IF(L12.EQ.0.AND.L5.NE.1)WRITE(6,308)
      IF(L12.EQ.0.AND.L5.EQ.1)WRITE(6,309)
  307 FORMAT(1H ,10X,1H*,75H  SCHEDULE WEIGHTING ADJUSTMENT INCLUDED IN
     1SELECTING THE BEST STATION SIZE,33X,1H*)
  308 FORMAT(1H ,10X,1H*,79H  SCHEDULE WEIGHTING ADJUSTMENT NOT INCLUDED
     1 IN SELECTING THE BEST STATION SIZE,29X,1H*)
  309 FORMAT(1H ,10X,1H*,78H  NO SCHEDULE WEIGHTING ADJUSTMENT INCLUDED
     1IN SELECTING THE BEST STATION SIZE,30X,1H*)
      WRITE(6,208)
      WRITE(6,225)
  225 FORMAT(1H ,10X,110H**************************************************
     1***************************************************************//)
C     *************** ASSIGNMENT SECTION ***************
      IF(L5.EQ.1)CALL ASSIGN31 (IS3,J10,T6,T5,C,L11,C2,L5,L10,I99,L3,L4,
     1L12,L7)
      IF(L5.EQ.2)CALL ASSIGN2 (IS3,J10,T6,T5,C,L11,C2,L5,L10,I99,L3,L4,L
     112,L7)
      IF(L5.EQ.3)CALL ASSIGN31 (IS3,J10,T6,T5,C,L11,C2,L5,L10,I99,L3,L4,
     1L12,L7)
      IF(I99.EQ.1)GOTO 9999
      CALL RESULTS (T5,T6,IS,C2,L5)
      CALL ASSESS (T5,T6,C,IS,BD1,BD3,BD2,BD4,SI1,SI3,SI2,SI4,C2)
C     *********  WRITTING THE OUTPUT LINE INFORMATION TO F3A  *********
      WRITE(8,301)IS,T6,T5
  301 FORMAT(3I4)
      WRITE(8,302)C
  302 FORMAT(F6.2)
      WRITE(8,303)(E1(I),I=1,T6)
  303 FORMAT(10I6)
```

```
      WRITE(8,304)(ADJ(I),I=1,T6)
  304 FORMAT(10F6.2)
      X=0.0
      DO 804 I=1,IS
      X=C*(FLOAT(IZ(I)))
      WRITE(8,305)I,IZ(I),X
  305 FORMAT(2I4,F6.2)
      DO 801 K=1,20
      IC(K)=0
  801 CONTINUE
      JJ=0
      DO 803 J=1,T5
      DO 802 K=1,T6
      IF(IAS(J,K).NE.I)GOTO 802
      JJ=JJ+1
      IC(JJ)=F1(J)
      GOTO 803
  802 CONTINUE
  803 CONTINUE
      WRITE(8,306)(IC(J),J=1,20)
  306 FORMAT(20I4)
      IF(JJ.GT.20)WRITE(6,310)I
  310 FORMAT(///1H ,44H*****   NUMBER OF ELEMENTS IN WORK STATION ,I2,3
     16H  IS GREATER THAN 20 ELEMENTS  *****/)
      IF(JJ.GT.20)GOTO 9999
  804 CONTINUE
      DO 805 I=1,T5
      WRITE(8,311)(IAS(I,J),J=1,T6)
  311 FORMAT(10I4)
  805 CONTINUE
      WRITE(8,312)BD1,BD3,BD2,BD4,SI1,SI3,SI2,SI4
  312 FORMAT(8F6.2)
 9999 STOP
      END
      SUBROUTINE ASSIGN2 (IS3,J10,T6,T5,C,L11,C2,L5,L10,I99,L3,L4,L12,L7
     1)
      INTEGER F1,T5,T6,F1,F6,F4
      DIMENSION A(40,4,10),IAS(100,10),IEM(100),IFW(100,10),F1(100),F2(1
     100),F4(100,10),F6(100,10),F3(100),F21(100),LR(100,10),ADJ(10),E1(1
     20),F8(100),IAS1(100,10),IAS2(100,10),IZ(40),IEM1(100)
      COMMON/SLAB1/F1,IFW,IEM/SLAB3/F2,F4,F6/SLAB5/A,IAS,IZ/SLAB6/F3,F8/
     1SLAB2/F21,LR/SLAB4/ADJ,E1
C     *************** MULTIPLE ASSIGNMENT-MIXED MODEL ***************
C     ************    A(  ,3,  ) = TOTAL TIME DEVIDED BY ST'N SIZE
C     ************    A(  ,2,  ) = TOTAL TIME DEVIDED BY ST'N SIZE THEN
C                                  RAISED TO THE MIN. DURATION IF REQUIRED
C
      IS2=0
      J10=0
C     *************** SET A( ) TO ZERO ***************
      DO 500 I1=1,40
      DO 500 I2=1,4
      DO 500 I3=1,10
  500 A(I1,I2,I3)=0.0
C     *************** START NEW STATION ***************
  601 J10=J10+1
      IZ(J10)=L11
      DO 750 I1=1,T5
      DO 750 I2=1,T6
  750 IAS1(I1,I2)=0
```

```
C       *************** START NEW STATION SIZE ***************
        DO 900 I1=L10,L11
        IF(L7.EQ.1) WRITE(6,200)J10,I1,C
   200 FORMAT(//1H ,10X,16HSTATION NUMBER :,I4,3X,14HSTATION SIZE :,I3,14
      1H  CYCLE TIME :,F6.2/)
        IF(L7.EQ.1)WRITE(6,210)
   210 FORMAT(1H ,10X,17HACCEPTED ELEMENTS)
        DO 901 I2=1,10
        A(J10,1,I2)=0.0
        A(J10,4,I2)=0.0
   901 A(J10,2,I2)=0.0
        DO 710 I5=1,T5
        DO 710 I4=1,T6
   710 IAS2(I5,I4)=0
C       *************** START A NEW MODEL **************
        DO 506 II=1,T6
        IF(L7.EQ.1)WRITE(6,198)E1(II)
   198 FORMAT(/1H ,10X,14HMODEL NUMBER :,I4)
        J3=0
C       *********  SET UP IEM & IEM1 & IFW   **********
        DO 801 I4=1,T5
        IEM(I4)=0
        IEM1(I4)=0
        DO 801 I5=1,10
        IFW(I4,I5)=0
   801 CONTINUE
        DO 802 I4=1,T5
        IF(IAS(I4,II).GT.0)GOTO 802
        DO 803 I5=1,10
        IF(F4(I4,I5).EQ.0)GOTO 803
        IFW(I4,I5)=F4(I4,I5)
        IEM(F4(I4,I5))=IEM(F4(I4,I5))+1
   803 CONTINUE
   802 CONTINUE
C       *********  THE EFFECT OF THE FALSE ELEMENTS  ******
  5069 ICNT=0
        DO 5061 I4=1,T5
        IF(IEM(I4).NE.0.OR.IAS(I4,II).NE.0) GO TO 5061
        IF(IEM1(I4).EQ.1) GO TO 5061
        IEM1(I4)=1
        DO 5062 I5=1,10
        IF(IFW(I4,I5).EQ.0) GO TO 5062
        IEM(IFW(I4,I5))=IEM(IFW(I4,I5))-1
        ICNT=1
  5062 CONTINUE
  5061 CONTINUE
        IF(ICNT.EQ.1) GO TO 5069
C       ******* FINDING NEXT AVAILABLE ELEMENT ********
C       *********** & SELECTING NEXT RANK *********
   604 J1=101
        I2=0
        DO 503 I4=1,T5
        IF(LR(I4,II).GT.J1)GOTO 503
        IF(LR(I4,II).LE.J3)GOTO 503
        I2=I4
        J1=LR(I4,II)
   503 CONTINUE
        IF(I2.EQ.0)GOTO 506
        J3=J3+1
C       *************** CHECK AVAILABILITY AND PRECEDENCE ***************
```

```
      IF(IAS(I2,II).EQ.0)GOTO 604
      IF(IAS(I2,II).GT.0)GOTO 604
      IF(IEM(I2).GT.0)GOTO 604
C     *************** CHECK TIME ***************
      X=(F2(I2)+SQRT(F3(I2)*C2))/FLOAT(I1)
      IF(X.LT.F8(I2))X=F8(I2)
      IF(F8(I2).GT.(C-A(J10,1,II)))GOTO 604
      IF(X.GT.(C-A(J10,2,II)))GOTO 604
      XX=(C-A(J10,2,II))-X
      IF(L7.EQ.1)WRITE(6,201)F1(I2),F2(I2),X,XX
  201 FORMAT(1H ,10X,7HELEMENT,I4,2X,6HTIME =,F6.2,2X,16HEFFECTIVE TIME
     1=,F6.2,2X,34HEFFECTIVE STATION TIME REMAINING =,F6.2)
C     *************** ASSIGN ELEMENT AND UPDATE IEM & IEM1 & IFW ********
      IAS2(I2,II)=J10
      DO 5059 I5=1,10
      IF(IFW(I2,I5).EQ.0) GO TO 5059
      IEM(IFW(I2,I5))=IEM(IFW(I2,I5))-1
 5059 CONTINUE
 5051 ICNT=0
      DO 5054 I4=1,T5
      IF(IEM(I4).NE.0.OR.IAS(I4,II).NE.0) GO TO 5054
      IF(IEM1(I4).EQ.1) GO TO 5054
      IEM1(I4)=1
      DO 5053 I5=1,10
      IF(IFW(I4,I5).EQ.0) GO TO 5053
      IEM(IFW(I4,I5))=IEM(IFW(I4,I5))-1
      ICNT=1
 5053 CONTINUE
 5054 CONTINUE
      IF(ICNT.EQ.1) GO TO 5051
C     ********  UPDATE TIME IN A( 2 ) & A( 1 ) & A( 4 ) FOR EACH STATION SIZE
      A(J10,1,II)=A(J10,1,II)+F8(I2)
      A(J10,2,II)=A(J10,2,II)+X
      A(J10,4,II)=A(J10,4,II)+(F2(I2)+SQRT(F3(I2)*C2))/FLOAT(I1)
      GOTO 604
  506 CONTINUE
C     *************** SELECT BEST OVERALL STATION SIZE ***************
      X1=0.0
      X2=0.0
      X3=0.0
      DO 508 I2=1,T6
      IF(L12.EQ.1)X1=A(J10,4,I2)*ADJ(I2)*FLOAT(T6)*FLOAT(I1)+X1
      IF(L12.EQ.0)X1=A(J10,4,I2)*FLOAT(I1)+X1
      IF(L12.EQ.1)X2=A(J10,3,I2)*ADJ(I2)*FLOAT(T6)*FLOAT(IZ(J10))+X2
      IF(L12.EQ.0)X2=A(J10,3,I2)*FLOAT(IZ(J10))+X2
      IF(X3.LT.A(J10,2,I2))X3=A(J10,2,I2)
  508 CONTINUE
      IF(L7.EQ.1)WRITE(6,211)C,X3
  211 FORMAT(/1H ,60X,12HCYCLE TIME =,F10.2,4X,23HMAXIMUM WORK DURATION
     1=,F10.2)
      X4=C*FLOAT(T6)*FLOAT(I1)
      X5=X4-X1
      IF(L7.EQ.1)WRITE(6,212)X4,X1
  212 FORMAT(1H ,45X,27HTIME AVAILABLE ALL MODELS =,F10.2,3X,24HESTIMATE
     1D WORK CONTENT =,F10.2)
C     *************** COPYING IAS2()  IN IAS1() ***************
      IF(L7.EQ.1)WRITE(6,213)X5
  213 FORMAT(1H ,51X,21HESTIMATED LOST TIME =,F10.2)
      IF(L12.EQ.1.AND.L7.EQ.1)WRITE(6,214)
  214 FORMAT(1H+,94X,21H( SCHEDULE ADJUSTED )/)
```

```
      IF(X1.EQ.0.0.AND.I1.EQ.1.AND.L12.EQ.1)GOTO 910
      IF((((T6*C*I1)-X1)+0.000001).GE.((T6*C*IZ(J10))-X2)) GOTO 900
  910 DO 510 I2=1,T6
      DO 509 I3=1,T5
      IAS1(I3,I2)=IAS2(I3,I2)
  509 CONTINUE
  510 A(J10,3,I2)=A(J10,4,I2)
      IZ(J10)=I1
  900 CONTINUE
C     *************** TRANSFER BEST SOLUTION AND STATION SIZE FOR THIS STATION
      DO 512 I2=1,T6
      DO 511 I3=1,T5
      IF(IAS1(I3,I2).EQ.0)GOTO 511
      IAS(I3,I2)=IAS1(I3,I2)
      IS2=IS2+1
  511 CONTINUE
  512 CONTINUE
      DO 754 I=1,10
      A(J10,1,I)=0.0
  754 A(J10,2,I)=0.0
      DO 752 I=1,T5
      DO 751 J=1,T6
      IF(IAS(I,J).NE.J10)GOTO 751
      A(J10,1,J)=A(J10,1,J)+F8(I)
      X=(F2(I)+SQRT(F3(I)*C2))/FLOAT(IZ(J10))
      IF(X.LT.F8(I))X=F8(I)
      A(J10,2,J)=A(J10,2,J)+X
  751 CONTINUE
  752 CONTINUE
      IF(L7.EQ.1) WRITE(6,220)
  220 FORMAT(1H ,97X,23H***********************)
      IF(L7.EQ.1)WRITE(6,221)
  221 FORMAT(1H ,97X,1H*,21X,1H*)
      IF(L7.EQ.1)WRITE(6,222)
  222 FORMAT(1H ,97X,23H*  STATION BALANCED   *)
      IF(L7.EQ.1)WRITE(6,223)IZ(J10)
  223 FORMAT(1H ,97X,9H*  SIZE =,I2,12H ACCEPTED  *)
      IF(L7.EQ.1) WRITE(6,221)
      IF(L7.EQ.1) WRITE(6,220)
      IF(IS2.EQ.IS3)GOTO 610
      IF(L3.EQ.0)GOTO 601
      L=L4-J10
      CALL STNSZ (T5,T6,C2,C,L,L10,I99)
      IF(I99.EQ.1)GOTO 610
      GOTO 601
  610 RETURN
      END
      SUBROUTINE ASSIGN31 (IS3,J10,T6,T5,C,L11,C2,L5,L10,I99,L3,L4,L12,L
     17)
      INTEGER F1,T5,T6,E1,F6,F4
      DIMENSION A(40,4,10),IAS(100,10),IEM(100),IFW(100,10),F1(100),F2(1
     100),F4(100,10),F6(100,10),F3(100),F21(100),LR(100,10),F8(100),ADJ(
     210),E1(10),IAS1(100,10),IAS2(100,10),IZ(40)
      COMMON/SLAB1/F1,IFW,IEM/SLAB3/F2,F4,F6/SLAB5/A,IAS,IZ/SLAB6/F3,F8/
     1SLAB2/F21,LR/SLAB4/ADJ,E1
C     *************** SINGLE ASSIGNMENT-MIXED MODEL ****************
C     ***********   A(  ,3,  )  = TOTAL TIME DEVIDED BY THE ST'N SIZE
C     ***********   A(  ,2,  )  = TOTAL TIME DEVIDED BY THE ST'N SIZE THEN
C                                 RAISED TO THE MIN. DURATION IF REQUIRED
      IS2=0
```

```
      J10=0
      DO 500 I1=1,40
      DO 500 I2=1,4
      DO 500 I3=1,10
  500 A(I1,I2,I3)=0.0
      DO 501 I1=1,T5
      DO 501 I2=1,10
  501 IFW(I1,I2)=F4(I1,I2)
  601 J10=J10+1
      IZ(J10)=L11
C     *************** START STATION SIZE ***************
      DO 991 I1=L10,L11
      IF(L7.EQ.1) WRITE(6,200)J10,I1,C
  200 FORMAT(//1H ,10X,16HSTATION NUMBER :,I4,3X,14HSTATION SIZE :,I3,14
     1H  CYCLE TIME :,F6.2/)
      IF(L7.EQ.1)WRITE(6,210)
  210 FORMAT(1H ,10X,17HACCEPTED ELEMENTS)
      DO 888 I8=1,10
      A(J10,1,I8)=0.0
      A(J10,2,I8)=0.0
      A(J10,4,I8)=0.0
      DO 888 I7=1,T5
  888 IAS2(I7,I8)=0
C     *************** FINDING NEXT AVAILABLE ELEMENT ***************
      J3=0
C     *************** SET UP THE CURRENT FOLLOWERS ***************
      DO 666 I4=1,T5
      DO 667 I5=1,10
  667 IFW(I4,I5)=0
      DO 665 I6=1,T6
      IF(IAS(I4,I6).GT.0)GOTO 666
  665 CONTINUE
      DO 633 I5=1,10
  633 IFW(I4,I5)=F4(I4,I5)
  666 CONTINUE
  602 CALL PREC (T5)
  604 J1=101
      I2=0
      DO 502 I4=1,T5
      IF(LR(I4,1).GT.J1)GOTO 502
      IF(LR(I4,1).LE.J3)GOTO 502
      I2=I4
      J1=LR(I4,1)
  502 CONTINUE
      J3=J3+1
      IF(I2.EQ.0)GOTO 603
C     ************** CHECK AVAILABILITY ***************
      DO 503 I3=1,T6
      IF(IAS(I2,I3).GT.0)GOTO 604
  503 CONTINUE
      IF(IEM(I2).EQ.1)GOTO 604
      XX=10000.0
      DO 504 I3=1,T6
      IF(IAS(I2,I3).EQ.0)GOTO 504
      X=(F2(I2)+SQRT(F3(I2)*C2))/FLOAT(I1)
      IF(X.LT.F8(I2))X=F8(I2)
      IF(F8(I2).GT.(C-A(J10,1,I3)))GOTO 604
      IF(X.GT.(C-A(J10,2,I3)))GOTO 604
      XXX=(C-A(J10,2,I3))-X
      IF(XX.GT.XXX)XX=XXX
```

```
  504 CONTINUE
      IF(L7.EQ.1) WRITE(6,201)F1(I2),F2(I2),X,XX
  201 FORMAT(1H ,10X,7HELEMENT,I4,2X,6HTIME =,F6.2,2X,16HEFFECTIVE TIME
     1=,F6.2,2X,34HEFFECTIVE STATION TIME REMAINING =,F6.2)
C     *************** ASSIGN ELEMENT **************
      DO 505 I3=1,T6
      IF(IAS(I2,I3).EQ.0)GOTO 505
      A(J10,1,I3)=A(J10,1,I3)+F8(I2)
      A(J10,2,I3)=A(J10,2,I3)+X
      A(J10,4,I3)=A(J10,4,I3)+(F2(I2)+SQRT(F3(I2)*C2))/FLOAT(I1)
      IAS2(I2,I3)=J10
  505 CONTINUE
      DO 506 I4=1,10
  506 IFW(I2,I4)=0
      GOTO 602
C     *********  SELECT THE BEST STATION SIZE   **********
  603 X1=0.0
      X2=0.0
      X3=0.0
      DO 508 I2=1,T6
      IF(L12.EQ.1)X1=A(J10,4,I2)*ADJ(I2)*FLOAT(T6)*FLOAT(I1)+X1
      IF(L12.EQ.0)X1=A(J10,4,I2)*FLOAT(I1)+X1
      IF(L12.EQ.1)X2=A(J10,3,I2)*ADJ(I2)*FLOAT(T6)*FLOAT(IZ(J10))+X2
      IF(L12.EQ.0)X2=A(J10,3,I2)*FLOAT(IZ(J10))+X2
      IF(X3.LT.A(J10,2,I2))X3=A(J10,2,I2)
  508 CONTINUE
      IF(L7.EQ.1)WRITE(6,211)C,X3
  211 FORMAT(/1H ,60X,12HCYCLE TIME =,F10.2,4X,23HMAXIMUM WORK DURATION
     1=,F10.2)
      X4=C*FLOAT(T6)*FLOAT(I1)
      X5=X4-X1
      IF(L7.EQ.1)WRITE(6,212)X4,X1
  212 FORMAT(1H ,45X,27HTIME AVAILABLE ALL MODELS =,F10.2,3X,24HESTIMATE
     1D WORK CONTENT =,F10.2)
      IF(L7.EQ.1)WRITE(6,213)X5
  213 FORMAT(1H ,51X,21HESTIMATED LOST TIME =,F10.2)
      IF(L12.EQ.1.AND.L7.EQ.1)WRITE(6,214)
  214 FORMAT(1H+,94X,21H( SCHEDULE ADJUSTED )/)
      IF(X1.EQ.0.0.AND.I1.EQ.1.AND.L12.EQ.1)GOTO 901
      IF((((T6*C*I1)-X1)+0.000001).GE.((T6*C*IZ(J10))-X2))GOTO 991
C     *************** COPPING IAS2() IN IAS1()
  901 DO 510 I2=1,T6
      DO 509 I3=1,T5
      IAS1(I3,I2)=IAS2(I3,I2)
  509 CONTINUE
  510 A(J10,3,I2)=A(J10,4,I2)
      IZ(J10)=I1
  991 CONTINUE
C     *** TRANSFER BEST SOLUTION AND STATION SIZE FOR THIS STATION ***
      DO 512 I2=1,T6
      DO 511 I3=1,T5
      IF(IAS1(I3,I2).EQ.0)GOTO 511
      IAS(I3,I2)=IAS1(I3,I2)
      IS2=IS2+1
  511 CONTINUE
  512 CONTINUE
      DO 750 I=1,10
      A(J10,1,I)=0.0
      A(J10,2,I)=0.0
  750 CONTINUE
```

```
      DO 752 I=1,T5
      DO 751 J=1,T6
      IF(IAS(I,J).NE.J10)GOTO 751
      A(J10,1,J)=A(J10,1,J)+F8(I)
      X=(F2(I)+SQRT(F3(I)*C2))/FLOAT(IZ(J10))
      IF(X.LT.F8(I))X=F8(I)
      A(J10,2,J)=A(J10,2,J)+X
  751 CONTINUE
  752 CONTINUE
      IF(L7.EQ.1) WRITE(6,220)
  220 FORMAT(1H ,97X,23H***********************)
      IF(L7.EQ.1) WRITE(6,221)
  221 FORMAT(1H ,97X,1H*,21X,1H*)
      IF(L7.EQ.1)WRITE(6,222)
  222 FORMAT(1H ,97X,23H*  STATION BALANCED   *)
      IF(L7.EQ.1)WRITE(6,223)IZ(J10)
  223 FORMAT(1H ,97X,9H*  SIZE =,I2,12H ACCEPTED  *)
      IF(L7.EQ.1)WRITE(6,221)
      IF(L7.EQ.1)WRITE(6,220)
      IF(IS2.EQ.IS3)GOTO 610
      IF(L3.EQ.0)GOTO 601
      L=L4-J10
      CALL STNSZ (T5,T6,C2,C,L,L10,I99)
      IF(I99.EQ.1)GOTO 610
      GOTO 601
  610 RETURN
      END
      SUBROUTINE STNSZ (T5,T6,C2,C,L,L10,I99)
      INTEGER T5,T6,F6,F4
      DIMENSION F2(100),F4(100,10),F6(100,10),A(40,4,10),IAS(100,10),F3(
     1100),F8(100),IZ(40)
      COMMON/SLAB3/F2,F4,F6/SLAB5/A,IAS,IZ/SLAB6/F3,F8
      L101=0
      I99=0
      DO 704 I1=1,T6
      TT2=0.0
      TT3=0.0
      DO 701 I=1,T5
      IF(IAS(I,I1).GT.-1)GOTO 701
      TT2=TT2+F8(I)
      TT3=TT3+F2(I)+SQRT(F3(I))*C2
  701 CONTINUE
      V1=TT3/(L*C)
      L100=INT(V1)
      IF((L100*(L*C)).NE.TT3)L100=L100+1
      IF(TT2.LE.(C*L))GOTO 703
      I99=1
      WRITE(6,20)
   20 FORMAT(1H ,////)
      WRITE(6,21)
   21 FORMAT(1H ,100H**************************************************
     1**************************************************)
      WRITE(6,22)
   22 FORMAT(1H ,1H*,98X,1H*)
      WRITE(6,23)TT2
   23 FORMAT(1H ,1H*,5X,29HTOTAL MINIMUM DURATION TIME :,F6.2,58X,1H*)
      WRITE(6,22)
      WRITE(6,24)C
   24 FORMAT(1H ,1H*,5X,40HCAN NOT BE ACHEIVED WITH A CYCLE TIME OF,F6.2
     1,47X,1H*)
```

```
      WRITE(6,22)
      WRITE(6,25)L
   25 FORMAT(1H ,1H*,5X,30HAND A REMAINING LINE LENGTH OF,I4,59X,1H*)
      WRITE(6,22)
      WRITE(6,22)
      WRITE(6,22)
      WRITE(6,26)
   26 FORMAT(1H ,1H*,5X,15HBALANCE STOPPED,78X,1H*)
      WRITE(6,22)
      WRITE(6,22)
      WRITE(6,21)
      GO TO 705
  703 IF(L100.GT.L101)L101=L100
  704 CONTINUE
  705 L10=L101
      RETURN
      END
      SUBROUTINE RESULTS (T5,T6,IS,C2,L5)
      INTEGER T5,T6,E1,F1,F6
      DIMENSION E1(10),F1(100),F2(100),A(40,4,10),IAS(100,10),F6(100,10)
     1,F4(100,10),ADJ(10),IFW(100,10),IEM(100),EM(10),IZ(40),F3(100),F8(
     2100)
      COMMON/SLAB3/F2,F4,F6/SLAB4/ADJ,E1/SLAB5/A,IAS,IZ/SLAB1/F1,IFW,IEM
     1/SLAB6/F3,F8
C     *************** WRITTING UP THE RESULTS **************
      IS=0
      DO 502 I=1,T5
      DO 501 J=1,T6
      IF(IAS(I,J).GT.IS) IS=IAS(I,J)
  501 CONTINUE
  502 CONTINUE
      WRITE(6,20)
   20 FORMAT(///1H ,120H************************************************
     1******************************************************************
     2******)
      WRITE(6,21)
   21 FORMAT(1H ,1H*,118X,1H*)
      WRITE(6,22)
   22 FORMAT(1H ,1H*,5X,15HBALANCE RESULTS,98X,1H*)
      WRITE(6,23)
   23 FORMAT(1H ,1H*,24H************************,94X,1H*)
      WRITE(6,21)
      WRITE(6,21)
      WRITE(6,21)
      DO 510 KK=1,IS
      IF(L5.EQ.1) WRITE(6,24)KK,IZ(KK)
   24 FORMAT(1H ,1H*,9X,16HSTATION NUMBER :,I3,16H  STATION SIZE :,I3,5X
     1,23HSINGLE MODEL PRODUCTION,43X,1H*)
      IF(L5.EQ.2) WRITE(6,35)KK,IZ(KK)
   35 FORMAT(1H ,1H*,9X,16HSTATION NUMBER :,I3,16H  STATION SIZE :,I3,5X
     1,49HMIXED MODEL PRODUCTION / MULTI-ELEMENT ASSIGNMENT,17X,1H*)
      IF(L5.EQ.3) WRITE(6,36)KK,IZ(KK)
   36 FORMAT(1H ,1H*,9X,16HSTATION NUMBER :,I3,16H  STATION SIZE :,I3,5X
     1,50HMIXED MODEL PRODUCTION / SINGLE-ELEMENT ASSIGNMENT,16X,1H*)
      WRITE(6,21)
      WRITE(6,25)
   25 FORMAT(1H ,1H*,6X,106H********************************************
     1**************************************************************,6X,
     21H*)
      WRITE(6,26)
```

```
   26 FORMAT(1H ,1H*,6X,1H*,104X,1H*,6X,1H*)
      WRITE(6,27)
   27 FORMAT(1H ,1H*,6X,1H*,22X,6HMODELS,76X,1H*,6X,1H*)
      WRITE(6,28)(E1(I),I=1,T6)
   28 FORMAT(1H ,1H*,6X,1H*,8X,8HELEMENTS,1X,10I8)
      WRITE(6,29)
   29 FORMAT(1H*,112X,1H*,6X,1H*)
      WRITE(6,26)
      DO 506 I=1,T5
      DO 503 I1=1,T6
      IF(IAS(I,I1).EQ.KK)GO TO 1000
  503 CONTINUE
      GOTO 506
 1000 DO 504 JJ=1,T6
      EM(JJ)=0.0
  504 CONTINUE
      DO 505 JJ=1,T6
      IF(IAS(I,JJ).EQ.KK)EM(JJ)=(F2(I)+(SQRT(F3(I)*C2)))
  505 CONTINUE
      WRITE(6,30)F1(I),(EM(JJ),JJ=1,T6)
   30 FORMAT(1H ,1H*,6X,1H*,13X,I3,2X,10F8.2)
      WRITE(6,29)
  506 CONTINUE
      DO 508 J=1,T6
      EM(J)=0.0
  508 CONTINUE
      DO 509 J=1,T6
      EM(J)=A(KK,3,J)*FLOAT(IZ(KK))
  509 CONTINUE
      WRITE(6,26)
      WRITE(6,31)(EM(JJ),JJ=1,T6)
   31 FORMAT(1H ,1H*,6X,1H*,4X,14HWORK CONTENT :,10F8.2)
      WRITE(6,29)
      WRITE(6,26)
      WRITE(6,32)(A(KK,2,JJ),JJ=1,T6)
   32 FORMAT(1H ,1H*,6X,1H*,3X,15HWORK DURATION :,10F8.2)
      WRITE(6,29)
      WRITE(6,26)
      WRITE(6,33)(A(KK,1,JJ),JJ=1,T6)
   33 FORMAT(1H ,1H*,6X,1H*,1X,17HCOMPRESSED TIME :,10F8.2)
      WRITE(6,29)
      WRITE(6,26)
      WRITE(6,25)
      WRITE(6,21)
      WRITE(6,21)
      WRITE(6,21)
      WRITE(6,21)
  510 CONTINUE
      WRITE(6,21)
      WRITE(6,34)
   34 FORMAT(1H ,120H**************************************************
     1*******************************************************************
     2***///)
      RETURN
      END
      SUBROUTINE ASSESS (T5,T6,C,IS,BD1,BD3,BD2,BD4,SI1,SI3,SI2,SI4,C2)
      INTEGER T5,T6,E1,F6,F4
      DIMENSION ST(40,4),F2(100),F4(100,10),F6(100,10),ADJ(10),E1(10),A(
     140,4,10),IAS(100,10),TH(10),IZ(40),F3(100),F8(100)
      COMMON/SLAB3/F2,F4,F6/SLAB4/ADJ,E1/SLAB5/A,IAS,IZ/SLAB6/F3,F8
```

```
C       *******************  ASSESSING THE BALANCE *****************
C       ****** CALCULATION OF SOME FEATURES OF EACH STATION ********
C
C       ****************               WRITE NEW BLOCK        **************
C
        WRITE(6,20)
     20 FORMAT(1H ,120H***********************************************************
       1************************************************************
       2***)
        WRITE(6,21)
     21 FORMAT(1H ,1H*,118X,1H*)
        WRITE(6,22)
     22 FORMAT(1H ,1H*,25H          BALANCE EFFICIENCY,93X,1H*)
        WRITE(6,23)
     23 FORMAT(1H ,30H******************************,89X,1H*)
        WRITE(6,21)
C       *****************  TRADITIONAL BALANCE EFFICIENCY  ****************
        X1=0.0
        BD3=0.0
        BD1=0.0
        DO 701 J=1,T6
        DO 700 I=1,IS
        BD1=BD1+(FLOAT(IZ(I))*(C-A(I,3,J)))
        BD3=BD3+(FLOAT(IZ(I))*(C-A(I,2,J)))
        X1=X1+(FLOAT(IZ(I))*C)
    700 CONTINUE
    701 CONTINUE
        BD1=(BD1/X1)*100.00
        BD3=(BD3/X1)*100.00
C       **************  MODIFIED BALANCE DELAY  ****************
        X1=0.0
        BD2=0.0
        BD4=0.0
        DO 705 J=1,T6
        X=0.0
        XX=0.0
        DO 702 I=1,IS
        X=X+FLOAT(IZ(I))*(C-A(I,3,J))
        XX=XX+FLOAT(IZ(I))*(C-A(I,2,J))
        X1=X1+FLOAT(IZ(I))*C
    702 CONTINUE
        BD2=BD2+X*ADJ(J)*T6
        BD4=BD4+XX*ADJ(J)*T6
    703 CONTINUE
        BD2=BD2*100.00/X1
        BD4=BD4*100.00/X1
C       **************  TRADITIONAL SMOOTHNESS INDEX  ****************
        SI1=0.0
        SI3=0.0
        DO 705 J=1,T6
        DO 704 I=1,IS
        SI1=SI1+(FLOAT(IZ(I))*(C-A(I,3,J)))**2.00
        SI3=SI3+(FLOAT(IZ(I))*(C-A(I,2,J)))**2.00
    704 CONTINUE
    705 CONTINUE
        SI1=SQRT(SI1/FLOAT(T6))
        SI3=SQRT(SI3/FLOAT(T6))
C       **************  MODIFIED SMOOTHNESS INDEX  ****************
        SI2=0.0
        SI4=0.0
```

```
      DO 707 J=1,T6
      X=0.0
      X1=0.0
      DO 706 I=1,IS
      X=X+(FLOAT(IZ(I))*(C-A(I,3,J)))**2.00
      X1=X1+(FLOAT(IZ(I))*(C-A(I,2,J)))**2.00
  706 CONTINUE
      SI2=SI2+(X+ADJ(J)*T6)
      SI4=SI4+(X1*ADJ(J)*T6)
  707 CONTINUE
      SI2=SQRT(SI2/T6)
      SI4=SQRT(SI4/T6)
      WRITE(6,24)BD1,BD3,SI1,SI3
   24 FORMAT(1H ,1H*,20X,5HBD1 =,F6.2,10X,5HBD3 =,F6.2,20X,5HSI1 =,F6.2,
     110X,5HSI3 =,F6.2,14X,1H*)
      WRITE(6,21)
      WRITE(6,25)BD2,BD4,SI2,SI4
   25 FORMAT(1H ,1H*,20X,5HBD2 =,F6.2,10X,5HBD4 =,F6.2,20X,5HSI2 =,F6.2,
     110X,5HSI4 =,F6.2,14X,1H*)
      WRITE(6,21)
      WRITE(6,20)
      DO 643 I=1,IS
      ST(I,1)=0.0
      ST(I,3)=0.0
      ST(I,4)=0.0
      ST(I,2)=1000000.0*C
  643 CONTINUE
      DO 646 K=1,IS
      DO 645 JJ=1,T6
      TIME=0.0
      DO 644 I=1,T5
      IF(IAS(I,JJ).NE.K) GO TO 644
      TIME=TIME+F2(I)+SQRT(F3(I))*C2
  644 CONTINUE
      IF(TIME.GT.ST(K,1)) ST(K,1)=TIME
      IF(TIME.LT.ST(K,2)) ST(K,2)=TIME
      ST(K,3)=ST(K,1)-ST(K,2)
  645 CONTINUE
  646 CONTINUE
C     ************** CALCULATION OF THE TOTAL WORK ***************
      DO 649 K=1,IS
      DO 648 I=1,T5
      DO 647 J=1,T6
      IF(IAS(I,J).NE.K) GO TO 647
      ST(K,4)=ST(K,4)+F2(I)+SQRT(F3(I))*C2
      GO TO 648
  647 CONTINUE
  648 CONTINUE
  649 CONTINUE
      WRITE(6,223)
  223 FORMAT(///1H ,120H************************************************
     1******************************************************************
     2******)
      WRITE(6,224)
  224 FORMAT(1H ,1H*,118X,1H*)
      WRITE(6,33)
   33 FORMAT(1H ,1H*,5X,28HWORK DISTRIBUTION EFFICIENCY,85X,1H*)
      WRITE(6,34)
   34 FORMAT(1H ,39H***************************************,80X,1H*)
      WRITE(6,224)
```

```
      WRITE(6,224)
      WRITE(6,40)
   40 FORMAT(1H ,1H*,4X,7HSTATION,3X,7HSTATION,5X,4HTIME,4X,7HMAXIMUM,3X
     1,7HMINIMUM,3X,7HSTATION,9X,6HNORMAL,13X,8HWEIGHTED,9X,4HWORK,8X,1H
     2*)
      WRITE(6,41)
   41 FORMAT(1H ,1H*,5X,6HNUMBER,4X,4HSIZE,4X,9HAVAILABLE,4X,4HWORK,6X,4
     1HWORK,5X,5HRANGE,4X,7HAVERAGE,3X,7HST. DV.,3X,7HAVERAGE,3X,7HST. D
     2V.,4X,7HVARIETY,6X,1H*)
      WRITE(6,224)
      DO 651 I=1,IS
C     *************  STATION INFORMATION  ******************
      X=C*FLOAT(IZ(I))
      AV=0.0
      AV1=0.0
      DO 721 J=1,T6
      AV=AV+A(I,3,J)*FLOAT(IZ(I))
      AV1=AV1+A(I,3,J)*FLOAT(IZ(I))*ADJ(J)
  721 CONTINUE
      AV=AV/FLOAT(T6)
      SD=0.0
      SD1=0.0
      DO 722 J=1,T6
      SD=SD+(AV-(A(I,3,J)*FLOAT(IZ(I))))**2.00
      SD1=SD1+(AV1-(A(I,3,J)*FLOAT(IZ(I))))**2.00
  722 CONTINUE
      SD=SQRT(SD)
      SD1=SQRT(SD1)
      WRITE(6,218)I,IZ(I),X,(ST(I,J),J=1,3),AV,SD,AV1,SD1,ST(I,4)
  218 FORMAT(1H ,1H*,4X,I4,6X,I4,2X,9F10.2,8X,1H*)
  651 CONTINUE
      TT=0.0
      TWV=0.0
      DO 720 K=1,IS
      TWV=TWV+ST(K,3)
      TT=TT+ST(K,4)
  720 CONTINUE
      WRITE(6,30)
   30 FORMAT(1H ,1H*,54X,6H------,44X,6H------,8X,1H*)
      WRITE(6,31)TWV,TT
   31 FORMAT(1H ,1H*,54X,F6.2,40X,F10.2,8X,1H*)
      WRITE(6,224)
C     *************  LINE INFORMATION  ******************
      WT1=0.0
      DO 723 I=1,IS
      WT1=WT1+ST(I,4)
  723 CONTINUE
      WT1=WT1/FLOAT(IS)
      WT2=0.0
      DO 724 I=1,IS
      WT2=WT2+(ST(I,4)-WT1)**2.00
  724 CONTINUE
      WT2=SQRT(WT2)
      MAX=0.0
      MIN=1000.0
      DO 725 I=1,IS
      IF(ST(I,4).GT.MAX)MAX=ST(I,4)
      IF(ST(I,4).LT.MIN)MIN=ST(I,4)
  725 CONTINUE
      WT3=MAX-MIN
```

```
      WRITE(6,224)
      WRITE(6,224)
      WRITE(6,36)TWV,WT1,WT3
   36 FORMAT(1H ,1H*,10X,5HWB1 =,F8.2,20X,5HWT1 =,F8.2,20X,5HWT3 =,F8.2,
     129X,1H*)
      WRITE(6,224)
      WRITE(6,37)TT,WT2
   37 FORMAT(1H ,1H*,10X,5HWB2 =,F8.2,20X,5HWT2 =,F8.2,20X,42X,1H*)
      WRITE(6,224)
      WRITE(6,225)
  225 FORMAT(1H ,120H************************************************************
     1*************************************************************
     2***/////)
      RETURN
      END
      SUBROUTINE PREC (T5)
      INTEGER F1,T5
      DIMENSION F1(100),IFW(100,10),IEM(100)
      COMMON/SLAB1/F1,IFW,IEM
      DO 500 I1=1,T5
      IEM(I1)=0
  500 CONTINUE
      DO 503 I1=1,T5
      DO 502 I2=1,10
      IF(IFW(I1,I2).EQ.0) GO TO 503
      IEM(IFW(I1,I2))=1
  502 CONTINUE
  503 CONTINUE
      RETURN
      END
      SUBROUTINE WTCALC (T5,L5,T6)
      INTEGER T5,T6,F1,F4,F6,E1
      DIMENSION F1(100),IFW(100,10),ADJ(10),IEM(100),F21(100),LR(100,10)
     1,F2(100),F4(100,10),F6(100,10),E1(10),A(40,4,10),IAS(100,10),IZ(40
     2)
      COMMON/SLAB1/F1,IFW,IEM/SLAB2/F21,LR/SLAB3/F2,F4,F6/SLAB4/ADJ,E1/S
     1LAB5/A,IAS,IZ
C     SELECT THE ELEMENT WHICH WE ARE GOING TO CALCULATE ITS WEIGHT
C                                     LR( )  CONTAIN  ONES & ZEROS  HERE ONLY
      TADJ=0.0
      DO 499 I=1,T6
      DO 498 I1=1,T5
  498 LR(I1,I)=0
  499 TADJ=TADJ+ADJ(I)
      IF(L5.EQ.2)GOTO 1003
      I=1
      GOTO 1004
 1003 DO 513 I=1,T6
      DO 500 I1=1,T5
      F21(I1)=0.0
  500 CONTINUE
 1004 DO 509 I1=1,T5
      IF(L5.NE.2)GOTO 1002
      IF(IAS(I1,I).EQ.0)GOTO 509
 1002 DO 501 I2=1,T5
      LR(I2,I)=0
  501 CONTINUE
      LR(I1,I)=1
      J1=1
 1000 DO 504 I2=1,T5
```

```
      IF(LR(I2,I).EQ.0) GO TO 504
      DO 503 I3=1,10
      IF(F4(I2,I3).EQ.0) GO TO 503
      LR(F4(I2,I3),I)=1
  503 CONTINUE
  504 CONTINUE
      J2=0
      DO 505 I4=1,T5
      IF(LR(I4,I).EQ.0) GO TO 505
      J2=J2+1
  505 CONTINUE
      IF(J2.EQ.J1) GO TO 1001
      J1=J2
      GO TO 1000
C     **********  CALCULATE THE WEIGHTS IN  F21( )  ************
C     ***  ADDING THE EFFECT OF ADJUSTMENT IN CASE OF PROCEDURE 3 ***
 1001 DO 508 I4=1,T5
      IF(LR(I4,I).EQ.0)GOTO 508
      IF(L5.EQ.1)F21(I1)=F21(I1)+F2(I4)
      IF(L5.EQ.2.AND.IAS(I4,I).NE.0)F21(I1)=F21(I1)+F2(I4)
      IF(L5.NE.3)GOTO 508
      DO 507 I3=1,T6
      IF(IAS(I4,I3).EQ.0)GOTO 507
      F21(I1)=F21(I1)+F2(I4)*(ADJ(I3)/TADJ)
  507 CONTINUE
  508 CONTINUE
  509 CONTINUE
C     ***  RANKING THE WEIGHT F21( ) IN THE MATRIX LR( ) ***
C     *****  WHICH WILL CONTAIN THE RANK AT THIS POINT  *****
      DO 510 I1=1,T5
      LR(I1,I)=0
  510 CONTINUE
      J1=1
      DO 512 I1=1,T5
      VAL=-100.0
      DO 511 I2=1,T5
      IF(LR(I2,I).GT.0.OR.F21(I2).LE.(VAL+0.000001)) GO TO 511
      VAL=F21(I2)
      I3=I2
  511 CONTINUE
      LR(I3,I)=J1
      J1=J1+1
  512 CONTINUE
      IF(L5.NE.2)GOTO 1005
  513 CONTINUE
 1005 RETURN
      END
      SUBROUTINE PROB (L1,C1,C2)
      C2=0.0
      IF(L1.EQ.0.OR.C1.EQ.50.0)GOTO 610
      IF(C1.GT.50.0)V1=(C1-50.0)/100.0
      IF(C1.LT.50.0)V1=(50.0-C1)/100.0
      V2=0.0
      V3=1.0
  601 V2=V2+V3
      V5=0.0
      DO 500 I=1,100
      X=(V2/200)+(I-1)*V2/100.0
      Y1=(EXP(-0.5*X*X))/(SQRT(2*3.14))
      V5=V5+Y1*V2/100.0
```

```
  500 CONTINUE
      IF(ABS(V1-V5).LE.0.001)GOTO 602
      IF(V5.LT.V1)GOTO 601
      V2=V2-V3
      V3=V3/4.0
      GO TO 601
  602 C2=V2
      IF(C1.LT.50.0)C2=-1.0*C2
  610 RETURN
      END
      FINISH
EJ
****
```


0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
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0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
0000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000000
****

ALB 3

DATA VERIFICATION AND AMALGAMATION

(Preparation for line simulation)

ALB3 DATA CHECKING AND AMALGAMATION

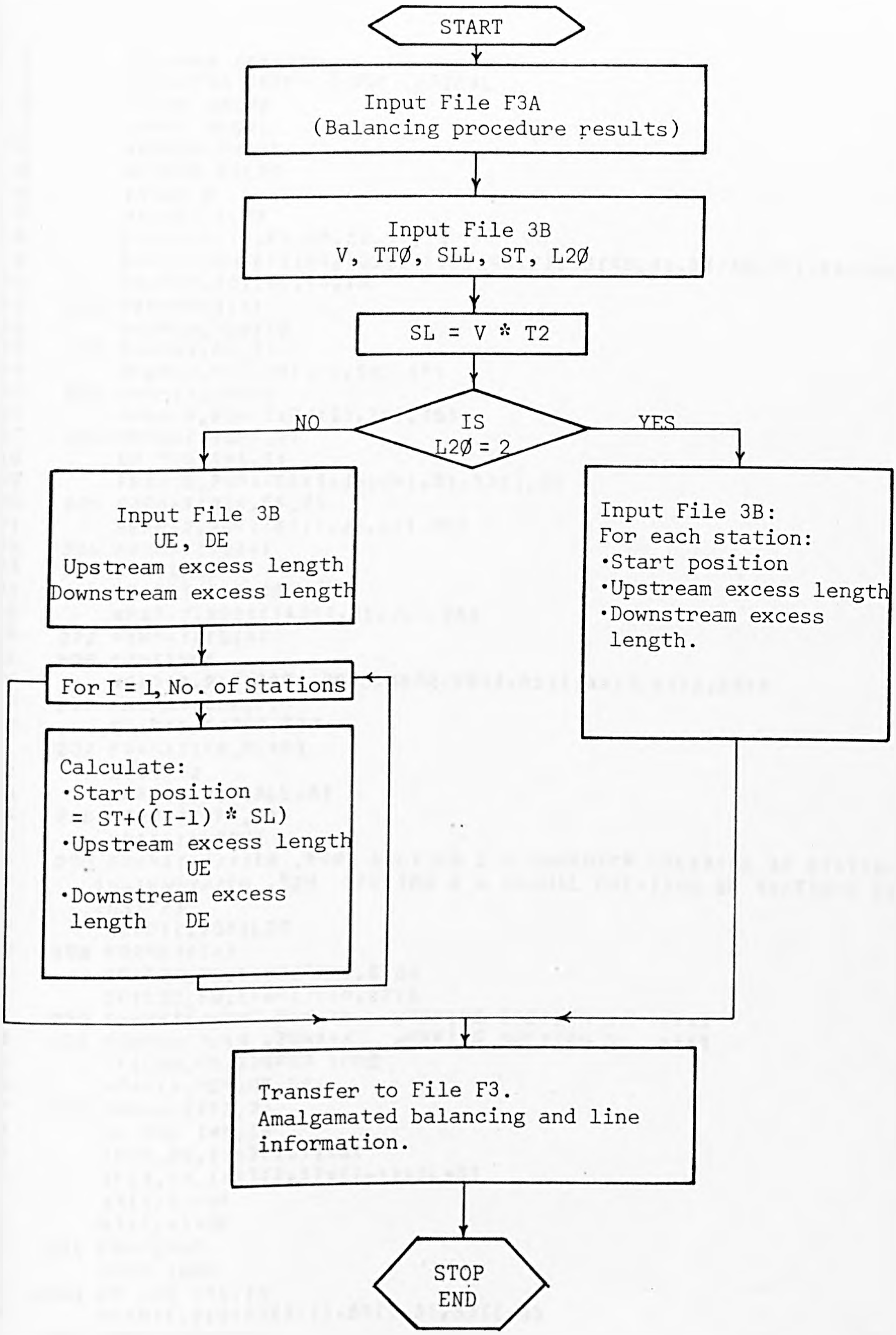

FIG. (C.12) ALB3 GENERAL FLOW CHART.

ALB3 PROGRAM

```
      PRØGRAM (FXXXX)
      CØMPRESS INTEGER AND LØGICAL
      INPUT 1=CR0
      INPUT 2=CR1
      ØUTPUT 5=CP1
      ØUTPUT 6=LP0
      TRACE 2
      MASTER ALB3
      INTEGER T4,E1,T6,S1,S4,T5
      DIMENSIØN E1(10),ADJ(10),S1(40,2),S3(40,4),S4(40,20),IAS(100,10)
      READ(2,201)T4,T6,T5
  201 FØRMAT(3I4)
      READ(2,202)T2
  202 FØRMAT(F6.2)
      READ(2,203)(E1(I),I=1,T6)
  203 FØRMAT(10I6)
      READ(2,204)(ADJ(I),I=1,T6)
  204 FØRMAT(10F6.2)
      DØ 500 I=1,T4
      READ(2,205)(S1(I,J),J=1,2),S3(I,2)
  205 FØRMAT(2I4,F6.2)
      READ(2,206)(S4(I,J),J=1,20)
  206 FØRMAT(20I4)
  500 CØNTINUE
      DØ 505 I=1,T5
      READ(2,222)(IAS(I,J),J=1,T6)
  222 FØRMAT(10I4)
  505 CØNTINUE
      READ(2,217)BBD1,BBD3,BBD2,BBD4,BSI1,BSI3,BSI2,BSI4
  217 FØRMAT(8F6.2)
      READ(1,207)V,TT0
  207 FØRMAT(F6.2,A8)
      SL=V*T2
      READ(1,218)SLL,ST
  218 FØRMAT(2F6.2)
      WRITE(6,200)
  200 FØRMAT(////1H ,54H  SECTIØN 1 = CØMPUTER CREATING ØF STATIØNS DIME
     1NSIØNS///1H ,52H  SECTIØN 2 = MANUAL CREATING ØF STATIØNS DIMENSIØ
     2NS///)
      READ(1,208)L20
  208 FØRMAT(I4)
      IF(L20.EQ.1)WRITE(6,220)
      IF(L20.EQ.2)WRITE(6,221)
  220 FØRMAT(//1H ,29H***   WØRKING SECTIØN 1    ***)
  221 FØRMAT(//1H ,29H***   WØRKING SECTIØN 2    ***)
      IF(L20.EQ.2)GØTØ 1000
      READ(1,209)UE,DE
  209 FØRMAT(2F6.2)
      DØ 501 I=1,T4
      IF(I.EQ.1)S3(I,1)=ST
      IF(I.GT.1)S3(I,1)=(I-1)*SL+ST
      S3(I,3)=UE
      S3(I,4)=DE
  501 CØNTINUE
      GØTØ 1001
 1000 DØ 502 I=1,T4
      READ(1,210)S3(I,1),S3(I,3),S3(I,4)
  210 FØRMAT(3F6.2)
  502 CØNTINUE
C     CHECK IF THE LINE LENGTH ACCØMØDATES ALL THE STATIØNS ØR NØT
```

```
      DØ 507 I=1,T4
      IF((S3(I,1)+SL+S3(I,4)).LT.SLL)GØTØ 507
      WRITE(6,219)I
  219 FØRMAT(//1H ,43H***  ERRØR : LINE LENGTH IS NØT ENØUGH  ***)
      GØTØ 900
  507 CØNTINUE
 1001 WRITE(5,211)T4,T6,T5
  211 FØRMAT(3I4)
      WRITE(5,212)T2,SL,SLL,V,TTO
  212 FØRMAT(4F6.2,A8)
      WRITE(5,215)(E1(I),I=1,T6)
  215 FØRMAT(10I6)
      WRITE(5,216)(ADJ(I),I=1,T6)
  216 FØRMAT(10F6.2)
      DØ 503 I=1,T4
      WRITE(5,213)(S1(I,J),J=1,2),(S3(I,J),J=1,4)
  213 FØRMAT(2I4,4F6.2)
      WRITE(5,214)(S4(I,J),J=1,20)
  214 FØRMAT(20I4)
  503 CØNTINUE
      DØ 506 I=1,T5
      WRITE(5,222)(IAS(I,J),J=1,T6)
  506 CØNTINUE
      WRITE(5,217)BBD1,BBD3,BBD2,BBD4,BSI1,BSI2,BSI3,BSI4
  900 STØP
      END
      FINISH
 EJ
 ****
```

```
*************************************************************************
```

ALB 4

PRODUCTION CALENDAR PREPARATION PROGRAM

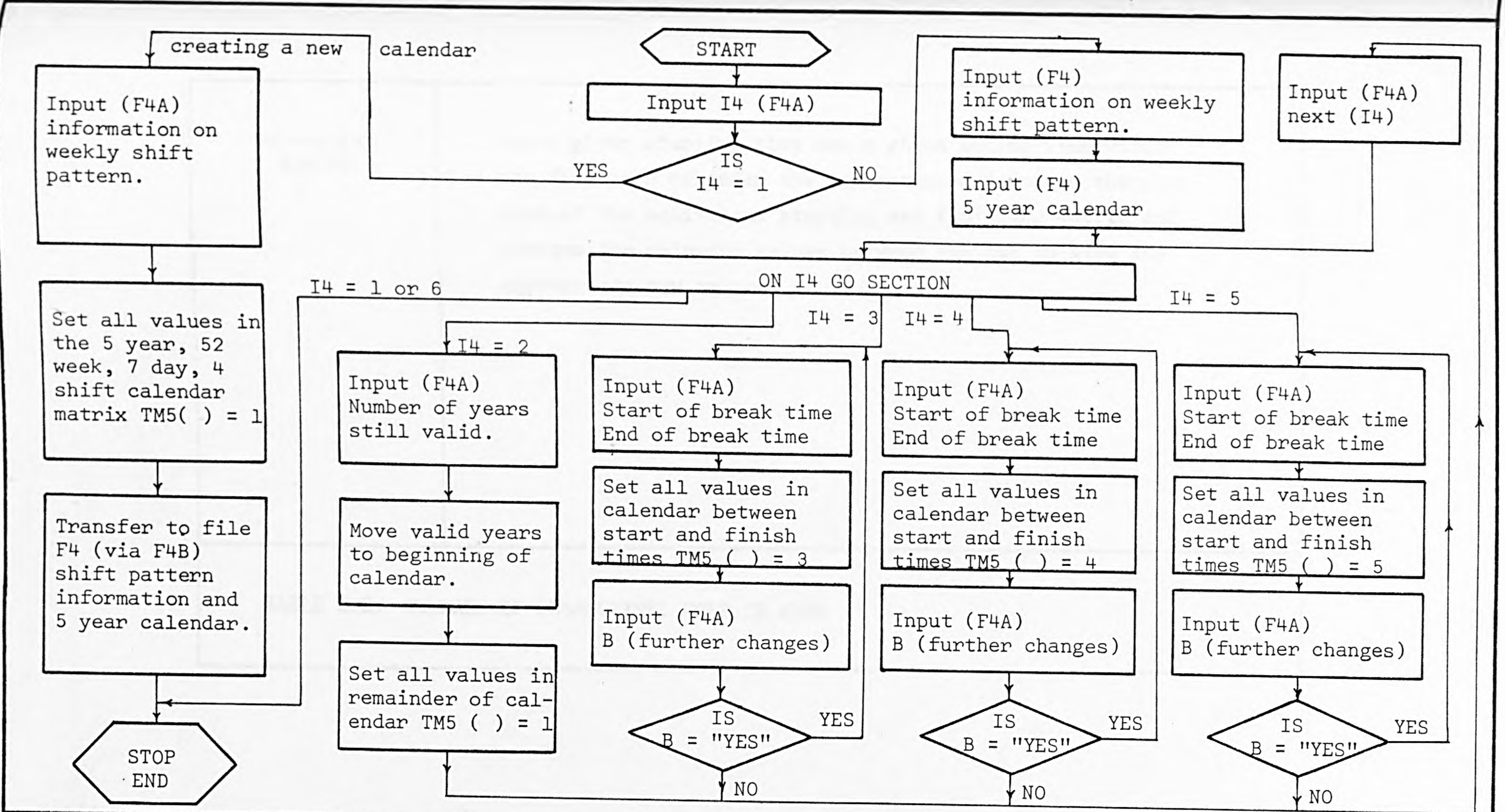

FIG. (C.13) ALB4 GENERAL FLOW CHART.

Subroutine ADDING	For a given starting time and a given ending time within the five year calendar the subroutine determines the position of the equivalent starting and finishing shifts and changes the calendar values between the two to give the appropriate new values.

TABLE C.2. SUMMARY OF SUBROUTINES USED IN ALB4

ALB4: ADDING

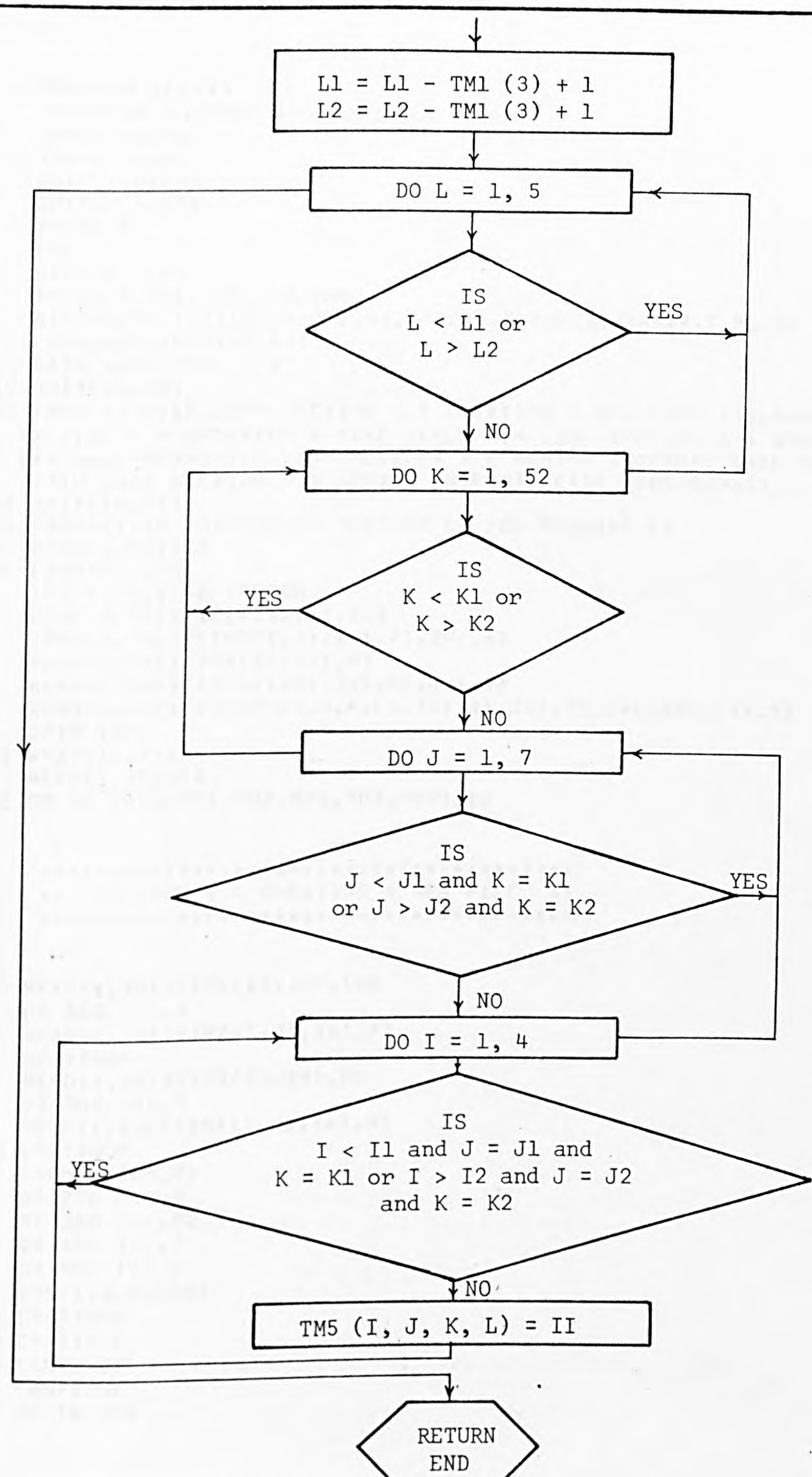

FIG. (C.14) DETAILED FLOW CHART FOR SUBROUTINE ADDING.

ALB4 PROGRAM

```
      PRØGRAM (FXXX)
      CØMPRESS INTEGER AND LØGICAL
      INPUT 1=CR0
      INPUT 2=CR1
      ØUTPUT 6=LP0
      ØUTPUT 5=CP1
      TRACE 2
      END
      MASTER ALB4
      INTEGER TM1,TM2,TM3,TM5
      DIMENSIØN TM1(10),TM2(7,4),TM3(8),TM4(8,2),TM5(4,7,52,5)
      CØMMØN/SLAB1/TM5,TM1
      DATA A/8H YES     /
   19 WRITE(6,20)
   20 FØRMAT(///1H ,38H SECTIØN 1 = CREATING A NEW TIME TABLE//1H ,34H S
     1ECTIØN 2 = UPDATING A TIME TABLE//1H ,38H SECTIØN 3 = ADDING HØLID
     2AY SHUT-DØWNS//1H ,44H SECTIØN 4 = ADDING INTERNAL CASE SHUT-DØWNS
     3//1H ,44H SECTIØN 5 = ADDING INTERNAL CASE SHUT-DØWNS)
   18 WRITE(6,21)
   21 FØRMAT(/1H ,31H WHICH SECTIØN DØ YØU REQUIRE ?)
      READ(1,301)I4
  301 FØRMAT(20I4)
      IF(I4.EQ.1)GØ TØ 900
      READ(2,301)(TM1(I),I=1,10)
      READ(2,301)((TM2(I,J),I=1,7),J=1,4)
      READ(2,301)(TM3(I),I=1,8)
      READ(2,302)((TM4(I,J),I=1,8),J=1,2)
      READ(2,301)((((TM5(I,J,K,L),I=1,4),J=1,7),K=1,52),L=1,5)
      GØTØ 102
  181 WRITE(6,21)
      READ(1,301)I4
  102 GØ TØ (900,901,902,903,904,999),I4
C
C
C     ****************************************
C     **  SECTIØN 1 = CREATING A NEW FILE   **
C     ****************************************
C
C

  900 READ(1,301)(TM1(I),I=1,10)
      DØ 303 J=1,4
      READ(1,301)(TM2(I,J),I=1,7)
  303 CØNTINUE
      READ(1,301)(TM3(I),I=1,8)
      DØ 304 J=1,2
      READ(1,302)(TM4(I,J),I=1,8)
  304 CØNTINUE
  302 FØRMAT(8F5.2)
      DØ 200 L=1,5
      DØ 300 K=1,52
      DØ 400 J=1,7
      DØ 500 I=1,4
      TM5(I,J,K,L)=1
  500 CØNTINUE
  400 CØNTINUE
  300 CØNTINUE
  200 CØNTINUE
      GØ TØ 909
C
C
```

```
C        ****************************************
C        **  SECTIØN 2 = UPDATING A TIME TABLE   **
C        ****************************************
C
C
  901 WRITE(6,22)
   22 FØRMAT(/1H ,55H HØW MANY YEARS ØF EXISTING TIME TABLE ARE TØ BE KE
     1PT ?/)
      READ(1,301)I5
      IF(I5.LT.1) GØ TØ 32
      IF(I5.GT.4) GØ TØ 34
      GØ TØ 36
   32 WRITE(6,33)
   33 FØRMAT(/1H ,50H ERRØR NUMBER ØF YEARS TØ BE KEPT IS LESS THAN ØNE/
     11H ,6H *****)
      GØ TØ 1000
   34 WRITE(6,35)
   35 FØRMAT(/1H ,51H ERRØR NUMBER ØF YEARS TØ BE KEPT IS MØRE THAN FØUR
     1/1H ,6H *****)
      GØ TØ 1000
   36 DØ 603 L=1,I5
      DØ 602 K=1,52
      DØ 601 J=1,7
      DØ 600 I=1,4
      TM5(I,J,K,L)=TM5(I,J,K,L+(5-I5))
  600 CØNTINUE
  601 CØNTINUE
  602 CØNTINUE
  603 CØNTINUE
      DØ 607 L=I5+1,5
      DØ 606 K=1,52
      DØ 605 J=1,7
      DØ 604 I=1,4
      TM5(I,J,K,L)=1
  604 CØNTINUE
  605 CØNTINUE
  606 CØNTINUE
  607 CØNTINUE
      TM1(3)=TM1(3)+5-I5
      WRITE(6,56)TM1(3)
   56 FØRMAT(/1H ,46H NEW STARTING YEAR ØF THE PRØDUCTIØN PRØGRAM :,I6/1
     1H ,46H ********************************************)
      ITS=(TM1(3)-1)*52*7*4
      ITE=(TM1(3)-1+5)*52*7*4
      GØ TØ 181
C
C
C        ****************************************
C        **  SECTIØN 3 = ADDING HØLIDAY SHUT-DØWNS  **
C        ****************************************
C
C
  902 READ(1,41)I1,J1,K1,L1
   41 FØRMAT(4I4)
      WRITE(6,40)I1,J1,K1,L1
   40 FØRMAT(/1H ,23H START ØF HØLIDAY BREAK//1H ,8H SHIFT :,I4/1H ,8H D
     1AY   :,I4/1H ,8H WEEK  :,I4/1H ,8H YEAR  :,I4/)
      IT1=(L1-1)*52*7*4+K1*7*4+(J1-1)*4+(4+1-I1)
      READ(1,43)I2,J2,K2,L2
      WRITE(6,42)I2,J2,K2,L2
```

```
      READ(1,43)I2,J2,K2,L2
      WRITE(6,42)I2,J2,K2,L2
   42 FORMAT(/1H ,21H END OF HOLIDAY BREAK//1H ,8H SHIFT :,I4/1H ,8H DAY
     1    :,I4/1H ,8H WEEK  :,I4/1H ,8H YEAR  :,I4/)
   43 FORMAT(4I4)
      IT2=(L2-1)*52*7*4+K2*7*4+(J2-1)*4+(4+1-I2)
      N=0
      IF(IT1.LT.ITE) GO TO 45
      WRITE(6,44)
   44 FORMAT(/1H ,66H ERROR-START OF HOLIDAY BREAK AFTER THE END OF THE
     1FIVE YEARS PLAN/1H ,6H *****)
      N=1
   45 IF(IT2.LT.ITE) GO TO 47
      WRITE(6,46)
   46 FORMAT(/1H ,64H ERROR-END OF HOLIDAY BREAK AFTER THE END OF THE FI
     1VE YEARS PLAN/1H ,6H *****)
      N=1
   47 IF(IT1.GT.ITS) GO TO 49
      WRITE(6,48)
   48 FORMAT(/1H ,69H ERROR-START OF HOLIDAY BREAK BEFORE THE START OF T
     1HE FIVE YEARS PLAN/1H ,6H *****)
      N=1
   49 IF(IT2.GT.ITS) GO TO 51
      WRITE(6,50)
   50 FORMAT(/1H ,67H ERROR-END OF HOLIDAY BREAK BEFORE THE START OF THE
     1 FIVE YEARS PLAN/1H ,6H *****)
      N=1
   51 IF(IT2.GT.IT1) GO TO 53
      WRITE(6,52)
   52 FORMAT(/1H ,44H ERROR-START OF HOLIDAY BREAK AFTER IT'S END/1H ,6H
     1 *****)
      N=1
   53 IF(N.EQ.1) GO TO 1000
      II=3
      CALL ADDING (II,I1,I2,J1,J2,K1,K2,L1,L2)
      WRITE(6,54)
   54 FORMAT(/1H ,47H ANY MORE ENTERIES FOR HOLIDAY BREAK SHUT-DOWNS/)
      READ(1,55)B
      WRITE(6,55)B
   55 FORMAT(A8)
      IF(B.EQ.A) GO TO 902
      GO TO 181
C
C
C     ****************************************************
C     **  SECTION 4 - ADDING INTERNAL CASE SHUT-DOWNS   **
C     ****************************************************
C
C
  903 READ(1,61)I1,J1,K1,L1
   61 FORMAT(4I4)
      WRITE(6,60)I1,J1,K1,L1
   60 FORMAT(/1H ,36H START OF BREAK TIME (INTERNAL CASE)//1H ,8H SHIFT
     1:,I4/1H ,8H DAY   :,I4/1H ,8H WEEK  :,I4/1H ,8H YEAR  :,I4/)
      IT1=(L1-1)*52*7*4+K1*7*4+(J1-1)*4+(4+1-I1)
      READ(1,61)I2,J2,K2,L2
      WRITE(6,62)I2,J2,K2,L2
   62 FORMAT(/1H ,34H END OF BREAK TIME (INTERNAL CASE)//1H ,8H SHIFT :,
     1I4/1H ,8H DAY   :,I4/1H ,8H WEEK  :,I4/1H ,8H YEAR  :,I4/)
      IT2=(L2-1)*52*7*4+K2*7*4+(J2-1)*4+(4+1-I2)
```

```
      N=0
      IF(IT1.LT.ITF) GO TO 65
      WRITE(6,64)
   64 FORMAT(/1H ,79H ERROR-START OF BREAK TIME (INTERNAL CASE) AFTER TH
     1E END OF THE FIVE YEARS PLAN/1H ,6H *****)
      N=1
   65 IF(IT2.LT.ITE) GO TO 67
      WRITE(6,66)
   66 FORMAT(/1H ,77H ERROR-END OF BREAK TIME (INTERNAL CASE) AFTER THE
     1END OF THE FIVE YEARS PLAN/1H ,6H *****)
      N=1
   67 IF(IT1.GT.ITS) GO TO 69
      WRITE(6,68)
   68 FORMAT(/1H ,82H ERROR-START OF BREAK TIME (INTERNAL CASE) BEFORE T
     1HE START OF THE FIVE YEARS PLAN/1H ,6H *****)
      N=1
   69 IF(IT2.GT.ITS) GO TO 71
      WRITE(6,70)
   70 FORMAT(/1H ,76H ERROR-END OF BREAK TIME (INTERNAL CASE) BEFORE THE
     1 START OF FIVE YEARS PLAN/1H ,6H *****)
      N=1
   71 IF(IT2.GT.IT1) GO TO 73
      WRITE(6,72)
   72 FORMAT(/1H ,57H ERROR-START OF BREAK TIME (INTERNAL CASE) AFTER IT
     1IS END/1H ,6H *****)
      N=1
   73 IF(N.EQ.1) GO TO 1000
      II=4
      CALL ADDING (II,I1,I2,J1,J2,K1,K2,L1,L2)
      WRITE(6,74)
   74 FORMAT(/1H ,48H ANY MORE ENTERIES FOR INTERNAL BREAK SHUT-DOWNS/)
      READ(1,75)B
      WRITE(6,75)B
   75 FORMAT(A8)
      IF(B.EQ.A) GO TO 903
      GO TO 181
C
C
C     ***************************************************************
C     **  SECTION 5 = ADDING EXTERNAL CASE SHUT-DOWNS  **
C     ***************************************************************
C
C
  904 READ(1,81)I1,J1,K1,L1
   81 FORMAT(4I4)
      WRITE(6,80)I1,J1,K1,L1
   80 FORMAT(/1H ,36H START OF BREAK TIME (EXTERNAL CASE)//1H ,8H SHIFT
     1:,I4/1H ,8H DAY    :,I4/1H ,8H WEEK   :,I4/1H ,8H YEAR   :,I4/)
      IT1=(L1-1)*52*7*4+K1*7*4+(J1-1)*4+(4+1-I1)
      READ(1,81)I2,J2,K2,L2
      WRITE(6,82)I2,J2,K2,L2
   82 FORMAT(/1H ,34H END OF BREAK TIME (EXTERNAL CASE)//1H ,8H SHIFT :,
     1I4/1H ,8H DAY    :,I4/1H ,8H WEEK   :,I4/1H ,8H YEAR   :,I4/)
      IT2=(L2-1)*52*7*4+K2*7*4+(J2-1)*4+(4+1-I2)
      N=0
      IF(IT1.LT.ITE) GO TO 85
      WRITE(6,84)
   84 FORMAT(/1H ,75H ERROR-START OF BREAK TIME (EXTERNAL CASE) AFTER TH
     1E END OF FIVE YEARS PLAN/1H ,6H *****)
      N=1
```

```
   85 IF(IT2.LT.ITF) GO TO 87
      WRITE(6,86)
   86 FORMAT(/1H ,77H ERROR-END OF BREAK TIME (EXTERNAL CASE) AFTER THE
     1END OF THE FIVE YEARS PLAN/1H ,6H *****)
      N=1
   87 IF(IT1.GT.ITS) GO TO 89
      WRITE(6,88)
   88 FORMAT(/1H ,82H ERROR-START OF BREAK TIME (EXTERNAL CASE) BEFORE T
     1HE START OF THE FIVE YEARS PLAN/1H ,6H *****)
      N=1
   89 IF(IT2.GT.ITS) GO TO 91
      WRITE(6,90)
   90 FORMAT(/1H ,80H ERROR-END OF BREAK TIME (EXTERNAL CASE) BEFORE THE
     1 START OF THE FIVE YEARS PLAN/1H ,6H *****)
      N=1
   91 IF(IT2.GT.IT1) GO TO 93
      WRITE(6,92)
   92 FORMAT(/1H ,57H ERROR-START OF BREAK TIME (EXTERNAL CASE) AFTER IT
     1'S END/1H ,6H *****)
      N=1
   93 IF(N.EQ.1) GO TO 1000
      II=5
      CALL ADDING (II,I1,I2,J1,J2,K1,K2,L1,L2)
      WRITE(6,94)
   94 FORMAT(/1H ,48H ANY MORE ENTERIES FOR EXTERNAL BREAK SHUT-DOWNS/)
      READ(1,95)B
      WRITE(6,95)B
   95 FORMAT(A8)
      IF(B.EQ.A) GO TO 904
  999 WRITE(5,301)(TM1(I),I=1,10)
      WRITE(5,96)((TM2(I,J),I=1,7),J=1,4)
   96 FORMAT(7I4)
      WRITE(5,301)(TM3(I),I=1,8)
      WRITE(5,302)((TM4(I,J),I=1,8),J=1,2)
      WRITE(5,301)((((TM5(I,J,K,L),I=1,4),J=1,7),K=1,52),L=1,5)
 1000 STOP
      END
C
C
      SUBROUTINE ADDING (II,I1,I2,J1,J2,K1,K2,L1,L2)
C
C
      INTEGER TM1,TM5
      DIMENSION TM5(4,7,52,5),TM1(10)
      COMMON/SLAB1/TM5,TM1
C
C     CHANGING THE FIGURES IN THE TM5 MATRIX TO THE APPROPRIATE FIGURES
C
      L1=L1-TM1(3)+1
      L2=L2-TM1(3)+1
      DO 504 L=1,5
      IF(L.LT.L1.OR.L.GT.L2) GO TO 504
      DO 503 K=1,52
      IF(K.LT.K1.OR.K.GT.K2) GO TO 503
      DO 502 J=1,7
      IF(J.LT.J1.AND.K.EQ.K1) GO TO 502
      IF(J.GT.J2.AND.K.EQ.K2) GO TO 502
      DO 501 I=1,4
      IF(I.LT.I1.AND.J.EQ.J1.AND.K.EQ.K1) GO TO 501
      IF(I.GT.I2.AND.J.EQ.J2.AND.K.EQ.K2) GO TO 501
```

```
    502 CØNTINUE
    503 CØNTINUE
    504 CØNTINUE
        RETURN
        END
        FINISH
C
C       ****  CARD INPUT DATA AT THIS PØINT  ***
C
1LAB
IF NØT DISP(ØK),EJ
LF F4B,*LP
IF REPLY(FILE EMPTY),EJ
CY F4B,F4
ER F4B
EJ
****
```

ALB 5

PRODUCTION SIMULATION PROGRAM

ALB5

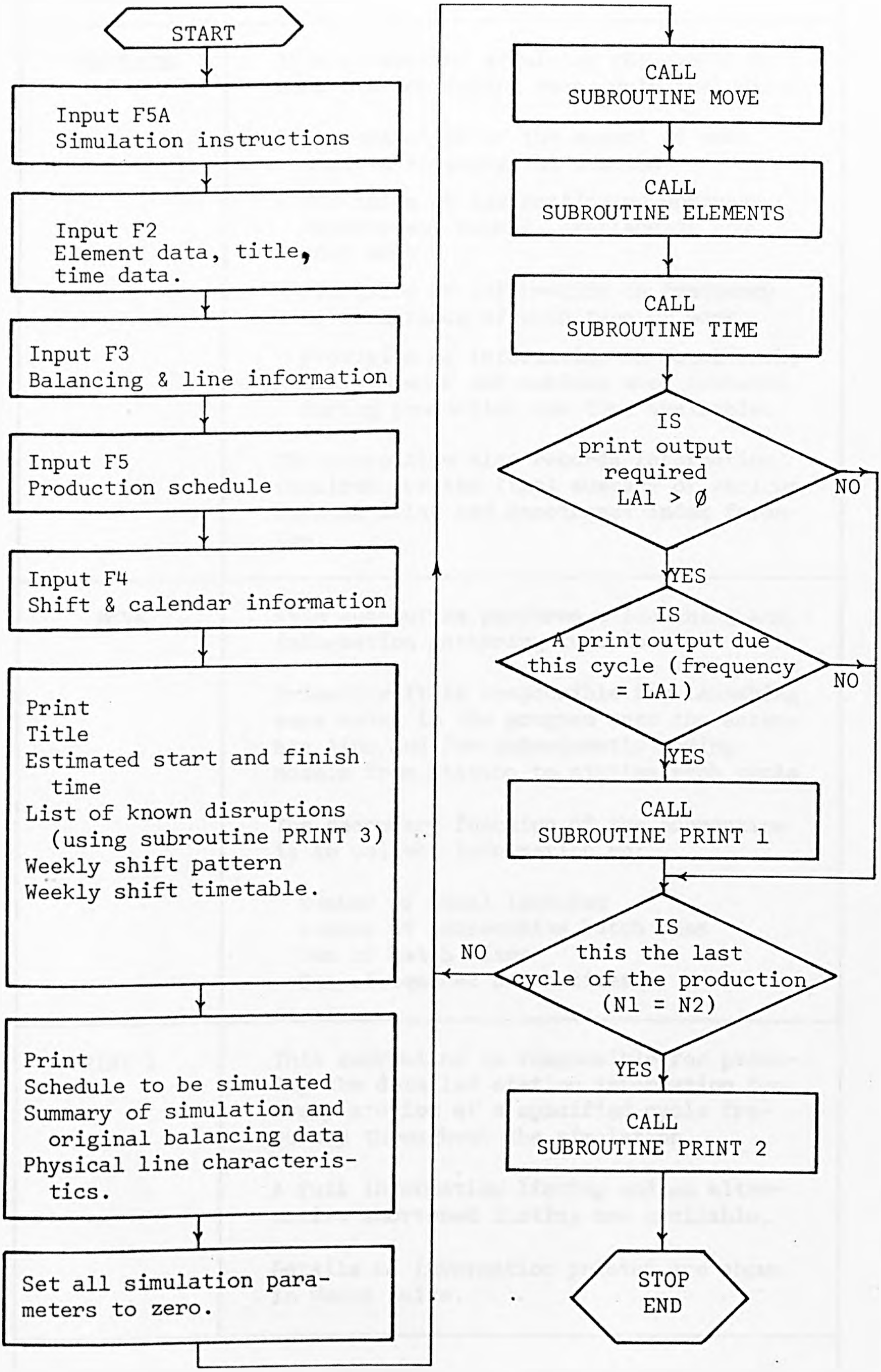

FIG. (C.15) ALB5 GENERAL FLOW CHART.

SUBROUTINE	PURPOSE
ELEMENTS	This subroutine simulates the events at each station during each cycle including: - Determination of the amount of work undertaken along the station - Provision of information on upstream, downstream, normal, overlapping and lost work - Provision of information on frequency of occurrence of each type of work - Provision of information on total work, minimum work and maximum work achieved during production and time available. The subroutine also records information required for the final summary of various balance delay and smoothness index formulae.
MOVE	This subroutine performs a launching and information gathering function. Primarily it is responsible for launching each model in the program onto the assembly line and for subsequently moving models from station to station each cycle. The secondary function of the subroutine is to collect information on: Number of model launched Number of consecutive batch runs Sum of batch sizes Sum of squared batch sizes.
PRINT 1	This subroutine is responsible for printing the detailed station information for every station at a specified cycle frequency throughout the simulation. A full information listing and an alternative shortened listing are available. Details of information printed are shown in Users Guide.

TABLE (C.3) SUMMARY OF SUBROUTINES USED IN ALB5.

SUBROUTINE	PURPOSE
PRINT 2	This subroutine is responsible for carrying out the calculation required to print the final analysis after the completion of the simulation run. Details of the information printed are given in Users Guide.
PRINT 3	This subroutine calculates the starting and finishing time for a given production program and uses this information to list all the planned disruptions between the two dates.
TIME	Given a known start time this subroutine can determine the real time at which any cycle of the production program will take place. Included in this subroutine and data checks against the production schedule and calendar.

TABLE (C.3) SUMMARY OF SUBROUTINES USED IN ALB5 (Cont.)

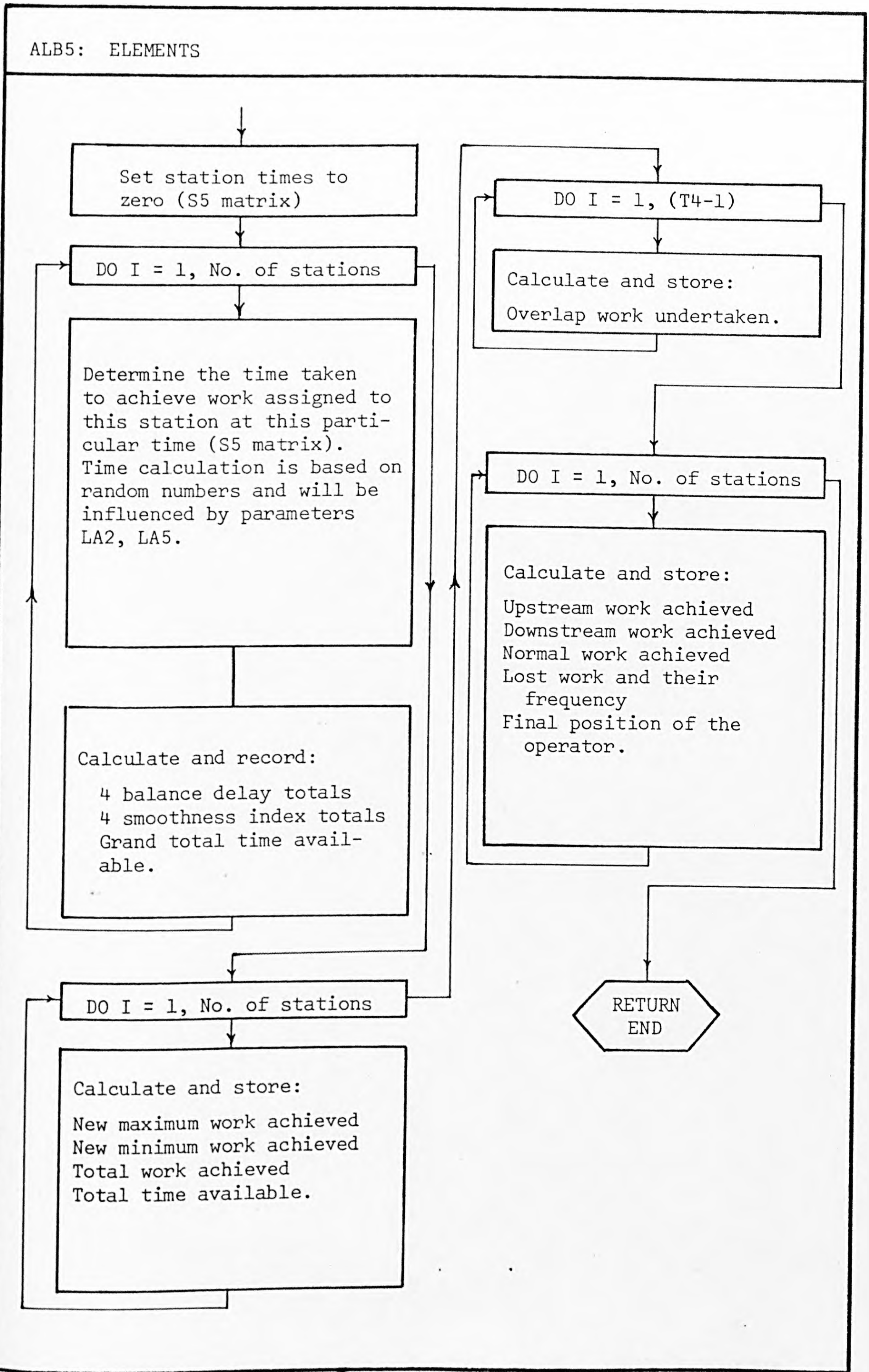

FIG. (C.16) FLOW CHART FOR SUBROUTINE ELEMENTS.

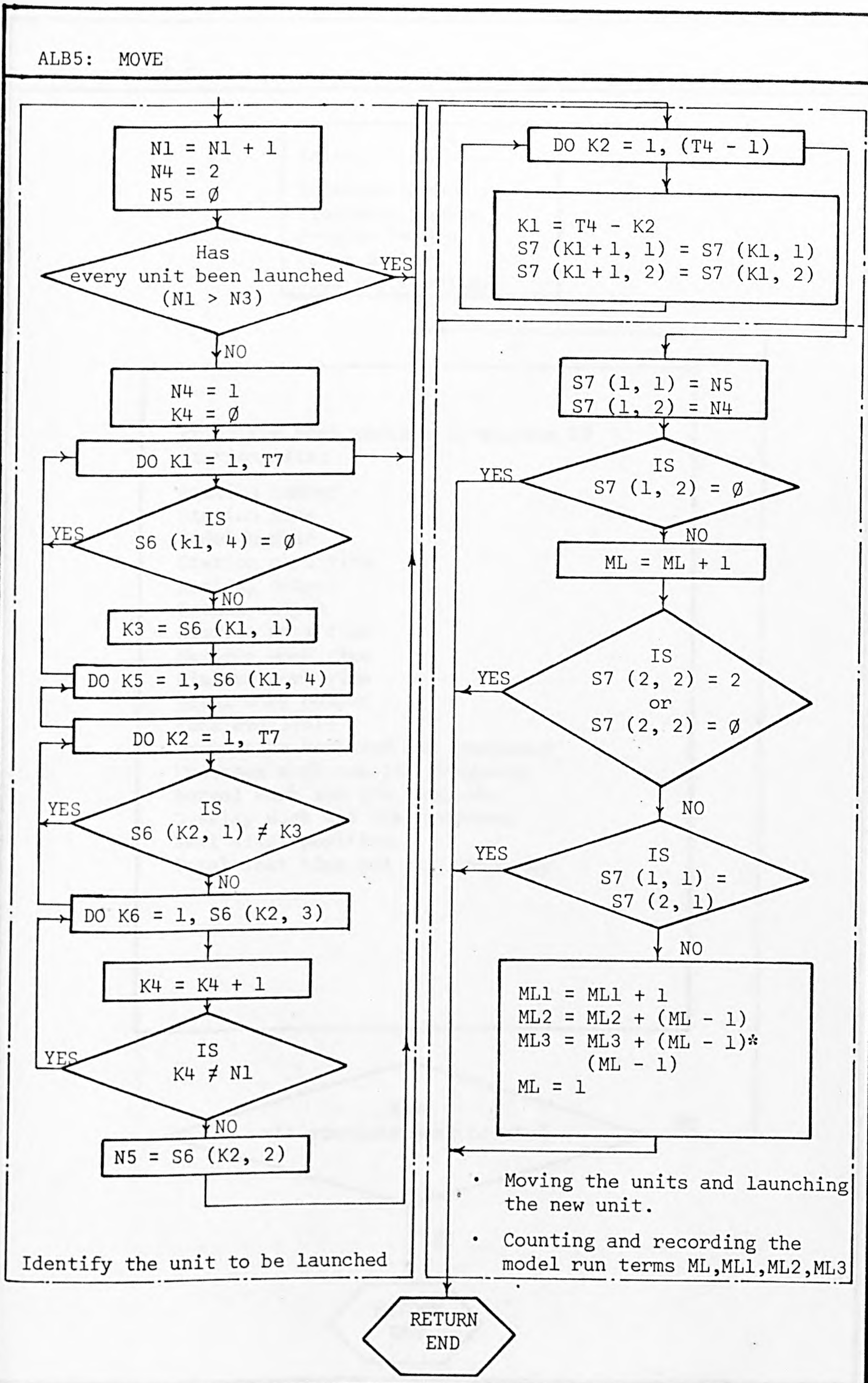

FIG. (C.17) FLOW CHART FOR SUBROUTINE MOVE.

ALB5: PRINT 1

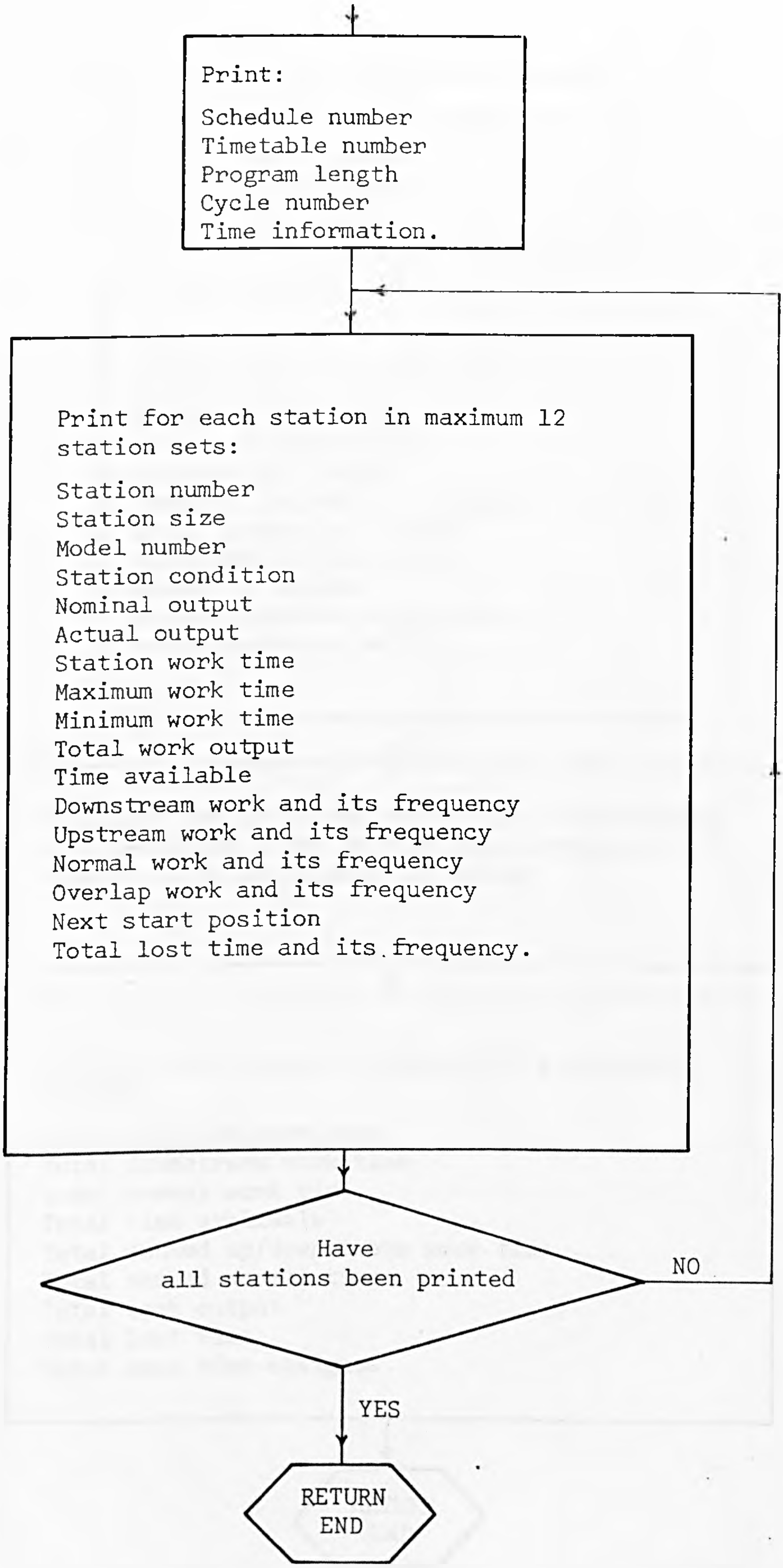

FIG. (C.18) FLOW CHART FOR SUBROUTINE PRINT 1.

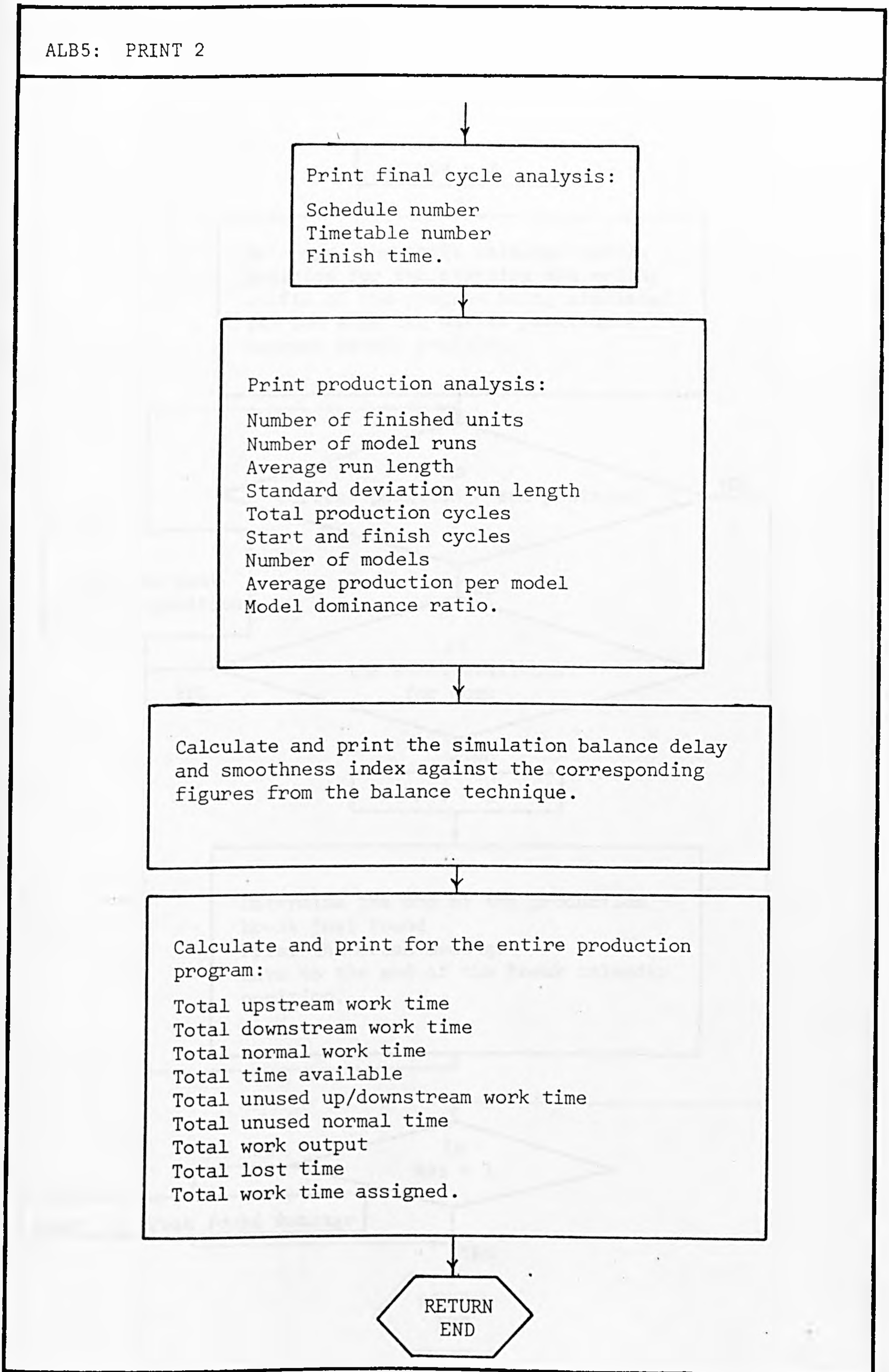

FIG. (C.19) FLOW CHART FOR SUBROUTINE PRINT 2.

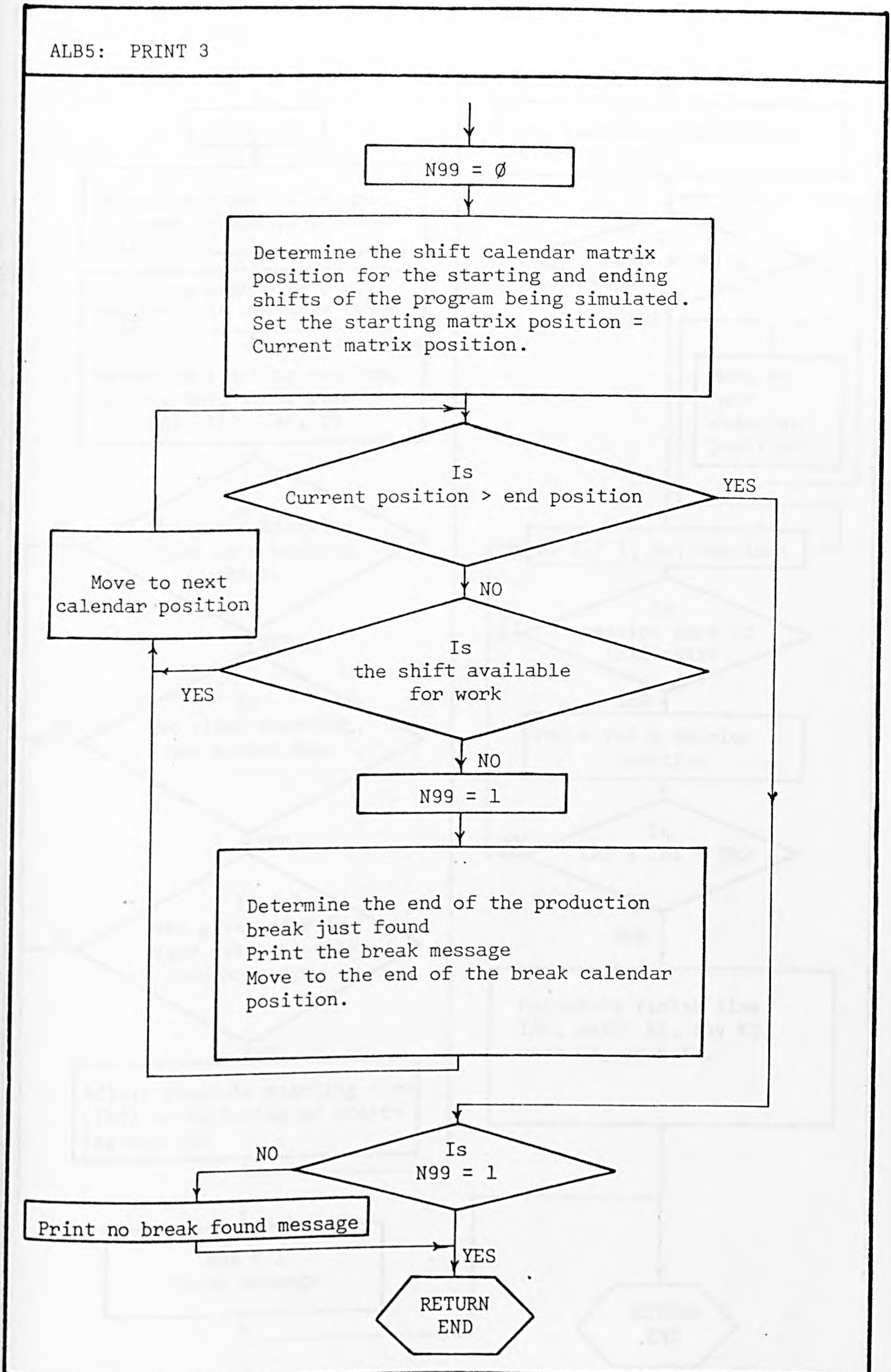

FIG. (C.20) FLOW CHART FOR SUBROUTINE PRINT 3.

ALB5: TIME

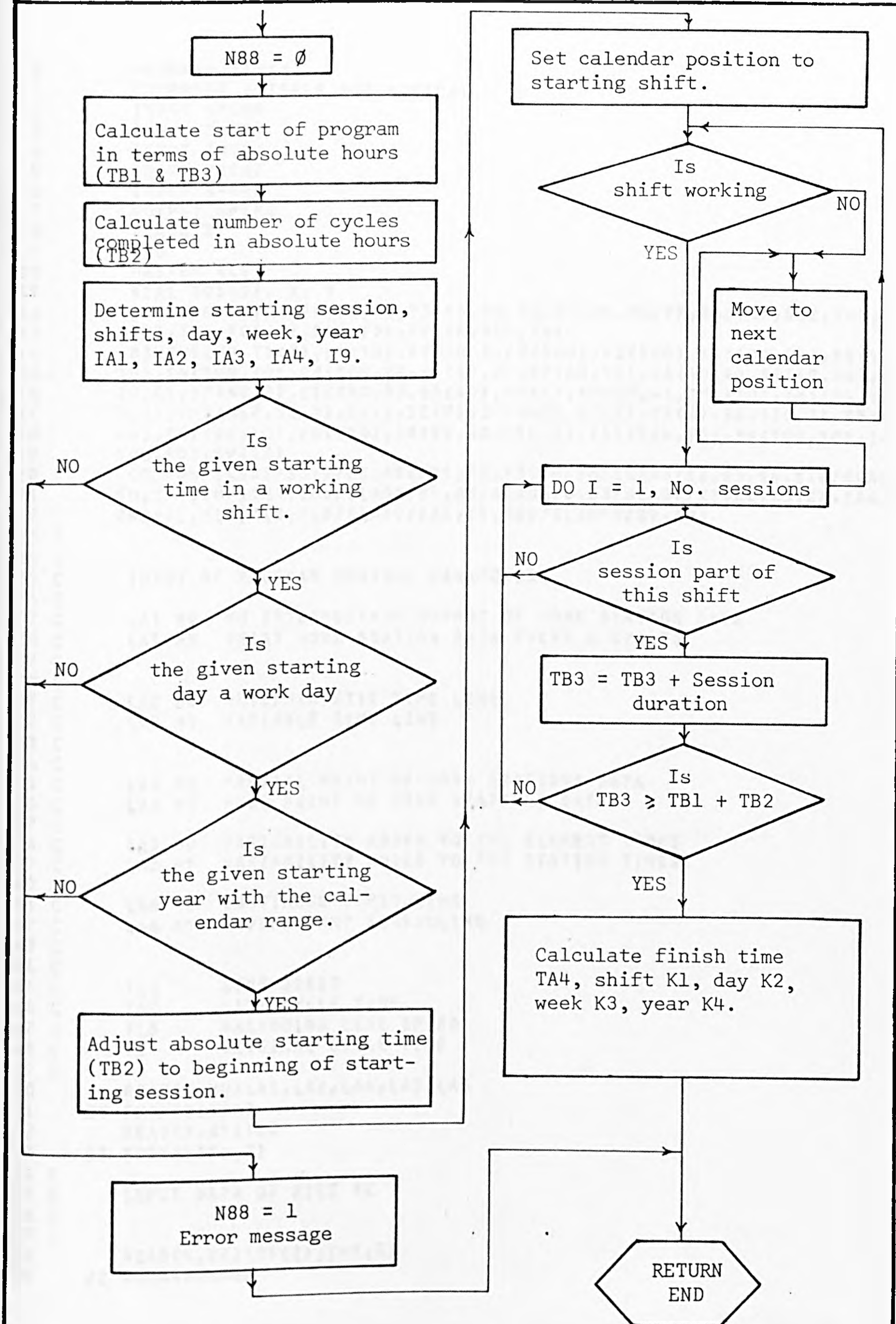

FIG. (C.21) FLOW CHART FOR SUBROUTINE TIME.

ALB5 PROGRAM

```
      PROGRAM (FXXX)
      COMPRESS INTEGER AND LOGICAL
      INPUT 4=CR0
      INPUT 5=CR1
      INPUT 3=CR2
      INPUT 7=CR7
      INPUT 8=CR8
      OUTPUT 6=LP0
      TRACE 2
      END
      MASTER ALB5
      REAL G05ADF, X, Y
      INTEGER E1,F1,F4,F5,F6,T3,T5,T6,T4,S1,S4,S6,T7,S66,S7,S12,TM2,TM1,
     1TM3,TM5,SC1,D2,S60,F51,F9,T6,T11,T61
      DIMENSION T1(8),E1(10),F1(100),F2(100),F3(100),F4(100,10),F5(100,1
     10),F6(100,10),F7(100,7),S1(40,2),S2(40,12),S3(40,4),S4(40,20),S6(3
     20,4),S7(40,2),S12(40,8),S5(40),TM(4),TM2(7,4),TM1(10),TM3(8),TM4(8
     3,2),TM5(4,7,52,5),D(7),SC(7),SC1(40),D2(7),D3(2),S60(30,3),S8(40,1
     40),S81(40,10),F8(100),IR(9),ADJ(10,2),F51(100,10),F9(100,10),IAS(1
     500,10),S9(12)
      COMMON/SLAB1/S6,S7/SLAB2/F1,F2,F3,F6,F8/SLAB3/S2,S3,S4,S12/SLAB4/T
     1M,TM1,TM3,TM4,TM5/SLAB5/S1,S5/SLAB6/D,D3/SLAB7/K1,K2,K3,K4,TA4/SLA
     2B8/ML,ML1,ML2,ML3/SLAB9/IAS,E1,S60/SLAB10/S9,ADJ
C
C
C     INPUT OF PROGRAM CONTROL PARAMETERS
C
C     LA1 =0  NO INTERMEDIATE OUTPUT OF WORK STATION DATA
C     LA1 =N  PRINT WORK STATION DATA EVERY N CYCLES
C
C
C     LA2 =0  DETERMINISTIC TIME LINE
C     LA2 =1  VARIABLE TIME LINE
C
C
C     LA4 =0  PARTIAL PRINT OF WORK STATIONS DATA
C     LA4 =1  FULL PRINT OF WORK STATIONS DATA
C
C     LA5 =0  VARIABILITY ADDED TO THE ELEMENT TIMES
C     LA5 =1  VARIABILITY ADDED TO THE STATION TIMES
C
C     LA6 =0  CONTINOUS SCHEDULING
C     LA6 =1  INDEPENDANT SCHEDULING
C
C
C     TL1     LINE SPEED
C     TL2     LINE CYCLE TIME
C     TL3     BALANCING LINE SPEED
C     TZ      ORIGINAL CYCLE TIME
C
      READ(7,20)LA1,LA2,LA4,LA5,LA6
   20 FORMAT(5I4)
      READ(7,21)TL2
   21 FORMAT(F6.2)
C
C     INPUT DATA OF FILE F2
C
C
      READ(4,22)(T1(I),I=1,8)
   22 FORMAT(8A8)
```

```
      READ(4,23)T5
   23 FORMAT(I4)
      DO 500 I=1,T5
      READ(4,24)F1(I),F2(I),F8(I),F3(I),(F7(I,J),J=1,7)
   24 FORMAT(I4,3F6,2,7A8)
      READ(4,25)(F4(I,J),J=1,10)
      READ(4,25)(F5(I,J),J=1,10)
      READ(4,25)(F51(I,J),J=1,10)
      READ(4,25)(F6(I,J),J=1,10)
      READ(4,25)(F9(I,J),J=1,10)
   25 FORMAT(10I4)
  500 CONTINUE
      READ(4,17)T0,T9,T10
   17 FORMAT(A8,2F10,2)
C
C
C     INPUT DATA OF FILE  F3
C
C     TT0  LENGTH UNITS
C
      READ(5,26)T4,T6,T5
   26 FORMAT(3I4)
      READ(5,27)T2,SL,SLL,TL3,TT0
   27 FORMAT(4F6,2,A8)
      READ(5,18)(E1(I),I=1,T6)
   18 FORMAT(10I6)
      READ(5,19)(ADJ(I,1),I=1,T6)
   19 FORMAT(10F6,2)
      DO 501 I=1,T4
      READ(5,28)(S1(I,J),J=1,2),(S3(I,J),J=1,4)
   28 FORMAT(2I4,4F6,2)
      READ(5,29)(S4(I,J),J=1,20)
   29 FORMAT(20I4)
  501 CONTINUE
      DO 492 I=1,T5
      READ(5,16)(IAS(I,J),J=1,T6)
   16 FORMAT(10I4)
  492 CONTINUE
      READ(5,19)BBD1,BBD3,BBD2,BBD4,BSI1,BSI2,BSI3,BSI4
C
C
C     INPUT DATA OF FILE F5
C
C
      READ(3,30)T7,T11
   30 FORMAT(2I4)
      DO 502 I=1,T7
      READ(3,31)(S6(I,J),J=1,4)
   31 FORMAT(4I4)
  502 CONTINUE
C
C
C     INPUT DATA OF TIME  &  F4
C
C
      READ(7,32)(TM(I),I=1,4)
   32 FORMAT(4F8,2)
      READ(8,33)(TM1(I),I=1,10)
   33 FORMAT(20I4)
      READ(8,12)((TM2(I,J),I=1,7),J=1,4)
```

```
   12 FORMAT(/I4)
      READ(8,33)(TM3(I),I=1,8)
      READ(8,34)((TM4(I,J),I=1,8),J=1,2)
   34 FORMAT(8F5.2)
      READ(8,33)((((TM5(I,J,K,L),I=1,4),J=1,7),K=1,52),L=1,5)
C
C     SETTING THE STARTING POSITION FOR ALL WORK STATIONS AT THE BEGINING
C
C
      WRITE(6,90)
   90 FORMAT(1H1)
      WRITE(6,91)
   91 FORMAT(////1H ,10X,100H*******************************************
     1*****************************************************************)
      WRITE(6,92)
   92 FORMAT(1H ,10X,1H*,98X,1H*)
      WRITE(6,93)(T1(I),I=1,8)
   93 FORMAT(1H ,10X,1H*,5X,8HTITLE : ,8A8,21X,1H*)
      WRITE(6,92)
      WRITE(6,94)T11,TM1(5)
   94 FORMAT(1H ,10X,1H*,5X,28HPRODUCTION SCHEDULE NUMBER :,I4,27X,18HTI
     1METABLE NUMBER :,I4,12X,1H*)
      WRITE(6,92)
      WRITE(6,95)
   95 FORMAT(1H ,10X,100H***********************************************
     1*************************************************************//////)
C
      N1=0
      CALL TIME (TL2,N1,N88,T10)
      ITM1=K1
      IF(N88.EQ.1) GO TO 516
C
C
C     CALCULATION OF TOTAL NUMBER OF MOVES IN SCHEDULE N2
C     & TOTAL NUMBER OF UNITS  N3
C
C
      N3=0
      DO 305 K1=1,T7
      IF(S6(K1,4).EQ.0) GO TO 305
      K3=S6(K1,1)
      DO 304 K2=1,T7
      IF(S6(K2,1).NE.K3) GO TO 304
      N3=N3+S6(K2,3)*S6(K1,4)
  304 CONTINUE
  305 CONTINUE
      N2=N3+T4-1
      N1=N2
      CALL TIME (TL2,N1,N88,T10)
C
C     WRITE TIME SCHEDULE
C
C
      WRITE(6,35)
   35 FORMAT(////1H ,10X,100H  *****************************************
     1***************************************************************)
      WRITE(6,36)
   36 FORMAT(1H ,10X,3H  *,95X,2H *)
      WRITE(6,37)
   37 FORMAT(1H ,10X,27H  *  PRODUCTION TIMETABLE :,71X,2H *)
```

```
      WRITE(6,38)
   38 FORMAT(1H ,10X,27H  *************************,71X,2H *)
      WRITE(6,39)
   39 FORMAT(1H ,10X,3H  *,95X,2H *)
      WRITE(6,39)
      WRITE(6,40)
   40 FORMAT(1H ,10X,3H  *,5X,86H*******************************************
     1*******************************************,5X,1H*)
      WRITE(6,41)
   41 FORMAT(1H ,10X,3H  *,5X,1H*,84X,1H*,5X,1H*)
      WRITE(6,44)TM(1),TA4
   44 FORMAT(1H ,10X,3H  *,26H      *      PROGRAM START :,F6.2,20X,25H  E
     1STIMATED FINISH TIME :,F6.2,7X,1H*,5X,1H*)
      WRITE(6,441)
  441 FORMAT(1H ,10X,3H  *,26H      *      ***************,26X,25H  ******
     1*****************,13X,1H*,5X,1H*)
      ITM2=INT(TM(2))
      ITM3=INT(TM(3))
      ITM4=INT(TM(4))
      WRITE(6,45)D(ITM2),D(K2)
   45 FORMAT(1H ,10X,3H  *,26H      *                 DAY :,2X,A8,20X,21H
     1               DAY :,2X,A8,3X,1H*,5X,1H*)
      WRITE(6,46)ITM3,K3
   46 FORMAT(1H ,10X,3H  *,26H      *                WEEK :,I4,20X,27H
     1                    WEEK :,I4,9X,1H*,5X,1H*)
      WRITE(6,47)ITM4,K4
   47 FORMAT(1H ,10X,3H  *,26H      *                YEAR :,2X,I4,20X,25H
     1                    YEAR :,2X,I4,7X,1H*,5X,1H*)
      WRITE(6,41)
      WRITE(6,41)
      WRITE(6,40)
      WRITE(6,48)
      WRITE(6,48)
      WRITE(6,42)
   42 FORMAT(1H ,10X,100H  *******************************************
     1*******************************************************)
      WRITE(6,48)
      WRITE(6,48)
   48 FORMAT(1H ,10X,3H  *,95X,2H *)
      WRITE(6,481)
  481 FORMAT(1H ,10X,3H  *,22H  PROGRAM DISRUPTION :,73X,2H *)
      WRITE(6,482)
  482 FORMAT(1H ,10X,3H  *,22H**********************,73X,2H *)
      CALL PRINT3 (ITM1,ITM2,ITM3,ITM4)
      WRITE(6,601)
  601 FORMAT(1H ,10X,3H  *,40H ---------------------------------------,6
     1X,39H---------------------------------------,2X,8H--------,2H *)
      WRITE(6,48)
      WRITE(6,48)
      WRITE(6,42)
      WRITE(6,48)
      WRITE(6,48)
      WRITE(6,40)
      WRITE(6,41)
      WRITE(6,49)
   49 FORMAT(1H ,10X,3H  *,5X,1H*,20H  WEEKLY TIMETABLE :,64X,1H*,5X,1H*
     1)
      WRITE(6,50)
   50 FORMAT(1H ,10X,3H  *,5X,1H*,20H********************,64X,1H*,5X,1H*
     1)
```

```
      WRITE(6,59)
      WRITE(6,51)TM1(1)
   51 FORMAT(1H ,10X,3H   *,5X,1H*,26H  STANDARD DAYS IN WEEK  :,I4,54X,1
     1H*,5X,1H*)
      WRITE(6,52)TM1(2)
   52 FORMAT(1H ,10X,3H   *,5X,1H*,26H  MAXIMUM SHIFTS PER DAY :,I4,54X,1
     1H*,5X,1H*)
      WRITE(6,53)
   53 FORMAT(1H ,10X,3H   *,5X,1H*,84X,1H*,5X,1H*)
      WRITE(6,54)(D(I),I=1,TM1(1))
   54 FORMAT(1H ,10X,3H   *,5X,1H*,26H                     DAY :,7(1X,A8)
     1)
      WRITE(6,55)
   55 FORMAT(1H*,10X,93X,1H*,5X,1H*)
      WRITE(6,56)
   56 FORMAT(1H ,10X,3H   *,5X,1H*,84X,1H*,5X,1H*)
      DO 505 J=1,TM1(2)
      DO 503 I=1,7
      D2(I)=2
  503 CONTINUE
      DO 504 I=1,7
      IF(TM2(I,J).NE.1) D2(I)=1
  504 CONTINUE
      WRITE(6,57)J,((D3(D2(I))),I=1,TM1(1))
   57 FORMAT(1H ,10X,3H   *,5X,1H*,22H                SHIFT  ,I2,2H :,7(1X
     1,A8))
      WRITE(6,58)
   58 FORMAT(1H*,10X,93X,1H*,5X,1H*)
  505 CONTINUE
      WRITE(6,59)
      WRITE(6,59)
   59 FORMAT(1H ,10X,3H   *,5X,1H*,84X,1H*,5X,1H*)
      WRITE(6,40)
      WRITE(6,39)
      WRITE(6,39)
      WRITE(6,42)
      WRITE(6,48)
      WRITE(6,39)
      WRITE(6,40)
      WRITE(6,41)
      WRITE(6,60)
   60 FORMAT(1H ,10X,3H   *,5X,1H*,27H  TIMES OF WORKING SHIFTS :,57X,1H*
     1,5X,1H*)
      WRITE(6,63)
   63 FORMAT(1H ,10X,3H   *,5X,1H*,27H***************************,57X,1H*
     1,5X,1H*)
      WRITE(6,59)
      WRITE(6,61)
   61 FORMAT(1H ,10X,3H   *,5X,1H*,19H  ( 24 HOUR CLOCK ),65X,1H*,5X,1H*)
      WRITE(6,59)
      WRITE(6,62)((TM3(I),TM4(I,1),TM4(I,2)),I=1,TM1(4))
   62 FORMAT(1H ,10X,3H   *,5X,1H*,26H                  SHIFT :,I2,16H
     1    START AT  :,F6.2,14H    DURATION :,F6.2,14X,1H*,5X,1H*)
      WRITE(6,59)
      WRITE(6,59)
      WRITE(6,40)
      WRITE(6,39)
      WRITE(6,39)
      WRITE(6,64)
   64 FORMAT(1H ,10X,100H  **********************************************
```

```
     1**************************************************////////////)
C
C
C      CALCULATIUN OF NUMBER OF MODELS N
C
C
       DO 306 I=1,T7
       S60(I,1)=S6(I,2)
  306  CONTINUE
       N=0
       DO 309 I=1,T7
       J1=0
       DO 307 J=1,T7
       IF(S60(J,1),NE,S6(I,2)) GO TO 307
       S60(J,1)=0
       J1=1
  307  CONTINUE
       IF(J1,EQ,1) N=N+1
       J=0
       DO 308 K=1,T7
       IF(S60(K,1),NE,0) J=1
  308  CONTINUE
       IF(J,EQ,0) GO TO 310
  309  CONTINUE
C
C      CALCULATEION OF MODEL DOMINANCE RATIO  XD
C       (NUMBER OF LARGEST MODEL / AVERAGE NUMBER OF MODELS)
C
  310  DO 312 J=1,T7
       IF(S6(J,4),EQ,0) GO TO 312
       K=S6(J,1)
       DO 311 I=1,T7
       IF(S6(I,1),EQ,K) S60(I,2)=S6(J,4)
  311  CONTINUE
  312  CONTINUE .
       DO 313 I=1,T7
       S60(I,1)=S6(I,2)
  313  CONTINUE
       DO 317 J=1,T7
       IF(J,EQ,1) GO TO 315
       DO 314 I=1,(J-1)
       IF(S6(J,2),EQ,S6(I,2)) GO TO 317
  314  CONTINUE
  315  DO 316 I=1,T7
       IF(S6(I,2),NE,S6(J,2)) GO TO 316
       S60(J,3)=S60(J,3)+S60(I,2)*S6(I,3)
  316  CONTINUE
  317  CONTINUE
       M=0
       M1=10000
       DO 318 I=1,T7
       IF(S60(I,3),EQ,0) GO TO 318
       IF(S60(I,3),GT,M) M=S60(I,3)
       IF(S60(I,3),LT,M1) M1=S60(I,3)
  318  CONTINUE
       XD=FLOAT(M)/(FLOAT(N3)/FLOAT(T6))
C
C      WRITING THE PRODUCT SCHEDULE SUMMARY
C
       WRITE(6,115)
```

```
  115 FORMAT(///1H ,10X,100H  ****************************************
     1************************************************************)
      WRITE(6,116)
  116 FORMAT(1H ,10X,3H  *,95X,2H *)
      WRITE(6,117)
  117 FORMAT(1H ,10X,3H  *,28H  PRODUCT SCHEDULE SUMMARY :,67X,2H *)
      WRITE(6,118)
  118 FORMAT(1H ,10X,31H  *****************************,67X,2H *)
      WRITE(6,116)
      WRITE(6,119)N
  119 FORMAT(1H ,10X,3H  *,35H  TOTAL NUMBER OF MODELS REQUIRED =,I4,56X
     1,2H *)
      WRITE(6,120)N3
  120 FORMAT(1H ,10X,3H  *,35H   TOTAL NUMBER OF UNITS REQUIRED =,I4,56X
     1,2H *)
      WRITE(6,121)XD
  121 FORMAT(1H ,10X,3H  *,35H              MODEL DOMINANCE RATIO =,F5.2,5
     15X,2H *)
      WRITE(6,116)
      WRITE(6,122)
  122 FORMAT(1H ,10X,3H  *,16H  MODEL RATIOS :,79X,2H *)
      WRITE(6,123)
  123 FORMAT(1H ,10X,19H  *****************,79X,2H *)
      WRITE(6,116)
      DO 321 I=1,T6
  321 ADJ(I,2)=0.0
      T61=0
      DO 320 I=1,T7
      IF(S60(I,3).EQ.0) GO TO 320
      X11=FLOAT(S60(I,3))/FLOAT(N3)
      X1=0.0
      DO 319 J=1,T6
      IF(S60(I,1).NE.E1(J))GOTO 319
      X1=ADJ(J,1)
      ADJ(J,2)=X11
      T61=T61+1
  319 CONTINUE
      WRITE(6,124)S60(I,1),S60(I,3),X11,X1
  124 FORMAT(1H ,10X,3H  *,9H  MODEL =,I4,1X,18H  UNITS REQUIRED =,I4,1X
     1,15H  MODEL RATIO =,F4.2,2X,33H  ORIGINAL BALANCING ADJUSTMENT =,F
     24.2,2H *)
  320 CONTINUE
      WRITE(6,116)
      J1=0
      DO 322 I=1,T6
      IF(ADJ(I,2).NE.0.0)GOTO 322
      WRITE(6,89)E1(I),ADJ(I,1)
      J1=1
   89 FORMAT(1H ,10X,3H  *,16H  MODEL NUMBER :,I4,41H    NOT INCLUDED IN
     1 THIS SCHEDULE PROGRAM,6X,24H  BALANCING ADJUSTMENT =,F4.2,2H *)
  322 CONTINUE
      WRITE(6,116)
      IF(J1.EQ.0.AND.T6.EQ.1)WRITE(6,1000)
      IF(J1.EQ.0.AND.T6.EQ.1)GOTO 1001
 1000 FORMAT(1H ,10X,3H  *,31H  SINGLE MODEL SCHEDULE PROGRAM,65X,1H*)
      IF(J1.EQ.0)WRITE(6,901)
  901 FORMAT(1H ,10X,3H  *,50H  ALL MODELS ARE INCLUDED IN THIS SCHEDULE
     1 PROGRAM,46X,1H*)
 1001 IF(J1.EQ.0)WRITE(6,116)
      WRITE(6,125)
```

```
  125 FORMAT(1H ,10X,100H  *********************************************
     1**************************************************************///////////)
      WRITE(6,833)
  833 FORMAT(1H1)
      WRITE(6,115)
      WRITE(6,116)
      WRITE(6,151)
  151 FORMAT(1H ,10X,3H  *,19H  ACTUAL SCHEDULE :,77X,1H*)
      WRITE(6,152)
  152 FORMAT(1H ,10X,3H  *,19H*******************,77X,1H*)
      WRITE(6,116)
      WRITE(6,153)
  153 FORMAT(1H ,10X,3H  *,20X,11HCYCLE GROUP,10X,5HMODEL,10X,8HQUANTITY
     1,10X,10HNO. CYCLES,12X,1H*)
      WRITE(6,116)
      K=0
      DO 355 I=1,T7
      IF(S6(I,1).GT.K)K=S6(I,1)
  355 CONTINUE
      DO 356 J=1,K
      DO 351 I=1,T7
      IF(S6(I,4).GT.0.AND.S6(I,1).EQ.J)WRITE(6,154)(S6(I,L),L=1,4)
      IF(S6(I,4).EQ.0.AND.S6(I,1).EQ.J)WRITE(6,155)(S6(I,L),L=1,3)
  154 FORMAT(1H ,10X,3H  *,22X,I4,15X,I4,11X,I4,15X,I4,17X,1H*)
  155 FORMAT(1H ,10X,3H  *,22X,I4,15X,I4,11X,I4,36X,1H*)
  351 CONTINUE
      WRITE(6,357)
  357 FORMAT(1H ,10X,3H  *,22X,61H---------------------------------------
     1----------------------,13X,1H*)
      WRITE(6,116)
  356 CONTINUE
      WRITE(6,116)
      WRITE(6,125)
      WRITE(6,65)
   65 FORMAT(//1H ,10X,100H  ******************************************
     1*********************************************************)
      WRITE(6,66)
   66 FORMAT(1H ,10X,3H  *,95X,2H *)
      WRITE(6,67)
   67 FORMAT(1H ,10X,3H  *,30H  SIMULATION RUN INFORMATION :,65X,2H *)
      WRITE(6,68)
   68 FORMAT(1H ,10X,3H  *,30H******************************,65X,2H *)
      WRITE(6,69)
      WRITE(6,69)
   69 FORMAT(1H ,10X,3H  *,95X,2H *)
      WRITE(6,156)
  156 FORMAT(1H ,10X,3H  *,10X,1H*,75H**********************************
     1*****************************************,10X,1H*)
      WRITE(6,157)
  157 FORMAT(1H ,10X,3H  *,10X,1H*,74X,1H*,10X,1H*)
      WRITE(6,158)T11,TM1(5)
  158 FORMAT(1H ,10X,3H  *,10X,1H*,5X,17HSCHEDULE NUMBER :,I4,16X,18HTIM
     1ETABLE NUMBER :,I4,10X,1H*,10X,1H*)
      WRITE(6,157)
      WRITE(6,156)
      WRITE(6,69)
      WRITE(6,691)
  691 FORMAT(1H ,10X,3H  *,34H  ORIGINAL BALANCING INFORMATION :,61X,2H
     1 *)
      WRITE(6,692)
```

```
  692 FORMAT(1H ,10X,3H   *,34H**********************************,61X,2H
     1*)
      J=0
      IF(T7.EQ.1) GO TO 507
      DO 506 I=1,(T7-1)
      IF(S6(I,2).NE.S6(I+1,2)) J=1
  506 CONTINUE
  507 IF(J.EQ.0) WRITE(6,71)
      IF(J.EQ.1) WRITE(6,72)
   71 FORMAT(1H ,10X,3H   *,23H      SINGLE MODEL LINE,72X,2H *)
   72 FORMAT(1H ,10X,3H   *,22H      MIXED MODEL LINE,73X,2H *)
      IF(LA2.EQ.1) WRITE(6,74)
      IF(LA2.EQ.0) WRITE(6,73)
   73 FORMAT(1H ,10X,3H   *,29H      DETERMINISTIC TIME LINE,66X,2H *)
   74 FORMAT(1H ,10X,3H   *,24H      VARIABLE TIME LINE,71X,2H *)
      WRITE(6,741)T2,TO
  741 FORMAT(1H ,10X,3H   *,28H      BALANCING CYCLE TIME :,F6.2,2X,A8,51
     1X,2H *)
      WRITE(6,742)TL3,TTO,TO
  742 FORMAT(1H ,10X,3H   *,28H      BALANCING LINE SPEED :,F6.2,2X,A8,5H
     1 PER ,A8,38X,2H *)
      WRITE(6,69)
      WRITE(6,69)
      WRITE(6,743)
  743 FORMAT(1H ,10X,3H   *,27H  SIMULATION INFORMATION   :,68X,2H *)
      WRITE(6,836)
  836 FORMAT(1H ,10X,3H   *,27H***************************,68X,2H *)
      IF(LA1.EQ.0) WRITE(6,81)
      IF(LA1.GT.0) WRITE(6,80)LA1
   80 FORMAT(1H ,10X,3H   *,41H      FREQUENCY OF WORKSTATION PRINTOUT :,
     1I4,7H CYCLES,44X,1H*)
   81 FORMAT(1H ,10X,3H   *,49H      NO INTERMEDIATE OUTPUT OF WORKSTATIO
     1NS DATA,46X,2H *)
      IF(LA1.EQ.0) GO TO 84
      IF(LA4.EQ.0) WRITE(6,82)
      IF(LA4.EQ.1) WRITE(6,83)
   82 FORMAT(1H ,10X,3H   *,40H      PARTIAL PRINT OF WORK STATION DATA,5
     15X,2H *)
   83 FORMAT(1H ,10X,3H   *,37H      FULL PRINT OF WORK STATION DATA,58X,
     12H *)
      IF(LA5.EQ.1)WRITE(6,838)
      IF(LA5.EQ.0)WRITE(6,839)
  838 FORMAT(1H ,10X,3H   *,44H      STATION VARIABILITY USED WHEN REQUIR
     1ED,52X,1H*)
  839 FORMAT(1H ,10X,3H   *,44H      ELEMENT VARIABILITY USED WHEN REQUIR
     1ED,52X,1H*)
      IF(LA6.EQ.1)WRITE(6,840)
      IF(LA6.EQ.0)WRITE(6,841)
  840 FORMAT(1H ,10X,3H   *,28H      INDEPENDANT SCHEDULING,68X,1H*)
  841 FORMAT(1H ,10X,3H   *,27H      CONTINUOUS SCHEDULING,69X,1H*)
      WRITE(6,69)
      WRITE(6,69)
   84 WRITE(6,832)
  832 FORMAT(1H ,10X,3H   *,19H  LINE PARAMETERS :,76X,2H *)
      WRITE(6,837)
  837 FORMAT(1H ,10X,3H   *,19H*******************,76X,2H *)
      TL1=T2*TL3/TL2
      WRITE(6,86)TL2,TO
      WRITE(6,85)TL1,TTO,TO
   85 FORMAT(1H ,10X,3H   *,18H      LINE SPEED :,F6.2,2X,A8,5H PER ,A8,4
```

```
     18X,2H *)
  86 FORMAT(1H ,10X,3H  *,23H      LINE CYCLE TIME :,F6.2,2X,A8,56X,2H
     1*)
      WRITE(6,87)
  87 FORMAT(1H ,10X,3H  *,95X,2H *)
      DO 495 I=1,T4
      DO 495 J=1,T6
      S8(I,J)=0.0
      S81(I,J)=0.0
 495 CONTINUE
      DO 498 I=1,T4
      DO 520 JJ=1,T6
      X=0.0
      DO 497 I=1,20
      DO 496 K=1,T5
      IF(F1(K).NE.S4(I,J))GOTO 496
      DO 519 JJJ=1,10
      IF(F6(K,JJJ).NE.E1(JJ))GOTO 519
      X=F2(K)/FLOAT(S1(I,2))
      IF(X.LT.F3(K))X=F3(K)
      S8(I,JJ)=S8(I,J)+X
      GOTO 497
 519 CONTINUE
 496 CONTINUE
 497 CONTINUE
 520 CONTINUE
 498 CONTINUE
      J=0
      DO 521 I=1,T4
      WRITE(6,876)
      WRITE(6,871)I,S1(I,2),S3(I,2)
 871 FORMAT(1H ,10X,3H  *,22H      STATION NUMBER :,I4,5X,14HSTATION SI
     1ZE :,I4,5X,16HTIME AVAILABLE :,F6.2,20X,1H*)
      J1=0
      DO 499 JJ=1,T6
      IF(S8(I,JJ).LE.TL2)GOTO 499
      S81(I,JJ)=S81(I,JJ)-TL2
      WRITE(6,872)E1(JJ),S8(I,JJ),S81(I,JJ)
 872 FORMAT(1H ,10X,3H  *,14X,14HMODEL NUMBER :,I4,4X,14HWORKING TIME :
     1,F6.2,4X,24HEXCEEDED CYCLE TIME BY :,F6.2,6X,1H*)
      J1=J1+1
      J=J+1
 499 CONTINUE
      IF(J1.EQ.0)WRITE(6,874)
 874 FORMAT(1H ,10X,3H  *,31X,55HNO BASIC TIME FOR ANY MODEL EXCEEDS TH
     1E LINE CYCLE TIME,10X,1H*)
 521 CONTINUE
      IF(J.EQ.0)WRITE(6,876)
      IF(J.EQ.0)WRITE(6,876)
      IF(J.EQ.0)WRITE(6,875)
 875 FORMAT(1H ,10X,3H  *,6X,79HBASIC TIME FOR ALL MODELS AT ALL STATIO
     1NS BELOW OR EQUAL TO THE LINE CYCLE TIME,11X,1H*)
      WRITE(6,876)
 876 FORMAT(1H ,10X,3H  *,95X,2H *)
      WRITE(6,88)
  88 FORMAT(1H ,10X,100H  *********************************************
     1***********************************************************////////////)
C
C
      WRITE(6,833)
```

```
      WRITE(6,101)
  101 FORMAT(////1H ,120H  ******************************************
     1**********************************************************
     2*******)
      WRITE(6,102)
  102 FORMAT(1H ,3H  *,115X,2H *)
      WRITE(6,103)
  103 FORMAT(1H ,3H  *,44H  LINE CHARACTERISTICS  (DIMENSION IN METRE),7
     11X,2H *)
      WRITE(6,104)
  104 FORMAT(1H ,3H  *,44H********************************************,7
     11X,2H *)
      WRITE(6,102)
      TUP=0.0
      TDN=0.0
      DO 200 I=1,T4
      TUP=TUP+S3(I,3)
      TDN=TDN+S3(I,4)
  200 CONTINUE
      TTR=0.0
      TPO=0.0
      PO=0.0
      DO 301 I=1,T4
      E=S3(I,1)+SL
      IF(I.EQ.T4) GO TO 301
      TTR=TTR+S3(I+1,1)-(S3(I,1)+SL)
      PO=(S3(I,1)+SL+S3(I,4))-(S3(I+1,1)-S3(I+1,3))
      IF(PO.LT.0.0)GO TO 300
      TPO=TPO+PO
      PO=0.0
  300 TPE=TPE-PO
  301 CONTINUE
C
C     CALCULATION OF RELATION BETWEEN START & FIRST STATION
C                    & RELATION BETWEEN END & LAST STATION
C
C     TUD  TOTAL UP&DOWN STREAM EXCESS
C     TDN  TOTAL DOWN STREAM EXCESS
C     TPO  TOTAL OVERLAP
C     TPE  TOTAL EXCESS TRANSIT LENGTH
C     UTUD  TOTAL UNUSED TRANSIT LENGTH =TUP-TPO
C
C     TRS  TRANSIT LENGTH FOR FIRST STATION
C     POS  POSSIBLE OVERLAP FOR FIRST STATION
C     PES     ''      EXCESS FOR FIRST STATION
C     TRE  TRANSIT LENGTH FOR LAST STATION
C     POE  POSSIBLE OVERLAP FOR LAST STATION
C     PEE     ''      EXCESS FOR LAST STATION
C
C     CALCULATING THE RELATION BETWEEN THE START AND FIRST STATION
C                                AND    "          END  "   LAST STATION
C
      TRS=S3(1,1)
      POS=0.0
      PES=S3(1,1)-S3(1,3)
      TRE=SLL-E
      POE=0.0
      PEE=TRE-S3(T4,4)
C
C     ADDING THE EFFECT OF THE START & END RELATION TO THE TOTAL RELATION
```

```
C
      TTR=TTR+TRS+TRE
      TPO=TPO+PUS+POE
      TPE=TPE+PES+PEE
      TSL=SL*FLOAT(T4)
      WRITE(6,105)TUP
  105 FORMAT(1H ,3H  *,16X,25H  TOTAL UPSTREAM EXCESS =,F6.2,68X,2H *)
      WRITE(6,106)TDN
  106 FORMAT(1H ,3H  *,16X,25HTOTAL DOWNSTREAM EXCESS =,F6.2,68X,2H *)
      WRITE(6,141)
      TUD=TUP+TDN
      WRITE(6,107)TUD
  107 FORMAT(1H ,3H  *,34X,7HTOTAL =,F6.2,69X,1H*)
      WRITE(6,102)
      WRITE(6,142)TPO
  142 FORMAT(1H ,3H  *,27X,14HLESS OVERLAP =,F6.2,69X,1H*)
      WRITE(6,141)
      UTUD=TUD-TPO
      WRITE(6,107)UTUD
      WRITE(6,1421)SLL
 1421 FORMAT(1H ,3H  *,82X,13HLINE LENGTH =,F6.2,15X,1H*)
      WRITE(6,143)TPE,TSL
  143 FORMAT(1H ,3H  *,18X,23HUNUSED TRANSIT LENGTH =,F6.2,26X,22HTOTAL
     1STATION LENGTH =,F6.2,15X,1H*)
      WRITE(6,144)
  144 FORMAT(1H ,3H  *,41X,6H======,48X,6H======,15X,1H*)
      TTR1=SLL-TSL
      WRITE(6,145)TTR,TTR1
  145 FORMAT(1H ,3H  *,34X,7HTOTAL =,F6.2,41X,7HTOTAL =,F6.2,15X,1H*)
  141 FORMAT(1H ,3H  *,16X,25X,6H------,68X,2H *)
      WRITE(6,102)
      WRITE(6,102)
      J=0
      SUM=0.0
      Y=0.0
      YY=1000.0
      DO 347 I=1,T4
      IF(S1(I,2).EQ.1) GO TO 346
      J=J+1
  346 SUM=SUM+S3(I,2)
      IF(Y.LT.S3(I,2)) Y=S3(I,2)
      IF(YY.GT.S3(I,2)) YY=S3(I,2)
  347 CONTINUE
      AVE=SUM/FLOAT(T4)
      J11=T4-J
      WRITE(6,109)T4
  109 FORMAT(1H ,3H  *,41H                TOTAL NUMBER OF STATIONS =,I4,7
     10X,2H *)
      WRITE(6,110)J11
  110 FORMAT(1H ,3H  *,41H               NUMBER OF SIMPLE STATIONS =,I4,7
     10X,2H *)
      WRITE(6,112)J
  112 FORMAT(1H ,3H  *,41H  NUMBER OF INCREASED CAPACITY STATIONS =,I4,7
     10X,2H *)
      WRITE(6,102)
      WRITE(6,146)Y
  146 FORMAT(1H ,3H  *,41H                MAXIMUM STATION CAPACITY =,F6.
     12,68X,2H *)
      WRITE(6,147)YY
  147 FORMAT(1H ,3H  *,41H                MINIMUM STATION CAPACITY =,F6.
```

```
     12,68X,2H *)
      WRITE(6,148)AVE
  148 FORMAT(1H ,3H  *,41H                          AVERAGE STATION CAPACITY =,F6,
     12,68X,2H *)
      WRITE(6,102)
      DO 3990 I=1,9
      IR(I)=0
 3990 CONTINUE
      DO 353 I=1,5
      J1=0
      DO 352 J=1,T4
      IF(S1(J,2).NE.I) GO TO 352
      J1=J1+1
  352 CONTINUE
      IR(I)=J1
  353 CONTINUE
      WRITE(6,149)
  149 FORMAT(1H ,3H  *,41H   NUMBER OF OPERATORS IN GROUP WORKING :,27H
     1 1  2  3  4  5  6  7  8  9,47X,2H *)
      WRITE(6,150)(IR(I),I=1,9)
  150 FORMAT(1H ,3H  *,41H                          FREQUENCY OF OCCURNCE :,9I3
     1,47X,2H *)
      WRITE(6,102)
      WRITE(6,102)
      WRITE(6,130)
  130 FORMAT(1H ,120H  *-----------------------------------------------------
     1-------------------------------------------------------------------
     2---*)
      WRITE(6,102)
      WRITE(6,131)
  131 FORMAT(1H ,3H  *,16H  LINE DETAILS :,99X,2H *)
      WRITE(6,132)
  132 FORMAT(1H ,19H  ****************,99X,2H *)
      WRITE(6,102)
      WRITE(6,130)
      WRITE(6,133)
  133 FORMAT(1H ,3H  *,25X,2H *,66X,11H  POSSIBLE ,11H  POSSIBLE ,2H *)
      WRITE(6,134)
  134 FORMAT(1H ,3H  *,25X,2H *,11H   START   ,11H    END    ,11X,11H  U
     1PSTREAM ,11H D-STREAM ,11H  TRANSIT  ,11H  OVERLAP  ,11H   EXCESS
     1  ,2H *)
      WRITE(6,135)
  135 FORMAT(1H ,3H  *,25X,2H *,11H  POSITION ,11H  POSITION ,11H   LENG
     1TH  ,11H   LENGTH  ,11H   LENGTH  ,11H   LENGTH  ,11H   LENGTH  ,1
     21H   LENGTH  ,2H *)
      WRITE(6,130)
      WRITE(6,139)
      TSL=0.0
      PO=0.0
      PE=0.0
      TR=0.0
      WRITE(6,160)TRS,POS,PES
  160 FORMAT(1H ,3H  *,27HRELATION BETWEEN START & 1*,55H...............
     1........................................,3(3X,F6.2,2X),2H *)
      DO 350 I=1,T4
      E=S3(I,1)+SL
      WRITE(6,139)
      WRITE(6,136)S1(I,1),S3(I,1),E,SL,S3(I,3),S3(I,4)
  136 FORMAT(1H ,3H  *,18H  STATION NUMBER. ,I3,4X,2H *,5(3X,F6.2,2X),33
     1X,2H *)
```

```
      TSL=TSL+SL
      IF(I.EQ.T4) GO TO 350
      TR=S3(I+1,1)-(S3(I,1)+SL)
      PO=(S3(I,1)+SL+S3(I,4))-(S3(I+1,1)-S3(I+1,3))
      IF(PO.LE.0.0) GO TO 348
      GO TO 349
  348 PE=-PO
      PO=0.0
  349 J=I+1
      WRITE(6,139)
  139 FORMAT(1H ,3H  *,25X,2H *,88X,2H *)
      WRITE(6,137)I,J,TR,PO,PE
  137 FORMAT(1H ,3H  *,16HRELATION BETWEEN,I3,2H &,I3,3H  *,55H.........
     1..............................................,3(3X,F6.2,2X),2H *)
      PE=0.0
  350 CONTINUE
      WRITE(6,139)
      WRITE(6,161)T4,TRE,POE,PEE
  161 FORMAT(1H ,3H  *,16HRELATION BETWEEN,I3,6H & END,2H *,55H.........
     1..............................................,3(3X,F6.2,2X),2H *)
      WRITE(6,139)
      WRITE(6,130)
      WRITE(6,139)
      WRITE(6,138)TSL,TUP,TDN,TTR,TPO,TPE
  138 FORMAT(1H ,3H  *,8H  TOTALS,17X,2H *,22X,6(3X,F6.2,2X),2H *)
      WRITE(6,139)
      WRITE(6,140)
  140 FORMAT(1H ,120H  ********************************************
     1*************************************************************
     2***///)
C
      N1=0
C
C
C     SET INITIAL PARAMETERS TO ZERO   ML,S & S2(I,J) & SI2(I,J)
C
C
      ML=0
      ML1=0
      ML2=0
      ML3=0
      DO 510 I=1,40
      DO 508 J=1,12
      S2(I,J)=0
  508 CONTINUE
      S2(I,11)=S3(I,1)
      DO 509 J=1,8
      SI2(I,J)=0
  509 CONTINUE
      S2(I,8)=S3(I,2)*TL2*10.0
  510 CONTINUE
C
C
  513 CALL MOVE (T7,T4,N1,N2,N3)
      CALL ELEMENTS (T4,T5,LA2,TL2,TL1,SL,T6,T61,LA5,LA6)
      CALL TIME (TL2,N1,N88,T10)
      IF(LA1.EQ.0) GO TO 516
      X9=N1/LA1
      N99=INT(X9)
      JTM4=INT(TM(4))
```

```
      KSC=TM5(K1,K2,K3,(K4+1-JTM4))
      IF(N99*LA1,EQ,N1) CALL PRINT1 (T4,N1,LA4,KSC,N3,T11)
  514 IF(N1,EQ,N2) GO TO 515
      GO TO 516
  515 CALL PRINT2 (T4,N1,N3,T7,T2,TL2,T5,N,XD,T6,BBD1,BBD3,BBD2,BBD4,BSI
     11,BSI3,BSI2,BSI4,T11,T61,LA6)
  516 STOP
      END
C
C
      SUBROUTINE MOVE (T7,T4,N1,N2,N3)
C
C
      INTEGER T4,S6,T7,S7
      DIMENSION S6(30,4),S7(40,2)
      COMMON/SLAB1/S6,S7/SLAB8/ML,ML1,ML2,ML3
C
C
C     CALCULATING NEXT ITEM AND NEXT STATION CONDITION
C
C
      N1=N1+1
      N4=2
      N5=0
      IF(N1,GT,N3) GO TO 504
      N4=1
      K4=0
      DO 503 K1=1,T7
      IF(S6(K1,4),EQ,0) GO TO 503
      K3=S6(K1,1)
      DO 502 K5=1,S6(K1,4)
      DO 501 K2=1,T7
      IF(S6(K2,1),NE,K3) GO TO 501
      DO 500 K6=1,S6(K2,3)
      K4=K4+1
      IF(K4,NE,N1) GO TO 500
      N5=S6(K2,2)
      GO TO 504
  500 CONTINUE
  501 CONTINUE
  502 CONTINUE
  503 CONTINUE
  504 DO 505 K2=1,(T4-1)
      K1=T4-K2
      S7(K1+1,1)=S7(K1,1)
      S7(K1+1,2)=S7(K1,2)
  505 CONTINUE
      S7(1,1)=N5
      S7(1,2)=N4
      IF(S7(1,2),EQ,0) GO TO 507
      ML=ML+1
      IF(S7(2,2),EQ,2,OR,S7(2,2).EQ,0) GO TO 507
      IF(S7(1,1),EQ,S7(2,1)) GO TO 507
      ML1=ML1+1
      ML2=ML2+(ML-1)
      ML3=ML3+(ML-1)*(ML-1)
      ML=1
  507 RETURN
      END
C
```

```
C
      SUBROUTINE ELEMENTS (T4,T5,LA2,TL2,TL1,SL,T6,T61,LA5,LA6)
C
C
C     DETERMINES WORK ELEMENTS FOR MODEL  PRESENTLY AT STATION
C
C
      INTEGER T4,T5,S7,S4,F1,F6,SI2,S6,S1,T6,T61,E1,S60
      DIMENSION S4(40,20),F1(100),F6(100,10),S7(40,2),S2(40,12),SI2(40,8
     1),S5(40),S3(40,4),S6(30,4),F2(100),F3(100),S1(40,2),F8(100),IAS(10
     20,10),E1(10),S60(30,3),S9(12),ADJ(10,2)
      COMMON/SLAB1/S6,S7/SLAB2/F1,F2,F3,F6,F8/SLAB3/S2,S3,S4,SI2/SLAB5/S
     21,S5/SLAB9/IAS,E1,S60/SLAB10/S9,ADJ
C
C     S9(10)=UPSTREAM TIME AVAILABLE
C     S9(11)=DOWNSTREAM TIME AVAILABLE
C     S9(12)=NORMAL TIME AVAILABLE
      DO 500 I=1,T4
      S5(I)=0,0
  500 CONTINUE
      DO 503 I=1,T4
      IF(LA6,EQ,0,AND,S7(I,2),NE,1)GOTO 503
      S9(10)=S9(10)+(S3(I,3)/TL1)*FLOAT(S1(I,2))
      S9(11)=S9(11)+(S3(I,4)/TL1)*FLOAT(S1(I,2))
      S9(12)=S9(12)+(SL/TL1)*FLOAT(S1(I,2))
      X1=0,0
      X2=0,0
      X11=1,0/FLOAT(T61)
      XX1=0,0
      XX2=0,0
      XX3=0,0
      IF(LA5,EQ,1)GOTO 5025
      DO 502 I1=1,T6
      IF(E1(I1),NE,S7(I,1))GOTO 502
      X11=ADJ(I1,2)
      DO 501 I2=1,T5
      IF(IAS(I2,I1),NE,I)GOTO 501
      X=G05ADF(Y)
      IF(X,LT,-3,5)X=-3,5
      IF(X,GT,3,5)X=3,5
      RT=F2(I2)+((X*SQRT(F3(I2)))*LA2)
      RT=RT/FLOAT(S1(I,2))
      X1=X1+RT
      IF(RT,LT,F8(I2))RT=F8(I2)
      S5(I)=S5(I)+RT
  501 CONTINUE
  502 CONTINUE
      GOTO 5026
 5025 DO 5022 I1=1,T6
      IF(E1(I1),NE,S7(I,1))GOTO 5022
      DO 5023 I2=1,T5
      IF(IAS(I2,I1),NE,I)GOTO 5023
      X11=ADJ(I1,2)
      XX1=XX1+F2(I2)
      XX2=XX2+F8(I2)
      XX3=XX3+F3(I2)
 5023 CONTINUE
      X=G05ADF(Y)
      IF(X,LT,-3,5)X=-3,5
      IF(X,GT,3,5)X=3,5
```

```
      XX1=(XX1+(X*SQRT(XX3))+LA2)/FLOAT(S1(I,2))
      X1=XX1
      IF(XX1.LT.XX2)XX1=XX2
      S5(I)=XX1
 5022 CONTINUE
 5026 X2=S5(I)
      IF(X1.GT.TL2)X1=TL2
      IF(X2.GT.TL2)X2=TL2
      S9(1)=S9(1)+S1(I,2)*(TL2-X1)
      S9(3)=S9(3)+S1(I,2)*(TL2-X2)
      S9(5)=S9(5)+(S1(I,2)*(TL2-X1))**2.00
      S9(7)=S9(7)+(S1(I,2)*(TL2-X2))**2.00
      S9(9)=S9(9)+S1(I,2)*TL2
  503 CONTINUE
C
C     WORKING OUT STANDARD STATION  MAX. & MIN. & TOTAL WORK &TOTAL TIME AV.
C
      DO 505 I=1,T4
      IF(LA6.EQ.0.AND.S7(I,2).NE.1) GO TO 505
      S2(I,9)=S2(I,9)+S5(I)*FLOAT(S1(I,2))
      S2(I,10)=S2(I,10)+(S1(I,2)*TL2)
      IF((S5(I)*FLOAT(S1(I,2))).LT.S2(I,8))S2(I,8)=S5(I)*FLOAT(S1(I,2))
      IF((S5(I)*FLOAT(S1(I,2))).GT.S2(I,7))S2(I,7)=S5(I)*FLOAT(S1(I,2))
      SI2(I,8)=SI2(I,8)+1
      IF(S5(I).GT.0.0) SI2(I,7)=SI2(I,7)+1
  505 CONTINUE
C
C     WORKING OUT OVERLAPPING   DOL : OVERLAP
C
      DO 506 I=1,(T4-1)
      AA1=S2(I,11)
      AB1=S2(I+1,11)
      AA2=AA1+S5(I)*TL1
      IF(AA2.GT.(S3(I,1)+SL+S3(I,4)))AA2=S3(I,1)+SL+S3(I,4)
      AB2=AB1+S5(I+1)*TL1
      IF(AB2.GT.(S3(I+1,1)+SL+S3(I+1,4)))AB2=S3(I+1,1)+SL+S3(I+1,4)
      DOL=0.0
      AC1=AA1
      IF(AB1.GT.AC1)AC1=AB1
      AC2=AA2
      IF(AB2.LT.AC2)AC2=AB2
      DOL=AC2-AC1
      IF(DOL.LE.0.0)GOTO 506
      SI2(I,6)=SI2(I,6)+1
      SI2(I+1,6)=SI2(I+1,6)+1
      S2(I,6)=S2(I,6)+DOL/TL1
      S2(I+1,6)=S2(I+1,6)+DOL/TL1
  506 CONTINUE
      DO 514 I=1,T4
C
C     CALCULATING FT1 ,FT2 ,FT3 ,AND FT4
C
      FT2=S3(I,1)
      FT1=FT2-S3(I,3)
      FT3=FT2+SL
      FT4=FT3+S3(I,4)
C
C     WORKING OUT A1 ,A2 ,A3 AND A4
C
      A1=0.0
```

```
      A2=0,0
      A3=0,0
      A4=0,0
      EP=S2(I,11)+S5(I)*TL1
      IF(FT2,LE,S2(I,11))GOTO 510
C     *******       A1       **********
      A1=FT2-S2(I,11)
      IF(A1,GT,(EP-S2(I,11)))A1=EP-S2(I,11)
      S2(I,2)=S2(I,2)+A1*FLOAT(S1(I,2))/TL1
      IF(A1,GT,0.000001) SI2(I,2)=SI2(I,2)+1
  510 IF(EP,LE,FT3)GOTO 511
C     ********       A3       ***********
      A3=EP-FT3
      IF(A3,GT,(FT4-FT3))A3=FT4-FT3
      IF(A3,GT,(EP-S2(I,11)))A3=EP-S2(I,11)
      S2(I,1)=S2(I,1)+A3*FLOAT(S1(I,2))/TL1
      IF(A3,GT,0.000001)SI2(I,1)=SI2(I,1)+1
  511 IF(EP,LT,FT4)GOTO 512
C     *********       A4       ***********
      A4=EP-FT4
      IF(A4,GT,(EP-S2(I,11)))A4=EP-S2(I,11)
      IF(A4,LT,0,0)A4=0,0
      S2(I,4)=S2(I,4)+A4*FLOAT(S1(I,2))/TL1
      IF(A4,GT,0.000001)SI2(I,4)=SI2(I,4)+1
C     ********       A2       ***********
  512 A2=(EP-S2(I,11))-(A1+A4+A3)
      IF(A2,EQ,0,0)GOTO 513
      S2(I,3)=S2(I,3)+(A2*FLOAT(S1(I,2)))/TL1
      SI2(I,3)=SI2(I,3)+1
C
C     DETERMINING THE NEW STARTING POSITION
C
  513 IF(EP,GT,FT4)EP=FT4
      S2(I,11)=EP-TL2*TL1
      IF(S2(I,11),LT,FT1)S2(I,11)=FT1
  514 CONTINUE
      RETURN
      END
C
C     CALCULATE STARTING VARIABLE AND TOTAL TIME ELAPSED
C
      SUBROUTINE TIME (TL2,N1,N88,T10)
C
C
      INTEGER TM1,TM3,TM5
      DIMENSION TM(4),TM1(10),TM3(8),TM4(8,2),TM5(4,7,52,5)
      COMMON/SLAB4/TM,TM1,TM3,TM4,TM5/SLAB7/K1,K2,K3,K4,TA4
      N88=0
      K4=INT(TM(4))
      IA3=INT(TM(2))
      IA4=INT(TM(3))
      TB1=(INT(TM(1)))+((TM(1))-(INT(TM(1))))/0,6+TM(2)*24,0+TM(3)*7*24
      TB3=TB1
      TB2=TL2*N1/T10
      IA2=0
      DO 500 I=1,TM1(4)
      IF(TM(1),LT,TM4(I,1),OR,TM(1),GT,(TM4(I,1)+TM4(I,2))) GO TO 500
      IA2=TM3(I)
      IA1=I
  500 CONTINUE
```

```fortran
      IF(IA2.NE.0) GO TO 501
      WRITE(6,20)
      N88=1
  501 IF(IA3.LE.TM1(1)) GO TO 502
      WRITE(6,21)
      N88=1
  502 I9=1+(INT(TM(4))-TM1(3))
      IF(I9.LE.5) GO TO 503
      WRITE(6,22)
      N88=1
      GO TO 504
  503 IF(TM5(IA2,IA3,IA4,I9).EQ.1) GO TO 504
      WRITE(6,23)
      N88=1
  504 IF(N88.EQ.1) GO TO 510
      TB3=TB3+TM4(IA1,1)-((INT(TM(1)))*((TM(1))-(INT(TM(1)))))/0.6)
   20 FORMAT(/1H ,41H ERROR STARTING TIME NOT IN A KNOWN SHIFT)
   21 FORMAT(/1H ,34H ERROR STARTING DAY DOES NOT EXIST)
   22 FORMAT(/1H ,28H ERROR -OUTSIDE 5 YEARS PLAN)
   23 FORMAT(/1H ,49H ERROR STARTING SHIFT ON THIS DAY NOT OPERATIONAL)
      K1=IA2
      K2=IA3
      K3=IA4
  505 IF(K2.GT.TM1(1)) GO TO 508
      DO 507 K=K1,4
      IF(TM5(K,K2,K3,I9).NE.1)GO TO 507
      DO 506 L=1,8
      IF(TM3(L).NE.K) GO TO 506
      TB3=TB3+TM4(L,2)
      TA4=TB3-(TB1+TB2)
      IF((TB1+TB2).LE.TB3) GO TO 509
  506 CONTINUE
  507 CONTINUE
      K1=1
      K2=K2+1
      IF(K2.LE.TM(4)) GO TO 505
  508 K2=1
      K3=K3+1
      IF(K3.LE.52) GO TO 505
      K3=1
      I9=I9+1
      IF(I9.GT.5) WRITE(6,22)
      K4=K4+1
      GO TO 505
  509 K1=K
      TA4=TM4(L,1)*TM4(L,2)-TA4
      IF(TA4.GT.24.0) TA4=TA4-24.0
  510 RETURN
      END
C
C
C
      SUBROUTINE PRINT1 (T4,N1,LA4,KSC,N3,T11)
C
C
      INTEGER T4,S7,SI2,S1,S6,S4,SC1,T11,TM1,TM3,TM5
      DIMENSION S7(40,2),S6(30,4),S2(40,12),S3(40,4),S4(40,20),SI2(40,8)
     1,S1(40,2),S5(40),D(7),SC(7),SC1(40),D3(2),TM(4),TM1(10),TM3(8),TM4
     2(8,2),TM5(4,7,52,5)
      COMMON/SLAB1/S6,S7/SLAB3/S2,S3,S4,SI2/SLAB5/S1,S5/SLAB6/D,D3/SLAB7
```

```
      1/K1,K2,K3,K4,TA4/SLAB4/TM,TM1,TM3,TM4,TM5
       DATA SC(1)/7HWAITING/,SC(2)/7HWORKING/,SC(3)/7H FINISH/,SC(4)/7H
      1EMPTY/,SC(5)/7HIDLE=IN/,SC(6)/7HIDLE=EX/,SC(7)/7HIDLE=HO/
       I3=1
       I2=12
  500  I4=T4
       IF(I4,GT,I2) I4=I2
       I6=I4
       I5=I3
       WRITE(6,15)
   15  FORMAT(1H1)
       WRITE(6,20)
   20  FORMAT(////1H ,120H  ********************************************
      1************************************************************************
      2*******)
       WRITE(6,24)
       WRITE(6,21)
   21  FORMAT(1H ,3H  *,24H  STATIONS INFORMATION  ,91X,2H *)
       WRITE(6,80)
   80  FORMAT(1H ,3H  *,24H************************,91X,2H *)
       JJ1=N3+T4=1
       WRITE(6,24)
       WRITE(6,23)
       WRITE(6,19)
   19  FORMAT(1H ,3H  *,23X,1H*,69X,1H*,22X,1H*)
       WRITE(6,81)T11,TM1(5)
   81  FORMAT(1H ,3H  *,23X,1H*,3X,17HSCHEDULE NUMBER =,I4,19X,18HTIMETAB
      1LE NUMBER =,I4,4X,1H*,22X,1H*)
       WRITE(6,19)
       WRITE(6,82)JJ1,N1
   82  FORMAT(1H ,3H  *,23X,1H*,3X,17HPROGRAM LENGTH  =,I4,23X,14HCYCLE N
      1UMBER =,I4,4X,1H*,22X,1H*)
       WRITE(6,19)
       WRITE(6,83)TA4,K1,D(K2),K3,K4
   83  FORMAT(1H ,3H  *,23X,1H*,3X,6HTIME =,F6,2,9H  SHIFT =,I3,7H  DAY =
      1,A8,8H  WEEK =,I3,8H  YEAR =,I6,2X,1H*,22X,1H*)
       WRITE(6,19)
       WRITE(6,23)
   23  FORMAT(1H ,3H  *,23X,71H*******************************************
      1****************************,22X,1H*)
       WRITE(6,24)
   24  FORMAT(1H ,3H  *,115X,2H *)
       WRITE(6,24)
       WRITE(6,25)(S1(J,1),J=I5,I6)
   25  FORMAT(1H ,3H  *,20H STATION NUMBER     ,12I8)
       WRITE(6,26)
   26  FORMAT(1H*,118X,2H *)
       WRITE(6,18)(S1(J,2),J=I5,I6)
   18  FORMAT(1H ,3H  *,20H STATION SIZE       ,12I8)
       WRITE(6,28)
       WRITE(6,27)(S7(J,1),J=I5,I6)
   27  FORMAT(1H ,3H  *,20H MODEL NUMBER       ,12I8)
       WRITE(6,28)
   28  FORMAT(1H*,118X,2H *)
       DO 505 J3=1,T4
       IF(S7(J3,2),GT,0) GO TO 501
       SC1(J3)=1
       GO TO 505
  501  IF(S7(J3,2),LT,2) GO TO 502
       SC1(J3)=3
```

```
      GO TO 503
  502 SC1(J3)=2
      GO TO 503
      IF(S5(J3),EQ,0) SC1(J3)=4
      IF(KSC,EQ,2) SC1(J3)=5
      IF(KSC,EQ,3) SC1(J3)=6
      IF(KSC,EQ,4) SC1(J3)=7
  503 CONTINUE
      WRITE(6,29)(SC(SC1(J)),J=I5,I6)
   29 FORMAT(1H ,3H  *,20H STATION CONDITION I,12(1X,A7))
      WRITE(6,30)
   30 FORMAT(1H*,118X,2H *)
      WRITE(6,31)
   31 FORMAT(1H ,3H  *,115X,2H *)
      WRITE(6,32)(SI2(J,8),J=I5,I6)
   32 FORMAT(1H ,3H  *,20H NOMINAL M, OUTPUT I,12I8)
      WRITE(6,33)
   33 FORMAT(1H*,118X,2H *)
      WRITE(6,34)(SI2(J,7),J=I5,I6)
   34 FORMAT(1H ,3H  *,20H ACTUAL M, OUTPUT  I,12I8)
      WRITE(6,35)
   35 FORMAT(1H*,118X,2H *)
      WRITE(6,36)
   36 FORMAT(1H ,3H  *,115X,2H *)
      DO 507 J=I5,I6
      S2(J,5)=0,0
      S2(J,5)=S5(J)*FLOAT(S1(J,2))
  507 CONTINUE
      WRITE(6,37)(S2(J,5),J=I5,I6)
   37 FORMAT(1H ,3H  *,20H STATION WORK TIME I,12F8,1)
      WRITE(6,38)
   38 FORMAT(1H*,118X,2H *)
      WRITE(6,39)(S2(J,7),J=I5,I6)
   39 FORMAT(1H ,3H  *,20H MAXIMUM WORK TIME I,12F8,1)
      WRITE(6,40)
   40 FORMAT(1H*,118X,2H *)
      WRITE(6,41)(S2(J,8),J=I5,I6)
   41 FORMAT(1H ,3H  *,20H MINIMUM WORK TIME I,12F8,1)
      WRITE(6,42)
   42 FORMAT(1H*,118X,2H *)
      WRITE(6,43)(S2(J,9),J=I5,I6)
   43 FORMAT(1H ,3H  *,20H WORK ASSIGNED      I,12F8,1)
      WRITE(6,44)
   44 FORMAT(1H*,118X,2H *)
      WRITE(6,45)(S2(J,10),J=I5,I6)
   45 FORMAT(1H ,3H  *,20H TIME AVAILABLE     I,12F8,1)
      WRITE(6,46)
   46 FORMAT(1H*,118X,2H *)
      WRITE(6,47)
   47 FORMAT(1H ,3H  *,115X,2H *)
      IF(LA4,EQ,0) GO TO 504
      WRITE(6,48)(S2(J,1),J=I5,I6)
   48 FORMAT(1H ,3H  *,20H DOWNSTREAM WORKINGI,12F8,1)
      WRITE(6,49)
   49 FORMAT(1H*,118X,2H *)
      WRITE(6,50)(SI2(J,1),J=I5,I6)
   50 FORMAT(1H ,3H  *,20H FREQUENCY          I,12I8)
      WRITE(6,51)
   51 FORMAT(1H*,118X,2H *)
      WRITE(6,52)(S2(J,2),J=I5,I6)
```

```
   52 FORMAT(1H ,3H  *,20H UPSTREAM WORKING    |,12F8.1)
      WRITE(6,53)
   53 FORMAT(1H*,118X,2H *)
      WRITE(6,54)(SI2(J,2),J=I5,I6)
   54 FORMAT(1H ,3H  *,20H FREQUENCY           |,12I8)
      WRITE(6,55)
   55 FORMAT(1H*,118X,2H *)
      WRITE(6,56)(S2(J,3),J=I5,I6)
   56 FORMAT(1H ,3H  *,20H NORMAL WORKING      |,12F8.1)
      WRITE(6,57)
   57 FORMAT(1H*,118X,2H *)
      WRITE(6,58)(SI2(J,3),J=I5,I6)
   58 FORMAT(1H ,3H  *,20H FREQUENCY           |,12I8)
      WRITE(6,59)
   59 FORMAT(1H*,118X,2H *)
      WRITE(6,60)
   60 FORMAT(1H ,3H  *,115X,2H *)
      WRITE(6,65)(S2(J,6),J=I5,I6)
   65 FORMAT(1H ,3H  *,20H OVERLAP WORK TIME   |,12F8.1)
      WRITE(6,66)
   66 FORMAT(1H*,118X,2H *)
      WRITE(6,67)(SI2(J,6),J=I5,I6)
   67 FORMAT(1H ,3H  *,20H FREQUENCY           |,12I8)
  504 WRITE(6,68)
   68 FORMAT(1H*,118X,2H *)
      WRITE(6,71)
      WRITE(6,69)(S2(J,11),J=I5,I6)
   69 FORMAT(1H ,3H  *,20H NEXT START POS'N    |,12F8.1)
      WRITE(6,70)
   70 FORMAT(1H*,118X,2H *)
      WRITE(6,71)
   71 FORMAT(1H ,3H  *,115X,2H *)
      WRITE(6,72)(S2(J,4),J=I5,I6)
   72 FORMAT(1H ,3H  *,20H TOTAL LOST WORK     |,12F8.1)
      WRITE(6,73)
   73 FORMAT(1H*,118X,2H *)
      WRITE(6,74)(SI2(J,4),J=I5,I6)
   74 FORMAT(1H ,3H  *,20H FREQUENCY           |,12I8)
      WRITE(6,75)
   75 FORMAT(1H*,118X,2H *)
      WRITE(6,76)
   76 FORMAT(1H ,3H  *,115X,2H *)
      WRITE(6,77)
   77 FORMAT(1H ,120H ********************************************************
     1****************************************************************************
     2***//)
  505 IF(I4.EQ.T4) GO TO 506
      I3=I4+1
      I2=I2+12
      GO TO 500
  506 RETURN
      END
      SUBROUTINE PRINT2 (T4,N1,N3,T7,T2,TL2,T5,N,XD,T6,BBD1,BBD3,BBD2,BB
     1D4,BSI1,BSI3,BSI2,BSI4,T11,T61,LA6)
C
      INTEGER T4,T7,S6,S7,S60,SI2,S4,F1,T5,F6,T6,S1,E1,T11,TM1,TM3,TM5,T
     161
      DIMENSION D(7),D3(2),S6(30,4),S7(40,2),S2(40,12),S3(40,4),S4(40,20
     1),SI2(40,8),S60(30,3),F1(100),F2(100),F3(100),F6(100,10),IAS(100,1
     20),F8(100),S1(40,2),S5(40),E1(10),TM(4),TM1(10),TM3(8),TM4(8,2),TM
```

```
      35(4,7,52,5),S9(12),ADJ(10,2)
       COMMON/SLAB6/D,D3/SLAB7/K1,K2,K3,K4,TA4/SLAB1/S6,S7/SLAB3/S2,S3,S4
      1,SI2/SLAB8/ML,ML1,ML2,ML3/SLAB2/F1,F2,F3,F6,F8/SLAB9/IAS,E1,S60/SL
      2AB5/S1,S5/SLAB4/TM,TM1,TM3,TM4,TM5/SLAB10/S9,ADJ
C
       WRITE(6,15)
    15 FORMAT(1H1)
       WRITE(6,20)
    20 FORMAT(////1H ,120H   ***********************************************
      1*****************************************************************
      2*******)
       WRITE(6,21)
    21 FORMAT(1H ,3H  *,115X,2H *)
       WRITE(6,25)
    25 FORMAT(1H ,3H  *,18H  FINAL ANALYSIS :,97X,2H *)
       WRITE(6,26)
    26 FORMAT(1H ,3H  *,18H******************,97X,2H *)
       WRITE(6,21)
C
C      JJ    :START/FINISH CYCLES
C      JJ1   :TOTAL PRODUCTION CYCLES
C      AV    :AVERAGE BATCH SIZE
C      SS    :AVERAGE RUN LENGTH
C      SSS   :STANDARD DEVIATION OF THE AVERAGE RUN LENGTH
C
       JJ=T4-1
       JJ1=JJ+N3
       AV=FLOAT(N3)/FLOAT(N)
       SS=FLOAT(ML2)/FLOAT(ML1)
       SSS=SQRT((FLOAT(ML3)-SS*SS)/FLOAT(ML1))
       WRITE(6,80)
    80 FORMAT(1H ,3H  *,20X,76H********************************************
      1**********************************,20X,1H*)
       WRITE(6,81)
    81 FORMAT(1H ,3H  *,20X,1H*,74X,1H*,20X,1H*)
       WRITE(6,82)
    82 FORMAT(1H ,3H  *,20X,1H*,29H  SCHEDULE AS SHOWN COMPLETED,45X,1H*,
      120X,1H*)
       WRITE(6,81)
       WRITE(6,83)T11,TM1(5)
    83 FORMAT(1H ,3H  *,20X,1H*,19H  SCHEDULE NUMBER =,I4,22X,18HTIMETABL
      1E NUMBER =,I4,7X,1H*,20X,1H*)
       WRITE(6,81)
       WRITE(6,84)TA4,K1,D(K2),K3,K4
    84 FORMAT(1H ,3H  *,20X,1H*,15H  FINISH TIME =,F6.2,9H  SHIFT =,I2,7H
      1  DAY =,A8,7H WEEK =,I2,7H YEAR =,I5,6X,1H*,20X,1H*)
       WRITE(6,81)
       WRITE(6,80)
       WRITE(6,21)
       WRITE(6,21)
       WRITE(6,70)
    70 FORMAT(1H ,3H  *,14H  PRODUCTION :,102X,1H*)
       WRITE(6,71)
    71 FORMAT(1H ,3H  *,14H**************,102X,1H*)
       WRITE(6,21)
       WRITE(6,21)
       WRITE(6,72)
    72 FORMAT(1H ,3H  *,10X,96H*********************************************
      1***************************************************,10X,1H*)
       WRITE(6,73)
```

```
   73 FORMAT(1H ,3H  *,10X,1H*,94X,1H*,10X,1H*)
      WRITE(6,85)JJ1
   85 FORMAT(1H ,3H  *,10X,1H*,59X,25HTOTAL PRODUCTION CYCLES =,I4,6X,1H
     1*,10X,1H*)
      WRITE(6,86)JJ
   86 FORMAT(1H ,3H  *,10X,1H*,56X,28HLESS START & FINISH CYCLES =,I4,6X
     1,1H*,10X,1H*)
      WRITE(6,87)
   87 FORMAT(1H ,3H  *,10X,1H*,84X,4H----,6X,1H*,10X,1H*)
      WRITE(6,88)N3,N3
   88 FORMAT(1H ,3H  *,10X,1H*,10X,26HNUMBER OF FINISHED UNITS =,I6,16X,
     126HNUMBER OF FINISHED UNITS =,I4,6X,1H*,10X,1H*)
      WRITE(6,89)ML1
   89 FORMAT(1H ,3H  *,10X,1H*,14X,22HNUMBER OF MODEL RUNS =,I6,52X,1H*,
     110X,1H*)
      WRITE(6,90)N
   90 FORMAT(1H ,3H  *,10X,1H*,38X,4H----,24X,18HNUMBER OF MODELS =,I4,6
     1X,1H*,10X,1H*)
      WRITE(6,91)SS,AV
   91 FORMAT(1H ,3H  *,10X,1H*,16X,20HAVERAGE RUN LENGTH =,F6.2,12X,30HA
     1VERAGE PRODUCTION PER MODEL =,F6.2,4X,1H*,10X,1H*)
      WRITE(6,92)SSS,XD
   92 FORMAT(1H ,3H  *,10X,1H*,5X,31HSTANDARD DEVIATION RUN LENGTH =,F6.
     12,19X,25HMODEL DOMINANCE RATIO =,F6.2,4X,1H*,10X,1H*)
      WRITE(6,73)
      WRITE(6,72)
      WRITE(6,21)
      WRITE(6,21)
      SBD1=S9(1)*100.00/S9(9)
      SBD2=SBD1
      SBD3=S9(3)*100.00/S9(9)
      SBD4=SBD3
      IF(LA6.EQ.1)GOTO 520
      SSI1=SQRT(S9(5)/FLOAT(N3))
      SSI2=SSI1
      SSI3=SQRT(S9(7)/FLOAT(N3))
      SSI4=SSI3
      GOTO 521
  520 SSI1=SQRT(S9(5)/FLOAT(JJ1))
      SSI2=SSI1
      SSI3=SQRT(S9(7)/FLOAT(JJ1))
      SSI4=SSI3
  521 WRITE(6,93)
   93 FORMAT(1H ,3H  *,23H  EFFICIENCY MEASURES :,93X,1H*)
      WRITE(6,94)
   94 FORMAT(1H ,3H  *,23H***********************,93X,1H*)
      WRITE(6,21)
      WRITE(6,95)
   95 FORMAT(1H ,3H  *,33X,9HBALANCING,30X,10HSIMULATION,34X,1H*)
      WRITE(6,96)
   96 FORMAT(1H ,3H  *,33X,9H---------,30X,10H----------,34X,1H*)
      WRITE(6,21)
      WRITE(6,97)BBD1,SBD1
   97 FORMAT(1H ,3H  *,33X,5HBD1 =,F6.2,28X,5HBD1 =,F6.2,33X,1H*)
      WRITE(6,21)
      WRITE(6,102)BBD3,SBD3
  102 FORMAT(1H ,3H  *,33X,5HBD3 =,F6.2,28X,5HBD3 =,F6.2,33X,1H*)
      WRITE(6,21)
      WRITE(6,98)BBD2,SBD2
   98 FORMAT(1H ,3H  *,33X,5HBD2 =,F6.2,28X,5HBD2 =,F6.2,33X,1H*)
```

```
      WRITE(6,21)
      WRITE(6,103)BBD4,SBD4
  103 FORMAT(1H ,3H  *,33X,5HBD4 =,F6.2,28X,5HBD4 =,F6.2,33X,1H*)
      WRITE(6,21)
      WRITE(6,99)BSI1,SSI1
   99 FORMAT(1H ,3H  *,33X,5HSI1 =,F6.2,28X,5HSI1 =,F6.2,33X,1H*)
      WRITE(6,21)
      WRITE(6,100)BSI3,SSI3
  100 FORMAT(1H ,3H  *,33X,5HSI3 =,F6.2,28X,5HSI3 =,F6.2,33X,1H*)
      WRITE(6,21)
      WRITE(6,101)BSI2,SSI2
  101 FORMAT(1H ,3H  *,33X,5HSI2 =,F6.2,28X,5HSI2 =,F6.2,33X,1H*)
      WRITE(6,21)
      WRITE(6,104)BSI4,SSI4
  104 FORMAT(1H ,3H  *,33X,5HSI4 =,F6.2,28X,5HSI4 =,F6.2,33X,1H*)
      WRITE(6,21)
      WRITE(6,21)
      WRITE(6,21)
      SUM1=0.0
      SUM2=0.0
      SUM3=0.0
      SUM4=0.0
      SUM5=0.0
      SUM6=0.0
      UP=0.0
      DN=0.0
      RN=0.0
      L1=0
      L2=0
      L3=0
      L4=0
      DO 513 I=1,T4
      SUM1=SUM1+S2(I,1)
      SUM2=SUM2+S2(I,2)
      SUM3=SUM3+S2(I,3)
      SUM4=SUM4+S2(I,4)
      SUM5=SUM5+S2(I,1)+S2(I,2)+S2(I,3)
      SUM6=SUM6+S2(I,10)
      L1=L1+SI4(I,1)
      L2=L2+SI4(I,2)
      L3=L3+SI4(I,3)
      L4=L4+SI4(I,4)
  513 CONTINUE
      UP=S9(10)
      DN=S9(11)
      RN=S9(12)
      TOT2=UP+DN+RN
      TOT=SUM1+SUM2+SUM3+SUM4
      AV1=(SUM1/TOT)*100.0
      AV2=(SUM2/TOT)*100.0
      AV3=(SUM3/TOT)*100.0
      AV4=(SUM4/TOT)*100.0
      AV5=(SUM5/TOT)*100.0
      AVT=(TOT/TOT)*100.0
      DE=SUM6-SUM3
      AVE1=(SUM3/SUM6)*100.0
      AVE2=(DE/SUM6)*100.0
      AVE3=(SUM6/SUM6)*100.0
      UUD=UP+DN-SUM2-SUM1
      UN=RN-SUM3
```

```
      TOT1=TOT2-UUD-UN
      WRITE(6,21)
      WRITE(6,21)
      WRITE(6,120)
  120 FORMAT(1H ,3H  *,30X,10H   USED   ,5X,11H  PERCENT  ,10X,9HFREQUEN
     1CY,13X,9HAVAILABLE,19X,1H*)
      WRITE(6,121)
  121 FORMAT(1H ,3H  *,30X,10H   ----   ,5X,11H  -------  ,10X,9H-------
     1--,13X,9H---------,19X,1H*)
      WRITE(6,21)
      WRITE(6,105)SUM2,AV2,L2,UP
  105 FORMAT(1H ,3H  *,6X,21HTOTAL UPSTREAM TIME =,F10.1,7X,3H ( ,F5.1,4
     1H % ),12X,I5,12X,F10.1,21X,1H*)
      WRITE(6,21)
      WRITE(6,107)SUM1,AV1,L1,DN
  107 FORMAT(1H ,3H  *,4X,23HTOTAL DOWNSTREAM TIME =,F10.1,7X,3H ( ,F5.1
     1,4H % ),12X,I5,12X,F10.1,21X,1H*)
      WRITE(6,21)
      WRITE(6,108)SUM3,AV3,L3,RN
  108 FORMAT(1H ,3H  *,8X,19HTOTAL NORMAL TIME =,F10.1,7X,3H ( ,F5.1,4H
     1% ),12X,I5,12X,F10.1,21X,1H*)
      WRITE(6,21)
      WRITE(6,109)
  109 FORMAT(1H ,3H  *,27X,10H----------,48X,10H----------,21X,1H*)
      WRITE(6,21)
      WRITE(6,122)TOT2
  122 FORMAT(1H ,3H  *,57X,28HTHEORETICAL TIME AVAILABLE =,F10.1,21X,1H*
     *)
      WRITE(6,123)
  123 FORMAT(1H ,3H  *,63X,4HLESS,49X,1H*)
      WRITE(6,124)UUD
  124 FORMAT(1H ,3H  *,64X,21HUNUSED UP/DOWN TIME =,F10.1,21X,1H*)
      WRITE(6,125)UN
  125 FORMAT(1H ,3H  *,65X,20HUNUSED NORMAL TIME =,F10.1,21X,1H*)
      WRITE(6,21)
      WRITE(6,126)
  126 FORMAT(1H ,3H  *,85X,10H----------,21X,1H*)
      WRITE(6,21)
      WRITE(6,110)SUM5,AV5,TOT1
  110 FORMAT(1H ,3H  *,8X,19HTOTAL WORK OUTPUT =,F10.1,7X,3H ( ,F5.1,4H
     1% ),10X,19HTOTAL WORK OUTPUT =,F10.1,21X,1H*)
      WRITE(6,21)
      WRITE(6,111)SUM4,AV4
  111 FORMAT(1H ,3H  *,10X,17HTOTAL LOST TIME =,F10.1,7X,3H ( ,F5.1,4H %
     1 ),60X,1H*)
      WRITE(6,112)L4
  112 FORMAT(1H ,3H  *,16X,11HFREQUENCY =,I8,81X,1H*)
      WRITE(6,21)
      WRITE(6,113)
  113 FORMAT(1H ,3H  *,27X,10H----------,79X,1H*)
      WRITE(6,21)
      WRITE(6,114)TOT,AVT
  114 FORMAT(1H ,3H  *,6X,21HTOTAL WORK ASSIGNED =,F10.1,7X,3H ( ,F5.1,4
     1H % ),60X,1H*)
      WRITE(6,21)
      WRITE(6,21)
      WRITE(6,21)
      WRITE(6,52)
   52 FORMAT(1H ,120H  ************************************************
     1*************************************************************
```

```
     2***)
      RETURN
      END
C
C
C
      SUBROUTINE PRINT3 (ITM1,ITM2,ITM3,ITM4)
C
C
      INTEGER TM1,TM3,TM5
      DIMENSION TM(4),TM1(10),TM3(8),TM4(8,2),TM5(4,7,52,5),D(7),D3(2)
      COMMON/SLAB4/TM,TM1,TM3,TM4,TM5/SLAB6/D,D3/SLAB7/K1,K2,K3,K4,TA4
      N99=0
      I1=ITM1
      I2=ITM2
      I3=ITM3
      ITM4=ITM4-TM1(3)+1
      K4=K4-TM1(3)+1
      I4=ITM4
      IX9=(K4-1)*52*7*4+(K3-1)*7*4+(K2-1)*4+K1
      II1=TM5(I1,I2,I3,I4)
      DD=0
  500 DO 504 L=I4,5
      DO 503 K=I3,52
      DO 502 J=I2,7
      DO 501 I=I1,4
      IX8=(L-1)*52*7*4+(K-1)*7*4+(J-1)*4+I
      IF(IX8.GT.IX9) GO TO 800
      IF(TM5(I,J,K,L).NE.1.AND.II1.NE.TM5(I,J,K,L)) GO TO 505
      II1=TM5(I,J,K,L)
  501 CONTINUE
      I1=1
  502 CONTINUE
      I2=1
  503 CONTINUE
      I3=1
  504 CONTINUE
      GO TO 800
  505 N99=1
      IS=I
      JS=J
      KS=K
      LS=L+TM1(3)-1
      II1=TM5(I,J,K,L)
      DO 509 LL=L,5
      DO 508 KK=K,52
      DO 507 JJ=J,7
      DO 506 II=I,4
      IF(TM5(II,JJ,KK,LL).NE.II1) GO TO 600
      IE=II
      JE=JJ
      KE=KK
      LE=LL+TM1(3)-1
  506 CONTINUE
  507 CONTINUE
  508 CONTINUE
  509 CONTINUE
  600 GO TO (900,900,631,611,621),II1
  611 WRITE(6,21)
   21 FORMAT(1H ,10X,3H  *,95X,2H *)
```

```
      IF(OO.EQ.1) GO TO 612
      WRITE(6,22)
   22 FORMAT(1H ,10X,3H  *,18X,4HFROM,42X,2HTO,22X,5HCAUSE,2X,2H *)
      WRITE(6,23)
   23 FORMAT(1H ,10X,3H  *,18X,4H****,41X,4H****,21X,5H*****,2X,2H *)
      OO=1
  612 WRITE(6,21)
      WRITE(6,24)IS,D(JS),KS,LS,IE,D(JE),KE,LE
   24 FORMAT(1H ,10X,3H  *,6H SHIFT,I2,5H DAY:,A8,6H WEEK:,I3,6H YEAR:,I
     14,5X,6H SHIFT,I2,5H DAY:,A8,6H WEEK:,I3,6H YEAR:,I4,2X,8HINTERNAL,
     22H *)
      WRITE(6,499)
  499 FORMAT(1H ,10X,3H  *,40H ---------------------------------------,6
     1X,39H---------------------------------------,2X,8H--------,2H *)
      GO TO 700
  621 WRITE(6,21)
      IF(OO.EQ.1) GO TO 622
      WRITE(6,22)
      WRITE(6,23)
  622 WRITE(6,21)
      WRITE(6,25)IS,D(JS),KS,LS,IE,D(JE),KE,LE
   25 FORMAT(1H ,10X,3H  *,6H SHIFT,I2,5H DAY:,A8,6H WEEK:,I3,6H YEAR:,I
     14,5X,6H SHIFT,I2,5H DAY:,A8,6H WEEK:,I3,6H YEAR:,I4,2X,8HEXTERNAL,
     22H *)
      WRITE(6,499)
      GO TO 700
  631 WRITE(6,21)
      IF(OO.EQ.1) GO TO 632
      WRITE(6,22)
      WRITE(6,23)
      OO=1
  632 WRITE(6,21)
      WRITE(6,26)IS,D(JS),KS,LS,IE,D(JE),KE,LE
   26 FORMAT(1H ,10X,3H  *,6H SHIFT,I2,5H DAY:,A8,6H WEEK:,I3,6H YEAR:,I
     14,5X,6H SHIFT,I2,5H DAY:,A8,6H WEEK:,I3,6H YEAR:,I4,2X,8H HOLIDAY,
     22H *)
      WRITE(6,499)
  700 I1=II
      I2=JJ
      I3=KK
      I4=LL
      GO TO 500
  800 IF(N99.NE.0) GO TO 900
      WRITE(6,21)
      WRITE(6,50)
   50 FORMAT(1H ,10X,3H  *,31H  NO INTERUPTIONS  NO LOST TIME,64X,2H *)
      WRITE(6,21)
  900 RETURN
      END
      BLOCK DATA
      DIMENSION D(7),D3(2)
      COMMON/SLAB6/D,D3
      DATA D(1)/8HMONDAY  /,D(2)/8HTUESDAY /,D(3)/8HWEDNSDAY/,D(4)/8HTHU
     1RSDAY/,D(5)/8HFRIDAY  /,D(6)/8HSATURDAY/,D(7)/8HSUNDAY  /
      DATA D3(1)/8H        /,D3(2)/8HWORKING /
      END
      FINISH
EJ
****
```

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