Development of a Manufacturing Engineering System for the Motor Industry

EXECUTIVE SUMMARY

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The RIMES system has been written principally by Tim Hardy, James O'Reilly, and Margaret Low of the University of Warwick, who turned the ideas expressed in this submission into a working computer system.

Declaration

I declare that all the work described in this dissertation was undertaken by myself unless otherwise acknowledged in the text. To the best of my knowledge none of the work has been previously submitted for any academic degree, and all sources of quoted information have been acknowledged by means of references.

Michael Allchurch.

Abstract

Manufacturing Engineering is concerned with converting a product specification into the most appropriate method of manufacture to produce the product to the correct cost and quality. Lack of integration and 'over the wall' engineering between design and manufacturing engineering adds to the time and cost of product development, and has significant effects on the subsequent cost and quality of the product. Because of the size and complexity of manufacturing engineering within the motor industry, the task is often divided between disparate, isolated, departments that traditionally have their own goals and objectives, supported by different business processes and systems. The adverse effects of the lack of integration between design and manufacturing engineering re-emerge within manufacturing engineering itself.

As a part of this research, the author analysed the existing information flows through manufacturing engineering within Rover Group, and showed that the business processes and systems generated a high duplication of effort and data, and reinforced functional demarcation between the departments. The new Rover Integrated Manufacturing Engineering System (RIMES) has been developed to address these issues. RIMES has been developed using TQM techniques and evolutionary delivery, new to Rover, to involve the manufacturing engineering customer in all aspects of business analysis and system development. The resultant system deliverables have therefore more closely met the customer requirements and have consequently been implemented with greater customer support. The subsequent changes to manufacturing engineering culture have been promoted from within manufacturing engineering, with the RIMES system acting as a lever for the change.

The research has been primarily concerned with the analysis and development of appropriate solutions in three main areas: integration of design and manufacturing engineering, change control procedures to maintain data integrity, and business processes to improve efficiency of manufacturing engineering and the quality of its output. These are all issues that are important for supporting concurrent engineering but were found not to have been adequately addressed, either in the research literature or in commercial systems, for applications involving large, complex products.

The new system provides support for the electronic integration of design and manufacturing engineering information, which is based on a technique developed that combines data 'push' and 'pull' principles, and enables the efficient communication of product specification to manufacturing engineering. It provides a single system and repository of manufacturing engineering knowledge, a common fundamental business process, and a common and consistent way of presenting manufacturing engineering information and reports. Concurrent engineering is promoted through early availability of information for downstream processes and strict change control procedures have been developed to maintain data integrity. The previously disparate departments of process engineering and industrial engineering are now working concurrently from the same data which has improved the accuracy, consistency and understanding of information both internally and in external reporting. The time to market has been reduced because product specification information is provided earlier and simultaneously to all manufacturing engineering functions. The manufacturing engineering process and its output have been redesigned. New working methods introduced through the RIMES system have promoted reorganisation and the elimination of demarcation within manufacturing engineering to further facilitate concurrent engineering. Newly designed multi media forms for communication of process information to manufacturing, developed in consultation with the RIMES user community, has promoted team working on the shop-floor.

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Glossary of Terms

Computer Aided Process Planning (CAPP)
CAPP is the term used for computer support of process engineering. CAPP has evolved through time from simple data repositories aimed primarily at metal cutting, to assembly operations planning, to the use of artificial intelligence techniques and has a current goal of seamless integration with Design.

Concurrent Engineering
Concurrent engineering is the systematic approach to the integrated concurrent design of products and related processes including manufacture and support. The approach is to cause the developers, from the outset, to consider all the elements of the product life cycle from conception through disposal including quality, cost schedule and user requirements.

Conformance Engineering
Conformance engineering is concerned with the day to day production problems and ensures that production operating methods comply with the standards and procedures set down by process engineers, - e.g. ensuring that tooling is to the required standard and torque, addressing any temporary variations to the standard process etc.

Design Integration
The objective of design integration is to make design information available to all contributors to the product development cycle in a timely manner in a form that they can understand and make use of.

Evolutionary Delivery
Evolutionary Delivery is the process of sub-dividing a design or plan so that its intended results can be delivered to the users in many smaller, maximum value increments which can then be used to enhance the value of subsequent increments.

Industrial Engineering
Industrial engineering is concerned with the task of providing detailed methods of work, and standard work times from the process engineers' process, and assigning that work to specific operators or teams in precise areas of the factory.

Manufacturing Engineering
Manufacturing Engineering is concerned with converting a product specification into the most appropriate method of manufacture to produce the specification to the correct cost and quality.

Prime Authorship
The prime author of a piece of information is the person who holds the authority to create and change the information. They are the people directly responsible for the implications to the business of any information or changes to it. Adherence to principles of prime authorship is essential to maintain the integrity of the data.

Process Engineering
Process engineering is a function of manufacturing engineering responsible for the development of the manufacturing method. This includes such considerations as facilities, machines, tools and equipment, safety, ergonomics, quality, and economics.

Total Quality Management (TQM)
TQM is a management process for achieving continual customer satisfaction by harnessing everyone's commitment. It is a management led process involving everyone in the company in continually improving their work, through measurement of the cost of quality, preventing rather than detecting faults and 'getting it right first time'.

List Of Abbreviations

AIT	Advanced Information Technology
CAD	Computer Aided Design
CAM	Computer Aided Manufacture
CAPP	Computer Aided Process Planning
CIM	Computer Integrated Manufacture
EOS	Engineering Operations Standard
ISO	International Standardisation Organisation
IT	Information Technology
PC	Personal Computer
SIMES	Solihull Interim Manufacturing Engineering System
SPC	Statistical Process Control
STEP	Standard for the Exchange of Product Model Data
QFD	Quality Function Deployment
RIMES	Rover Integrated Manufacturing Engineering System
TIFF	Tagged Information File Format
TQM	Total Quality Management

1 Introduction

1.1 Concurrent Engineering

The traditional approach to design is to undertake the various stages of design development in a sequential order; each task (generically: feasibility / concept study, specification and planning, development and design, validation / prototype proving, full production) is completed before the next stage begins. This 'over the wall' approach is used because of its simplicity in controlling the design process. Each task can have a defined start and finish, each function has easily defined tasks and the development can be monitored and managed through each stage. The two main disadvantages are that:

1. Decisions taken in the early stages obviously impact on later stages and without an input from the later stages, incorrect and costly decisions may be made. Figure 1 gives a typical cost commitment profile for a project and the actual expenditure, showing that the major commitment is made in the early stages.
2. Work does not begin in one function in the procedure until the previous function has completed all its work so that the time required to complete the design task through to implementation is extended.

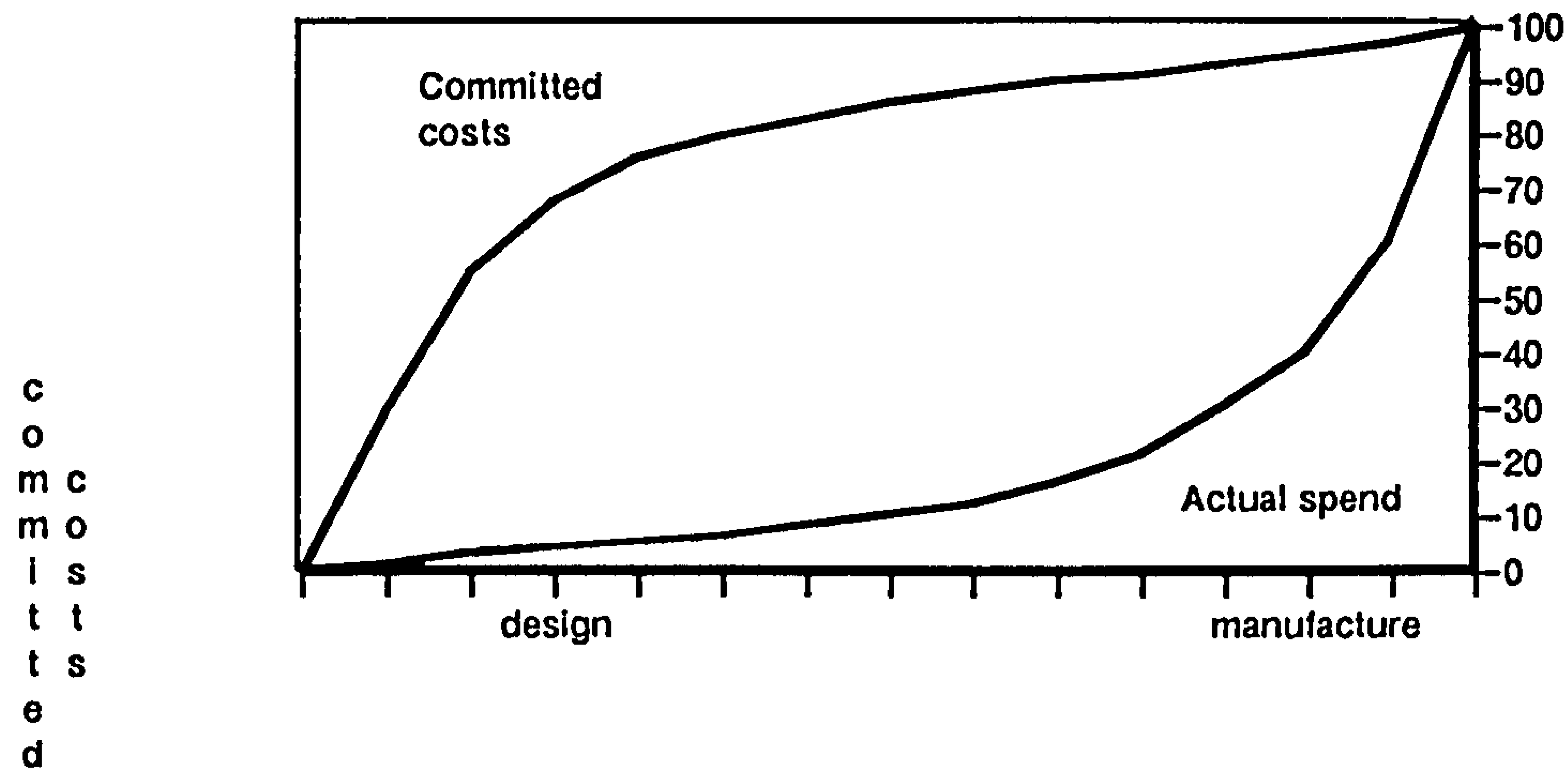

Figure 1. Diagram of typical committed costs and actual spend during the product development cycle.

Concurrent engineering is the systematic approach to the integrated concurrent design of products and related processes including manufacture and support. The approach is to cause the developers, from the outset, to consider all the elements of the product life cycle from conception through disposal including quality, cost schedule and user requirements [Syan, 94].

Concurrent engineering does not eliminate any of the design or process activities; it simply promotes the development of each of these processes simultaneously. The concurrent engineering systems approach seeks to optimise the time from initial design to manufacture, the design lead time and the manufacturing engineering lead time, by considering the whole process as a single system [Williams, 94], and this can be extended to include suppliers and customers.

1.2 Manufacturing Engineering

Manufacturing Engineering is concerned with converting a product specification into the most appropriate method of manufacture to produce the specification to the correct cost and quality. Design information is converted into information assets:- the tools, equipment, process control software, worker skills and standard operating procedures that will be employed in the production process [Clark & Fujimoto, 91].

Manufacturing engineering, like the design process, is a series of design-build-test cycles. The usual procedure is to develop a high level plan for the production facility, develop plans for the individual processes (machining lines, metal weld lines etc.) and then construct detailed designs of facilities, tools, and equipment. This equipment is purchased, installed and tested while more detailed methods are developed during pilot runs. Cycles of modifications and improvements are undergone until production sign off is agreed.

Once the manufacturing process is known, the exact method of work is broken down to constituent elements and measured to generate standard times. The work can then be allocated to men or machines and the timings used for capacity planning and as a measure against which manufacturing performance can be monitored.

1.3 Concurrent Engineering for Manufacturing Engineering

In large companies involved in the manufacture of complex products, the activities of manufacturing engineering are often divided between disparate departments. In traditional organisations, the information flow between these functions is procedural and suffers the same problem as the traditional 'over the wall' design procedures.

There has been a great deal of research into concurrent engineering and this is now beginning to be applied in industry, on various scales, with greater or lesser success. However, the emphasis has always been placed on the relationship between manufacturing/ manufacturing engineering and design. There has been little research on the activities within manufacturing engineering, but to improve time compression, the principles of concurrent engineering must also be applied within manufacturing engineering.

For further information see [An Introduction to the Rover Integrated Manufacturing Engineering System Business Environment, 95]

1.4 Rover Integrated Manufacturing Engineering System - RIMES

The work described here, and in the portfolio as described in appendix 1, has been sponsored by Rover Group as part of a long term re-engineering of its information systems to support data integrity and time compression in all of its business processes, and improved product quality through better communication between decision makers.

From the start of the project until 1996, the author was the Rover Group Manufacturing Engineering Systems manager, with responsibility for the maintenance and development of all of the systems where data is prime authored by manufacturing engineering. In this role, the author examined the business processes and future requirements of all of the manufacturing engineering departments and, through research and personal experience as a practising manufacturing engineer, proposed a new Group wide system and common business process. The author has been responsible for the research and development of the vision and definition of the business processes, and high level system requirements for a new manufacturing engineering system for Rover Group (RIMES), based on the principles of concurrent engineering and time compression. He also had the responsibility for the project management of the development and implementation of the system, and its integration with other relevant Rover Group systems.

Technical support and system programming was undertaken by Warwick University, with Oracle UK responsible for some aspects of the data modelling. The RIMES team also consisted of the many users who shared the vision of concurrent engineering for manufacturing engineering, and helped in the introduction of the system within the company. The work described here focuses on the author's contribution to the development and implementation of the Rover (Group) Integrated Manufacturing Engineering System (RIMES), and discusses the necessary design considerations in achieving an efficient, integrated manufacturing engineering business process. Where the work relied on the assistance of other members of the RIMES team this has been acknowledged in the report.

Initially the work concentrated on the vehicle assembly areas of the business, but is currently being extended into the component manufacture and body fabrication operations. Although the work has been specifically carried out for the motor industry, it is expected to have application in other organisations with large/complex products.

With the proposal to develop this new group wide manufacturing engineering system, encompassing within its scope the functions that had been previously regarded as separate, the author has had the opportunity to re-engineer the manufacturing engineering business processes to include new ideas of time compression and concurrent engineering. This involves not only changes to the traditional information flows, but also to the manufacturing engineering organisations and culture.

The general objective of RIMES described in its Business Proposal was:-

> To provide manufacturing engineering with an integrated system that allows accurate receipt, control, validation, generation, presentation and archiving of process data and manufacturing engineering knowledge to meet the engineers performance requirements.

The users identified a number of system requirements that they would like to have included in a new manufacturing engineering system. However, the majority of these requirements were to make improvements to their existing working practices and gave little consideration to the role manufacturing engineering should play in the product specification information continuum throughout the company. They were also made in the context of the organisational demarcation inherent in the functional organisation and did nothing to break down these barriers, share information, or promote concurrent engineering within manufacturing engineering.

For further information on the RIMES business proposal, see the Portfolio submission [Portfolio Introduction and RIMES business proposal submission, 93].

As well as providing the functionality to allow the manufacturing engineers to perform all aspects of their own tasks, the author had to consider the flows, and availability of information, not only to all manufacturing engineers but also to upstream and downstream systems and users. Where the efficiency of the information flow was impeded by existing organisational demarcation, the use of the resultant system was to highlight this and the system was then used as a lever to instigate change.

The RIMES project was initiated in 1991. The first implementation of the system was at the Rover Group Solihull plant to support the new Range Rover development during November 1993. Progressive enhancements and roll out to different models and different plants has continued through to 1998.

2 Background

2.1 History of Concurrent Engineering

The principles of concurrent engineering are not new and can be traced back to Henry Ford, Ransom Olds and others [Womack et al, 90], [Ziemke & Spann, 93], [Chesolm, 94]. These pioneers of modern industry used small, integrated, multi disciplinary teams of informed, broadly experienced personnel, with adequate resources and experienced leadership working on dedicated projects. This practice still exists today in many small firms, although the culture is rarely called concurrent engineering.

As industry grew, firms became more complex organisations that required specialist people to run them. Departments began to produce standard operating procedures that stated the departmental responsibilities, scope, and interactions with other departments. Such operating standards can lead to overly rigid systems and behaviour that support the specific goals of the department rather than the business as a whole.

In engineering, this departmentalisation has resulted in what has now come to be known as the 'traditional' product introduction and development cycle. A design is carried out in relative isolation, manufacturing and the test departments only see the design in an almost complete state. As the process is sequential in progression, each stage of product development following completion of the previous stage, it is commonly known as sequential engineering and, because a design can arrive at manufacturing with little notice or involvement of the manufacturing engineers, it is also known as 'over the wall' engineering [Syan, 94]

2.2 Requirements for Concurrent Engineering

Research has identified a number of key features that are essential for concurrent engineering [Eversheim et al, 95],[Syan, 94],[Belson & Nickelson, 92], [Douglas & Brown, 94],[Hitchens, 94]. These can be summarised as:-

- Organisation and culture

  Committed, multi disciplinary, informed, team working from top management through all levels of the organisation.

- Information

  Sustained communication and co-operation across different disciplines and organisations involved with the product. Available information in design must be passed on early to downstream process planning activities. This means that partial information that is of value to others must be passed, not just completed documents.

- Tools and methods

  Use of quality management methods and principles. In anticipation of decisions to be taken, critical information should be generated on product and process parameters early on using appropriate methods (QFD, SPC, simulation etc.)

2.3 Organisations and Culture

The time needed for the introduction of a new product in the motor industry is typically 3-5 years; however it is often based on an existing model rather than always from a blank sheet. Further developments of the product to improve it or upgrade it, and the introduction of new variants are common throughout its life cycle. Thus product development is a continuous process over many years with peaks of work load. The manufacturing engineering organisation will have to change over time to reflect these peaks, so mobility of manufacturing engineers is important to business efficiency and the continuity of an engineer's personal knowledge of a manufacturing process cannot be guaranteed over the life of the product.

The most common organisational forms in modern industry are the traditional functional organisation and the matrix organisation. Generally within Rover group, matrix organisations are used for major projects and the functional form, by far the most common, is used to support product enhancements and day to day manufacture.

In matrix organisations, typically one team of manufacturing engineers is responsible for the complete development of process and work allocation related to a defined process area, and concurrent engineering becomes more of an inherent part of day to day activities.

In a functional organisation, the activities of manufacturing engineering, because of their complexity and diversity, may be distributed amongst several departments each of which may have responsibility for only one particular aspect of the overall task.

[Bertodo, 97], notes 'Diagnostic studies of typical western hierarchical organisation show that the level of comprehension of information that cascades between two hierarchical levels does not exceed 25 per cent; within functions, a one level hierarchical separation reduces direct communication and hence understanding, by a level of four or five; the interposition of a functional boundary between individuals at the same hierarchical level degrades direct communication frequency by one order of magnitude; and communication between individuals falls exponentially with geographical separation.'. In order to achieve the 'desired seamless integration between the various modules in a CIM environment' [ElMaraghy, 93], the principles of concurrent engineering must be extended to the work undertaken within the functional manufacturing engineering organisation, and IT and information management can be used to alleviate many of the problems Bertodo describes.

Where the activities of manufacturing engineering are divided amongst different departments, concurrent engineering has to be implemented at two levels.

2.4 Information Flow

To complete design of a product economically, the relevant information should be available in a timely manner. At the beginning of the design process the information is generally incomplete. As the design process proceeds, more information and knowledge becomes available, and consequently more people become concerned with the manipulation of the information.

For an efficient flow of information, due to the volume of information involved, some sophisticated methods of developing the knowledge base and releasing the information need to be established. [Kusiak & Belhe, 92]. It has been widely recognised that the integration of a manufacturing system as a continuum is a must to meet today's highly competitive market demands [Jo et al, 93].

However, there is a lack of a language for design methodology transfer.

Some international research is taking place into data protocols that allow the communication of information between design and manufacturing. The most predominant of these is STEP, which is an ISO standard for the representation and exchange of product data, but this has yet to become generally established.

Without a protocol such as STEP to facilitate the communication of design data, the geometry information created by the designer has to be interpreted by the manufacturing engineer to create a manufacturing process. Any issues concerning the design that then arise from manufacturing have to undergo a reverse translation to relate to the geometry.

Techniques such as feature based design have been tried to bridge the gap between the geometry of the design world and the process of the manufacturing world [Prijic & Bobrowski, 97], [Shah & Mantyla, 95], [Peters et al, 90]. Extracting features from a geometric design is, at present, beyond the capability of available technology. The alternative is to pre-define the manufacturing features and make them an integral part of the design process. This requires an early input from the manufacturing engineer to specify suitable features to the designer, which will promote a better understanding of each other's requirements. Unfortunately, as each set of requirements for the manufacturing process will be different, there cannot be a generic feature definition algorithm, and so the task will be manually intensive for each part and process type [Subrahmanian et al, 89], [Prijic & Bobrowski, 97].

From the research literature it is apparent that there are no techniques or systems currently available to automatically generate process from the design geometry, and little support for the interpretation of the design to a manufacturing process. This will for the time being remain a manual task for a skilled engineer. At present the only consistent information key that appears in both the manufacturing and design worlds is the part identification or reference number. This part number key can be used to ensure that the information generated about parts in the design world is matched with corresponding process information in the manufacturing world. To support concurrent engineering, clearly business processes need to be examined and developed for seamless flow of information at two levels.

2.4.1 Information Flow: Level One

Manufacturing engineers have to receive and give information to other systems, both upstream and downstream, in order to promote concurrent engineering within the company and improve the quality of decision making. The most important of these is the Bill of Materials as the prime author of product specification, and the shop-floor as the user of its output. To achieve this, manufacturing engineers have to make use of the company wide change control processes and procedures. Research in this area has so far focused on concurrent engineering team working [Buzacott, 94], or on automatic translation of geometry [Santochi et al, 95], but there has been little research in the area of change control between two disparate groups.

2.4.2 Information Flow: Level Two

In a large organisation, dealing with complex products, the task of manufacturing engineering may be divided amongst many specialist departments. These, in Rover, are typically process development, facilities engineering, work study (or industrial engineering), and, on the shop-floor, process maintenance or conformance engineering, though the scope of each department may vary in different parts of the company. Each department has traditionally owned its own repository of information, in isolation, and there was little team working or feedback between them. Quality improvements made by the conformance engineers on the shop-floor were not generally known to the process development engineers working on the next generation of the process.

With these different departments, the traditional design/ manufacturing procedures of 'throwing information over the wall' to the next function in the product development sequence re-emerged at this lower level in the product development hierarchy. The traditional information flows and the systems used to support these activities tended to reinforce the traditional functional demarcations and, according to [Alting & Zhang, 89], 'in spite of the tremendous effort that has been made in developing Computer Aided Process Planning, CAPP, as a main element in the integration of design and production, has not kept pace with the development of CAD and CAM'.

For further information on existing working practices in Rover Group, see the submission [Using RIMES, 97]

2.5 Background to Rover's Existing Manufacturing Engineering Tools and Methods

The organisational history of the company from British Leyland through Jaguar-Rover-Triumph, Austin-Morris and Land Rover Vehicles to the present Rover Group, and the geographical diversity and virtual independence of the manufacturing sites have meant that manufacturing engineering systems, sometimes starting out as common, had diverged over time. Where these common systems failed to support the changing requirements of the disparate manufacturing engineering departments, they were abandoned in favour of locally developed applications, taking advantage of spreadsheets and word processors, on the now widely available PC's.

In the early 1990's a number of issues were causing the manufacturing engineers to become dissatisfied with their existing systems. The mainframe systems in use were expensive to run, inflexible and slow to change. The manufacturing engineers were facing new challenges with a range of new product introductions from the partnership with Honda, and pressures to reduce the time to market. Locally developed solutions were failing due to ever increasing demands to integrate, manage and store more diverse data.

For a more detailed explanation on the failure of existing tools and methods see [Portfolio Introduction and RIMES business proposal, 93].

2.6 Objectives of RIMES

Analysis of the existing organisation, information flow, and tools and methods within Rover Group, and the research literature, suggested that the RIMES system had to meet a number of specific objectives to promote concurrent engineering within manufacturing engineering [Eversheim, et al, 95],[Syan, 94],[Belson & Nickelson, 92], [Douglas & Brown, 94],[Hitchens, 94]:-

1. To provide a single, stable, Group wide manufacturing engineering system that allows the engineers to develop and present information consistently across the Group.
2. To support the integration of design and manufacturing engineering information to enable the efficient communication and

exchange of knowledge.

3. To promote concurrent engineering between the disparate departments existing within manufacturing engineering, and where possible their subsequent integration.
4. To lever changes within the manufacturing engineering process to minimise functional barriers and focus collective effort on improving quality of output to meet customer requirements.
5. To create the appropriate data structures to ease and speed up the task of data management.
6. To improve the quality and presentation of the information to the shop-floor to improve the build quality of the product.
7. To provide a repository of best practice information that can be re-used on future processes and design. This should help both in time compression and improvement of the quality of future processes.

To achieve these objectives the RIMES system had to address three issues:-

1. Integration of information between design and manufacturing engineering and within manufacturing engineering. (Objectives 1-3)
2. Concurrent engineering, and maintenance of data integrity. (Objectives 3-5)
3. Improving the manufacturing engineering business process and the quality of its output. (Objectives 4, 6-7)

3 Integration of Information Flow Between Design and Manufacturing Engineering

From the research of the many factors that contribute to successful concurrent engineering (organisations, team working, open culture, tools and methods etc.), some of the most important are the working procedures adopted and the management of the information that flows between the people engaged on concurrent engineering projects [Hunt et al, 93], [Miller, et al 93].

3.1 Design and Manufacturing Engineering Information

Ideally, the data supporting design and manufacturing engineering should be available from a shared common database. In this way, up to date information would be simultaneously available to both sets of engineers to ensure consistency between product and process definitions, but change control and management in such a tightly coupled data base would be difficult to manage.

The database would also have to serve two areas of the business, each of which has a different view and understanding of the data. The differences arise because design engineers focus on the part and its attributes whereas manufacturing engineers relate to the work being undertaken, the process operation. Each use different primary keys to access and control their information.

The designer's product specification is structured in the form of a hierarchical engineering Bill of Materials for each product with each part having a defined parent to child link. The principal key is the part number. (Figure 2.)

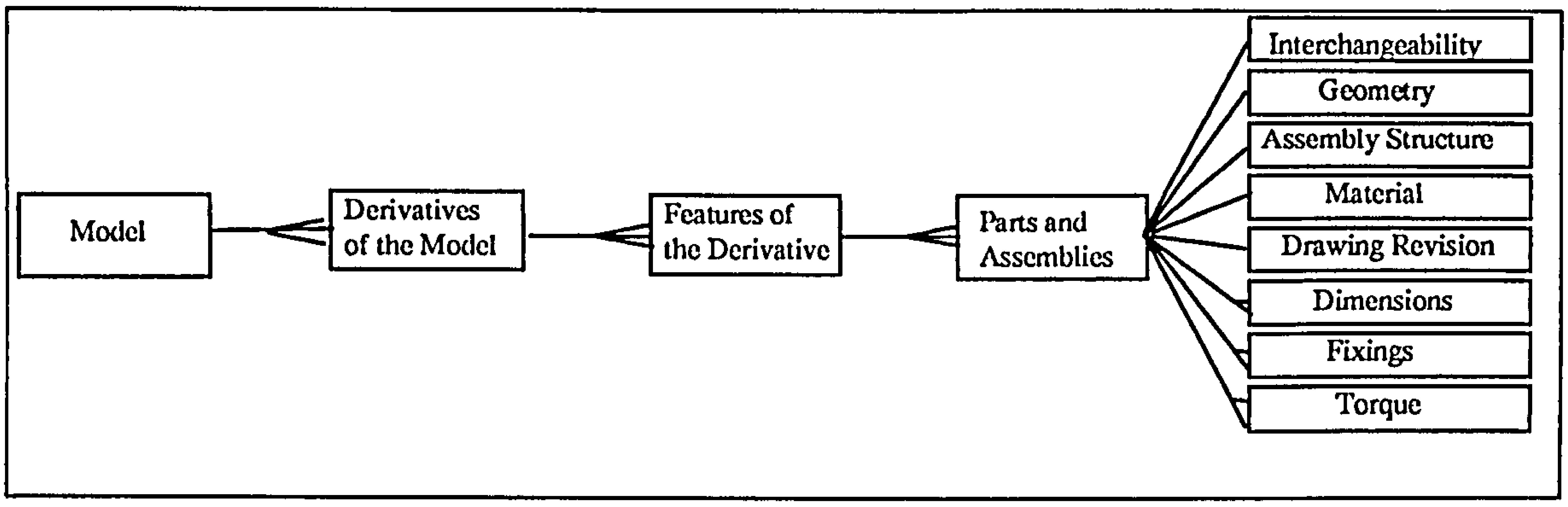

Figure 2. Schematic View of Product Specification Data

In the motor industry there are large differences in the work content between the thousands of variants of a product (or model) that exist and it is not feasible to issue manufacturing instruction for each; instead operations are developed for combinations of products to which they are applicable so as to reduce the complexity of instructions to the shop-floor. The focus for manufacturing/ engineering is the work being undertaken, not the part, and so the principal key for manufacturing engineering information is the process operation (Figure 3.). For example a vehicle may have an option take of many heater types - standard, cold country, hot country, air conditioning etc. Each heater assembly will have a different part number and component assembly structure, and use different connection hoses, and cabling. All of this information will be required, and identified separately, by the design engineer. The manufacturing engineer, however, is only interested in the assembly numbers to tell the operator what heater assembly to fit on which vehicle and the work required to fit the heater. If all of the heaters without air conditioning have the same process and time to fit, there will only be one operation required to cover all of those heater assembly options so that the vehicle applicability for the process operation could be 'All minus air conditioning'

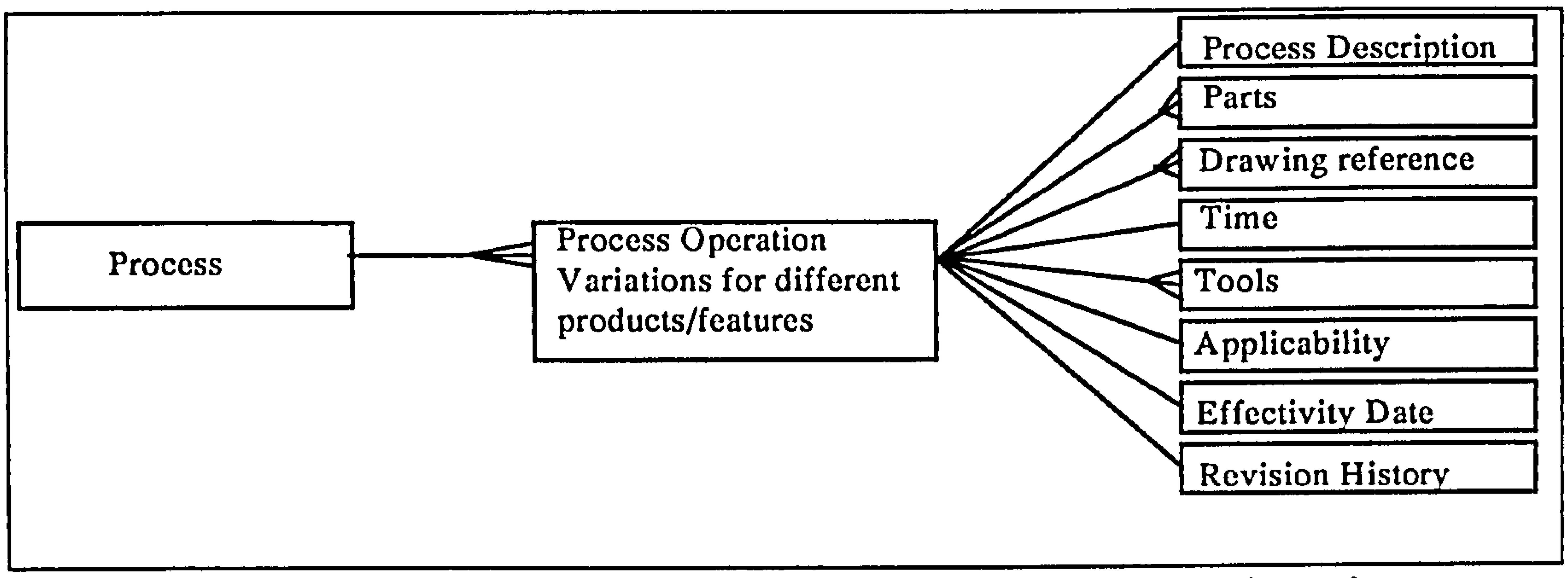

Figure 3. Schematic Process View of Vehicle Assembly Engineering Data

This distinction between the organisation of the design and manufacturing engineering data allows the respective databases to be conveniently de-coupled. However, loosely coupled databases require strong, formal, change control mechanisms to maintain data integrity between them.

For more information on this topic see [Integration, 96].

3.2 Data Integration: Push and Pull

Once the design information has been approved for manufacture, it is released and distributed throughout the company so that various downstream systems and processes can implement the new design change. The way such information is released is a key consideration in the development of concurrent engineering. The submission [Integration, 96] identifies research from the European Union project on Advanced Information Technology (AIT) showing two approaches with which this data distribution process can be classified: the Push approach and the Pull approach [AIT, 94].

The push approach applies best when the exact requirements are known. This includes the data content, the recipient and the triggers that cause data to be sent. The push approach has the advantage of delivering exactly the right amount of information at the right place and at the right time. There is no need for the user who wants the data to perform further search or filter operations.

If one of these requirements is not known, then the user has to pull the information. The user has to decide when entities are needed, or investigate which ones are required or where to find them. To search and get the required data under these conditions, users often have to pass several references, and use different systems with inconsistent user interfaces. Information from one system needed for reference within another system must usually be transferred manually, though modern GUI cut and paste facilities can assist this process.

3.2.1 Traditional Engineering Information Distribution

The push principle is the most common method of distributing information in the business today, whether it be, for example, management communications to the workforce, engineering change approval requiring a feedback, or engineering change release requiring implementation. However each of these examples is targeting a different audience and requires a different response.

The management communications brief is globally issued to everyone either by direct posting, perhaps according to the payroll personnel list, or by posting on notice boards. It is assumed that all recipients have, or can get, access to the information and no response is required.

For the engineering change approval process the target audience and sequence of approval is limited to known fact holders who have an interactive involvement with the development process. The name and address of these people will be known and a response will be required to approve the change, otherwise progress cannot be made. If the approval request is not received, a response will not be forthcoming, the sequence will be broken and the owner of the change will take steps to find out what went wrong.

The engineering change release procedure, the authority to implement the change, requires information to be passed to a much wider audience of people and departments, such as suppliers, machining, fabrication, paint, assembly etc., and within these departments support functions such as logistics, training, manufacturing engineering, and scheduling. The target audience may well be different for each type of change, may be working in parallel, and may be geographically dispersed. The Engineering Release is an instruction to make the change happen and so no response to the issuing authority is required from this audience unless the change is delayed or new problems arise. As there is no feedback, the issuing authority has no guarantee that that the correct target audience has received the Engineering Release until this fact itself causes problems.

The Engineering Release is issued according to a distribution list that, in a large organisation, will include many different people, departments and companies. Within each of these departments and companies the organisation is continually changing: people are leaving, arriving, and changing responsibilities. For a system utilising the push distribution method, these changes must be registered with the distributing system to maintain the integrity of the information flow. Within a large organisation this is a heavy administrative load that is difficult to manage and maintain.

3.2.2 Commercial Workflow Systems

A number of commercially available 'workflow' modules for the management of change within Product Data Management (PDM) systems were assessed. In each case the workflow management is based upon push data distribution, effectively automating and speeding up the existing paper manual system without addressing the problems identified above. The workflow systems do not have any intelligence about the content of the change, they only push the change through the routing as a document.

For more information on commercial workflow systems see [Integration, 96]

3.2.3 Information Flow Between Design and RIMES

A solution designed by the author and adopted for use in the RIMES system to the problems described above, is to mix push and pull methods.

The solution has been possible because:-

a) the manufacturing engineering system (RIMES) is to be used by all manufacturing engineers throughout the group and provides a single point of contact with the Bill of Materials,

b) the Engineering Release is a set of accessible data field and not just a document. All changes released from the Bill of Materials are electronically collected together and 'pushed' to the manufacturing engineering system automatically as an overnight batch file transfer.

All the information to satisfy the 'pushed' data distribution approach is known. The data required has been identified, the trigger is the release by the design engineer, and the recipient is the manufacturing engineering system.

The manufacturing engineering system receives the Engineering Release and when the manufacturing engineer logs on to the system, he/she is alerted to the arrival of the Engineering Release which is then 'pulled' to the engineer's work area. This procedure has been automated by allowing the engineer to specify in advance which fields, and then what data within those fields, would be of interest to him/her. This process, called Engineering Release targeting, compares attributes of all Engineering Releases with those pre-selected by the manufacturing engineer, and then alerts that engineer of any that match.

The attributes selected as of interest to the manufacturing engineer filter the Rover Group Engineering Release information, and allow the manufacturing engineers to see only the Engineering Releases in which they may be interested. The remaining Engineering Releases are available (subject to security) should the engineers wish to see them.

The system can also identify to the manufacturing engineer any other manufacturing engineering system user who has been allocated the Engineering Release. If the manufacturing engineer thinks that another engineer should be aware of the Engineering Release, they can send it to him/her.

If an Engineering Release remains 'unclaimed' because it does not match any engineer's selected attributes, or if an Engineering Release is nearing an implementation date without being actioned, then warning messages are issued to senior manufacturing engineers, and then the system administrator, to take further action.

For a more detailed explanation see [Integration, 96].

4 Concurrent Engineering

4.1 Information Management for Concurrent Engineering

A primary goal of RIMES has been to support concurrent engineering, which is concerned with the release, management, change control and information flow to support time compression and improve quality of output of the product introduction process. Research carried out in the European Union project Advanced Information Technology, in which the author collaborated, suggests that there are four important elements in information systems design to achieve the objectives of concurrent engineering in a distributed work environment [AIT, 95]:

1. **Staged Release:** This can take two forms:-
   - The ability to release information on individual parts of an assembly or product to downstream areas of the business.
   - The ability to release incomplete information about those parts.
2. **Prime Authorship:** The prime author of a piece of information is the person who holds the authority to create and change the information. They are the people directly responsible for the implications to the business of any information or changes to it. Adherence to principles of prime authorship is essential to maintain the integrity of the data.
3. **Formal Change Management** - the communication of change in a clear and controlled manner is essential to maintain data integrity, and becomes even more important in a concurrent engineering

environment.

4. **Feedback:** The mechanisms and processes by which downstream areas are able to feedback information to the authors of the released information, in order that the quality of the product can be improved.

The two main objectives of concurrent engineering are time compression of the product development process, and improving the quality of the product and efficiency of the manufacturing process. The ability to re-use historical knowledge about the product and process also helps to achieve these objectives.

RIMES system requirements have been developed and the relevant business processes re-aligned to support the objectives of concurrent engineering based on the four elements in information systems design previously defined.

For a more detailed discussion see [Change Control, 97]

4.2 Existing Change Control Procedures within Manufacturing Engineering.

Engineering change in the existing manufacturing engineering change process was traditionally initiated by the receipt of the Engineering Release paperwork. Other changes to affect quality, process, efficiency etc. or short term changes could be authorised by various local procedures.

Because of the diversity of organisation structures and roles within Rover Group manufacturing engineering, both for new product actions and for current products, many internal change control procedures had evolved over the years. In all cases the approach was to formally pass a completed set of work, sequentially, from one department to another. In practice this generally involved copying data files from one system to another, editing them and passing them on to the next customer as illustrated in figure 4.

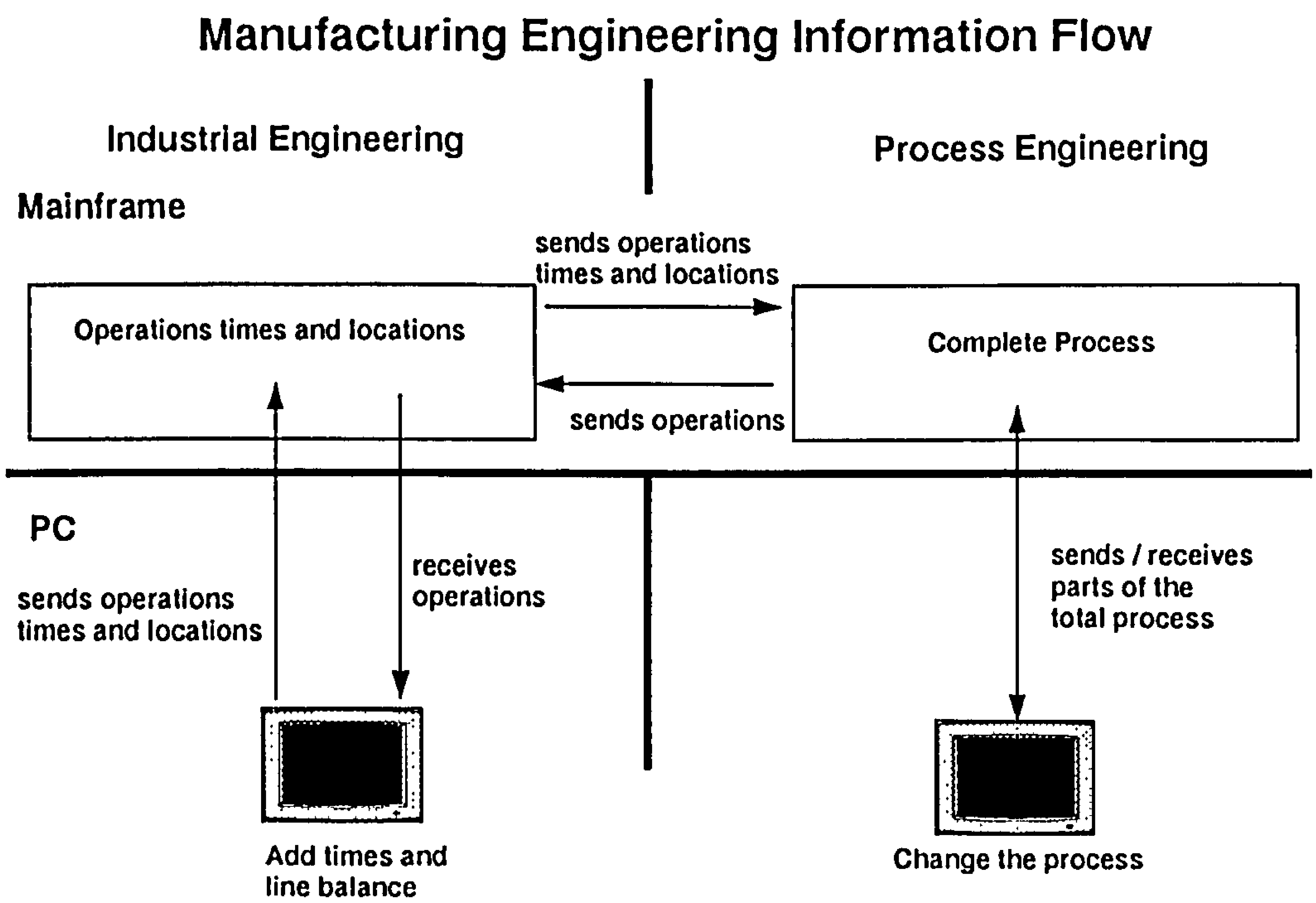

Figure 4. Existing Manufacturing Engineering Information Transfer

A detailed explanation of the existing manufacturing engineering change procedure between process engineering and industrial engineering is given in the submission [Change Control, 97]

4.3 Existing System Barriers to Concurrent Engineering

The existing process for managing change within manufacturing engineering placed a number of barriers in the way of concurrent engineering.

- The information flow described from the Bill of Materials through process engineering, industrial engineering and onto production and logistics was strictly sequential. The downstream departments did not have a formal notification that a change was imminent until the preceding department had actioned and discharged their responsibilities for the change.
- The existing process and systems support required that all information for a sector was complete before any part of the information could be released.
- The information generated by each department was kept within the confines of the department (and sometimes limited to an individual engineer) until all the work on the change had been completed.
- Only one version of the process could exist in the database at any one time. Any changes had to be held locally, and therefore in

isolation, until close to the implementation date because the changes would overwrite the existing process. Any subsequent changes to the same process would also have had to be queued in this isolated state.

- The information actually transferred between departments was not complete and was not sufficient to implement the changes. It did not include change administration information such as what had changed, why it had changed or when the change should be implemented; nor did it include information that would improve the industrial engineer's decision making, such as that on tool and parts to be used.
- Additional information was only available in paper copy form and relied on the printing, distribution and postal systems.
- The lack of electronic feed of this additional information meant that the industrial engineer preferred to wait for the complete information to arrive so that the potential time compression benefits of electronic transfer of the data were lost.

Prime authorship was not enforced on product specification information and the process engineer was able to change the engineering specification information at any time. The process engineering information that was transferred to industrial engineering was protected but, as this was only a subset of the total process engineering information, the industrial engineer had to type in any additional information they may have wanted to use.

For further information on the existing system see [Change Control, 97]

4.4 Conclusion from Change Control Within Existing Systems

There is little information generated by one department within manufacturing engineering that is of interest only to that one department. Even with the separately developed existing systems many links had to be made to pass data between them. With this transfer method, and by holding many copies of the same data, the systems had been loosely coupled but with a limited and ineffective change control procedure. This was in part due to the technology that was available at the time that the systems were being developed, and partly arose from demarcation between the manufacturing engineering departments, with each department having its own responsibilities and success factors and not wishing to be restricted or dependent on another department.

For a major change some information was disseminated by project and management meetings and general hearsay. Information received in this manner was, however, outside of the formal release procedure and was uncontrolled.

In the procedures and culture described above, reinforced by the systems constraints, the issuer of any such informal information bore little responsibility for its accuracy until they formally released it. It is only then that they took any responsibility for the administrative burden of informing downstream functions of any further changes. The effect of this was that the issuing engineer would not release information until they were confident that further changes would not be made, and downstream functions would not begin work and commit resource to work on information that may be incorrect. This goes against the principles of concurrent engineering and extends the time to market of the proposed change.

4.5 RIMES Change Control Procedures

4.5.1 The Work List

When the manufacturing engineers begin work on an Engineering Release, they first compile a work list of process operations that require modifying, creating or deleting. The Engineering Release document allows a controlled implementation and change, and provides the information for a revision history and audit trail.

Using the existing manual Engineering Release and process sheets, the engineer would have traditionally used index information, such as the part grouping reference, to identify the general process area affected. The Engineering Release note would have identified any parts that had been replaced by another part and the engineer would then manually search through the process sheets for that area to find parts identified as replaced. They would then create a work list of the process operations that needed to be changed.

The electronic Engineering Release management process designed for RIMES receives information from the Bill of Materials to automatically identify any parts in the database that have been replaced by a new part, and create a work list of associated process operations. The engineer may select more process operations to be added to this list if they decide that they are affected by the proposed change. The completion status of this list can be used to monitor the progress made in implementing the change.

4.5.2 Development Levels

Formal changes issued from the Bill of Materials are not necessarily in the sequence in which the changes are to be implemented. Future model facelifts and major changes will typically be issued some months prior to the introduction date while smaller running changes may have a much shorter lead time. There may, therefore, be a queue of changes waiting to be implemented on the same process. It is important to give as much information about these changes to all manufacturing engineers as soon as possible; both that a change is about to happen and what the effect of the change is as the new process evolves. The existing systems and business processes prevented this dissemination of information.

To allow the manufacturing engineer to manage these sequenced changes, the RIMES system has been designed to provide a number of development levels and a 'current process' level. The current process level is the set of process operations that are being used to manufacture the product at that point in time. No change can be made directly to operations in the current process level, so the engineer can never mix up current and development processes (See Figure 5).

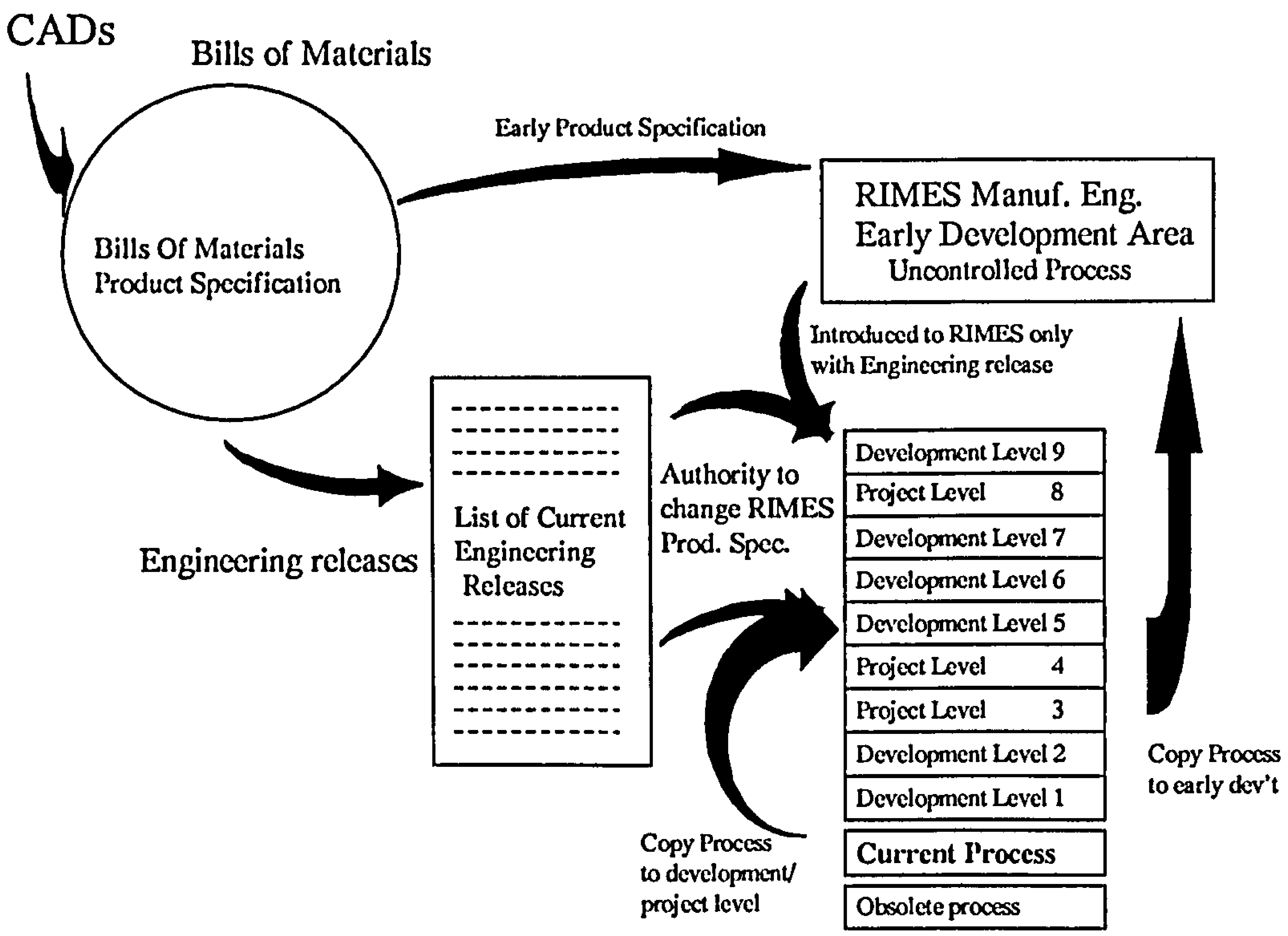

Figure 5 RIMES Development Levels and Change Management

To make a change to the current process, an operation has to be copied to a development level under a change authority where modifications to the operation can be made. Subsequent changes can be raised, either from a development level or again from the current process, to a different development level to allow sequences of changes to be developed simultaneously The change is released back to the current process under strict change control procedures that facilitate concurrent engineering, protect the integrity of the current process, allow an audit trail of changes, and archive the new process.

For major, long lead, projects, a series of changes may be made within the project before the first of them is actually implemented. This situation occurs regularly when new products are in development and are subject to continuous design improvements. To facilitate concurrent engineering, manufacturing engineers will require advance information before the design is fixed and this means that they will have to manage many more changes to the process during this period. As many of the changes may never be implemented, the change control rigour that archives the process operations are not required and the normal procedure may be relaxed. To allow this, and to differentiate these types of changes from normal changes, a development level may be nominated as a 'Project level'. This allows multiple sequential changes to be completed and then released to the project level, without having to make them current between changes. When the design is fixed for the project, the final process will be released to 'current' under the authority of the Engineering Release.

The number of development levels allow the manufacturing engineer to collect changes together that satisfy some common criteria. For example, changes may be collected together because they are part of a major project, or they may have a common introduction date, or a level may be dedicated to running changes. The choice of what significance to apply to the development levels is left to the manufacturing engineer because each process area will manage their work in a manner that supports their own objectives.

See the submission [Change Control, 97] for more information.

4.5.3 Change Control Status Reporting

Once the operations have been copied to a development level, further controls implemented in RIMES monitor the development progress of the change. The development cycle is divided into two generic activities:- developing the process and timing the process. Each of the process operations undergoing change has a status of 'process', 'timing', or 'finished' as the change progresses through its development cycle. In a project level the process can have an additional status of 'issued' when the change has been completed and agreed for implementation but will not actually be implemented because a further change on the same process may take effect first.

Once a change has been 'issued' then no further changes can be made without going through the complete change process again and then the original change will remain as a statement on the audit trail.

See the submission [Change Control, 97] for more information.

4.5.4 Roles

The existing functional organisations within Rover Group allocate different manufacturing engineering responsibilities to different departments, and in some cases these responsibilities change throughout the product life cycle. The typical demarcation is between process planners, who develop the tools and methods, and industrial engineers, who set standard times and allocate the work to the shop-floor (line balancing). The data modelling and analysis of information flows through manufacturing engineering, undertaken during the RIMES development, identified considerable data duplication in the different existing manufacturing engineering systems.

The duplication had occurred because each department was independent of the other, had different goals and success factors, and used the common information to achieve their different ends. For this reason each had been reluctant to relinquish control of the information, and systems and procedures had grown up over time within each department to support the different uses to which the information was put. The data duplication required a duplication of data maintenance effort and resulted in a loss of data integrity.

In developing the RIMES system this duplication has been eliminated. The system does not fundamentally recognise any demarcation of ownership of any of the manufacturing engineering development tasks or the resultant information. At this fundamental level, any engineer who has authorised access to a process area may undertake the complete range of manufacturing engineering tasks supported by RIMES. This situation is ideal for the matrix organisation supporting project work and concurrent engineering, but is in conflict with the demarcation inherent in the more commonly adopted functional organisations.

In the functional organisations, process engineers and industrial engineers are held responsible for their individual aspects of the manufacturing engineering work, and the system, therefore, has to ensure prime authorship by allowing the different engineers the correct level of access to the data for which they are responsible. Some departments have had to relinquish control of information and others have had to provide information in a different format or in more detail. The prime author of the information has to recognise the requirements of all the users of the information, not just their own. The system manages authorised write access to the database by assigning each type of engineer a role. By virtue of this role, the engineer is then granted write permissions to particular parts of the RIMES database.

For further information see the submission [Using RIMES, 97].

As the manufacturing engineers now all work with the same data, instead of having the freedom to change the data to suit their own requirements, communication between the different departments has improved because the prime author has to generate information that is mutually suitable. RIMES has raised the awareness between the departments of each other's business role and requirements and how much of the work previously undertaken was a duplication of effort. This better understanding has led to an improvement in the quality of information and service both within manufacturing engineering and to downstream functions. More importantly, many of the departments themselves are more aware of the futility of the demarcation and are making organisational changes to integrate the manufacturing engineering departments. The RIMES system is being used as a lever to promote business improvements sponsored by the users themselves.

4.5.5 Managing Operations Within a Development Level

Where the functional organisation is still in operation, changes have to be managed in such a way that concurrent engineering is promoted within manufacturing engineering. Therefore the four elements for concurrent engineering:- staged release, prime authorship, feedback, and formal change management, needed to be implemented within manufacturing engineering.

Using the roles of 'process engineer' and 'industrial engineer' as examples, any engineer assigned the 'process engineer' role initiates the procedures to make changes to the current process. The process engineer receives the Engineering Release, decides which process operations need to be changed, and which development levels should be used to manage the change. The process engineer also identifies the general production area where the work should be completed. This, in effect, identifies which industrial engineer will be responsible for balancing the work into the production area.

The industrial engineer is responsible for developing the standard time for the new process and allocating the work to an operator in the production area.

At all times, the work being undertaken by the process engineer and the industrial engineer in the development of the manufacturing engineering data is visible to each other. The industrial engineer can begin development of the standard time as soon as the information on the process is entered. It is, however, necessary to identify the completeness of the process and industrial engineering work, so that each engineer can work with the information with a degree of confidence.

Any process operation that has the status 'process' is being worked on by the process engineer. The industrial engineer can begin developing the standard times and allocating work, but the operation is subject to change. When the process engineer has finished the task, the status of the operation is changed to 'timing' so that the industrial engineer can add the standard time with a high degree of confidence that the process is now stable. Once the timing of the operation has been completed, the industrial engineer changes its status to 'Finished'.

An engineer can change the status of 'Timing' or 'Finished' operations back to 'Process' if amendments are to be made. Any downstream engineer knows that this has happened because the status indicator 'Process' will have changed colour. An engineer can change the status 'Finished' to 'Timing' in the same way.

Any downstream engineer unhappy with the operations, can return it to the previous status with an appended electronic note to explain his/her concerns. Any operations 'returned' in this way are identified by a colour change to the status level text. This alerts the issuing engineer to the problem and that the operation is not just work in progress.

Any operation that has an 'issued' status has had the reason for change registered in a revision audit trail. Such an operation cannot be changed by altering the status; instead a new authority for change has to be raised and the operation has to progress again through 'process', 'timing' and 'finished' for the new change.

If the manufacturing engineering organisation is such that the entire task cannot be completed by one engineer, or department, then each contributing engineer, or department, must approve the completed process before the operation can be issued to 'current'. For example, a process engineer cannot issue a process as 'current' without the industrial engineer completing his/her work and effectively approving the process engineer's work.

For more detail see the [Change Control, 97] submission.

4.6 Visibility of Early Engineering Changes.

To facilitate concurrent engineering, the manufacturing engineers need early visibility of any potential changes that may affect their processes. The Bill of Materials holds many parts that are in the early stages of specification and have not received engineering approval for release. The Bill of Materials system has a facility to collect these changes together and issue them electronically to manufacturing engineering on a daily basis . Once a manufacturing engineer is aware of the change, he/she needs an area to develop the process without impacting on authorised changes.

RIMES has been designed to allow an unauthorised process to be developed in an 'early development level' using the same system functions (process development, graphics, time generation etc.) as the formal process, but without the strict change control mechanisms (Figure 5). This allows the manufacturing engineer to begin work on parts or assemblies even before part numbers are allocated.

As the specification progresses, the process can be updated. At the point that the part receives formal approval, and therefore has engineering release, the informal process can be copied to the formal RIMES change control part of the system, and would have been already developed to a more complete state than if the manufacturing engineer had waited for the Engineering Release. This development has taken place without risking the integrity of the data in the formal change control procedure.

5 Manufacturing Engineering Processes

System requirements have to be based on an analysis and, where necessary, streamlining of the business processes that affect the process owners and the process customers. The user of RIMES is the manufacturing engineer population, while the customer of these engineers is the shop-floor personnel.

The RIMES system has been designed to assist manufacturing engineering manage changes, in particular, changes to the product specification, from early concept through to product volume build and post-volume support. Wherever possible, the methods used to develop the process plan (e.g. bottom up: detailing the operation and compiling the process, or top down: starting with an outline and developing the detail of the operations) is left to the manufacturing engineer's own preference. However, where necessary, strict procedures have been built into the system to promote concurrency within the various manufacturing engineering departments, lay the foundation for closer relationships with product specification and design departments as well as the shop-floor, and maintain data integrity.

At the core of the system is a relational database, developed by Warwick University, servicing manufacturing engineering throughout the Group. The system provides the functionality to produce the process plan including work methods, supporting illustrations, tools, facilities, standard times, and line balancing.

An objective of RIMES has been to improve the quality and presentation of the information to the shop-floor to improve the build quality of the product. RIMES has been designed to make the manufacturing engineer more directly focused on the shop-floor as their principal customer. To aid communication between the manufacturing engineer and the shop-floor, the process documentation includes an image to better describe the process requirements. Images are created from scratch, or scanned or photographed or taken from CAD and edited as required, and then stored as TIFF files.

All information held by the RIMES system is conditioned by its change status or development level, is held once only, and every manufacturing engineer works off the same information (Figure 6.).

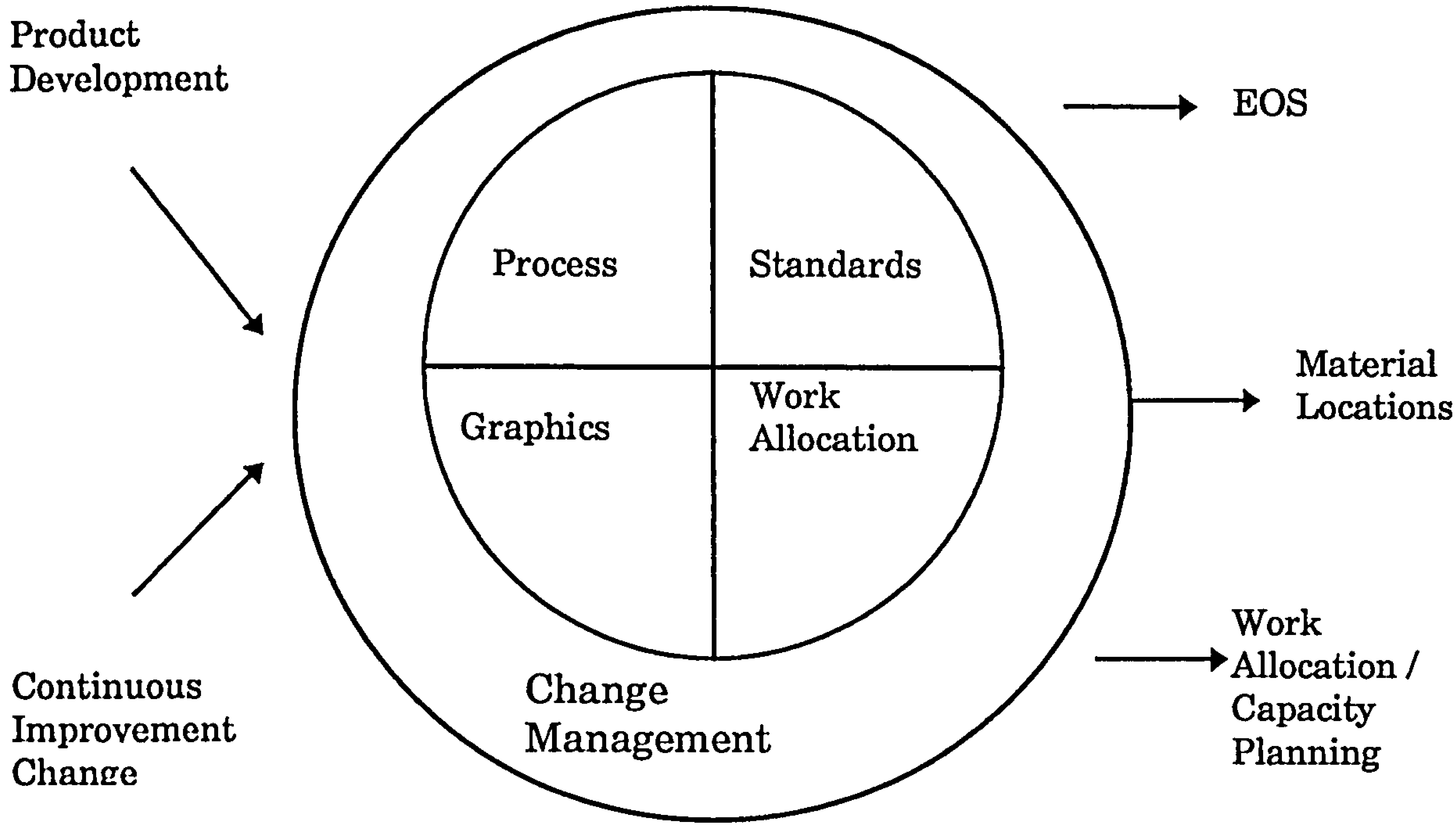

Figure 6. RIMES functions and Major inputs / outputs

5.1 Process

The process operation lies at the core of manufacturing engineering. It is an instruction to the operator on how to assemble/produce the parts for a particular product and comprises the work method, the parts to be worked upon for a particular product, and the tools to be used. It also includes any specific quality, safety or standard information that must be adhered to.

The process operation developed using RIMES is issued as a document called the Engineering Operations Standard (EOS) sheet, which has been designed in consultation with the RIMES team, and which includes an illustration to add clarity to the method descriptions. The sheet is described as a 'standard' sheet because whatever is written on the sheet is mandatory. It does not include information that is arbitrary. For example, if a set of four nuts have to be tightened in a particular order, then the order will be specified and shown on the diagram. If the order of tightening is irrelevant then the process description will simply state 'tighten four nuts'.

The scope of work covered by the process operation differs greatly. In complex robotic or machining operations, for example, one process may take several pages to describe. This is because the instructions are more concerned with setting up machinery and maintenance than on how to perform the actual manufacturing tasks. As the tasks do not have to be carried out by a human, a large amount of work is collected together and described as a single operation for convenience.

For manual assembly, however, it is the manufacturing task that is described and this has to be allocated to an operator to perform. If a heater has to be secured with four bolts, then a decision has to be made on how to describe the operation. The minimum work may be to locate the heater to position, locate and loosely fit one bolt which holds the heater in place; the remainder of the heater fit may be described by other operations of fitting each of the remaining three bolts loosely and then another four operations to finally tighten them. This very fine breakdown of work may suit the industrial engineer; their task is to assign the most work possible to as few operators as possible throughout the manufacturing facility, and the finer each operations time, the easier this task becomes. However, the quality of the heater fit is jeopardised. The heater is only partially secured until the remaining bolts are fitted, and is subject to knocks and damage. The work may also be allocated amongst different operators and this reduces the accountability of the operators for a finished product. For manual assembly, an operation should describe work that is the minimum task that an operator should complete to satisfy a quality standard.

It is this difference in requirements between industrial engineering and process engineering that, in the past, has led to disagreements and arguments between the two departments. The problem has been compounded because of the traditional sequential business process adopted. The process plan had to be complete before the industrial engineer had sight of it, and then changes were difficult to make once production deadlines were that much closer.

5.2 Standard Time

The standard time is used to monitor company performance. For example, by comparing the standard time that should be taken to produce a number of products against the time actually taken by the number of people employed, the efficiency of the labour utilisation can be measured. As the standard time is critical to measuring business performance, a complete auditable record of changes made to the standard time for each product must be kept by causal factor.

Within Rover Group, using the existing systems and processes, this was an extremely labour intensive task requiring constant monitoring. The total time reconciliation was performed once a year, when all change records for the year were summarised. With the existing systems, this task relied heavily on accurate manual records being kept throughout the year and inevitably, when under pressure to make changes, the engineer would often neglect this piece of administration. The task of standard time reconciliation often took the entire industrial engineering department two weeks at budget time.

The RIMES system allows a detailed breakdown of each process operation into elements of work so that a finer analysis of the operation can take place. Time is generated from a time study, or more likely from standard data or a pre-determined motion time standard, and allocated to each element.

The times for each element are then totalled to give that for the operation. All of the operations for a product can then be added together to provide the total standard time to produce the product.

RIMES monitors all changes to the standard times and requires the engineer to provide an explanation and reason for the change at the time that the change is made to the system. A reconciliation report of all time changes by change reason can then be provided automatically for any given period of time.

5.3 Graphics

The existing manufacturing engineering systems were text based, incapable of using integrated graphics, and because of this all work instructions had to be written at length to convey the manufacturing engineer's instructions. This meant that these instructions became technical and often required another technician, for example a training officer, to interpret the instructions for the shop-floor operator. The instructions then became a reference document filed away and rarely used.

With the advent of the graphical user interface and new systems technology, affordable graphic editing has become possible and RIMES makes use of this technology to allow images to be scanned, downloaded from other systems, created and edited, and dynamically linked to a process operation. This combination of text and graphics process can then be printed on a single document for the shop-floor. The text has been reduced because the picture explains most of the process, and the operators make far more direct use of the sheet, both for their work instructions and to help them make constructive comments.

5.4 Work Allocation

Motor vehicle manufacturers rely heavily on paced production flow-line working, where a moving facility carries an assembly through a succession of working areas, progressively adding value, until a finished vehicle is driven off the end. The moving facility is known as a track and the working areas are stations. The track is of fixed length, determined at the vehicle development stage, and the individual station lengths are determined predominantly by the length of the vehicle or assembly.

Each shop-floor operator is allocated a station in which to work. As the vehicle/assembly moves into a work station, the operator moves to the vehicle and performs the predetermined work. This should be completed on average in the time it takes for the vehicle to move through the work station. This is the cycle time. The operator then leaves the vehicle and moves back to begin work on the next vehicle which will be entering the station.

Each process operation has to be assigned to an operator. The list of operations given to the operator is known as the man assignment. The collection of all the man assignments for a process area is the line balance. It is normally the role of the industrial engineer to undertake line balancing although, as a result of the introduction of the RIMES system and the use of a common process operation, the roles of process planning and industrial engineering are merging.

Using the existing systems and procedures, the engineer assigning work had to wait until all of the processes for an area or product were complete before they could start work and then this line balancing would have often taken up to six weeks. The line balancing engineer was also working from a different version of the process that they could change if they wanted. These two factors alone extended the time to market and corrupted the integrity of the information.

The RIMES system has been designed not only to allow the work allocation engineers access to process operations as they are being developed, they have become a part of the change control process and actually have to approve the process operation before it can be marked as completed. As the engineer generating the process is the prime author of the information, the work allocation engineer is not allowed to change the process operation and the integrity of the information is protected. The engineer can also begin developing the line balance concurrently with the process development so as to reduce the time taken to implement new designs.

A more detailed description of the RIMES system is given in [Using RIMES, 97]

5.5 The Engineering Operations Standard Sheet (EOS)

The existing system's principal output was a technical document known formally as 'Process Work Instruction Sheet' and commonly as the 'Process Sheet'. This sheet was a text document of many pages, written in a technical language by engineers for other engineers. The average shop-floor operator had neither the technical knowledge or inclination to read the process sheet.

The existing process sheets described every detail of the method that the process engineer stated should be used by the operator to manufacture the part. In the then existing scientific management environment, if something went wrong the first check was 'is the operator working to process'. If the operator was not working to the process instructions then he/she could face disciplinary action. The operation standard time was measured to 1/100th of a minute and the operations were assigned to an operator in such a way as to utilise as much of the available cycle time as possible. In these circumstances operators would only officially work to the process sheet instructions. An operator could well be completing the same sequence of tasks hundreds of times a day; for example, the Rover 200/400 line runs at 60 vehicles per hour and so each operator's cycle time is only 60 seconds. With this level of repetition, operators would eventually establish the best method for performing their assigned work. If this method was more efficient than the one laid out in the process sheet, an operator would typically complete the allotted work more quickly and take longer breaks or finish work early. Shop-floor operators did not consider themselves as part of a team working towards continuous improvement for the benefit of the company.

In a reassessment of the role of manufacturing engineers, the shop-floor operators were considered as the principal customers of manufacturing engineering and the process sheet as the main means of communication with them. The existing process sheets, with their detailed engineering terminology, were seen as too restrictive, too dictatorial and not very customer friendly.

The author, under the directive of the RIMES steering committee, chaired several meetings and workshops throughout 1991 to establish a new format for the presentation of manufacturing engineering information. The workshops were attended by manufacturing engineers from all sites and process areas, and finally agreed on the format now known as the Engineering Operation Standard Sheet. The main requirements for the sheet were:-

- It is principally an instruction to the shop-floor operator as well as any interested engineers, and has to be written with this in mind.

- It should contain only mandatory information. Team working and empowerment means that the shop-floor operator should have as much input to the way the work is carried out as possible and be constrained as little as possible by the EOS information.
- The sheet should be as informative as possible, and so an illustration is seen as important for each process sheet.
- The sheet should contain a minimum portion of work that can be completed to a measurable quality standard, i.e. no elements of work should be left unfinished for completion on another sheet, and no large portions of work that can be divided should be included in a single sheet.
- No unnecessary or overlong text. No abbreviations.
- All the information should be on a single sheet so that the operator does not have to collate documents or refer to more than one to understand their task. (Hence an A3 size EOS sheet).
- The format should be consistent throughout the company.

Surveys of production operator opinion on the EOS sheet indicate that because the sheet is far easier to read and all the relevant information is on a single page, the sheet does tend to be read, if only when initially issued; traditional process sheets tended to be put to one side until time could be found to study them. The improvement manifests itself in the greatly increased feedback from the shop-floor that includes many corrections and suggestions for improvement. The EOS sheet is facilitating shop-floor team working [Henderson, 96].

5.6 Images and Mark-up Layers

The images used in the creation of the EOS sheet can come from a number of sources. Initially, external contractors were commissioned to draw pictures of the part or assembly and then these were scanned to provided electronic image files. These files provided the basis of a library of assemblies that can be electronically copied, edited and combined to generate the required EOS image. In addition to the image the system provides a facility to add mark-up layers. These are in effect transparent sheets that lie across the image and can be used to add additional information without affecting the underlying image. This facility is used presently to add text to the image and to highlight certain aspects of the image that the manufacturing engineer considers important, such as quality related points. The software system used by the RIMES development team stores the EOS sheet, its image and the mark-up layers all separately but with connecting pointers.

5.7 Electronic Distribution of EOS Documentation

It is possible to have many mark-up layers for any EOS sheet and each layer can be assigned an owner, or role. At present only the manufacturing engineer adds mark-up layers but the facility can be made available for other engineers to add comments. In the future it is proposed that the EOS should be electronically distributed to shop-floor terminals so that the operator can view an electronic EOS sheet at an adjacent terminal. In this way the EOS sheet can be treated fully as an electronic document.

Some advantages of this method of EOS distribution are:-

- The operator would always have the latest version of the EOS.
- There would not be any old copies left lying around.
- The EOS could be selected against a number of search criteria.
- As the order of work changed, the line balance and the sorting and re-issuing of the EOSs would be automatic.
- The process maintenance and operator roles could 'own' a mark-up layer and this could be used to capture operator comments, concerns and improvements for electronic feed back to the manufacturing engineer.
- A video could be added to the image area of the EOS to allow the method or points of concern to be demonstrated visually.

When manufacturing process problems occur today Rover uses many local, predominantly manual, systems to try to identify the source of the problem and provide corrective action. Some of these systems simply involve escalating the problem up and across the management chain, or filling out cards and sending them to a manager of an area thought by the writer of the card to be responsible for the problem. The management structure is used to target the card to the perceived problem area and while this can be effective, some problems are mis-directed and lost in the process.

Another issue is the communication of the exact problem. Often the part number is used to identify the part or assembly that is giving a problem but the part may not be the cause of the problem; the process method or one adopted by the operator may instead be causing the problem. Brief descriptions or thumbnail sketches to identify what the problem is are often used but these tend to be inadequate and result in misunderstandings and conflict. Face to face meetings are often required to resolve simple issues. The internal communication within manufacturing is in a similar situation to that between manufacturing and design. There needs to be a communication 'carrier', similar to the features approach offered by feature based design, to allow all interested parties to communicate in a way in which all understand the information.

An extremely powerful use of the electronic mark-up and distribution is to allow an operator to communicate with other operators using the EOS to carry the information and to target the correct recipient. For example an end-of-line inspection may identify a consistently poorly fitted part. The inspector could search the RIMES database by part name or number for the EOS describing the fitting of the part. The inspector could use the mark-up layer to identify the problem areas and send this marked up copy of the EOS to the operator assigned to fit the part. A terminal adjacent to the operator could flash a message asking him/her to view the sent EOS. An operator at one plant experiencing problems with parts or assemblies from another plant could use the same technique to identify the EOS concerned with the part at the originating plant, mark-up the EOS, and send it directly to the opposite number at that plant.

By integrating RIMES with existing and proposed Rover Group Problem and Management systems, a record can be kept of the problems being identified, EOSs sent, responses and delays incurred.

Together with the Engineering Release, the EOS provides a repository and audit trail of the process history so that the information can be used in the future to improve the quality of both the process methods and the product.

For further information see the submission [Using RIMES, 97].

6 RIMES Development and Deployment

6.1 Project Organisation and Development Culture

To oversee the development of the proposed manufacturing engineering system project, a steering committee was convened, chaired by an executive manufacturing engineering manager, and supported by representatives from each business unit and process area within the company. Under the auspices of this committee the RIMES project was initiated with the commissioning of a manufacturing engineering system business proposal. The business proposal was written by the author.

The submission [Using RIMES, 97] describes the business proposal development process.

6.2 RIMES System Development Process

Because of the lack of support for existing systems, the manufacturing engineering user community, and the steering committee, had little confidence in the systems department to provide a suitable solution. To overcome this lack of confidence, the author researched and adopted an approach new to Rover Group. Called 'evolutionary delivery' [Gilb, 88], the total system was broken down into small deliverable pieces of functionality each of which could be delivered separately, or in combination with others, to provide the manufacturing engineer with a usable piece of software.

The procedure is similar to prototyping except that the software is not thrown away after testing, but is used and added to when the next piece of software is delivered. This allows the customer to start using the system productively much earlier, learn what can be achieved from a computer system, and add that new knowledge into future development phases. The systems developers also become more familiar with the customers' culture and learn more about their requirements so that future deliverables are closer to the final solution. The approach requires far more involvement from the customer than the traditional method, but the involvement encourages 'ownership' of the system so that implementation becomes easier.

The major danger is 'scope creep', where more functionality is added than was originally proposed (or could even have been perceived of). This can be overcome by firm project management, change control, a good overall understanding of the original objective by all involved, and trust, honesty and teamwork by users and developers. These conditions are much the same as those required for TQM and Concurrent Engineering.

For more information see the submission [Using RIMES 97].

6.3 SIMES (Solihull Interim Manufacturing Engineering System)

The first implementation of RIMES was at the Land Rover, Solihull, manufacturing plant to support the new Range Rover launched in 1995. The location was chosen because the existing PC based systems (a number of IBM XT PC's supporting dumb terminal access) were failing rapidly. The building occupied by the manufacturing engineers had suitable communications infrastructure to support the RIMES client server architecture and the vehicle was completely new. This meant that there was no written process from an existing model so the process could be written from the start in the new format.

Under the strategy of evolutionary delivery, the system was implemented in a sequence of modules that were timed to deliver the functionality required by the manufacturing engineer to support the specific phases of product development. This first implementation of the RIMES system provided only the functionality required by the Solihull site manufacturing engineers and was called SIMES (Solihull Interim Manufacturing Engineering System).

An explanation of the SIMES project is given in the portfolio submission [SIMES, 94].

To develop and deploy the new SIMES system to meet the demanding timescales of the product development process for the new Range Rover, a multi-disciplinary project team was convened, chaired by the author. The personnel required to attend team meetings depended upon the development/deployment stage of the project, but a core team of developers and users was always present.

The project plan for the development and deployment of the SIMES application contained delivery milestones that were critical not only to the success of the SIMES project but to the launch of the Rover 'Flagship' model, the new Range Rover. The section 'Roles and Responsibilities' in the [SIMES Business Proposal, 93] identifies key personnel, both within Rover and from external service providers, whose contribution was critical to the system development and for its deployment.

The progress of SIMES development and deployment was closely monitored by this team while maintaining tight co-ordination with the timing of the product development activities. Any changes to the original delivery timing were agreed in this forum with each team member having the authority to agree actions for their area of responsibility. The author ensured that functionality developed locally for SIMES complied with the overall requirement for RIMES and were compatible with the RIMES business proposal.

6.4 RIMES Deployment

Following the successful introduction of SIMES, the author made a series of presentations to Manufacturing Engineering directors from all of the business units. The presentations are explained in the portfolio submission [RIMES presentations, 94]. As a result of these presentations and further local discussions, the Solihull system was further enhanced to accommodate differences between Land Rover and 'Cars' product definition and deployed at the Cowley manufacturing site to support the Rover 800 facelift launched in 1996. At present a version of RIMES is being introduced into the Rover Power Train business unit to support the development of machining processes.

7 Costs and Benefits

The full benefits of the RIMES system are difficult to quantify. Conservative cost and benefit estimates were made in the Business Proposal at the project initiation stage as a contribution to the project justification, but the main thrust of the justification was to improve business process and product quality rather than cost savings. As the project moved forward, and the manufacturing engineers and their customers began to realise the potential of the RIMES system, many additional benefits have been identified and the system enhanced to realise them.

7.1 Cost and Benefits

In the RIMES Business proposal the potential annual cost savings were divided into three categories and estimates made of the value of each:-

- Mainframe processing — £262,612 per annum
- Costs of enhancing the existing manufacturing engineering systems — £265,310 per annum
- Process control — £186,261 per annum

Not included in these costs is the cost of correcting the millennium bug for each of the existing manufacturing engineering systems.

Mainframe processing was the cost to Rover Group for the use of AT&T

Istel mainframe computing facilities. The new system does not use mainframe processing and so the costs are saved.

Costs of enhancing the existing manufacturing engineering systems were the costs already identified to make some improvements to the current manufacturing engineering systems to meet the changing company business requirements. These requirements are addressed by the proposed RIMES system and so are avoided.

Process control comprises the estimated savings to be made by the system users as a result of the increased performance and functionality of the proposed RIMES over the existing systems.

The mainframe savings have been realised, as has the cost avoidance of changing existing systems. The cost avoidance is particularly relevant in the light of the 'millennium bug'. Changing the existing mainframe systems to overcome this problem would have been considerable.

With approximately 50% of the manufacturing engineering activity now taking place using the RIMES system, the cost of maintaining RIMES system during 1996 was £47,000 against a cost of £34,000 for existing systems maintenance [Whittle, 97]. The increased cost over the existing systems is due to the additional complexity of the client server and the distributed application server architecture. To maintain the RIMES service under this architecture, communications and networks have to be extremely reliable and in 1996 approximately 20% of the reported faults that resulted in the £47,000 costs were attributable to communications problems.

7.2 Process Control Benefits

The process control benefits of £186,261 were extremely vague estimates based on an early assessment of the potential RIMES capabilities.

RIMES has changed the business process of manufacturing engineering and improved the quality and presentation of information so much that a direct comparison of activities on a cost basis is no longer possible. However, an early comparison of time taken to change process information using an existing system and using the RIMES system indicate a time saving of 15%.

On the product lines where the RIMES system and EOS have been implemented, the quality of the product has improved. These quality improvements have been attributed directly to RIMES such that early implementation of RIMES on other product lines has been demanded as a principal product quality improvement action at both Solihull and Cowley sites.

7.3 Training Costs.

Training an engineer to use the existing mainframe system to a competent level typically took three months. To use the existing system the engineer had to learn how to use a text editor, how to operate mainframe data transfer procedures, and the exact positions of data in each line of the file. The systems offered no help or prompts other than a batch procedure that checked for file structural errors such as incorrect line lengths. The manufacturing engineer had to have a considerable systems knowledge to operate the manufacturing engineering system and their effectiveness as a manufacturing engineer was limited until they could master the system.

The RIMES system by comparison can be used within a week. The system can be used to perform simple basic tasks because all the available commands are visible on screen and can be initiated by the mouse pointer. Like a word processor, the simple entry of data can be done by a novice, with more complicated functionality being learned as the engineer becomes more familiar and proficient. Once the engineer has been trained to use RIMES, he/she can be moved from one area to another without having to learn how to use the local manufacturing engineer system. A context sensitive help facility provides additional reminders, when required, on how to use the system.

7.4 Concurrent Engineering/Team Working

In the existing manufacturing engineering systems used by Rover, much of the process was split into elements or re-written (and called a recap sheet) by the industrial engineer for better work allocation and so that the shop-floor could understand the process.

The new EOS sheet replaces both the old process sheet and recap sheet produced by the process engineers and industrial engineers respectively. The production of these two different documents was identified by the RIMES data modelling as one of the major manufacturing engineering inefficiencies. Both documents served the same general purpose, to instruct on the correct work method, and were issued to the same customer, the production operator. The adoption of the common EOS sheet saves the industrial engineer the time taken to produce the recap sheets. More important benefits are that because the EOS is common now to both departments, the authoring engineer has to understand the requirements of both departments, and the shop-floor operator has a single, consistent work instruction.

The data transfer methods of the existing systems means that changes were not issued to the industrial engineer until a) each operation had been completely finished and b) all of the operations for a change had been completed. In the RIMES system each operation can be viewed by the industrial engineer as soon at it is copied into a development level. The industrial engineer has the opportunity to comment early on in the process development cycle. In addition the operation cannot be made a 'current' process until the industrial engineer approves the operation as 'timed'.

This has forced closer ties between process and industrial engineering departments and this greater understanding has improved the quality of the resultant process. The closer understanding of each other's roles has also led to improvements in working practices, promoting currency of manufacturing engineering development and in some cases, Convergence of the two departments.

The information generated by the manufacturing engineers is stored in a single database which, for current products (not those in development and subject to company security), is available to all engineers for future reference so that 'best practice' process and quality improvements from one product can be highlighted and implemented across the Group.

7.5 Integration of Product and Manufacturing Engineering

The basis of information flow between product design and manufacturing engineering is the Engineering Release which contains part number references. The part number reference is a consistent key data item used by both functions. As the RIMES system currently operates, the formal information flow is one way, from product design to manufacturing engineering. The system does not have a formal feedback mechanism to product design. The feedback, if classified and shared, would provide process knowledge for future use, thus helping to improve product and process quality.

8 Conclusions and Future Work

8.1 Conclusions

The literature survey identified three critical success factors in achieving concurrent engineering:- organisation and culture, information, and tools and techniques. This project has focused on the development of a manufacturing engineering system to manage information in support of concurrent engineering.

With the size and complexity of the product development process in the motor industry, informal communication through team working is not enough. RIMES has been developed to ensure data integrity between loosely coupled systems, and formal procedures have been defined to manage information flow and change control. The primary research contribution has been in the analysis and development of appropriate solutions in three main areas - integration of design and manufacturing engineering, change control procedures to maintain data integrity, and business processes to improve efficiency of manufacturing engineering and the quality of its output.

Integration:-

Manufacturing engineers have to receive (and give) information to other systems external to it, most importantly Bill of Materials as the prime author of product specification. To support this, integration of design and manufacturing engineering has been achieved through the use of an electronic interface between RIMES and the Rover Group Bill of Materials; a method that combines 'push' and 'pull' electronic data distribution techniques has been developed. An Engineering Release is sent (pushed) from the Bill of Materials to RIMES where it is collected and held until its implementation is complete. Once the RIMES system has received the Engineering Release, the engineer can 'pull' the information into his/her process area and search the list of Engineering Releases for relevant information; however, the system improves on this by allowing the engineer to specify in advance what attributes of an Engineering Release would be of interest to him/her.

Change Control:-

Within manufacturing engineering, change control procedures have been developed to promote concurrent engineering amongst the separate departments of, say, process planning development, industrial engineering, and process planning maintenance that are the principal users. The information flow between these departments is focused on the work required to produce a part (the process operation), rather than the part and its specification. With all manufacturing engineering departments adding value to the same item of information (the process operation), the change control procedures between the departments have had to be clearly defined. Through the use of development levels to collate information related to the same change programme, and a system of flags to identify the progress made on each Engineering Release, RIMES enables the engineers to work concurrently without losing data integrity. Since a number of revisions of a part or product may be in progress at the same time, procedures to maintain strict control over the different versions (revision levels) have been defined.

To facilitate concurrent engineering, the manufacturing engineers need early visibility of any potential changes that may affect their processes. RIMES has been designed to allow an unauthorised process to be developed in an 'early development level' using the same system functions (process development, graphics, time generation etc.) as the formal process, but without the strict change control mechanisms. This allows the manufacturing engineer to begin work on parts or assemblies even before part numbers are allocated. Once the formal release authority has been received, this early work can be copied to a development level and it then becomes part of the formal RIMES change control process. The work would have by then been developed to a more complete state than if the manufacturing engineer had waited for the Engineering Release.

Business Process Improvements:-

As a result of the analysis of data, information flows and issues of prime authorship, the manufacturing engineering departments have had to re-evaluate their roles and relationships. Some are now completely merging their functions into a single department. The use of RIMES as a lever for change in this area has been achieved because the departments using RIMES have been an integral part of the RIMES development team.

The RIMES system does not inherently differentiate between authorised users in different manufacturing engineering departments. At the basic operating level any authorised user has read and write access to the data for their area of responsibility. To accommodate existing departmental demarcation of the manufacturing engineering task, the system provides the users with a role that allows them write access to certain data. However, it quickly becomes apparent to the users that this demarcation is contrived and interferes with the natural flow of information within the manufacturing engineering process. This recognition by the users themselves prompts them to change their own business organisation and practices rather than have them imposed by the system. The changes are then far more acceptable to the user community and more likely to be successful.

As a result of all manufacturing engineers using a single data repository, which enforces the principles of prime authorship so that the data cannot be changed by anyone else, the prime author has to consider the requirements of other users of the data. The quality and value of the information produced is therefore higher and as the data only exists once, the customer's existing confusion over whose data is correct is eliminated. The information generated is also available to all manufacturing engineers to allow the reuse of 'best practice' process knowledge.

The use of graphics on the process sheet and the subsequent reduction of text has improved the quality of the process sheet. Because the text now only describes the minimum, mandatory, instruction , the process sheet is much more easily understood. The shop-floor operators now take the time to read the sheet and are able to understand what is required of them so that the quality of vehicle build has improved. They are more able to comment and feed back ideas on quality, using the EOS as a communication medium, to contribute to continuous improvement.

8.2 Future Work

8.2.1 Design Integration

[Maddox & Souder, 93] point out that acquiring technology, e.g. CAD/CAM, alone will not promote concurrent engineering. Far more attention has to be paid to the integration of the technology, and the information it provides, into the whole business. Concurrent engineering has to be considered and included as an integral part of the IT strategy for the whole business.

The information flow used by RIMES today makes use of a consistent thread of information, the part number, between design and manufacturing to ensure that the integrity of design information is maintained in manufacturing. This does not, however, promote a common understanding between design and manufacturing engineers of the form, fit and function that the design engineer intended or the manufacturing process that the manufacturing engineer has developed.

The use of advanced simulation techniques is helping to bridge the communication gap between design and manufacturing. Rover Group is now trialing a product from Tecnomatix Technologies Ltd called ROBCAD. The system integrates with multiple CAD systems (e.g. CV-CADDS and CATIA) and enables manufacturing engineers to use native CAD solid models concurrently with *the product design* engineers. One module of ROBCAD, ROBCAD Man, simulates the movement of a human operator and enables the engineer to design, simulate and analyse manual operations required to assemble the CAD parts in their electronic state. The system provides an accurate human model that can walk and reach target locations with either hand, so that the engineer can analyse operation time, reachability, expended energy, lift efforts and weight limits of human movement.

Rover Group is currently mapping data models between ROBCAD and RIMES with the intention of providing an electronic interface so that both systems use the same process operations. The ROBCAD simulation can be used to determine high level process definitions from early design release CAD solid models. These coarse process operations could be automatically transferred to RIMES for refinement and development of the detailed process plan and line balance. The results of this refinement could then be transferred back to ROBCAD for the simulation to run the following enquiries:-

- Ergonomics. To determine when an operator may be in a difficult working position.
- Sequence of Build. To determine an acceptable precedence of build with an equitable distribution of workload.
- Lineside Layout. Optimising positioning of parts for ease and speed

of access for both the operator and the material supply.

- Ease of Fit. Ensuring that there is suitable access to fit parts.
- Tooling. Ensuring that appropriate specialised tools have been considered for unusual operations. [Henderson, 96]

Any problem identified by the manufacturing engineer as a result of the simulation can be related directly back to the solid model generated by the design engineer and both engineers can see the effects of the problem and agree on the need for a solution.

8.2.2 Shop-floor Integration

'When it was first conceived the thought of one system providing all of the services that RIMES currently does, was not even imagined by its customers - manufacturing. However, since being launched at Oxford, RIMES has triggered the imagination of manufacturing in a way that could not have been predicted. [Henderson, 96].

Henderson is a manufacturing engineer at the Oxford plant responsible for the implementation of the RIMES system on Rover 600. With on-line access to a system that contains relationship between parts, geographic track locations, tools used, and process operations, many users outside of the scope of the RIMES system are recognising the value of such an integrated system and are requesting access or planning electronic interfaces. For example:-

- By integrating the process and work allocation functions, the geographic locations of parts and tools can be identified. Logistics functions can then plan accurate lineside material layouts and be alerted to any changes when the work is moved.
- The maintenance department wishes to access the tools records so that tools called up by the manufacturing engineer can be included in preventative maintenance and torque check schedules.
- Service repair instruction manual writers are considering the use of the original EOS sheet assembly instructions.
- The Quality department is using the EOS format and the RIMES system to write the quality audit checks with a direct link to the EOS sheets so that any emerging quality issues can be checked against the process instructions.

A major proposed enhancement is to provide access to RIMES from shop-floor terminals. This then opens up a new range of opportunities for example

- Shop-floor terminals will allow the operators to electronically view EOS sheets and add comments and suggestions to mark-up layers on the sheet for consideration by the manufacturing engineers.

- The operator would, by default, be presented with sheets relevant to their assigned work and, by linking RIMES to the build control system, the system could present the specific sheets for the batch of products being worked on at that time.

A major benefit would be realised by taking advantage of the system's inherent knowledge of where an EOS is performed. With shop-floor access to the RIMES system, an operator detecting a fault could search the RIMES database by part description, parts group etc., and view the EOS sheets related to the part or process causing concern. The operator identifying the problem could then electronically 'mark-up' the problem area on the selected EOS and, because RIMES holds the information on where the EOS was assigned, the marked up EOS could be sent to the terminal nearest to where the problem EOS work is performed. The operator responsible can then take immediate corrective action. As RIMES becomes the group wide manufacturing engineering system, this process could also work between a production line and the end of line audit or between remote factories and suppliers.

References

[AIT, 94]
Contributing partner companies: PSA - Peugeot - Citroën, Robert BOSCH, VW/AUDI.
Manufacturing Data Management, IT Requirements.
AIT TWP 3.4 - Description of useable results of relevant EC projects.
14-April 1994.

[AIT, 95]
Dr C. Hollemann, J. M. Azon, T. McDermott, F. Wagner, P. Mackin, B. Kinch, J. M. Leveaux, Gerald Jutteau, M. Allchurch.
Task 3.3 Simultaneous Engineering Among Different Production Sites. (COSIMAS).
AIT Consortium 1995.

[Alting & Zhang, 89]
Alting, L and Zhang, H.
'Computer - Aided Process Planning: A survey of a decade',
Int. J., of Prod. Res Vol. 27/4, 1989.

[Belson & Nickelson, 92]
David Belson, Diana Nickelson.
'Measuring Concurrent Engineering Costs and Benefits',
PED Vol. 59, ASME 1992.

[Bertodo, 97]
Bertodo, R.
'Time to market zero - ultimate benchmark of competitiveness'. Quoted in draft of Gregory, I and Rawling, S.
Profit from Time.
MacMillan Business, Oct 97.

[Buzacott, 94]
John A. Buzacott.
A Perspective on New Paradigms in Manufacturing.
Journal of Manufacturing Systems. Vol 14 No 2 pp118-125.

[Chesolm, 94]
Chelsom, J. V.
'Concurrent Engineering CAE Studies: Lessons from Ford Motor Company Experience'.
In Chanan S. Syan and Unny Menon.
Concurrent Engineering Concepts, implementation and Practice.
Chapman & Hall 1994.

[Clark & Fujimoto, 91]
Kim B. Clark & Takahiro Fujimoto.
Product Development Performance Strategy, Organisation, and Management in the World Auto Industry.
Harvard Business School Press 1991.

[Douglas & Brown, 94]
Robert E Douglas Jr, David C. Brown.
'Concurrent accumulation of knowledge: a view of concurrent engineering'.
In Channan S. Syan and Unny Menon.
Concurrent Engineering. Concepts implementation and practice.
Chapman & Hall 1994.

[ElMaraghy, 93]
Professor Hoda A. ElMaraghy.
'Evolution and future perspectives of CAPP'.
Annals of CIRP, Vol. 42/2/1993

[Eversheim, et al 95]
Prof. W. Eversheim, Prof. H. Rozenfeld, W. Bochtler, R. Graessler.
'A Methodology for an Integrated Design and Process Planning Based on a Concurrent Engineering Reference Model'.
Annals of the International Institution for Production Engineering Research. V44/1/95 p 403-406. 1995

[Gilb, 88]
T.Gilb.
Principles of Software Engineering Management.
Addison-Wesley 1988.

[Henderson, 96]
J C H Henderson, Rover Group.
'An Investigation of Manufacturing Process Planning Systems at Rover Group Ltd'.
IGDS project submission for the degree of Master of Science. University of Warwick. 1996

[Hitchens, 94]
S. C Hitchins.
'Software Tools for the Product Development Process'.
In Chanan S. Syan and Unny Menon.
Concurrent Engineering Concepts, implementation and Practice.
Chapman & Hall 1994.

[Hunt et al, 93]
Ian Hunt, Simon Roberts, and Roy Jones.
The Integration of Design and Manufacture - A Quantum Leap
Integrated Manufacturing Systems Vol 4, No 2 1993 pp 15-19

[Jo et al, 93]
Hyeon H. Jo, Hamid, R. Parsaei and William G. Sullivan.
'Principles of Concurrent Engineering'.
In Hamid R. Parsaei and William G. Sullivan.
Concurrent Engineering, Contemporary Issues and Modern Design Tools. Chapman & Hall 1993.

[Kusiak & Belhe, 92]
Andrew Kusiak and Upendra Belhe.
'Concurrent Engineering: A Design Perspective'.
PED-Vol. 59, Concurrent Engineering ASME 1992

[Maddox & Souder, 93]
Gary A. Maddox and William E. Souder.
'Overcoming barriers to the implementation of concurrent engineering'.
In Hamid R. Parsaei and Willian G. Sullivan.
Concurrent Engineering. Contemporary Issues and Modern Design Tools.
Chapman & Hall 1993.

[Miller, et al 93]
Eddy Miller, John MacKrell, Ken Amman.
PDM Buyers Guide, Product Data Management Systems for Engineering and Manufacturing, Fourth Edition.
3893 Research Park Drive, Ann Arbor, Michigan 48108.

[Peters et al, 90]
J. Peters, K.L. Krause, E.Agerman.
Design: An Integrated Approach.
Annals of CIRP Vol. 32/2/1990 pp599-607.

[Prijic& Bobrowski, 97]
A.Prijic and R. Bobrowski.
A Feature Based Approach to Press Tool Manufacturing.
Warwick Manufacturing Group. Dept of Eng. University of Warwick.
Proceedings of the Second national Conference on Rapid Prototyping and Tooling Research. 18th & 19th Nov. 1996.
Buckinghamshire College, Messenden Abbey, Great Messenden.

[Santochi et al, 95]
M. Santochi, G. Dini, F. Failli et al.
Technical Report: STC 'A' Co-operative work on Assembly Planning Software Systems.
Annals of CIRP Vol. 44/2/1995 pp651-658

[Shah & Mantyla, 95]
Jami J. Shah and Martti Mantyla.
Parametric and Feature-Based CAD/CAM. Concepts, Techniques and Applications.
John Wily & Son, Inc. 1995.

[Subrahmanian et al, 89]
Eswaran Subrahmanian, Arthur, Westerberg, Gregg Podnar.
Towards a Shared Computational Environment for Engineering Design.
Lecture notes on computer science Computer Aided Co-operation in Product Development, MIT JSME Cambridge University, Nov. 1989.

[Syan, 94]
C. S. Syan.
'Concepts, Implementation and Practice'.
In Chanan S. Syan and Unny Menon
Introduction to Concurrent Engineering.
Chapman & Hall 1994.

[Whittle, 97]
Colin Whittle, AT&T.
Private communication. Information extracted from the AT&T charges to Rover under systems maintenance contract.
AT&T, Rover Group, Cowley, Oxford. 1997

[Williams, 94]
D. J. Williams.
Manufacturing Systems An introduction to the technologies.
Chapman & Hall. 1994

[Womack et al, 90]
James, P. Womack, Daniel T. Jones, Daniel Roos.
The Machine That Changed the World.
Macmillan Publishing 1990.

[Ziemke & Spann, 93]
M. Carl Ziemke and Mary S. Spann.
'Concurrent engineering's roots in the World War II era'.
In Hamid R. Parsaei and William G. Sullivan.
Concurrent Engineering, Contemporary Issues and Modern Design Tools.
Chapman & Hall 1993.

Portfolio Submission References (Date Order)

[Portfolio Introduction and RIMES business proposal submission, 93]
M. Allchurch.
'Portfolio Introduction and RIMES business proposal submission'.
In Portfolio:- Development of a Manufacturing Engineering System for the Motor Industry.

[RIMES presentations, 94].
M. Allchurch.
'RIMES Presentations'.
In Portfolio:- Development of a Manufacturing Engineering System for the Motor Industry.

[SIMES, 94].
M. Allchurch.
'A Description of the Project Management and Control of the Introduction of the Solihull Interim Manufacturing Engineering System, SIMES'
In Portfolio:- Development of a Manufacturing Engineering System for the Motor Industry.

[An Introduction to the Rover Integrated Manufacturing Engineering System Business Environment, 95]
M. Allchurch
'An Introduction to the Rover Integrated Manufacturing Engineering System Business Environment'
In Portfolio:- Development of a Manufacturing Engineering System for the Motor Industry.

[Integration, 96]
M. Allchurch
'Integration'
In Portfolio:- Development of a Manufacturing Engineering System for the Motor Industry.

[Using RIMES, 97]
M. Allchurch
'Using RIMES'
In Portfolio Development of a Manufacturing Engineering System for the Motor Industry.

[Change Control, 97]
M. Allchurch
'Change Control'
In Portfolio Development of a Manufacturing Engineering System for the Motor Industry.

Appendix 1. Recommendation for the Order of Reading the Portfolio

This submission is intended to guide the reader through the portfolio submissions. In general each of the portfolio submissions covers a specific theme and can be read independently, but a complete view of the subject can be gained by reading the portfolio in the order recommended here. The portfolio can be divided into five sections:- a survey of the literature and industrial practice, the development of the Rover Integrated Manufacturing Engineering System, its description, a description of the project management procedures, and the executive summary and personal Profile. The executive summary should be read first, and then more detailed information can obtained by reading the other submissions in the following sequence.

1 [Literature Survey, 97] and [Advanced Information Technology Survey, 97]

The Literature survey provides background information to concurrent engineering practices, and tools and methods, including the latest research in the field of manufacturing engineering systems. The AIT submission is a survey of European businesses practices that includes a section on process planning. This section includes the latest thinking on concurrent engineering, statements on the 'state of the art' of concurrent engineering within the automotive and aerospace business and a vision of what concurrent engineering should look like in the future. The survey goes on to describe the requirements of an ideal manufacturing engineering system.

The literature and the AIT submission should be read in conjunction with the executive summary submission [Development of a Manufacturing Engineering System for the Motor Industry]. The AIT survey is confidential to the AIT consortium and will not be made publicly available.

2 [Portfolio Introduction and RIMES business proposal submission, 93]

This submission introduces the RIMES System and gives the initial reasons for investigating a new manufacturing engineering system.

- The scope of the system is explained in terms of both the information flow within the product development cycle and the areas of the business supported by the system.
- The RIMES business proposal is provided as an appendix.
- The traditional 'waterfall' system development process is discussed and an 'evolutionary delivery' approach proposed for the RIMES system.

3 [An Introduction to the Rover Integrated Manufacturing Engineering System Business Environment, 95]

In this submission:

- The roles of engineering, design engineering, and manufacturing engineering are defined.
- The role and organisation of manufacturing engineering within Rover Group is explained.
- Concurrent engineering is defined and its benefits explained.
- Four elements of information management for concurrent engineering are introduced:-
    1. staged release
    2. feed back
    3. communication of incomplete information
    4. change management
- The Rover Group product development procedure is explained.

4 [Integration, 96]

This submission discusses issues of integration of information between design and manufacturing engineering.

- The matrix and functional organisations, and their use within Rover Group are discussed.
- Prime authorship is introduced as a critical factor in information

management for concurrent engineering.

- The different data structures required for design and manufacturing engineering information are explained
- Concepts of information distribution are discussed (push/pull data distribution)
- Some commercial workflow management systems are examined.
- The existing Rover Group engineering release procedure is described and analysed
- The integration of design and manufacturing information developed for the RIMES system is discussed.

5 [Change Control, 97]

This submission describes the change control process within the tightly coupled manufacturing engineering database.

- The types of changes that may be made to the manufacturing process are explained.
- The existing manufacturing engineering change control processes are explained.
- An analysis of the existing manufacturing engineering change control processes is presented.
- The RIMES change control functionality is explained.
- An analysis of the RIMES change control functionality is presented.

6 [Using RIMES, 97]

This submission explains the operation of the RIMES system.

- The operations and user interfaces of the existing systems are explained.
- The development of the RIMES system using evolutionary delivery techniques is explained.
- The manufacturing engineering responsibilities and the use of roles within RIMES are described.
- The use of 'development levels' to manage process change is described.
- The Engineering Operation Standard sheet and its use is explained.
- Procedures for process planning and work allocation using the RIMES system are explained.
- The benefits of the RIMES system are discussed.

7 [RIMES Presentations, 94]

This submission is a collection of slides, and an explanation of the presentations made to Rover Group manufacturing engineering directors to promote the systems concepts, gain their approval for systems development, and secure their support for the subsequent implementation of the system within their area of responsibility.

8 [A Description of the Project Management and Control of the Introduction of the Solihull Interim Manufacturing Engineering System SIMES, 94]

This submission describes project management required for the first development and implementation of the RIMES system (initially named SIMES, Solihull Interim Manufacturing Engineering System) in support of the new Range Rover launched in 1995.

- The background to selecting RIMES to support the new Range Rover is discussed.
- The project planning and timing is explained.

The SIMES steering committee, its members and its role in developing and implementing the system are presented.

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