University of Groningen

From structure to schedule

Donk, Dirk Pieter van; Dam, Peter van; Gaalman, Gerard

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
1996

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):
Donk, D. P. V., Dam, P. V., & Gaalman, G. (1996). *From structure to schedule: experiences in the semi-process industries*. s.n.

Copyright
Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment.

Take-down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): http://www.rug.nl/research/portal. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Download date: 04-06-2022

FROM STRUCTURE TO SCHEDULE: EXPERIENCES IN THE SEMI-PROCESS INDUSTRIES[1]

Dirk Pieter van Donk[2]

Peter van Dam

Gerard Gaalman

Faculty of Management & Organization
University of Groningen
The Netherlands

Som theme A: Structure, Control and Organization of Primary Processes

---

[1] An earlier draft was presented to the Sixth Annual Meeting of the Production and Operations Management Society, October 7-10, 1995, Pittsburgh, PA.

[2] Dirk Pieter van Donk and Gerard Gaalman are both working in the field of Production/Operations Management at the Faculty of Management & Organization, University of Groningen, The Netherlands. Peter van Dam recently finished his PHD at this university and is now working as a management consultant at Moret Ernst & Young (The Netherlands).

Address for correspondence: Dirk Pieter van Donk, Faculty of Management and Organization, P.O.Box 800, 9700 AV Groningen, The Netherlands, Tel. 31-50-3637345, e-mail D.P.VAN.DONK@BDK.RUG.NL, Telefax 31-50-3633850.

ABSTRACT

Due to increasing product-variety and logistic demands, semi-processing industries (e.g. in food or pharmaceuticals) pay more attention to scheduling and (computerized) support of scheduling. An approach is given to analyze the structure of the scheduling problem, using two relatively new concepts: process routings (to assess the sequence of operations for a specific product(family)) and capacity groups (to assess the interdependency between machines). The emerging structure, based on the investigation of the physical goods flow and the production characteristics, is the basis for designing a planning and scheduling structure. Within this structure scheduling software and algorithms can be implemented to solve specific sub-problems.

1 INTRODUCTION

The research reported upon in this article, originates from a number of case-studies done by the authors and students, under the direction of the authors. From these case-studies a number of observations can be generated, unveiling trends and problems common to many semi-process industries such as foodprocessing industries or producers of pharmaceuticals. In this introduction we will restrict ourselves to highlighting some of the recent trends and to the problems for schedulers in facing prevailing business conditions in this type of industries.

Background

Most of the industries we investigated, produce products for the consumer-market. A common characteristic for these semi-process industries is the presence of a process stage and a packaging stage: each having distinct attributes. The process stage usually can be identified with a flow-like or batch process in which homogeneous products are processed. In the packaging stage discrete products emerge. In a number of cases we found both stages separated by a (limited) decoupling stock.

A typical production process consists of a number of steps such as: receiving materials, mixing/blending according to recipe, forming and processing (e.g. sterilizing), consumer packaging and adding a case packing, storage until delivery to clients. From a production planning and control point of view these industries have specific characteristics. These include high capital intensity in the process stage and high labour intensity in the packaging stage; limited storage-live for both the raw materials as the end-products (especially in food); hygienic factors causing considerable (often sequence-dependent) set-up times; flow-like production with limited work-in-progress and a product lay-out; variability in yields as well as in the quality of raw materials.

Scheduling

Due to the factors mentioned above, schedulers are facing a complex task in which a number of constraints have to be met. Moreover, their task becomes more complex due to a growing number of (new) end-products in a large variety of different packages (sizes and brands), a growing number of recipes (each having a specific need of machine capacity and labour requirements), a growing percentage of make-to-order mixed with the traditional make-to-stock. Furthermore, there is an emphasis on delivery speed, dependability and traceability and, simultaneously, a tendency to reduce stocks.

Still, as we found in our study, scheduling is usually performed manually, which makes it hard for schedulers to look for alternative schedules or to assess the financial implications of different schedules (Van Dam et al., 1993). In most cases the scheduler is happy to have found an acceptable schedule.

Research question

The afore-mentioned puts scheduling in this type of industries forward as vital element in keeping a competitive position in the market place. Therefore, not only schedulers realise that they have an interesting and important job, but also their superiors realise that scheduling is important. Under the current circumstances, there is a need for improved schedules and for accelerating the scheduling-process. The problem is, how to accomplish this. In this paper our contribution towards

answering this question is provided. In that, our principal aim is to develop a method to better understand and clarify the complexity of the scheduler's job as a first, crucial step to solve his problems.

Structure

The next section gives a short impression of the literature and makes clear that there are some drawbacks in scheduling literature. Next we will introduce two concepts for analyzing this kind of scheduling situations: process routing and capacity group. Within this framework we distinguish, in the fourth section, several scheduling characteristics and related decisions. These will be dealt with in the subsequent section about the development of a scheduling hierarchy. The last section of the paper summarises the main conclusions and gives directions for further research.

2 AN ASSESSMENT OF THE LITERATURE

Current literature in scheduling can be broadly divided in two streams. On the one hand, there is a large number of publications on mathematically oriented problems and ways to solve these problems by either analytical methods, algorithms or simulation experiments. Papers in this field usually describe well-structured problems, that are solved by well-articulated decision rules. Although some of the problems solved have a relation with real-life situations and problems, they are at best a strongly simplified abstraction of reality. As such they can be very useful for capturing a certain understanding for reality, but they do not solve real-life problems and are therefore not a real aid for schedulers.

On the other hand, a number of publications deals with the implementation of software-packages. Nowadays, there is a number of commercial packages available, ranging from rather simple electronic planboards, via database-applications to so called automatic planning packages. In this stream also a number of tailor-made applications find there place. Implementation seems to be promising and can be a quite powerful instrument to support a scheduler. However, literature gives little attention to the large problems of implementing such "generally applicable"

packages. These problems do not only apply to "resistance to change" or "fear" by the schedulers, but also to how a good model of the situation can be built within a certain software-environment. Moreover, literature does not guide the decision whether a successful implementation in one situation is also a good choice in another situation.

Although, there are a number of successful implementations in both streams, a general conclusion is that there seems to be a gap between reported findings and scheduling in practice (Buxey, 1989; Solberg, 1989). In our opinion, both directions miss an important prerequisite for scheduling, because they do not offer an instrument to analyze and structure the underlying complexity.

3 STRUCTURING SCHEDULING

In developing our frame we found inspiration in two sources. Bertrand et al. (1990) develop a frame for goods-flow control which proposes a decomposition of the goods-flow into relatively autonomous parts (production units), resulting in a hierarchy of goods-flow control. Taylor et al. (1991) and Bolander et al. (1993) also advocate decomposition. In contrast with Bertrand et al., they propose to decompose a production system into separate, non-interacting flows (trains). This seems attractive for process industries as these are characterised by more or less continuous flows, which will not (and can not) be interrupted once production on a batch has started. However, both concepts aim at structuring and supporting the production and/or goods-flow planning in an aggregate sense. Therefore, both do not pay attention to detailed planning and scheduling on the shop floor. In fact, many process industries will be structured as one train or one production unit, which makes these concepts less attractive for structuring scheduling. We will transpose their ideas to make them applicable for structuring a shop floor as a basis for understanding and structuring the scheduling. Two notions will be introduced within our frame: process routings and capacity groups.

Process routing

Elsewhere (Van Donk & Van Dam, 1996) the notion of *process routing* is introduced, as a transformation of the concept of a train. A process routing can be described as *a fixed sequential series of operations in which a family of products is produced*. Process routings can be discovered by identifying the different, sequential operations in the production process on each single product and grouping the products sharing the same operations into a family. In general, changing production from one member of such a family to another member will cause (sequence-dependent) set-ups. Typical examples apply to changing recipe or changing the packaging size. In other words, products of one product family are in fact competing with each other for the capacity on one process routing.

A separate process routing will be distinguished if there is at least one deviant operation (a production step or machine). Machines may be part of different process routings (e.g. a mixing unit for a number of processing lines), in contrast to the concept of train in which a machine (or process unit) is part of one train. Explicit attention for describing process routings is important in the semi-process industries, as production can not be stopped once started due to factors as the perishable nature of ingredients until final packaging (in food), the design of the process prohibits interruption or limited storage-space of tanks/buffers on the floor. A process routing may have several alternative routings. E.g. in the packaging stage there may be several machines suitable for final packaging.

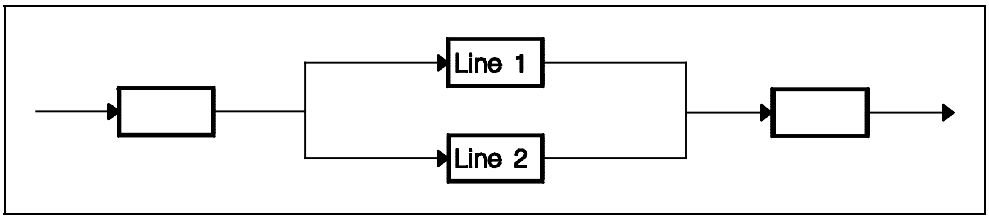

Figure 1: An example of process routings

We will illustrate the concept of process routing by exploring *Figure 1* which shows two parallel lines, being a part of a production process. From this figure it is not directly evident if one, two, or three process routings should be distinguished. Suppose that all products can be produced on both lines, then one

process routing will emerge with two alternative routings. Another configuration emerges if one group (family) of products can only be produced on line 1 and another group on line 2. In this case, we distinguish two process routings. A third possibility is that a first family has to be made on line 1, a second group on line 2, while there is a third family of products that can be made on both lines. In that case we have to distinguish three process routings. Moreover, we have to take into account that there are sub-routings for the third family. Distinguishing a third process routing arises because products of the third family can use both lines.

By distinguishing process routings we perform in essence a thorough analysis of the physical goods flow. Beginning at the incoming raw materials for each process routing the stages of the production process are charted, taking note of product range, variety in demand, production speed, set-up times and stocks in the process until the product is ready for delivery. Generally, one finds out what the capabilities of the process are. In quite a few cases we found that assigning products to certain lines is induced by custom rather than being absolutely necessary. Bauer et al. (1991) address also this phenomenon, that usually too little is known about how things are really done or could be done on the shop floor.

Capacity group

The concept of a production unit is transformed into the notion of *capacity group*. A capacity group is *a number (sometimes one) of interdependent machines in one stage and therefore performing the same kind of, although not necessarily identical, operations* (Van Dam, 1995; Van Donk & Van Dam, 1996). Interdependency can vary considerably and may apply to the use of the same group of operators or the use of the same tools. Machines can also be interdependent because they draw from the same stock of material or from the same machine in a preceding stage. In our research, it turned out that the notion of capacity group is useful aid in modelling production processes in the semi-process industries. In these industries successive stages are not so well balanced as in continuous flow processes, due to the mix of products and the circumstance that some machines are used for all products (e.g. mixing) and other machines are specific for a limited number of products (e.g. packaging).

From the perspective of scheduling, machines in the same capacity group can be treated as one entity or as a black-box with certain characteristics as capacity, leadtime etc. A capacity group can be a part of one process routing (e.g. several packaging machines that draw from one intermediate storage point). A capacity group can also intersect several process routings (e.g. (a) process unit(s) feeding several other machines/lines for different product families).
Identification of capacity groups depends heavily on the characteristics of the process, but also on a judgment to what extent (a number of) machines are interdependent.

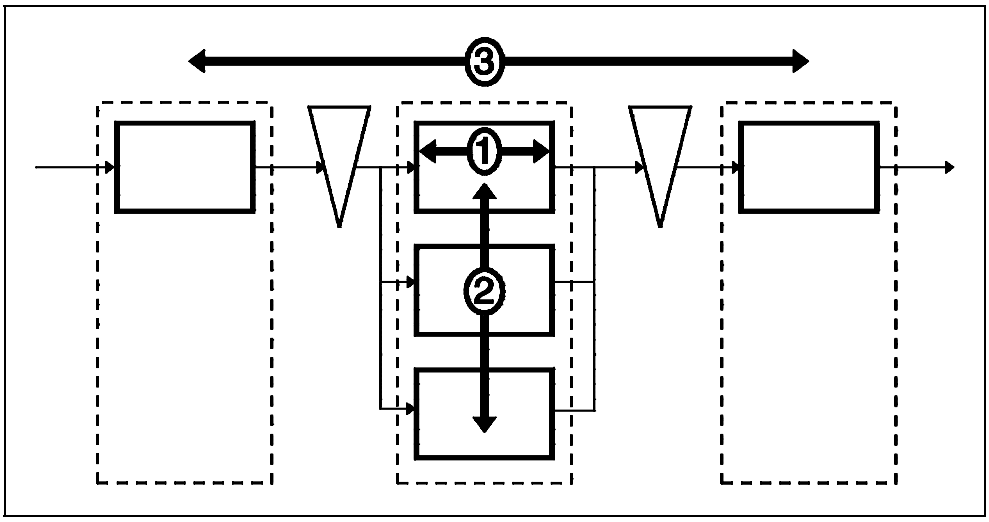

Figure 2: Interdependencies with respect to a capacity group (Van Dam, 1995)

Figure 2 gives some examples of interdependencies with respect to a capacity group. In this figure three interdependencies can be distinguished. Number 1 refers to the interdependency within one machine. This may arise from set-up times for different products or a preferred sequence of producing. Number 2 refers to dependencies within one capacity group e.g. several machines using the same personnel, limited availability of inputs. These interdependencies will, in general be the reason to model these parallel machines as one capacity group. Number 3 refers to interdependencies between capacity groups. These will limit the freedom for scheduling in general and may arise from limited possibilities to decouple different capacity groups.

An important factor, at this stage, are the stocks between the succeeding capacity groups. The magnitude of this stock determines to what extent the capacity groups can be scheduled independently of each other. If on one hand, there is a large stock between two succeeding capacity groups, e.g. a few months, both capacity groups can be scheduled independently. If, on the other hand, there is no stock, the scheduling of the capacity groups has to be more closely related. In this case it might still be relevant to distinguish different capacity groups as each capacity group might have a scheduling problem with specific characteristics.

4 SCHEDULING DECISIONS

A next step in analyzing scheduling is investigating in more detail the nature of different decisions to be made. From our case-studies we learned that the nature of decisions is related to a limited number of scheduling characteristics. These characteristics can be associated with the different types of coordination with respect to a capacity group. In the first place, for the coordination per machine, sequence-dependent set-up times are important. For the coordination between machines belonging to the same capacity group, two scheduling characteristics emerge, namely the presence of (partly) identical machines and the presence of shared resources (e.g. operators). Finally, the necessity for coordination between capacity groups arises when several capacity group have been distinguished in previous analyses. Each of the scheduling characteristics can be associated with a type of scheduling decision, as is summarised in *Table 1* (Van Dam, 1995, p.51).

Scheduling characteristic	Scheduling decision
Sequence-dependent set-up times	Sequencing of operations
(Partly) identical machines	Allocation of operations
Shared resources	Idle time determination per machine
Several capacity groups	Coordination of capacity groups

Table 1. Scheduling characteristics related to a decision (Van Dam, 1995, p.51)

Each of the decisions listed in Table 1, implies a type of scheduling problem, which can be encountered in the scheduling literature as a solitary problem. For example, due to sequence-dependent set-up times there arises a single machine sequencing problem in which several factors have to be taken into account including the minimization of the total set-up time.

In most of the cases (see *Table 2*) the scheduler has to deal with a mixture of two to four of these single scheduling problems. These scheduling problems cannot be separated from each other: a decision concerning one subproblem will in general influence another subproblem. For example, idle time determination in case of shared resources, can influence the coordination between capacity groups. Also, determination of set-up times and allocation to machines may be interrelated. The interrelatedness will differ significantly in various situations and is influenced by factors as the size of the set-up times and the storage capabilities between stages.

	Sequence dependent set-up times	(Partly) identical machines	Shared Resources	Several capacity groups
Case 1 (pharmaceuticals)	X	X	X	X
Case 2 (dairy products)	X		X	X
Case 3 (food)	X		X	X
Case 4 (pharmaceuticals)	X	X		
Case 5 (food)	X	X	X	X
Case 6 (pharmaceuticals)	X	X		
Case 7 (food)	X	X		X
Case 8 (tobacco)	X	X	X	X

Table 2. Scheduling characteristics in the cases (cf. Van Dam, 1995, p.52)

5 SCHEDULING LEVELS IN PRACTICE

In analyzing our case-studies we found that scheduling decisions usually were made on two different levels: a higher level labelled the Detail Planning Level (DPL) and a lower level labelled the Scheduling Level (SL) (Van Dam et al., 1993). Both levels are part of the operations level (Anthony, 1965). As usual in hierarchical (production) planning the higher level has a longer horizon than the lower level and the degree of detail and aggregation differs for both levels as well (McKay et al., 1995). In our cases the DPL has a planning horizon of a few weeks to a few months, with planning periods of a week or one month, while the SL has a planning horizon ranging from a day to a few weeks. The division of the scheduling decisions among the two levels is shown in *Table 3*.

	Sequencing of operations	Allocation of operations	Idle time determina-tion	Coordi-nation of capacity groups
Case 1 (pharmaceuticals)	SL	Constant	SL	SL
Case 2 (dairy products)	SL	-	SL	DLP
Case 3 (food)	SL	-	SL	SL
Case 4 (pharmaceuticals)	DPL/SL	Constant	-	-
Case 5 (food)	SL	Constant	SL	DPL
Case 6 (pharmaceuticals)	SL	Constant	-	-
Case 8 (tobacco)	SL	Constant	SL	DPL

Case 7 is omitted in this table, because there is no clear hierarchy in this company. In the table a "-" means not applicable (see also Table 2).

Table 3. Scheduling hierarchy in the cases (cf. Van Dam, 1995, p.52)

From Table 3 it is clear that the DPL is focusing on the balancing of capacities. Moreover, this level decides upon the ordering/purchasing of packaging materials and the determination of overtime levels, as these have a long lead-time. On the basis of customer orders, capacities and stocks, decision are made at the DPL concerning the allocation of production orders to periods. In some cases at this level sequence-dependent set-up times have to be taken into account, including the allocation of orders to certain lines: mostly in an aggregate way. In general, the Detailed Planning Level is a planning level which seems to be specific for this type of industries. In most cases it can be located between the aggregate plan (balancing demand and capacity in a rough sense) and the scheduling level in the usual meaning.

At the SL starting and finishing times are determined, and allocation and sequencing decisions are made. Also the rescheduling due to unforseen causes

(changes, disturbances) is done at this level.
A special remark is needed for the allocation of operations, if appropriate, where constant rules are used from which the scheduler usually does not deviate. A reason can be found in reducing complexity, custom and in differences in actual production speed between machines. In a conceptual connotation, this can be judged as an instruction of the higher level, which the lower level should apply.

6 HIERARCHICAL (RE)DESIGN OF SCHEDULING

In the previous section we recognised a hierarchical approach in scheduling. A hierarchical approach is understood as an approach in which the total amount of decisions is divided among several decisions-levels, in such a way that a higher level gives instructions, constraints and conditions for a lower level to solve the lower level's problems (Mesarovic et al., 1970). Each level solves it's own problems and feedback is given to the higher level. A hierarchical approach has the advantage that the complexity is reduced on each separate level. Decomposition of the total problem is therefore critical for the success of such an approach. Too much or too little decisions on one level makes the decomposition meaningless (Mesarovic et al., 1970). This description matches with the characteristics mentioned in a recent review of hierarchical production planning by McKay et al. (1995). In (re)designing a hierarchy of decisions several important questions have to be answered. From the literature (Bitran & Hax, 1977; Meal, 1984; McKay et al., 1995) we know that these apply to: how many levels are needed, what decisions are made on each level. Another important issue is the relation between aggregated decisions on a higher level and the disaggregation procedures to obtain feasible solutions at the detailed level (e.g. Bitran & Tirupati, 1993, p.536).

The basis of the design of a (decision-)hierarchy for scheduling lies in the analyses of the structure of the scheduling situation, and subsequently, the distinction of the various scheduling characteristics in that situation, and related scheduling decisions. As a starting point for (re)designing scheduling we have

chosen the aforementioned hierarchy of two levels. At the DPL it seems to be wise (in accordance to general practice) to make the following decisions: allocation of orders to periods; purchasing of packaging materials; balancing of capacities, in a sense of balancing required and supplied capacity (i.e. by overtime). For the decisions (taken from Table 1) listed in the cloud of Figure 3, we have to decide upon wether it is advantageous to locate them at the SL or at the DPL. As a general rule for reducing complexity, locating the decisions in the cloud at the lowest possible level, is profitable. This results in two relatively easy problems. At the DPL the main task is to assign orders to periods and at the SL the scheduling problem might still be complex, but decisions have to be made for only one (limited) period. A necessity for this division of decisions among the two levels is the presence of an adequate procedure for disaggregation, as pointed out.

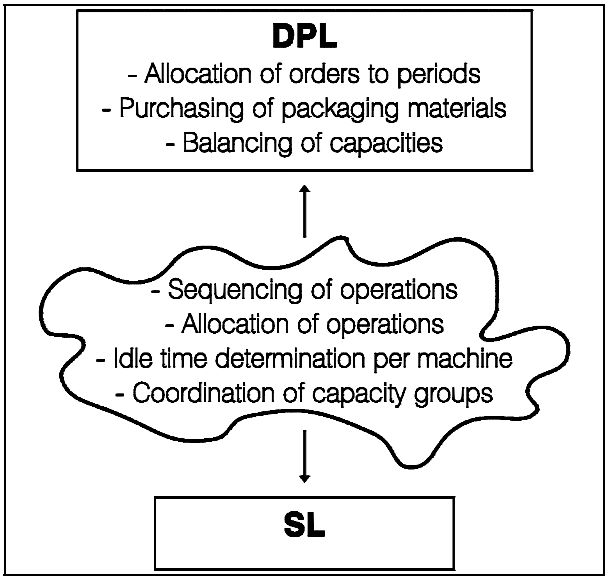

Figure 3. Starting points for the design of a scheduling hierarchy Van Dam, 1995, p. 55).

In other words, this division is only adequate if the DPL can allocate the orders in such a way that a realistic aggregate plan results for the SL. An important issue in designing the hierarchy at the DPL is finding the right way to aggregate orders and match them with aggregate capacity. Aggregation might be difficult (or even impossible) due to such factors as large sequence-dependent set-up times or large differences in production rate of (partly) identical machines. Adequate decisions at the DPL will only be achieved as these factors are taken into account already at this level. E.g. a preferred sequence is established at the DPL to limit the influence of large set-up times. As a result, these factors will limit the possibility for pushing decisions down in the decision

hierarchy.

Some general remarks can be made concerning the division of the scheduling decisions among the SL and the DPL. As a basic rule the scheduling decisions are best made at the SL. There are a number of circumstances, where we have to look in more detail.

In case of relatively large set-up times, it may give better schedules taking into account these set-up times at the DPL by allocating the products with the same set-ups to one period. Generally this can be done in an aggregate way, unless the sequence-dependency is very strong. Then, even the sequence must be fixed on the DPL. The same reasoning can be applied to the set-up times on identical machines. Once again, there are some gains in taking into account such set-up times at the DPL.

If there are any shared resources usually the SL will determine idle time for machines. However, if these resources limit the total production capacity, then the DPL has to deal with this problem.

With respect to the coordination between capacity groups it can be said that as long as the DPL has some good aggregate measures for matching different capacities to production orders, there is no need for more details on that level. In case of one clear bottle-neck, planning of that capacity group/bottle-neck takes place at the DPL. Then at the SL the ideas of Taylor et al. (1991) and Bolander et al. (1993) of forward/backward scheduling can be used in coordination between capacity groups. In case of shifting bottlenecks, the DPL will plan in an aggregate way, and the SL takes care of the coordination.

Using the hierarchical approach in a practical situation means of course that the qualitative remarks made so far, need to be quantified. An extensive case-study in a tobacco industry showed promising results in using this approach (Van Dam, 1995).

6 CONCLUSION AND FURTHER RESEARCH

This paper gives an approach to help schedulers and planners (and their bosses) to

understand better the process of scheduling. It starts with a complete analysis of the goodsflow. This analysis is supported by two concepts introduced in this paper: process routing and capacity group. The resulting decomposition of the production process, results in a distinction of different types of scheduling decisions. To reduce the complexity of the decision making process for scheduling, we suggest, based on experiences in the case-studies, a scheduling hierarchy consisting of two levels: Detailed Planning Level and Scheduling Level. This approach is, in our opinion a useful guide for improving scheduling in organisations. Firstly, insight is gained into the complexity and the structure of scheduling. Secondly, the hierarchical approach can be used to redesign the existing decision structure. Thirdly, the analysis and redesign form a solid basis for further improvement: either for guiding the choice (and implementation) for a scheduling package, or for selecting heuristics etc. to help solving specific subproblems.

Of course, we realize that there might be quite a few other reasons to select a specific course of action. Still, this type of analyses has proven to be worthwhile.

The framework developed so far, is a starting point for further research. Further refinement of the hierarchy is certainly needed. Next, it will be interesting if, despite an enormous difference in real-life situations, there are some "standard" configurations to be found. Next, it is important to elaborate the frame developed sofar, into the direction of existing literature on scheduling. Thereto, knowledge on algorithms and heuristics should be matched with the frame and the scheduling hierarchy.

REFERENCES

Anthony, R.N. (1965): *Planning and Control Systems: A Framework For Analysis*, Harvard Business School Press, Boston.

Bauer, A., R. Bowden, J. Browne, J. Duggan & G. Lyons (1991): *Shop Floor Control Systems: From design to implementation*, Chapman & Hall, London.

Bertrand, J.W.M., J.C. Wortmann & J. Wijngaard (1990): *Production Control: A Structural and Design Oriented Approach*, Elsevier, Amsterdam.

Bitran, G.R. & A.C. Hax (1977): On the design of hierarchical production planning systems, *Decision Science*, Vol. 8, No. 1, pp. 28-55.

Bitran, G.R. & D. Tirupati (1993): Hierarchical Production Planning, in: S.C. Graves, A.H.G. Rinnooy Kan & P.H. Zipkin (Eds.), *Handbooks in Operations Research and Management Science. Vol. 4: Logistics of Production and Inventory*, Elsevier, Amsterdam, Chapter 10, pp. 523-568.

Bolander, S.F. & S.G. Taylor (1993): System Framework for Process Flow Industries, in: *Production and Inventory Management Journal*, Fourth Quarter, pp. 12-17.

Dam, J.P. van (1995): *Scheduling Packaging Lines in the Process Industries*, Labyrint Publication, University of Groningen.

Dam, J.P. van, G.J.C. Gaalman & G. Sierksma (1993): Scheduling of packaging lines in the process industry: An empirical investigation, in: *International Journal of Production Economics*, Vol. 30-31, pp. 579-589.

Donk, D.P. van & J.P. van Dam (1996): Structuring Complexity in Scheduling: A Study in the Food-Processing Industry, *International Journal of Operations & Production Management* (to appear)

McKay, K.N., F.R. Safayeni & J.A. Buzacott (1995): A review of hierarchical production planning and its applicability for modern manufacturing, *Production Planning & Control*, Vol. 6, No. 5, pp. 384-394.

Meal, H.C. (1984): Putting production decisions where they belong, *Harvard Business Review*, Vol. 62, No. 2, pp. 102-111.

Mesarovic, M., D. Macko, Y. Takahara (1970): *Theory of Hierarchical, Multilevel*

Systems, Academic Press Inc., New York/London.

Taylor, S.G. & S.F. Bolander (1991): Process flow scheduling principles, in: *Production and Inventory Management Journal*, First Quarter, pp. 67-71.