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Shop floor design

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Chapter 1

Introduction

1.1. RESEARCH AREA

The main part of this thesis contains six papers that are submitted to (and most already accepted for or published in) international journals. The thesis can be regarded as a collection of these articles, preceded by this introduction to indicate the coherence in the issues addressed in these papers.

The title of this thesis "Shop floor design: layout, investments, cross-training, and labor allocation" roughly indicates which topics are addressed in this research. First of all, note that these topics all fall within the broad field of Operations Management (OM). OM is concerned with managing operations in manufacturing and service organizations. Operations can be regarded as input-transformation-output processes, where inputs such as labor, machines, materials, information, and customers are used to transform something, or are transformed themselves, into outputs of goods and services (Russel *et al.*, 1998; Slack *et al.*, 2001). Activities in OM include organizing work, selecting processes, arranging layouts, locating facilities, designing jobs, measuring performance, controlling quality, scheduling work, managing inventory, and planning production (Russel *et al.*, 1998). Major activity areas in OM are design, improvement, and planning and control (Slack *et al.*, 2001). Chase *et al.* (2004) define OM as "the design, operation, and improvement of the systems that create and deliver the firm's primary products and services". The topics addressed in this thesis all fall within the design activity area in OM.

The design activity area in operations management includes both the design of products and services and the design of the processes which create them (see figure 1, after Slack *et al.*, 2001). The design of products and services concerns the translation of customer needs into the shape and form of the product or service, thereby specifying the required capabilities of the operation. The stages in product and service design are concept generation, screening, preliminary design, design evaluation and improvement, and prototyping and final design (Slack *et al.*, 2001).

This thesis is restricted to the design of processes and focuses on several issues within three specific design activities addressed in the design of processes: 1) Layout, 2) Process technology, and 3) Job design (see figure 1). In contrast to network design, which is another design activity within the design of processes, these three design activities focus on an individual site in the total operations network. We look upon these three design activities as shop floor design activities, since their focus is on the shop floor level.
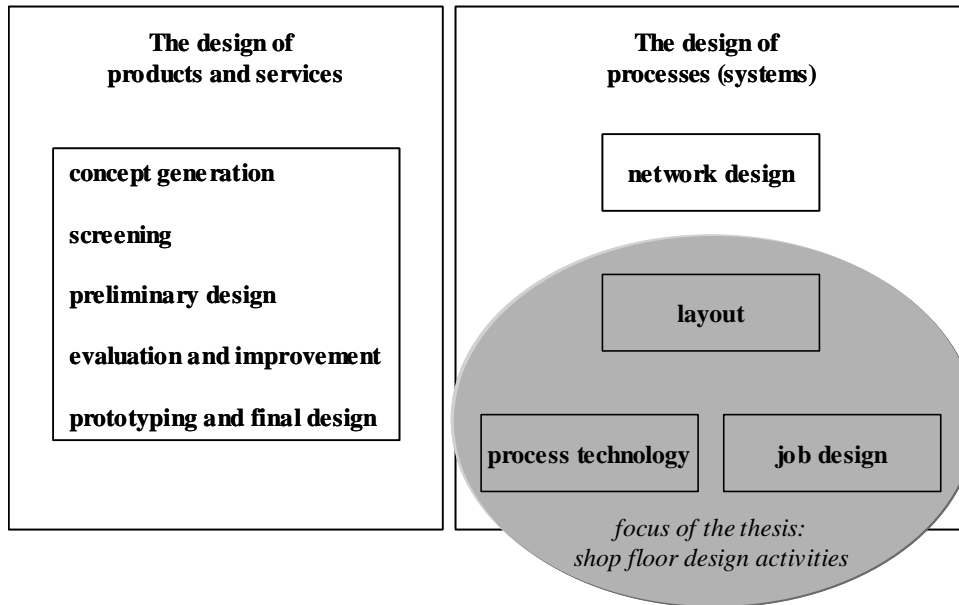
The design activity in OM

Figure 1. The design activity in OM (based on Slack *et al.* 2001) and focus on shop floor design activities.

1.2. SHOP FLOOR DESIGN ACTIVITIES

This section gives a short overview of the three shop floor design activities and positions the specific works in this thesis within each of these design activities. Table 1 indicates which issues within the shop floor design activities are covered and by which papers.

Table 1. The six papers in this thesis related to the shop floor design activities

Shop floor design activity	Issue	Paper
Layout	Choice of a basic layout	• Decision support framework for the selection of a manufacturing layout (Slomp and Bokhorst, 2004)
Process technology	Investment appraisal	• An integrated model for part-operation allocation and investments in CNC technology (Bokhorst *et al.*, 2002)
Job design	Cross-training	• Cross-training in a cellular manufacturing environment (Slomp *et al.*, 2004)
		• Development and evaluation of cross-training policies for manufacturing teams (Bokhorst *et al.*, 2004a)
	Labor allocation	• On the who-rule in Dual Resource Constrained (DRC) manufacturing systems (Bokhorst *et al.*, 2004b)
		• Labour allocation rules in Dual Resource Constrained (DRC) manufacturing systems with worker differences (Bokhorst *et al.*, 2004c)

1.2.1. Layout

The layout shop floor design activity includes the choice of a process structure as a first design decision, the choice of a basic layout as a second design decision, and the filling-in of a detailed design of the layout as a third design decision.

With respect to process structures, production processes can be categorized into project processes, jobbing processes, batch processes, mass processes, or continuous processes. Hayes and Wheelwright (1979) introduced the concept of a "product-process matrix", linking product characteristics (volume, standardization and number of product types) to process structures similar to the processes described above (Jumbled flow (job shop), Disconnected line (batch), Connected line (assembly line), and Continuous flow). Usually, companies match their product structure with the appropriate process structure. As volume

and standardization increase and the number of product types decreases, more specialized equipment will be used in a more continuous flow.

The choice of a process structure directs the choice of a basic layout. Once the process structure is chosen, it is often obvious which basic layout to choose. However, companies still may have to decide which basic layout to use for their production process. There may be alternative basic layout options for a given process structure. The four basic layouts are the fixed-position layout, the process layout, the cell layout, and the product layout. The issue we address in this thesis regarding the layout design activity specifically deals with how to select a manufacturing layout, what is similar to the choice of a basic layout. Therefore, we will discuss this design decision in some more detail below.

The final layout shop floor design activity is filling-in the detailed design of the layout. Here, decisions on the precise location of the equipment in the available space have to be made. Further, specific decisions have to be made depending on the basic layout chosen in the previous design activity. For example, in a product layout, a specific issue such as line balancing is important.

The second design decision, the selection of the basic layout, has received quite some attention in literature. There are many papers dealing with the advantages and disadvantages of cell layouts versus process layouts (for overview articles, see e.g. Johnson and Wemmerlöv, 1996; Shambu *et al.*, 1996; and Agarwal and Sarkis, 1998). Simulation and analytical studies that compare the performance of cell layouts and process (or functional) layouts mostly use mean flow time and mean work-in-process (WIP) as performance measures. Empirical studies often include a broader set of performance measures apart from mean flow time and WIP, such as average materials handling, average set-up time, quality, and job satisfaction.

The paper "Decision support framework for the selection of a manufacturing layout" is our contribution to the research on layout. This paper presents a systematic method for the basic layout decision problem. The approach is integral, since it considers a broad set of performance objectives, including qualitative as well as quantitative aspects, and it shows how a decision can be made incorporating all these aspects. We use the AHP (Analytic Hierarchy Process) approach, since this approach is useful in multi-criteria situations where intuitive, qualitative and quantitative aspects play a role. We include several performance objectives and discuss how the basic layout types influence these objectives directly, or indirectly through various aspects. The paper thus shows which aspects have to be taken into account and presents a systematic method for the decision problem. The proposed method is illustrated by means of a practical instance.

1.2.2. Process technology

In order to produce products and services, the required transformation processes often use some kind of technology, which is called process technology. This should not be confused with technology used in the process industry (continuous flow environment), since we mean the technology used in all process structures (project, jobbing, batch, mass, and continuous processes). Another term that is used in the literature is "operations technology".

Process technologies are the machines, equipment, and devices which help the operation transform materials, information, and/or customers in order to add value and fulfill the

operation's strategic objectives (Slack *et al.*, 2001). In our research, we focus on materials-processing technologies and specifically on conventional machine technology and Computer Numerically Controlled (CNC) technology. For operations managers, it is important to understand the implications of using (investing in) alternative technologies or alternative variants of the same technology.

The paper "An integrated model for part-operation allocation and investments in CNC technology" is our contribution to the research on process technology. In this paper, we address the issue of investment appraisal of CNC machines in conjunction with optimal allocation of parts and operations as the investments take place. The part-operation allocation decision is the decision to allocate the parts and operations either to the conventional machines or to the new CNC machines. The aim is to achieve an optimum i.e., most profitable selection of part types and operations to be manufactured on current and/or new CNC machine types. This is an integral part of the economic justification of CNC machine tools. We present a mixed integer programming model to determine (i) which part types to manufacture (fully or partially), on new and/or current machines, and in what quantities each period, (ii) what new CNC-machine(s) to invest in and when, and (iii), which of the current machines to dispose of, and when. The optimality criterion is based on a maximization of net present value (NPV) over a specified planning horizon. The main message of the paper is that part allocation is an important consideration in the assessment of profitability from investments in CNC technology. The investment decision should be based upon an integral view on the effect of part allocation on the performance of the department.

1.2.3. Job design

The job design activity includes task analysis, worker analysis, and environmental analysis (Russel *et al.*, 1998). This involves defining and specifying tasks, determining worker capabilities and responsibilities, and paying attention to the work environment. Method study, work measurement, ergonomics, and several behavioral aspects are all fields of study within the job design activity. Developing an effective job design may be beneficial from an organizational point of view, to increase productivity or improve product quality, for example, but it may also be beneficial from a worker's point of view. That is, an effective job design also pays attention to the safety, satisfaction, and motivation of workers.

In this thesis, four papers address issues concerning job design. Our focus is on workers and their skills, or the tasks they are able to perform. We consider the tasks to be defined and specified and further do not address ergonomic issues (not in work environment nor workplace design).

One issue that is dealt with in two papers is cross-training. In previous research, it has been shown repeatedly that increases in the number of cross-trainings positively affect system performance. Furthermore, research shows that most of the positive effects are achieved without going to the extreme of full flexibility. However, even with a fixed number of cross-trainings in a system, there are many possible distributions of skills to workers. A remaining question that we specifically focus on is how to cross-train the workforce, or how to decide which workers should be trained for which tasks or machines. We not only consider this question from an operations management viewpoint, but also from a human resource management viewpoint.

In the paper "Cross-training in a cellular manufacturing environment", we address the question "Who should be cross-trained for which machine?" in a cellular manufacturing environment with variations in the demand mix and fluctuations in the labor supply. We take into account the training costs as well as the efficiency-levels workers can ultimately achieve on machines. We argue that cross-training in cells has to be performed in such a way that a balanced workload can be realized. The basic assumption in our approach is that training should lead to a situation in which all workers can be equally loaded in various circumstances. If this is the case, we argue that there will be no subgroups under any of these circumstances and that there will be what is called in literature "chaining" of workers and machines. Based on this insight, we have developed an integer programming model that can be used to select workers to be cross-trained for particular machines.

The paper "Development and evaluation of cross-training policies for manufacturing teams" is devoted to the question "What is an effective cross-training policy?" A cross-training policy can be regarded as a set of rules to determine the distribution of workers' skills. In this paper, we discuss which aspects are important in developing a cross-training policy, develop several alternative cross-training policies, and evaluate the policies by means of a simulation study. The concept of chaining is incorporated in all cross-training policies developed. The policies are based on different choices that are made with respect to the aspects of multifunctionality, machine coverage, and collective responsibility. Multifunctionality refers to the number of machines that can be operated by a worker, machine coverage is defined as the number of workers who are able to operate a machine, and collective responsibility measures the sum of all overlapping workloads of machines to which workers can be assigned. For the evaluation, we use mean flow time from an operations management viewpoint, and the standard deviation of the distribution of workload among workers from a human resource management viewpoint. Further, three routing structures are examined: a parallel routing structure, a serial routing structure, and a job shop routing structure.

The other two papers deal with labor allocation, addressing the question which rules should be designed to allocate workers to tasks in order to perform well. In these papers, the qualifications of workers or the tasks they are able to perform are fixed, but different labor allocation rules are designed that may alter the deployment of these qualifications. Previous studies on labor allocation mostly study the "when-rule" and the "where-rule", which decide when a worker is eligible for transfer, and where he/she should be transferred to, respectively. Furthermore, most studies consider a homogeneous workforce, or workers who have the same characteristics. Our studies include another labor allocation rule (the "who-rule") and investigate systems with worker differences.

The paper "On the who-rule in Dual Resource Constrained (DRC) manufacturing systems" focuses on the "who-rule", which is a rule that selects one worker out of several workers to be transferred to a work center. Previous studies either have not mentioned this rule or have treated it as a fixed factor. In the paper, we describe in detail at what decision moments the who-rule needs to be applied in simulation. Furthermore, we explore the flow time effects of applying different who-rules in several DRC systems where labor flexibility is limited and workers differ with respect to task proficiencies, the number of skills they possess, and the loads of work centers for which they are responsible.

The paper "Labour allocation rules in Dual Resource Constrained (DRC) manufacturing systems with worker differences" examines the flow time effects of the "when-rule", the "where-rule", and the "who-rule" in systems with limited labor flexibility with respect to

the number of machines workers can operate. We model workers who differ in their task proficiency and/or in the number of skills they possess.

1.3. COHERENCE IN THE PAPERS

This section focuses on the coherence in the issues addressed in the aforementioned six papers (see table 1). As we have seen, the issues are -at a high level- related by their process design focus within the field of Operations Management. Other similarities between the papers or subsets of the papers will be discussed in this section.

The papers deal with decisions that have to be made by companies with respect to the design of the shop floor. These decisions are at least tactical decisions, and some may even have impact on the strategic level. Tactical issues influence the effectiveness of the organization for a longer period of time, while they concern resources already available in the organization. The cross-training decision is such a tactical, medium term decision. The labor allocation decision is a tactical decision as well. That is, the decision which allocation rules are used is made for a longer period of time (tactical decision), while the daily allocation of workers according these rules is an operational issue. The layout and investment decisions may also have implications for the company's objectives. These decisions may affect the organization for an extended period of time and may be made by people working at high hierarchical levels in the organization. Furthermore, literature indicates that justifying investments in advanced manufacturing technology, such as CNC technology, often involves a strategic approach.

Another similarity in most of the papers is the attention to the human factor. Obviously, in dealing with cross-training and labor allocation, workers (and their characteristics) must be considered together with machines. These papers consider Dual Resource Constrained (DRC) systems, referring to the need for both workers and machines. The paper on the layout decision also pays attention to the human factor, since the objective "quality of labor" is included in the decision hierarchy. The investments paper is an exception. It focuses on machines and their characteristics and assumes the worker as input transforming resource to be available in the process.

An integrated approach is another similarity of the papers on layout, investments, and cross-training. These papers attempt to integrate aspects which are usually treated in separate research papers. The paper on layout takes a wide range of performance objectives into account in the decision which manufacturing layout to choose. The investment paper incorporates the part-operation allocation decision into the investments decision, using a NPV criterion. Finally, the cross-training papers also draw attention to human resource management issues, besides operations management performance measures.

The four papers dealing with cross-training and labor allocation show most coherence. Cross-training and labor allocation are two job design activities that can be related to labor flexibility. The extent and distribution of cross-training impacts the flexibility of the workforce, as well as do the allocation rules chosen to allocate workers to machines.

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1.4. OVERVIEW OF THE THESIS

The first part of this thesis (Chapter two) concerns layout and investment decisions. Here, the shop floor design activities of layout and process technology are addressed. The chapter starts with the paper "Decision support framework for the selection of a manufacturing layout" (Slomp and Bokhorst, 2004), in which we develop a decision support framework for the selection of a manufacturing layout. It is followed by the paper "An integrated model for part-operation allocation and investments in CNC technology" (Bokhorst *et al.*, 2002), which includes the issue of part-operation allocation in the investment decision process of CNC technology.

The second part of the thesis (Chapter three) deals with the issue of cross-training, which can be regarded as a job design activity. The main research question is who should be trained for which machine? For this, we start out with the paper "Cross-training in a cellular manufacturing environment" (Slomp *et al.*, 2004), where we develop a model that may help in trade-offs between training costs and the workload balance among workers in a manufacturing cell. Next, we develop and evaluate several cross-training policies for manufacturing teams within a parallel routing structure, a serial routing structure, and a job shop routing structure in the paper "Development and evaluation of cross-training policies for manufacturing teams" (Bokhorst *et al.*, 2004a). We address this issue from a human resource management and operations management viewpoint.

The third part of the thesis (Chapter four) deals with the design of labor allocation rules as part of the job design activity. The first paper "On the who-rule in Dual Resource Constrained (DRC) manufacturing systems" (Bokhorst *et al.*, 2004b) focuses on the who-rule, which is a labor allocation rule that selects one worker out of several workers to be transferred to a work centre. We explore the flow time effects of applying different who-rules in several DRC systems where labor flexibility is limited and workers differ with respect to task proficiencies, the number of skills they possess, and the loads of work centers for which they are responsible. The paper "Labour allocation rules in Dual Resource Constrained (DRC) manufacturing systems with worker differences" (Bokhorst *et al.*, 2004c) addresses the design of when-rules, where-rules, and who-rules in DRC systems with worker differences.

The final chapter (Chapter five) gives some concluding remarks and indicates issues for further research.

References

Agarwal, A. and Sarkis, J., 1998, A review and analysis of comparative performance studies on functional and cellular manufacturing layouts. Computers and Industrial Engineering, 34(1) 77-89.

Bokhorst, J.A.C., Slomp, J., and Suresh, N.C., 2002, An integrated model for part-operation allocation and investments in CNC technology. International Journal of Production Economics, 75(3), 267-285.

Bokhorst, J.A.C., Slomp, J., and Molleman, E, 2004[a], Development and evaluation of cross-training policies for manufacturing teams. IIE Transactions, 36(10), 969-984.

Bokhorst, J.A.C., Slomp, J., and Gaalman, G.J.C., 2004[b], On the who-rule in Dual Resource Constrained (DRC) manufacturing systems. International Journal of Production Research, 42(23), 5049-5074.

Bokhorst, J.A.C., Slomp, J., and Gaalman, G.J.C., 2004[c], Labour allocation rules in Dual Resource Constrained (DRC) manufacturing systems with worker differences. Submitted to the European Journal of Operational Research and currently with the authors for a revision.

Chase, R.B., Jacobs, F.R., and Aquilano, N.J., 2004, Operations Management for Competitive Advantage (New York: McGraw-Hill/Irwin).

Hayes, R.H. and Wheelwright S.C., 1979, Link manufacturing process and product life cycles. Harvard Business Review, 57(1), 133-140.

Johnson, D.J. and Wemmerlöv, U., 1996, On the relative performance of functional and cellular layouts – An analysis of the model-based comparative studies literature. Production and Operations Management, 5(4), 309-334.

Russell, R.S. and Taylor III, B.W., 1998, Operations Management – Focusing on Quality and Competitiveness (Upper Saddle River, N.J.: Prentice Hall, Inc.).

Shambu, G., Suresh, N.C., and Pegels, C.C., 1996, Performance evaluation of cellular manufacturing systems: a taxonomy and review of research. International Journal of Operations & Production Management, 16(8), 81-103.

Slack, N., Chambers, S., and Johnston, R., 2001, Operations Management (Harlow: Financial Times/Prentice Hall).

Slomp, J. and Bokhorst, J.A.C., 2004, Decision support framework for the selection of a manufacturing layout. Submitted to the International Journal of Production Research.

Slomp, J., Bokhorst, J.A.C., and Molleman, E., 2004, Cross-training in a cellular manufacturing environment. Computers and Industrial Engineering (in press).