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Chapter 5

Concluding remarks and directions for further research

This chapter summarizes the main conclusions of the four issues addressed in this thesis. It also indicates directions for further research. Specific and detailed conclusions and directions for further research can be found in the individual papers in the previous chapters.

5.1. CONCLUDING REMARKS

5.1.1. Layout

The paper "Decision support framework for the selection of a manufacturing layout" relates to the choice of a basic layout in the layout design activity. Many times, the choice between alternative basic layouts is not obvious. Previous research has compared alternative layouts (e.g. cell layouts versus process layouts), but it often focuses on a small set of factors, without explicitly assisting practitioners in making a choice between the alternative layouts in their specific situation.

Our paper presents a general decision support framework for the selection of a manufacturing layout, including a hierarchical decomposition of the decision problem. This decomposition simplifies the decision problem and enables an efficient and effective employee participation. In the decision which layout to choose, strengths and weaknesses of each layout alternative are related to the performance objectives of the firm. The framework is applied in several practical situations and, in our opinion, the decision hierarchy presented in the paper and the use of the Analytic Hierarchy Process (AHP) form a robust framework for the selection of a layout in many situations.

5.1.2. Investments

In (re)designing processes, an important consideration is what process technology to apply in the transformation of inputs to outputs. Each alternative process technology or alternative variant of the same technology has different characteristics and will contribute differently to the production system's effectiveness. Investing in new machines (either replacement or expansion investments) thus implies that the effectiveness of the production system may change. If we can quantify the benefits of the new technology, this information can be used in the financial investment appraisal of the technology.

In the paper "An integrated model for part-operation allocation and investments in CNC technology" we include different characteristics of current and new machines and present a model to maximize the overall net present value of the after-tax cash flows and 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

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contribution of this research is that it makes clear that the part-operation allocation decision, or the decision which parts to manufacture on the new or on the old machines, influences the benefits that can be achieved with investing in new technology. In our opinion and in line with our model, the investment decision should be based upon an integral view on the effect of part allocation on the effectiveness of the production system. Furthermore, CNC machine tools are often employed as multi-machine systems, and each CNC machine typically serves to replace more than one traditional machine. Using a phased implementation approach, the time horizon of the investment procedure (which not only decides what new machines to invest in, but also what current machines to dispose of) should be several years and numerous alternative investment options may be considered.

5.1.3. Cross-training

Cross-training is a job design activity to decide which workers should be trained for which machines. Of course, in a Dual Resource Constrained (DRC) system, where the number of operators is smaller than the number of machines, at least some of the operators need to be trained for more than one machine. The question is how much cross-training is needed and who should be cross-trained. In our research, we develop models to support in making these decisions.

An important basic assumption in our models is that the distribution of cross-training should enable an equal workload division among the workers, to encourage "chaining". A chain can be regarded as a connected bipartite graph where in case of labor chaining, the two subsets of vertices are workers and machines and the edges represent the worker skills. Previous research has shown that chaining is an effective policy. To obtain a chain, flexibility should be added in such a way that a path is created that connects every pair of vertices. Furthermore, we want the resulting cross-training configuration to be able to effectively deal with fluctuations. These may be fluctuations in the demand for jobs, or in the supply of labor. The latter can be caused by absenteeism, for instance.

The paper "Cross-training in a cellular manufacturing environment" takes into account the training costs as well as the efficiency that a worker can realize while operating a particular machine after training. The model is able to deal with several demand situations and labor supply situations. The model is helpful when making a trade-off between training costs and the workload balance among workers in a manufacturing cell. The workload balance indicates the usefulness of labor flexibility in a particular situation.

Next to developing an Integer Goal Programming (IGP) model to support a consequent application of alternative cross-training policies, the paper "Development and evaluation of cross-training policies for manufacturing teams" assesses the resulting cross-training configurations within three routing structures by means of simulation. For the IGP model, choices have to be made with respect to the desired number of additional cross-trainings, the minimal levels of multifunctionality and machine coverage, whether equal multifunctionality and machine coverage is strived for or not, and whether collective responsibility should be minimized or maximized. The simulation models incorporate absenteeism to evaluate the performance with fluctuations in the supply of labor. With respect to fluctuations in the demand of jobs, each machine has a different, but constant average utilization. Here, capacity balancing thus becomes an objective of cross-training. Jobs arrive according to a Poisson distribution, and the differences in utilization are modeled by specifying a different average processing time for each machine. The processing times of machines are distributed according to a 2-erlang distribution. In other

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words, the average demand per machine does not change, but at any specific moment, there can be large differences in the number of jobs in queue and in the processing times of jobs. In such a system, variability buffering becomes an important objective of cross-training as well. The results show that within the parallel and job shop structure, equal multifunctionality and equal machine coverage are important for achieving an optimal mean flow time. Within the serial structure, more attention should be paid to the bottleneck machines by combining unequal machine coverage and maximum collective responsibility. Within all routing structures presented, equal multifunctionality combined with maximum collective responsibility seems to enable a fair distribution of workload among workers. This measure relates to the social dimension of a manufacturing team.

5.1.4. Labor allocation

Designing labor allocation rules is another job design activity. Labor allocation rules are required in production environments where workers need to sequentially work on more than one machine. In labor limited systems, it may happen that there is sufficient machine capacity at a certain workplace, but jobs have to wait because there is not sufficient worker capacity. This can be caused by the fact that workers are busy at other workplaces or because they do not have the right skills to work at the specific workplace. Labor allocation rules usually decide when a worker becomes eligible for transfer to another machine (the so-called "when-rule"), and to which machine the worker should be transferred to (the so-called "where-rule"). Labor allocation rules are thus able to redirect a worker at a specified moment from his/her current activity to another activity that is given a higher priority. Designing rules that transfer labor at the right moment and to the right place improve system performance compared to less sophisticated labor allocation rules. Next to the when-rule and where-rule, we pay attention to the "who-rule" in our research. The who-rule decides who should be transferred if more than one worker is available.

In the paper "On the who-rule in Dual Resource Constrained (DRC) manufacturing systems", we focus on the role of the who-rule in simulation studies on labor flexibility and on performance effects of applying alternative who-rules. Although the who-rule seems to play a role in the daily practice of worker assignment, it is not systematically dealt with in simulation studies presented in the current literature. The who-rule may be applied in simulation when a job arrives at an empty work centre, or when a worker becomes available for transfer. The paper describes this in detail. Furthermore, an individual-based assignment approach and a team-based assignment approach are distinguished. In an individual-based assignment approach, reallocation to a specific machine is only considered for the worker who just left that machine. In contrast, a team-based assignment approach also checks whether other qualified workers are available for the machine. We show that the team-based assignment approach outperforms the individual-based assignment approach that is used in the current literature. Two simulation experiments are conducted to study the flow time effects of applying alternative who-rules. Factors likely to affect the extent of the effect of the who-rule are included as experimental factors as well. Next to the who-rule, experimental factors are the number of skills, disparity in work centre loads, and labor utilization. The first experiment models DRC systems with homogeneous labor with respect to task proficiencies, single or multilevel flexibility, and a disparity of work center loads, under three levels of average labor utilization. The second experiment models a DRC system with heterogeneous labor with respect to task proficiencies, single-level flexibility and a disparity of work center loads, with 60% labor utilization. The results of the study show that DRC shop characteristics influence the impact of the who-rule. The impact of the

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who-rule is larger under lower levels of labor utilization than under higher levels of labor utilization. Furthermore, the first experiment shows that under lower levels of labor utilization, the effect of the who-rule is relatively larger with multilevel flexibility, and with distributions of work centre loads which create larger worker differences in terms of unique workloads of workers. The second experiment modeling heterogeneous labor with respect to task proficiencies shows larger effects of the who-rule than the first experiment. The higher the load of the shared work center, the more the who-rule is applied and the more often the most efficient worker is assigned.

The paper "Labour allocation rules in Dual Resource Constrained (DRC) manufacturing systems with worker differences" evaluates the effect of the where-rule, the when-rule, and the who-rule on flow time performance in DRC systems with limited flexibility with respect to the number of skills in the system, task proficiency differences, and workers who differ in the number of skills they possess. Different configurations of a DRC system with 5 workers, 10 machines, and 30 skills are simulated in three experiments. The first experiment focuses on the where-rule and the who-rule in three configurations with increasing differences in task proficiency of workers. The results show that where-rules and who-rules that base their choice on task proficiency differences result in better flow times than a simple First In System First Served (FISFS) where-rule and a random (RND) who-rule in case there are task proficiency differences. The second experiment focuses on the who-rule in three configurations with increasing differences in the number of skills workers possess. The results show that with relatively large differences in the number of skills per worker, a who-rule that assigns the worker with the fewest number of skills (FNS) results in better flow time performance than a RND who-rule. The third experiment focuses on the when-rule, the where-rule, and the who-rule in a configuration with a large difference in task proficiency and a large difference in the number of skills workers possess. The results show that a centralized when-rule performs considerably better than a decentralized when-rule. Furthermore, the where-rule and who-rule that base their choice on task proficiency perform better than a FISFS where-rule and a FNS and RND who-rule, respectively. Finally, the effect of the where-rule and the who-rule seems to be larger in case of a centralized when-rule.

5.2. FUTURE RESEARCH ISSUES

This subsection only discusses some general issues for further research that apply to one or more of the shop floor design issues addressed in this thesis. Each individual paper has devoted attention to more specific issues for further research.

The studies in this thesis are primarily conceptual studies. Empirical studies as follow up of several studies undertaken in this thesis would be valuable to further develop the conceptual models presented in these papers or to apply and test the models in real life practical situations. This may increase the practical relevance of the models. The systematic approach for the selection of a manufacturing layout is applied in several practical situations (Posthumus, 1997; Groen, 2002) and has proven to be a valuable tool in practice. The integrated model for part-operation allocation and investments in CNC technology is quite large and complex and therefore may be less suitable for practical applications. However, one may distract submodels that focus on those elements of the model that are most dominant in the particular situation and are easier to solve. Empirical investigations may focus on developing solid investment procedures and finding the appropriate intangible aspects that should be taken into account. The IP models developed in the cross-

training papers can be applied in small problem contexts, and when using focused submodels, also in larger problem contexts. Here, empirical investigations may focus on the rules with respect to important aspects in a cross-training policy that are used in practice. These can be confronted with the rules we found to be attractive. For the labor allocation issue, empirical investigations may provide parameter settings and configurations that bear more resemblance to realistic operating environments. Another topic for empirical research is how to implement and apply labor allocation rules such as the who-rule in real industrial situations.

An interesting direction for further research is to integrally study the shop floor design issues of cross-training and labor allocation. As we discussed in the paper "Development and evaluation of cross-training policies for manufacturing teams", optimal labor allocation rules should be designed for each cross-training configuration developed. If the labor allocation rules are fixed in the comparison of cross-training configurations, there may be an interaction effect with the configurations, since it is conceivable that the fixed allocation rules perform differently within each cross-training configuration. In designing optimal labor allocation rules, it may be worthwhile to consider multidimensional and/or dynamic rules. This means that labor allocation rules may be developed that consider more than one dimension (such as the number of skills, or the task proficiency of workers) simultaneously. Further, information on the current state or even the "near future" state of the system may be incorporated to get dynamic rules instead of static rules. Dynamic rules frequently provide better operating performance, but they require more information. Again, this raises the question of how to apply the rules in practical situations.

In this thesis, various issues have been dealt with: the choice of a basic layout, investment appraisal, cross-training, and labor allocation. Even though these issues have been treated more or less independently in different papers, there is a link between the issues dealt with in the papers and it may be fruitful to integrally study some or all of these issues. As mentioned above, an integral study of cross-training and labor allocation seems relevant. An integral study of layout and investments, or layout and cross-training may also be fruitful. We have seen in practice that with investments in expensive automated machinery, the layout of the department is changed simultaneously. For instance, a new machine that replaces several machines that were grouped functionally may be operated in a cell in the new situation. This, in turn, may also impose other requirements for the level and/or distribution of cross-training. Studying the relations between these issues may enrich the research on shop floor design.

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