Worker flexibility in dual resource constrained (DRC) shops

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Summary

This thesis concerns the issue of worker flexibility in 'Dual Resource Constraint' (DRC) environments. There are more machines, or workstations, than workers, in such an environment. This means that workers need to be able to operate more than one workstation, on average. In the introduction of this thesis, we distinguish three types of DRC systems:

1. The parallel shop system. The task dependency in this system is minimal. Tasks, or jobs, arrive independently from each other and can be processed on one machine type, or workstation type. There is unlimited buffer space before each of the workstations.
2. The job shop system. Within this type of system, jobs arrive independently from each other and have each their own routing through the system. Buffers are usually no serious limitation. The system includes some task dependency because of the presence of routings.
3. The DRC-assembly line. In this situation, each product required the same sequence of operations. There is a limited buffer space between the subsequent stations. This type of DRC-system contains a substantial degree of task dependency.

DRC-research, so far, has been mainly focused on the job shop system. This thesis concerns worker flexibility issues in the parallel shop system and the DRC-assembly line. These are two extremes with respect to task dependency. It is theoretically and practically relevant to investigate how worker flexibility needs to be considered in opposite environments. This supports generalization of worker flexibility guidelines.

This thesis addresses a number of factors: (i) the level of cross training, (ii) the degree in which capabilities of workers are overlapping (i.e. chaining), (iii) the presence of different types of workers with respect to learning speed and the level of task efficiency that can be realized, (iv) worker deployment rules, and (v) staffing levels. Table 1 shows which factors are studied in the two environments.

Table 1. Factors that are considered in our study.

	Parallel shop system	DRC assembly line
Level of cross training	X	X
Degree of overlapping capabilities	X	X
Differences between workers with respect to learning speed and the level of task efficiency that can be realized	X	
Worker deployment rules		X
Staffing levels (no. workers/ no. work station types)		X

The level of cross training and the degree of overlapping capabilities play a role in the parallel shop system as well as in the DRC assembly line. The level of cross training can be expressed by the number of workstation types that can be handled by a worker. The degree of overlapping capabilities (i.e. chaining) indicates to what extent workers are connected with each other through common capabilities. Tables 2a and 2b present an example. All workers have a multi-functionality of 3; they are able to operate three types of workstations. In the situation of Table 2a, the workers are divided in two groups: there are two "chains". In the case of Table 2b, the division of capabilities is such that all workers are connected through overlapping capabilities. There is one "chain". A heavy loaded worker can be released by a less loaded worker, by means of movements of the workload through a chain of workers. In the situation of Table 2a, it may happen that one of the two groups is, temporarily, overloaded. This may cause unstable and long throughput times of jobs. Table 2b presents a situation with a limited level of overlapping capabilities. A larger level of overlap can be realized if workers are more multifunctional.

Tables 2a and 2b: qualifications of workers

worker\station	1	2	3	4	5	6
A	X	x	x			
B	X	x	x			
C				x	x	x
D				x	x	x

(a) multifunctionality=3, two chains

worker\station	1	2	3	4	5	6
A	X	x	x			
B		x	x	x		
C				x	x	x
D	X				x	x

(b) multifunctionality=3, one chain, with a limited overlap

The third factor 'differences between workers with respect to learning speed and the level of task efficiency that can be realized' will only play a role in the parallel shop system. Workers in a DRC-assembly system usually perform short cyclical work and will realize the required norm times, within a certain range, in a relative short period. In a parallel shop system, arrival of new job types may happen frequently and learning speed, as well as the final efficiency level that can be realized per worker, may have impact on the performance of the system. Deployment rules indicate to which workstation a worker has to go after finishing a job. This is especially important in case of an environment with a high task dependency. The flow of product can be controlled by means of appropriate deployment rules. The staffing level (i.e. number of workers / number of work stations) is a factor, which also needs to be considered in a DRC-assembly line. Staffing levels usually vary substantially in a DRC-assembly line. Firms choose for a DRC-assembly line because of the ease to adapt the production volume by adding to or removing workers from the line. It is conceivable that the staffing level has consequences for the desirable configuration of worker flexibility

The first part of the thesis is focused on worker flexibility in a parallel shop system. Task dependency is limited in this system. The second part of the thesis concerns a DRC assembly line, where task dependency is high. In the conclusions of the thesis, the differences between the two situations will be discussed with respect to the desired design of worker flexibility.

Part 1. Worker flexibility in a DRC parallel shop system

This part of the thesis starts with a literature review. Numerous studies on worker flexibility in DRC environments refer to the classical model of Nelson, which assumes to be a generic description of a DRC system. We have discussed the characteristics of this model and pointed out its limitations in terms of environmental uncertainty and human aspects. To overcome these limitations, we then extended the model by including three parameters: (i) environmental dynamics in terms of the arrival of new product types, (ii) learning and forgetting, and (iii) individual learning patterns. By adding these three elements, a better and more realistic insight can be gained into the meaning of worker flexibility in dynamic situations. Next, we reviewed the existing literature with respect to the effects of the level of cross training and the degree of chaining. We concluded that, though most of the previous studies indicate that these two policies could be beneficial, their effectiveness has not yet been examined in a dynamic environment, in which learning and forgetting are present and play a role in the performance of the system.

A number of research questions are formulated. The first one (research question 1) concerns the functioning of a dynamic DRC parallel shop. To be more specific, it addresses the impact of the newly included parameters, environmental dynamics and the individual learning patterns, on system performance. The aims of the first question is to obtain the performance range of these parameters, which in turn will help us to better understand answers on the other research questions. The second and third question relate to the effectiveness of cross training (research question 2) and the desirability of chaining in a dynamic parallel shop (research question 3).

For answering the research questions, we have applied computer simulation. This is the most appropriate methodology for studying DRC-systems. The complexity of DRC-systems cannot be handled by analytical queuing models.

With respect to research question 1, the impact of environmental dynamics and the individual learning patterns on system performance, our results show that environmental dynamics is negatively related to mean flow times and will give workers a higher load, given a constant arrival rate of jobs. In other words, the more dynamic the environment, the more workers will be loaded and the longer the throughput times of jobs will be. We also have shown that environmental dynamics (i.e. more frequent new product types) is negatively related to the maximal work load of the system (i.e. the production capacity boundary). Finally, we have demonstrated that fast learners perform better in a highly dynamic system, whereas slow learners perform better in a more stable system. This is mainly due to our assumption that fast learners learn and forget fast, but slow learners have higher final efficiency levels. This assumption was based upon the empirical study of Nembard and Uzumeri (2000). Although further empirical research is needed with respect to the patterns of learning and forgetting, it can be stated that managers need to consider capacity and personal effects in case of a more dynamic, or a more stable, environment.

As for research question 2, the relationship between the level of cross training and environmental dynamics, our results show that the optimal level of cross training depends on the degree of environmental dynamics. In a production system where learning and forgetting plays a role, the performance of the system will not only improve if the level of cross-training increases. A too high level of cross-training will lead to the situation where workers have to transfer to many stations and, consequently, learning opportunities are not used optimally.

Concerning research question 3, the effectiveness of chaining in a variety of dynamic environments, the results suggest that a long chain is always better than a short chain. The length of a chain indicates how many workers are linked by means of overlapping capabilities. Long chains increase the number of possibilities to release high loaded workers by less loaded workers. The relative advantage of long chains, with respect to the performance of short chains, depends on the degree of environmental dynamics. A long chain performs relatively best in a highly dynamic and a highly stable environment. In both environments, learning and forgetting are relatively not important. In an environment where learning and forgetting play a clear role (i.e. in a situation where frequently, but not continuously, new product types are introduced), chaining will be less advantageous since it may lead to less specialization (or learning profit) per worker. Chaining causes a more balanced workload. There are no subgroups. This balanced workload, however, can only be realized if workers move and accept a certain loss of learning effect. In summary, we can conclude that chaining is always advantageous in a parallel shop system, but that the degree in which it is advantageous depends on loss of specialization.

Part 2. Worker flexibility in a DRC assembly line

This part of the thesis is based on the situation in a Dutch manufacturing firm (Kalk 2005; Van den Brink 2005). The case situation presented in this chapter is quite general in nature and many firms can relate their situation with the one described in the chapter. The case situation concerns an assembly line in which there are more stations than workers, each station consists of only one assembly table, and there are only small buffers (with only space for one part) between stations. In such an assembly line, tasks are highly interdependent. In comparison with the DRC shop system, there are no resource duplications, no buffers and a fixed routing of parts. Most of previous research in the area of DRC assembly lines assumes less task interdependency; authors assume the presence of resource duplications and large buffer sizes, and conclude that an increase in cross training and skill overlap always improve shop performance. It is questionable to what extent these conclusions are valid for a highly task dependent assembly line. This is the subject of this part of the thesis. We investigated four elements of worker flexibility: the level of cross-training, the degree of chaining, deployment rules, and the staffing level.

Simulation research showed that in a highly task interdependent context, cross training and chaining may entail some negative consequences such as the idleness of workers caused by (i) the absence of parts (starving), (ii) the occupation of subsequent stations (product blocking), and (iii) the situation that other workers occupy the stations which can also be processed by them (worker blocking). Our results show that in a DRC assembly line, a minimal level of cross training may provide most of the benefits of full flexibility. Furthermore, the impact of chaining on the throughput performance seems to be contingent upon the level of skill overlaps, which results from the increase of cross training. For one skill overlap, a long chain may be valuable, but for multiple skill overlaps, short chains may be preferable. This has to be explained by the fact that overlapping qualifications increase the probability of worker blocking. Simulation research furthermore shows that the number of transfers (a transfer indicates that a worker moves to an other station) increases in case of longer chains. This is caused by the fact that, in case of long chains, local unbalance of workers with respect to their division over the assembly line can easily spread over the whole line. This causes labour transfers. Since transfers take time, which is not incorporated in our simulation study, we conclude that a long chain may lead to a lower efficiency in particular real life situations.

Our simulation study also shows that a DRC assembly line perform better at a relative high work-in-process (WIP) level. This level can be controlled by the deployment rule, which decides to which station a worker has to move after finishing the work at a station. A worker deployment rule that puts its priority upstream performs well. In case of a high WIP level, there is less starving. The amount of WIP is, obviously, limited by the number of stations and buffers.

Finally, system performance deteriorates as the station-to-worker ratio goes down (staffing level increases). In that case, the balancing loss caused by fluctuations in the processing times (within a uniform distribution) increases and leads to worker idleness. The impact of worker deployment rules diminishes with the decrease of station-to-worker ratio. The more workers at the assembly line, the less the deployment flexibility.

Overall implications and future research

The results of this thesis modify the idea that cross-training and chaining always lead to a better performance of a production system. The presence of environmental dynamics/learning may imply that it is wise not to strive to a maximal level of cross-training. In a more repetitive environment (DRC assembly line), the high degree of task dependency may play a role in the determination of the optimal level of cross-training. Too much flexibility may lead to the risk of unbalanced situations. Chaining appears to be always profitable in a situation with low task dependency (i.e. a parallel shop system), although the presence of learning and forgetting may limit the positive effect. In a situation with high task interdependency, the effect of chaining can be negative because of the probability of labour blocking.

This thesis also contributes to the knowledge in the area of team functioning in a production environment. It is established in previous literature that task interdependence is mainly affected by shop layout. Our results suggest that worker flexibility policies may have impact on the degree of task interdependence as well. To be more specific, our results show that the level of cross training and the degree of chaining are both positively related to task interdependence. For example, chaining, by involving more workers in the sharing of stations, increases task interdependency and, consequently, causes an increase of worker blocking and increases the number of worker transfers. This may play an important role in the performance of teams.

This thesis consists of two parts. Both parts concern DRC-systems. The systems differ with respect to the level of task dependency. It is interesting to focus new research on intermediate situations, which contain elements of the extreme situations studied in this thesis.