ANALYSING AND OPTIMISING A DUAL RESOURCE CONSTRAINT PRODUCTION SYSTEM USING SIMULATION

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ABSTRACT
In current markets with rapidly changing customer expectations and technology and severe competition, it is highly important for a company to effectively respond to these changes and the associated uncertainty. This paper focuses on workforce flexibility to deal with the current markets, and more specific on dual resource constrained production systems. A dual resource constrained (DRC) production system is one in which all equipment in the shop is not fully staffed and, furthermore, workers can be transferred from one piece of equipment to another as needed. The main dimensions of a DRC production system are worker flexibility, worker assignment, transfer costs, job release mechanism, job dispatching and specific methodologies for DRC scheduling. In this paper, a serial manufacturing line with flexible workers is studied. The melting line of a zinc-producing company in Belgium is simulated and the influence of DRC-concepts on the efficiency of the production line is tested.

Keywords: simulation, DRC production system, worker flexibility.

1. INTRODUCTION

In current markets with rapidly changing customer expectations and technology and severe competition, it is highly important for a company to effectively respond to these changes and the associated uncertainty. In general, researchers and manufacturing managers contend that the most important concept to cope with this uncertainty is manufacturing flexibility, which is the ability of a firm to manage production resources and uncertainty to meet the customer requests (Zhang et al., 2003). Although the manufacturing flexibility literature tends to emphasize equipment flexibility and neglect the potential impact of workers, the workforce plays a vital role in most production processes (Yildiz and Tunali, 2008).

A dual resource constrained (DRC) production system is one in which all equipment in the shop is not fully staffed and, furthermore, workers can be transferred from one piece of equipment to another as needed (Treleven, 1989).

Human operators, unlike machines, are capable of learning and acquiring new skills. It is often useful to take advantage of a flexible workforce where workers are trained in several skills or departments such that they can be assigned to a variety of jobs as the need arises. (Xu et al., 2011)

DRC production systems are more complicated than their single resource counterparts and present a number of additional technical challenges which must be considered during resource scheduling. (Xu et al., 2011)

The literature on flexible workers and DRC production systems can be classified in two groups: studies employing flexible workers in job shops (e.g. Fryer, 1974; Treleven, 1985, Weeks and Fryer, 1976) and studies employing flexible workers in serial manufacturing lines (e.g. Bartholdi and Eisenstein, 1996; Bischak, 1996; Zavadlav et al., 1996). DRC job shops have received much more attention in literature than serial manufacturing lines. In this paper, a serial manufacturing line with flexible workers is studied. The melting line of a zinc-producing company (Nyrstar) in Belgium is simulated and the influence of DRC-concepts on the efficiency of the production line is tested. In literature, simulation remains the most popular method in DRC research.

The paper is organized as follows. In section 2, a literature review on the main dimensions that exist in DRC production systems is given. In section 3, the simulation study is described and the two scenarios that are developed are explained. Furthermore, results of the simulation study are presented in this section. In section 4, conclusions on the use of simulation for analyzing and optimizing dual resource constraint production systems are formulated.

2. LITERATURE REVIEW

Based on literature, the additional challenges that must be considered in DRC production systems are divided into six dimensions based on Xu et al. (2011): worker flexibility, worker assignment, transfer costs, job release mechanism, job dispatching and specific methodologies for DRC scheduling.

2.1. Worker flexibility

Worker flexibility in general refers to the responsiveness of a system to variations in the supply and demand of workers. Workers are no longer treated like machines and their unique human characteristics are being acknowledged as an important influence on system performance. (Xu et al., 2011)

Worker flexibility can be viewed from a variety of perspectives. Yue et al. (2008) define three basic aspects of worker flexibility: the level of multi-functionality, the pattern of skill overlaps and the distribution of skills.

The *level of multi-functionality* is defined as the number of different skills mastered by a worker. The *pattern of skill overlaps* can be expressed by two parameters: the number of skill overlaps and the number of workers involved in a chain of skill overlaps. For example, if the average number of skill overlaps equals 2, each skill can be mastered by two workers. The number of workers involved in a chain of skill overlaps indicates the number of opportunities to transfer work. The *distribution of skills* describes to what extent workers are trained for the same number of skills. If workers receive the same degree of cross-training, it is referred to as an equal distribution of skills. If workers are trained to work in a different number of departments, it is termed an unequal distribution of skills.

The benefits of worker flexibility are well documented (e.g. Treleven 1989, Malhotra et al. 1993, Felan and Fry 2001). A flexible workforce may enhance the responsiveness of a system to unexpected and unbalanced workloads. As a result, it reduces manufacturing lead time, decreases the level of work-in-process, and improves customer service. Despite these benefits, worker flexibility may incur some costs which can counteract its benefits, such as learning and forgetting costs.

2.2. Worker assignment

There are two aspects of worker assignment to consider when scheduling human operators: when a worker is available to be transferred and where that worker is to be assigned when he is eligible for transfer.

When-rules dictate when a worker is eligible for transfer. The most widely used when-rules in the literature are the centralized and decentralized rules. The centralized rule provides the maximum worker flexibility because this rule implies that the worker is available for transfer whenever a job is completed. The decentralized rule implies that the workers are eligible for transfer when there is no job waiting to be processed at their current workstations. When transfer costs are significant, the decentralized rule is used more. (Xu et al., 2011)

Where-rules dictate which workstation a worker is to be assigned when that worker becomes eligible for transfer. Some widely used where-rules in DRC literature are first in system first serve (FISFS), largest number in queue (LNQ) and earliest due date (EDD). (Xu et al., 2011)

2.3. Worker transfer costs

The transfer costs are the costs and/or delays caused by worker transfer across different work stations. When transfer costs are taken into account, there is a negative impact on overall system performance if workers are transferred too often. Aside from the simple transfer delay times caused when a worker changes workstations and jobs, there is also a loss of productivity due to human learning and forgetting effects. (Xu et al, 2011)

2.4. Job release mechanisms

The job release mechanism is responsible for the pattern of work release onto the work floor. This mechanism has an influence on the distribution of arriving jobs. A good planning system will positively impact the performance of a DRC system by producing lower and more predictable costs. (Xu et al., 2011)

2.5. Job dispatching

Job dispatching determines the order of jobs to be processed. The selection of the most appropriate job dispatching rule to use is largely dependent on the desired performance measure to optimize. Dynamic selection of a dispatching rule based on current conditions is a promising approach. (Xu et al., 2011)

2.6. Specific methodologies for DRC scheduling

As more factors such as various human and job characteristics are considered in a DRC production system, the scheduling problem becomes increasingly larger and more complicated to solve. There is a move towards using less exact solving methods to find good solutions as opposed to one optimal solution. Yildiz and Tunali (2008) proposed an optimal worker flexibility policy for a constant WIP controlled DRC system using simulation optimization (response surface methodology). Their goal was to more efficiently assign workers to workstations.

3. SIMULATION STUDY

A simulation model representing the melting line at Nyrstar is built in Arena. The simulation model is based on data that was obtained through observations of the melting line and interviews with employees working at the production line and working at a strategic level.

The melting line produces both pure zinc and zinc alloys. The pure zinc is made on the SHG-line. This line consists of two parts: the loading part and the casting part. In the loading part, the zinc is loaded from a smelting furnace. The casting line consists of three separate lines. The zinc alloys are made on the ZAMAK-line. This line consist of three parts: the loading part, the mixing part and the casting part. In the mixing part, the alloys are composed in two mixing bowls, depending on the type of alloy. The casting line has four separate lines. In the basic scenario, there are operators working on the loading part, the smelting furnace, the mixing part and on the casting part. As an example, part of the simulation model implemented in Arena in shown in Appendix A.

To validate the simulation model, first, the output of the simulation model (in number of zinc cubes) is compared to the expected theoretical output of the casting line. In Table 1, the expected theoretical output is compared to the results of the simulation model. Second, the utilization rate on the different casting lines is compared with the mean utilization rate of the last 11 months. In Table 2, the theoretical utilization rate is compared to the simulated utilization rate. Both comparisons indicate that the simulation model is a good representation of the real casting line.

Table 1: Validation: Output of casting lines

Casting line	Theoretical output	Simulated output	LCL	UCL
Z1	149305	149227	127984	160512
Z2	107184	113635	112784	119776
Z3	61654	59353	48032	70528
Z4	18500	19545	19200	19584
SHG1	64397	57067	53496	59040
SHG2	77285	69748	65384	72160
SHG3	49068	55897	51200	68000

Table 2: Validation: Utilization rate

Casting line	Theoretical utilization	Simulated utilization
Z1	92.35%	92.72%
Z2	89.32%	80.67%
Z3	85.63%	/
Z4	94.87%	89.02%
SHG1	89.44%	/
SHG2	89.45%	87.94%
SHG3	70.99%	86.66%

A simulation of 7 days of 24 hours is run. The warm-up period is determined using the graphical method (see Figure in Appendix B) and is set to eight hours. 25 replications are made for each scenario of the simulation model.

Two alternative scenarios are developed to introduce DRC-concepts at the production line at Nyrstar.

Nyrstar works with a continuous production system and uses a rotating shift system. Nyrstar is considering changing this rotating shift system from 4 shift to 5 shifts. This would give employees more free evenings and weekends and would have a beneficial effect on the stress factor and the absenteeism of employees. In both alternative scenarios, the shift from 4 to 5 shifts is assumed.

The second adaptation of the simulation model in the alternative scenarios concerns the allocation of operators. The number of operators at the moulding line, a part of the casting line, is reduced with 1. The remaining 2 operators are more flexible and allocated where necessary. This reduction of operators at the moulding line is assumed in both alternative scenarios.

In the second scenario, additionally, the operator at the scratch line, a part of the casting line, is dropped and his tasks are taken over by the operator of the smelting furnace.

The results of both alternative scenarios are calculated and compared with the results of the basic scenario. A paired t-test is used to make the comparisons. The results for the first scenario are shown in Table 3. The results for the second scenario are shown in Table 4.

Table 3: Results Scenario 1

	LCL	UCL
Total costs	20061	20641
Total output	-4426	14422
Utilization operator 1	-0.00856	0.0208
Utilization operator 2	-0.512	-0.436

The difference in total costs between scenario 1 and the basic scenario is significantly different from zero. The total costs for scenario 1 are on average 20351 Euro per week lower than for the basic scenario. The difference in total output between the two systems is not significant. The utilization of the first operator at the moulding line does not change significantly. The utilization of the second operator at the moulding line increases with 40 to 50 percent points. This high difference in utilization is explained by the way the tasks are divided among the two operators. If the scenario is implemented, the tasks should be redivided so that both operators have a comparable utilization rate.

Table 4: Results Scenario 2

	LCL	UCL
Total costs	23547	24278
Total output	-3257	11581
Utilization operator 1	-0.00756	0.0206
Utilization operator 2	-0.512	-0.43
Utilization furnace operator	-0.0643	-0.051

When comparing scenario 2 with the basic scenario, the same conclusions as for the first scenario can be drawn: the total costs decrease significantly while the total output does not differ significantly. In the second scenario, the scratch operator is removed and his tasks are taken over by the furnace operator. The utilization of the furnace operator increases hereby by 5 to 6 percent points.

4. CONCLUSIONS

In general, researchers and manufacturing managers contend that the most important concept to cope with the uncertainty in current markets is manufacturing flexibility, which is the ability of a firm to manage production resources and uncertainty to meet the customer requests. Although the manufacturing flexibility literature tends to emphasize equipment flexibility and neglect the potential impact of workers, the workforce plays a vital role in most production processes. Dual resource constrained (DRC) production systems are systems in which all equipment in the shop is not fully staffed and, furthermore, workers can be transferred from one piece of equipment to another as needed.

In this paper, a serial manufacturing line with flexible workers is studied. The melting line of a zinc-producing company (Nyrstar) in Belgium is simulated and the influence of DRC-concepts on the efficiency of the production line is tested.

The results indicate that the introduction of DRC-concepts has a positive effect on the performance of the melting line of Nyrstar: while the total output does not differ significantly, the total costs decrease significantly. The utilization of some specific operators increases but remains at an acceptable level.

In the meantime, Nyrstar has successfully introduced some of these DRC-concepts in its existing production line. Thanks to this simulation study, the advantages of introducing these concepts was clear to the management. However, it was of utmost importance that the operators at the melting line were properly informed before introducing DRC.

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APPENDIX A

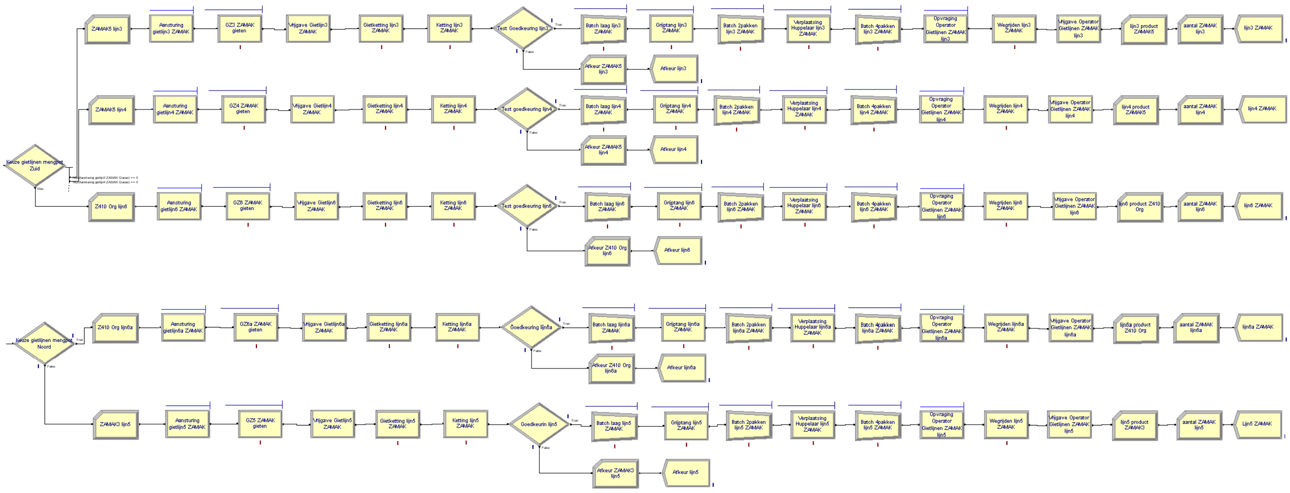

Figure : Casting line ZAMAK

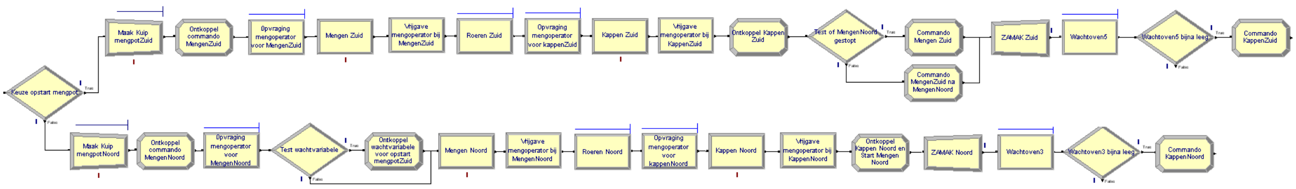

Figure : Mixing part ZAMAK

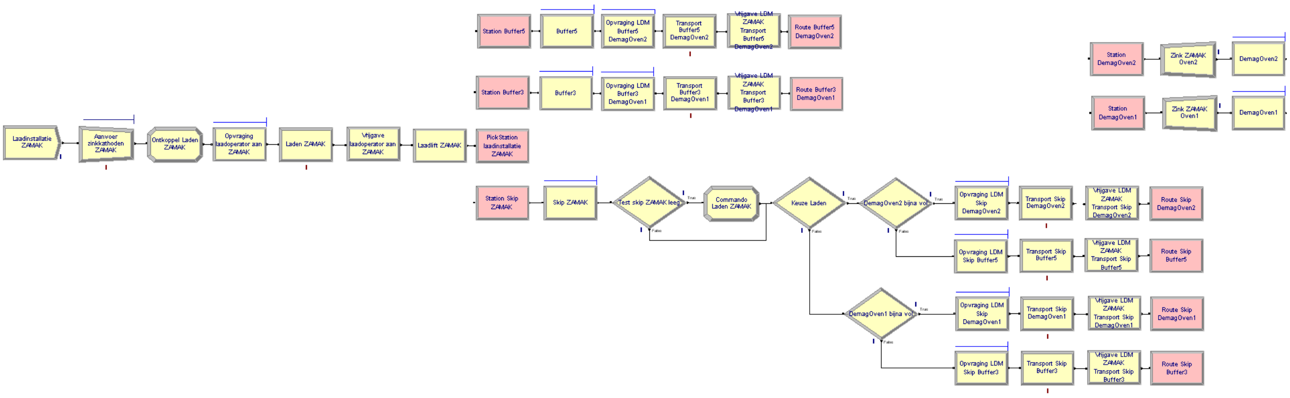

Figure : Loading part ZAMAK

APPENDIX B

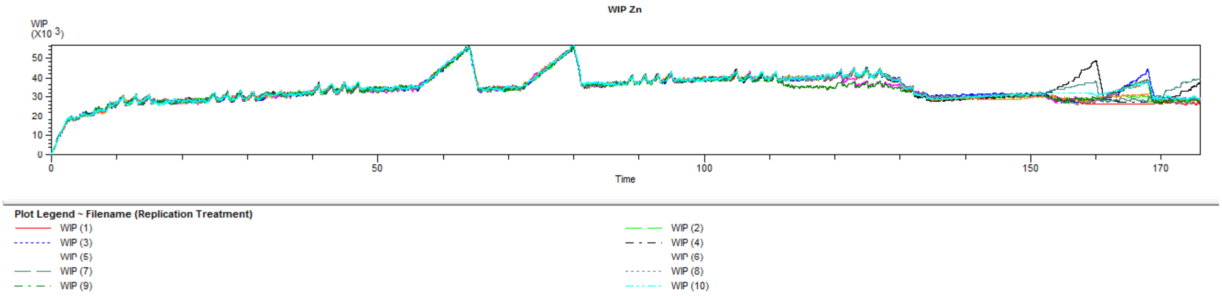

Figure: Warm-up period

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Katrien Ramaekers graduated as Master of Business Economics at the Limburg University Centre in 2002. In 2007, she obtained her Ph.D. in Applied Economic Sciences at Hasselt University, Belgium. Her Ph.D. research is on the integration of simulation and optimisation, especially as a support for complex logistics decision- making. Currently, she is a post-doctoral researcher at Hasselt University and is working on the integration of simulation and optimization.

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Lien Claes graduated as Master of Business Economics at Hasselt University in 2013. The topic of her masterthesis was the simulation of a DRC production system.