ADAPTED MASTER PRODUCTION SCHEDULING: POTENTIAL FOR IMPROVING HUMAN WORKING CONDITIONS

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ABSTRACT

This article illustrates the problem of deficient working conditions like high work intensity and underlines the possibilities of production planning and control to improve them. However, an included literature search presents that previous approaches have predominantly considered social aspects within a short planning horizon and that there is a need for a long-term consideration. To address this research gap a linear optimization model for Master Production Scheduling is presented, which has been extended by basic aspects of personnel requirements planning and a control of personnel work intensity. The results show that improvements in working conditions can be achieved through adapted production planning without an automatically increase in costs. However, challenges in quantifying the corresponding social correlations are identified as well.

INTRODUCTION

Sustainable developments have become increasingly important in research and industry. This is driven by various interest groups like environmental activists as well as government agencies and other factors like resource shortages or a shortage of skilled workers. Production planning and control (in short PPC) offers corresponding potential, since resources can be conserved due to adapting planning. For this article, the integration of social aspects is specifically chosen, because there are various deficits in current working conditions like high work intensity, so that a stronger consideration of social aspects appears to be necessary. In addition, the Master Production Scheduling (in short MPS) is chosen to enable a consideration of long-term effects, like changes in processing times due to exhaustion effects caused by high work intensity, which could not be observed in planning models with a short-term planning horizon. Therefore, a linear optimization model for MPS extended by social aspects will be presented and possibilities for improving actual working conditions will be demonstrated.

For this, the paper is structured as follows. Section 2 presents a literature review, which contains deficits in working conditions and the actual state of the art. In section 3 the case study is introduced and in section 4 the linear optimization model is described. The results and a discussion are outlined in section 5. The paper ends with a conclusion in section 6.

LITERATURE REVIEW

For considering sustainability, it must be noted that numerous definitions exist. The majority of definitions are similar to "*[...] sustainable development [...] must meet ecological, economic [and] social [criteria]*" (Rogall 2009). However, the definition of the individual sustainability dimensions has not yet been finalised. For this article the interpretation of the International Ergonomics Association is used, which defines human factors as: "*[...] scientific discipline concerned with the understanding of interactions among humans and other elements of a system [...] in order to optimize human well-being [...]*". Therefore, human factors have to be considered in production companies in case of manual activities, because an interaction between employees and the production system is given. For that, this interaction can be influenced by PPC (Grosse et al. 2017), for example, the concrete workload is determined by the PPC.

Furthermore, deficits in working conditions can be identified, which indicate an urgency of social improvements. In an evaluation of a survey of works councils, for example, the intensity of work, the pressure to perform, the number of overtime hours and the deviations from standard working hours are described as significant problems (WSI 2017). This is confirmed by Schmucker (2014), where work intensity is rated as poor. According to Nerdinger et al. (2014), the consequences of poor working conditions can be an increased heart rate, frustration or increased errors, which in the long term leads to psychosomatic illnesses, resignation and demotivation. For example, the BKK Health Report 2017 attributes 25% of lost days to musculoskeletal diseases and 16% to mental illness (Knieps and Pfaff 2017). In addition, the DAK Health Report 2018 shows an increase of more than 160% in days of incapacity to work between 1997 and 2017 (Storm 2018). This creates a need for adapted planning models.

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The levels MPS, Lot Sizing and Scheduling according to the concept of hierarchical production planning by Claus et al. (2015) are considered, to show the current state of the art on PPC approaches that aim to improve the identified deficits. For this, Vorderwinkler and Heiß (2011) report that no work is known that integrates social aspects into the PPC. The overview paper by Trost et al. (2016) confirms this for the MPS. In the area of lot sizing, within the work of Arslan and Turkay (2013) the personnel hours are considered as a minimization target respectively as a limit value in the constraints. Jaber and Bonney (2007) integrate a two-phase learning and forgetting model into a classic Economic Manufacture Quantity Model. At the scheduling level, reference is made to the work of Boysen und Fliedner (2011), which reduces the workload on airport ground staff, which can be transferred to a production environment. Peteghem and Vanhoucke (2015) also highlight potentials for reducing stress. Grosse et al. (2017) present a systematic literature review in which relevant papers are classified into a framework consisting of four social and three production and logistics levels. Transferred to the concept of hierarchical production planning, it can be summarised that for lot size planning there are only a few papers that contain the social dimension. These include, for example, the work of Khan et al. (2014), in which errors and learning effects are assumed. Andriolo et al. (2016) determine an ergonomic lot size using a multicriteria objective function in which in addition to costs, health risks are also taken into account. A larger number of papers can be assigned to the scheduling level. For example, Otto and Scholl (2011), Cheshmehgaz et al. (2012) and Bautista et al. (2016) consider health risks in the constraints by limiting the maximum workload. Directly in the target function, the workload is minimized in Choi (2009), Battini et al. (2016) and Mossa et al. (2016). Further work exists on job rotation and nurse scheduling. However, these are aimed at distributing the existing total load evenly. Due to the short planning horizon, however, a reduction in the total workload is not achieved. In the end a conclusion of the paper of Grosse et al. (2017) is, for example, that there is a lack in research for quantifying effects of social aspects like exhaustion. However, the few works that take exhaustion into account usually assume an exponential course (see Jaber et al. 2013; Zhang et al. 2014).

In summary, a the consideration of average work intensity, the number of overtime hours and deviations in regular working hours in a long-term planning horizon, which is to be assigned to the MPS, can be identified as gaps in research. Therefore, a corresponding approach is presented in chapter 4, which addresses this gap.

CASE STUDY

The case study examined here is oriented towards a manufacturing industrial company. The parameters used here are defined in chapter 4 regarding the model formulation. For the case study, at first, general parameters are presented in Table 1. The different employee groups (Staff) are interpreted as core employees (ma=1) and temporary employees (ma=2). In addition, for employee group ma=2, it is assumed that an external service provider is responsible for building and reducing the available capacity and that the employees have a backlog of experience compared to the core workforce, which is taken into account by a lower available capacity.

Table 1: General Parameters

Parameter	Value
J	2
K	2
S	3
Staff	2
T	60
W	3
Z	1

In addition, employee-related parameters from the findings of a Saxon industrial company are used. Table 2 shows the available capacity per employee (in time units), the cost rates for building and reducing a workforce and the lead times for adjusting the available capacity (in periods).

Table 2: Employee parameters per worker class (ma)

Parameter	ma=1	ma=2
$CAPA_{ma}$	524 400	393 300
m_{ma}^{Cost}	15 000	1 500
n_{ma}^{Cost}	60 000	100
we_{ma}	3	1
wf_{ma}	3	0

Table 3 shows the cost rate per worker as well as internal and external conditions for personnel requirements planning. The cost rate per worker is based on the IG Metal collective agreement for the metal and electrical industry (Saxony, Germany).

Table 3: Parameters for personnel requirement planning

Parameter		j=1	j=2
$Staff_{ma,j}^{Cost}$	ma=1	3 671	3 671
	ma=2	5 435	5 435
$Staff_{ma,j}^{Max}$	ma=1	1 000	2 500
	ma=2	1 500	4 500
$Staff_{ma,j}^{Min}$	ma=1	0	0
	ma=2	0	0
$Staff_{j}^{TotalMax}$	-	1 500	4 500
$Staff_{j}^{TotalMin}$	-	0	0

Finally, Table 4 and 5 contain the inventory cost rate and further inventory aspects (in quantity units) as well as shift bonuses and parameters for the determination of the shift model. Based on a 5-day week, a one- (s=1), two- (s=2) and three- (s=3) shift model are available.

Table 4: Parameters for warehousing

Parameter	k=1	k=2
h_k	115	165
I_k^{Init}	0	0
I_k^{Max}	30 000	37 500

Table 5: Parameters for determining the layer model

Parameter		s=1	s=2	s=3
$S_{j,s}^{Above}$	j=1	500	1 000	1 500
	j=2	1 500	3 000	4 500
$S_{j,s}^{Bottom}$	j=1	0	501	1 001
	j=2	0	1 501	3 001
S_s^{Cost}	-	0	0	0.083

MODEL FORMULATION

The linear optimization model presented here is based on Trost (2018) where a control of work intensity and basic aspects of personnel requirements planning are included. For this purpose, the relationship between capacity requirements and available capacity is constrained and in order to ensure the flexibility for the production system at the same time, the building and reducing of available capacity is integrated. The following parameters and decision variables are used:

Parameters

$CAPA_{ma}$	Available capacity per worker of a worker class ma
$d_{k,t}$	Product demand per product k and period t
$f_{z,j,k}$	Capacity requirement per forerun period z, production segment j, and product k
h_k	Cost rate for storage per product k
I_k^{Init}	Initial inventory per product k
I_k^{Max}	Maximum stock capacity per product k
J	Production segments (j = 1, 2, …, J)
K	Products (k = 1, 2, …, K)
MA	Worker class (ma = 1, 2, …, MA)
m_{ma}^{Cost}	Cost rate for building capacity per worker class ma
n_{ma}^{Cost}	Cost rate for reducing capacity per worker class ma
R_j^{Max}	Maximum worker utilization per production segment j
R_j^{Min}	Minimum worker utilization per production segment j
S	Number of shift models (s = 1, 2, …, S)
$S_{j,s}^{Above}$	Maximum limit for number of worker per production segment j and shift model s
$S_{j,s}^{Bottom}$	Minimum limit for number of worker per production segment j and shift model s
S_s^{Cost}	Cost factor for calculating shift bonuses per shift model s
$Staff_{ma,j}^{Cost}$	Cost rate per worker of worker class ma and production segment j
$Staff_{ma,j,s}^{Init}$	Initial number of worker per worker class ma, production segment j and shift model s
$Staff_{ma,j}^{Max}$	Maximum number of worker per worker class ma and production segment j
$Staff_{ma,j}^{Min}$	Minimum number of worker per worker class ma and production segment j
$Staff_j^{TotalMax}$	Maximum number of worker per production segment j
$Staff_j^{TotalMin}$	Minimum number of worker per production segment j
T	Planning horizon (t = 1, 2, …, T)
V	Number of periods for overtime balancing
W	Maximal number of forerun periods for modifying of capacity (w = 1, 2, …, W)
we_{ma}	Number of forerun periods for capacity building per employee group ma
wf_{ma}	Number of forerun periods for capacity reduction per employee group ma
x_k^{Fix}	Fixed production quantity per product k
Z	Number of forerun periods for production (z = 1, 2, …, Z)

Decision Variables

$a_{j,t}$	Available capacity per production segment j and period t
$b_{j,t}$	Capacity requirement per production segment j and period t
$I_{k,t}$	Inventory per product k and period t
$m_{ma,j,t}$	Number of recruitments per worker class ma, production segment j and period t
$n_{ma,j,t}$	Number of layoffs per worker class ma, production segment j and period t
$overtime_{j,t}$	Quantity of overtime per production segment j and period t
$p_{j,s,t}$	Boolean-Variable for shift model determination per production segment j, shift model s and period t
$Staff_{ma,j,s,t}$	Number of worker per worker class ma, production segment j, shift model s and period t
$x_{k,t}$	Produced quantity per product k and period t

Objective Function

The objective function minimizes the costs from inventories, employees, shift bonuses and capacity building as well as reducing (see equ. 1-7).

$$\text{ObjectiveFunction} = \text{Minimize}\left(\text{TotalCosts}\right) \quad (1)$$

$$\text{TotalCosts} = \text{InventoryCost} + \text{StaffCost} + \text{ShiftCost} + \text{BuildingCost} + \text{ReductionCost} \quad (2)$$

$$\text{InventoryCost} = \sum_t^T \sum_k^K h_k \cdot I_{k,t} \quad (3)$$

$$\text{StaffCost} = \sum_t^T \sum_s^S \sum_j^J \sum_{ma}^{MA} Staff_{ma,j}^{Cost} \cdot Staff_{ma,j,s,t} \quad (4)$$

$$\text{ShiftCost} = \sum_t^T \sum_s^S \sum_j^J \text{Staff}_{ma,j}^{Cost} \cdot \text{Staff}_{ma,j,s,t} \cdot S_s^{Cost} \quad (5)$$

$$\text{BuildingCost} = \sum_t^T \sum_j^J \sum_{ma}^{MA} m_{ma}^{Cost} \cdot m_{ma,j,t} \quad (6)$$

$$\text{ReductionCost} = \sum_t^T \sum_j^J \sum_{ma}^{MA} n_{ma}^{Cost} \cdot n_{ma,j,t} \quad (7)$$

Constraints

At first the general constraints: warehouse balance sheet, definition of initial stock, the fixing of an initial production quantity, the limitation of the maximum stock level and the determination of the capacity requirements are mapped in equ. 8-12.

$$x_{k,t} + I_{k,t-1} - I_{k,t} = d_{k,t} \qquad \forall 1 \le k \le K;\ \forall 1 \le t \le T \quad (8)$$

$$I_{k,t=0} = I_k^{Init} \qquad \forall 1 \le k \le K \quad (9)$$

$$x_{k,t=1} = x_k^{Fix} \qquad \forall 1 \le k \le K \quad (10)$$

$$I_{k,t} \le I_k^{Max} \qquad \forall 1 \le k \le K;\ \forall 1 \le t \le T \quad (11)$$

$$\sum_z^Z \sum_k^K f_{z,j,k} \cdot x_{k,t+z} = b_{j,t} \qquad \forall 1 \le j \le J;\ \forall 1 \le t \le (T-Z) \quad (12)$$

Next, the extensions by basic aspects of personnel requirements planning are described. Equ. 13-15 define the available capacity, the employee balancing sheet and the initial number of employees, whereby different employee groups are considered. In addition, internal and external conditions are taken into account in equ. 16-19. The minimum number of employees per production segment as well as per production segment and employee group are included in order to ensure the ability to work. The maximum number of employees per production segment is deduced from the number of workstations und the maximum number of employees per production segment and employee group consider the limitation of available skilled workers on the labour market. Furthermore, in equ. 20-22 it is taken into account that a variable number of employees may require different shift systems.

$$\sum_{ma}^{MA} \sum_s^S \text{Staff}_{ma,j,s,t} \cdot \text{CAPA}_{ma} = a_{j,t} \qquad \forall 1 \le j \le J;\ \forall 1 \le t \le T \quad (13)$$

$$\sum_s^S \text{Staff}_{ma,j,s,t-1} + m_{ma,j,t-we(ma)} - n_{ma,j,t-wf(ma)} = \sum_s^S \text{Staff}_{ma,j,s,t} \qquad \forall 1 \le ma \le MA;\ \forall 1 \le j \le J;\ \forall 1 \le t \le T \quad (14)$$

$$\text{Staff}_{ma,j,s,t=0} = \text{Staff}_{ma,j,s}^{Init} \qquad \forall 1 \le ma \le MA;\ \forall 1 \le j \le J;\ \forall 1 \le s \le S \quad (15)$$

$$\sum_s^S \text{Staff}_{ma,j,s,t} \ge \text{Staff}_{ma,j}^{Min} \qquad \forall 1 \le ma \le MA;\ \forall 1 \le j \le J;\ \forall 1 \le t \le T \quad (16)$$

$$\sum_{ma}^{MA} \sum_s^S \text{Staff}_{ma,j,s,t} \ge \text{Staff}_j^{TotalMin} \qquad \forall 1 \le j \le J;\ \forall 1 \le t \le T \quad (17)$$

$$\sum_s^S \text{Staff}_{ma,j,s,t} \le \text{Staff}_{ma,j}^{Max} \qquad \forall 1 \le ma \le MA;\ \forall 1 \le j \le J;\ \forall 1 \le t \le T \quad (18)$$

$$\sum_{ma}^{MA} \sum_s^S \text{Staff}_{ma,j,s,t} \le \text{Staff}_j^{TotalMax} \qquad \forall 1 \le j \le J;\ \forall 1 \le t \le T \quad (19)$$

$$\sum_{ma}^{MA} \text{Staff}_{ma,j,s,t} \ge p_{j,s,t} \cdot S_{j,s}^{Bottom} \qquad \forall 1 \le j \le J;\ \forall 1 \le s \le S;\ \forall 1 \le t \le T \quad (20)$$

$$\sum_{ma}^{MA} \text{Staff}_{ma,j,s,t} \le p_{j,s,t} \cdot S_{j,s}^{Above} \qquad \forall 1 \le j \le J;\ \forall 1 \le s \le S;\ \forall 1 \le t \le T \quad (21)$$

$$\sum_s^S p_{j,s,t} = 1 \qquad \forall 1 \le j \le J;\ \forall 1 \le t \le T \quad (22)$$

The next extension of control the work intensity is mapped in equ. 23-24, whereby this is interpreted as the ratio of capacity requirement to available capacity.

$$R_j^{Min} \cdot a_{j,t} \le b_{j,t} \qquad \forall 1 \le j \le J;\ \forall 1 \le t \le (T-Z) \quad (23)$$

$$R_j^{Max} \cdot a_{j,t} \ge b_{j,t} \qquad \forall 1 \le j \le J;\ \forall 1 \le t \le (T-Z) \quad (24)$$

Finally, due to the social orientation of this model, overtime planned for the long term is not permitted. But for the analysis of strategies that allow this, this can be considered with equ. 24. However, since no overtime costs are calculated, equ. 25-27 takes into account that overtime must be compensated within a fixed interval.

$$b_{j,t} - a_{j,t} = \text{overtime}_{j,t} \qquad \forall 1 \le j \le J;\ \forall 1 \le t \le (T-Z) \quad (25)$$

$$\sum_{t-V}^{t} \text{overtime}_{j,t} \le 0 \qquad \forall 1 \le j \le J;\ \forall 1 \le t \le (T-Z) \quad (26)$$

$$\sum_{t=0-V}^{t=0} \text{overtime}_{j,t} = 0 \qquad \forall 1 \le j \le J \quad (27)$$

RESULTS AND DISCUSSION

For the investigation three demand situations are distinguished on the basis of an earlier demand forecast (40 000 for k=1 and 50 000 for k=2) and a standard deviation of 5%, 10% and 20% in order to map different production situations. Furthermore the study distinguishes between three scenarios which are deduced from various possibilities to improve the deficits in working conditions identified in chapter 2. The first scenario (MPS) allows an employee utilization between 0% and 120% (RMax =1.2 and RMin =0). This represents the state of the art, whereby long-term planned overtime is allowed. For the compensation of the overtime (equ. 26) an interval of half a year (V=5) is considered in accordance with the working time law § 3 (Germany). As a first improvement in working conditions, the second scenario (MPS-OR) prohibits the long-term planning of overtime. This overtime reduction (OR) is achieved by limiting the maximum employee utilization (RMax=1.0). The third scenario (MPS-OR-WIC) considers a concrete work intensity control (WIC) to improve the working conditions. For this, four intervals per production segment between 80% and 100% with an interval width of 5% are considered as employee utilization (80-85%, 85-90%, 90-95% and 95-100% [RMin-RMax]). In addition, this enables the consideration of employee utilization-specific processing times. This is based on the assumption that the processing time increases with increasing employee utilization due to exhaustion effects. In this respect, 3 different exponential exhaustion courses are assumed (strong, low and no exhaustion). In total, the different employee utilization intervals per production segment results in 16 single solutions for each demand situation and the course of exhaustion. For the determination of the optimal solution out of this single solutions 3 different strategies are distinguished to analyse the respective improvements of working conditions. The first strategy stands for using the most cost-effective solution as the result. In the second strategy, the employee utilization interval of 95-100% is blocked and the now most cost-effective solution is taken as the result. Finally, the third strategy considers the solution of the employee utilization interval 80-85% as the result. The following results were obtained using CPLEX 12.7.1 and a 3.30 GHz PC with 192 GByte RAM. Each problem (in total 150 problems) could be solved within 300 seconds. At first, the corresponding costs are presented in Table 6. In order to examine the improvement of the scenarios on working conditions, the deviation of the regular working time is determined by the maximum amplitude of the employee utilization (see Table 7) and the work intensity is interpreted as average employee utilization (see Table 8). However, for the third scenario it should be noted that due to the control of work intensity the maximum amplitude of employee utilization is always 5%. The overtime hours are not explicitly reported, due they occur only in the first scenario. In order to make visible the improvements achieved in working conditions and the associated cost effects, for the first scenario the concrete numerical results are pointed out and for the second and third scenario the percentage deviations from the first scenario are presented.

Table 6: Total Costs for each scenario and demand trend

		Demand Trend	**5 %**	**10 %**	**20 %**
MPS			651 614 893 MU	660 484 851 MU	669 906 419 MU
MPS-OR			+ 0.76 %	+ 1.58 %	+ 5.01 %
MPS-OR-WIC	Strong Exhaustion	Strategy 1	- 0.38 %	+ 1.09 %	+ 5.35 %
		Strategy 2	- 0.29 %	+ 1.17 %	+ 5.43 %
		Strategy 3	+ 3.17 %	+ 4.59 %	+ 8.89 %
	Low Exhaustion	Strategy 1	+ 0.89 %	+ 2.38 %	+ 6.70 %
		Strategy 2	+ 2.88 %	+ 4.36 %	+ 8.70 %
		Strategy 3	+ 10.16 %	+ 11.60 %	+ 16.04 %
	No Exhaustion	Strategy 1	+ 0.89 %	+ 2.38 %	+ 6.70 %
		Strategy 2	+ 6.14 %	+ 7.63 %	+ 12.05 %
		Strategy 3	+ 18.51 %	+ 19.96 %	+ 24.64 %

Table 7: Amplitude of employee utilization for each scenario and demand trend per production segment

Demand Trend	**5 %**		**10 %**		**20 %**	
Production Segment	j = 1	j = 2	j = 1	j = 2	j = 1	j = 2
MPS	12.69 %	12.62 %	22.35 %	23.45 %	46.46 %	43.1 %
MPS-OR	- 35.8 %	- 36.72 %	- 37.95 %	- 38.63 %	- 47.01 %	- 50.7 %
MPS-OR-WIC*	- 60.59 %	- 60.39 %	- 77.63 %	- 78.68 %	- 89.24 %	- 88.4 %

* For all exhaustion courses and strategies identical, due to the fix employee utilization interval.

Table 8: Average employee utilization for each scenario and demand trend per production segment

		Demand Trend	**5 %**		**10 %**		**20 %**	
		Production Segment	j = 1	j = 2	j = 1	j = 2	j = 1	j = 2
MPS			99.22 %	99.20 %	98.38 %	98.37 %	96.50 %	97.01 %
MPS-OR			- 0.47 %	- 0.30 %	- 0.99 %	- 0.56 %	- 0.46 %	- 0.35 %
MPS-OR-WIC	Strong Exhaustion	Strategy 1	- 15.28 %	- 0.13 %	- 14.67 %	+ 0.63 %	- 12.95 %	+ 2.21 %
		Strategy 2	- 15.28 %	- 5.17 %	- 14.62 %	- 4.45 %	- 12.93 %	- 2.95 %
		Strategy 3	- 15.29 %	- 15.23 %	- 14.57 %	- 14.62 %	- 12.88 %	- 13.30 %
	Low Exhaustion	Strategy 1	- 0.21 %	- 0.14 %	+ 0.64 %	+ 0.63 %	+ 2.66 %	+ 2.21 %
		Strategy 2	- 5.20 %	- 5.15 %	- 4.45 %	- 4.47 %	- 2.54 %	- 2.97 %
		Strategy 3	- 15.25 %	- 15.16 %	- 14.53 %	- 14.53 %	- 12.96 %	- 13.38 %
	No Exhaustion	Strategy 1	- 0.21 %	- 0.14 %	+ 0.64 %	+ 0.63 %	+ 2.66 %	+ 2.21 %
		Strategy 2	- 5.24 %	- 5.18 %	- 4.43 %	- 4.46 %	- 2.55 %	- 2.99 %
		Strategy 3	- 15.25 %	- 15.14 %	- 14.65 %	- 14.43 %	- 13.1 %	- 13.49 %

For the first scenario (MPS) the results show that an increase of demand fluctuation is associated with an increase in costs and in the amplitude of employee utilization as well as a decrease in the average employee utilization. This is due to the fact that greater fluctuations in demand lead to higher capacity fluctuations. On the one hand, these are compensated by a greater amplitude of employee utilization and on the other hand the costs are rising due to increased pre-production and adjustments of the available capacity. With classical approaches these expected results cannot be investigated and it underlines the ability of the here presented approach to model typical effects of real production systems. Furthermore, an expected high work intensity is also apparent. In addition, overtime planned for the long term is permitted at the first scenario. For a 35 hour week, for example, this would be 7 hours per week with a maximum employee utilization of 120%. Furthermore, a high amplitude of employee utilization can be observed. 12%, for example, correspond to 4.5 hours per week for a 38 hour week. Accordingly, this results reflect the deficits in working conditions identified in chapter 2.

In the second scenario (MPS-OR), the first improvement in working conditions is the elimination of long-term planned overtime. Parallel to the first scenario, a cost increase due to rising fluctuations in demand can also be observed. In addition, the cost variances also increase in comparison to the first scenario with increasing fluctuations in demand. Furthermore, a lower amplitude of employee utilization of more than 35% can also be seen. However, the average working intensity can only be improved insignificantly.

In the third scenario (MPS-OR-WIC), the work intensity is improved by controlling employee utilization. It becomes clear that further reductions of up to 89% of the amplitude of employee utilization can be achieved as a result. In addition, the selection of a suitable strategy can improve the average work intensity. However, it can be seen that Strategy 1 cannot guarantee any improvements. For example, an improvement of more than 12% is achieved for strong exhaustion effects in production segment 1. This is due to the fact that for this cases the employee utilization interval of 80-85% is the most cost-effective. However, the other results of Strategy 1 show that no general conclusions can be drawn from it. In addition, next to the previous observations due to increased fluctuations in demand, a cost increase can also be observed with decreasing exhaustion and from strategy 1 to 3.

In order to analyse the improvements achieved in working conditions, these should be linked to the resulting cost implications. First, it can be rejected that improvements in working conditions are automatically associated with cost increases, as can be seen from the results of the third scenario for strategies 1 and 2 with strong exhaustion effects and 5% fluctuation in demand. Nevertheless, it must be taken into account for the evaluation of the indicated cost increases that the current model does not consider any further effects of improved working conditions apart from employee utilization-specific processing times. These are, for example, reduced illnesses, leaves or errors of employees. With the average illness rate in Germany of 4.28% (Statista 2019) and the findings from chapter 2, about 1.75% of illnesses can be attributed to muscular, skeletal and psychological causes. If this is only transferred to personnel costs, scenario 1 and a 5% fluctuation in demand, for instance, result in costs of over 11 400 000 money units, which corresponds to a cost increase of about 1.64%. Further costs are incurred due to the loss of production due to illness or the short-term replacement of employees. The leaving of employees and an increase in the number of errors also lead to additional costs, which should be considered by evaluation of the indicated cost increases. But it must be mentioned that such correlations currently cannot be quantified.

Finally, it is concluded that working conditions can be improved through an adapted MPS and that this is associated with a justifiable increase in costs or a reduction in costs. However, it also becomes clear that the investigated scenarios for strong fluctuations in demand lead to cost increases of more than 5%, so that future investigations should consider alternative strategies such as wider employee utilization intervals.

CONCLUSION

The article demonstrated that working conditions of manufacturing companies can be improved through adapted production planning. From the presented literature review it was pointed out that deficits in working conditions like high work intensity exists. Furthermore, it became clear that social aspects are predominantly considered in planning models with a short-term planning horizon and that there is a gap in research for planning models with a long-term planning horizon. To address this gap und to improve the mentioned deficits in working conditions a linear optimization model for MPS was presented, which include a control of work intensity. The representative case study shows that improvements in working conditions are not automatically associated with increasing costs, especially if, in addition to the employee utilization-specific processing times considered here, other effects of improved working conditions such as lower employee fluctuations are taken into account. However, the challenges of future research will initially consist in quantifying these correlations. In addition, there is a need for further research into the investigation of alternative strategies to improve working conditions, in particular for production situations with strong fluctuations in demand.

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