Employment of temporary workers and use of overtime to achieve volume flexibility using master production scheduling: monetary and social implications

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ABSTRACT

Flexibility and in particular volume flexibility is an important topic for industrial manufacturing companies. In this context, the harmonization of the available and required capacity is a central task, especially with increasing fluctuations in customer demand. In classical approaches, this is considered only by the use of additional capacities and there are only a few approaches that combine aspects of personnel planning with production planning. Therefore, this article presents a linear optimization model for master production scheduling that includes aspects of personnel requirements planning. It is used to investigate different strategies for the use of overtime and temporary workers in order to achieve different levels of volume flexibility. With regard to the monetary and social impacts, the results indicate that overtime has a stronger influence to achieve volume flexibility than the use of temporary workers. However, both are affected by substantial deficits in human working conditions. But the results also imply a promising potential for improving the social aspects without a significant increase in costs.

INTRODUCTION

Environmental uncertainty, the increasing variability of products and processes require a high degree of flexibility from industrial production companies (Jain et al. 2013). Thus, companies have to meet shorter delivery times and life cycles, a wider range of products as well as incresead customization (Toni and Tonchia 1998). The wider range of products and the shorter product life cycle have increased the fluctuations in demand (Francas et al. 2011). To overcome these fluctuations, companies have to achieve volume flexibility. For this, balancing available capacity with capacity requirements has become important (Francas et al. 2011). Companies implement a variety of strategies to attain this harmonization. These include the use of overtime and employment of temporary workers (Qin et al. 2015). An intuitive use of these flexibility measures can be disadvantageous, but a reasoned implementation can reduce costs (Hemig et al. 2014).
In conventional approaches of hierarchical production planning, as described e.g. in Herrmann and Manitz (2015), a harmonization of capacities is realized on the levels of Aggregate Production Planning (APP) and Master Production Scheduling (MPS) by pre-production and additional capacities. Further approaches integrate aspects of personnel requirement planning. However, the flexibility measures are not analysed in terms of volume flexibility as well as their monetary implications. For this reason, this paper investigates the employment of temporary workers and the use of overtime hours at the level of MPS. Different levels of the required volume flexibility are modelled by normally distributed customer demands with different standard deviations. The flexibility costs of the different fluctuations in demand are determined, whereby temporary workers and overtime are permitted or not permitted as flexibility strategies.
Additionally, 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 a shortage of skilled workers. For labor-intensive processes, the available capacity is primary defined by the number of employees and their utilization. Therefore, measures to achieve volume flexibility particularly influence the human working conditions. Thus, this paper also investigates the impact of flexibility measures on social aspects. These include the employee utilization, deviations from regular working hours, the amount of overtime and the share of temporary workers.
For this, the paper is structured as follows. Section 2 presents a literature review. In section 3 the optimization model is described and the case study as well as the investigated flexibility strategies are introduced in section 4. The results and the discussion are outlined in section 5. Finally, a conclusion is presented in section 6.

LITERATURE REVIEW

Flexibility at industrial manufacturing companies include several dimensions where there is no general agreement on its definition (Saleh et al. 2009; Yu et al. 2015). One reason for this is that each company has its individual understanding of flexibility (Jain et al. 2013). For an overview of the most common flexibility definitions used by different authors, the reader is referred to Jain et al. (2013). In the literature, the flexibility dimensions are assigned to different classes by several authors (e.g. Sethi and Sethi 1990; Koste and Malhotra 1999). Koste and Malhotra (1999) distinguish between the following four

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levels: individual resource level; shop floor level; plant level and functional level. This paper deals with the increasing fluctuations in demand, which require an appropriate volume flexibility of manufacturing companies. This volume flexibility is related to the plant level (Koste and Malhotra 1999) and has become an important competitive strategy (Jack and Raturi 2002). Volume flexibility is a measure of the ability of a production system to efficiently adapt to changing demands in response to changing socio-economic conditions (Jack and Raturi 2002; Sillekens et al. 2011; Jain et al. 2013).

The plant level of flexibility is reflected within the operational production planning. APP and MPS are the core elements of operational production planning (Günther and Tempelmeier 2020). The aim is to satisfy the fluctuating demand for the finished products with existing resources by defining production programs and determining the utilization of resources (Günther and Tempelmeier 2020). For this medium-term planning horizon, the working time flexibility of employees is of particular importance (Sillekens et al. 2011). The deployment of the workforce is organized, for instance, via shift models and working time accounts, and temporary workers additionally have a significant importance (Sillekens et al. 2011). A general working time flexibility is represented in basic models of APP and MPS by the use of additional capacities. However, concrete aspects such as legal restrictions or the costs of building up or removing resources are not considered. In addition, no distinction is made between concrete measures (e.g. use of temporary workers, use of overtime), which limits an analysis of concrete strategies for achieving volume flexibility.

Therefore, there are a few approaches which present an extension of the basic models in this respect by adding aspects of human resource requirements planning to the operational production planning. Hemig et al. (2014) consider an integrated production and workforce scheduling problem. The focus is on generating a minimum-cost schedule for the production of a forecasted demand, taking into account the application of volume flexibility tools. The problem is modeled as a (nonlinear) mixed-integer program and solved using dynamic programming. Bose et al. (2016) consider the strategic capacity planning in a multi-product, multi-plant configuration under demand uncertainty. A two-stage stochastic programming model is presented to determine capacity and product-plant configuration to maximize expected profit. The model is solved to understand the effect of product-plant configurations on expected profit and investment in capacity. Treber et al. (2016) present an approach for the management of production networks. The focus is on capacity planning and the use of tools that make the workforce more flexible. In particular, aspects of workforce flexibility are mapped via a mathematical optimization model. Furthermore, a function is implemented for accounting errors in the forecasted demand.

While the monetary evaluation of different flexibility strategies is established, impacts regarding social sustainability have not been considered so far. As already mentioned, flexible deployment of employees is necessary to ensure the required volume flexibility. But, this directly influences the human working conditions and is thus an influencing factor with regard to social sustainability. From a survey of works council ermerges, that there are deficitis in working conditions, e.g. 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 (Ahlers 2017). Further, the use of temporary workers can lead to social inequalities, as temporary workers are disadvantaged in terms of income and career mobility (Giesecke and Groß 2004). Furthermore, temporary workers seem to be exposed to higher psychological stress due to the uncertain work perspective (Virtanen et al. 2005). According to Nerdinger et al. (2014), the consequences of unhealthy working conditions can be an increased heart rate, frustration or increased errors, which in the long term leads to psychosomatic illnesses, resignation and demotivation. The BKK Health Report 2017, for example, attributes 25% of lost work days to musculoskeletal disorders and 16% to mental illnesses (Knieps and Pfaff 2017). In addition, the DAK Health Report 2018 shows an increase of more than 160% in days lost from work between 1997 and 2017 (Storm 2018). Furthermore, besides these significant consequences for health, the absence of employees also restricts the volume flexibility of companies.

To the best of the authors' knowledge, there are no papers that combining operational production planning with aspects of human resource requirements planning and considering the monetary and social effects of using temporary workers and overtime to ensure volume flexibility.

MODEL FORMULATION

The linear optimization model presented here is based on Trost (2018) and Trost et al. (2020) where a control of work intensity and basic aspects of personnel requirements planning are included. To ensure the volume flexibility, the building and reducing of available capacity (employees) is integrated. The following notation is used:

Sets

$EG = \{1, \dots, EG\}$	set of employee groups, indexed by *eg*
$J = \{1, \dots, J\}$	set of production segments, indexed by *j*
$K = \{1, \dots, K\}$	set of products, indexed by *k*
$T = \{1, \dots, T\}$	set of time periods, indexed by *t*
$Z = \{0, \dots, Z\}$	set of lead-time periods for capacity load, indexed by *z*

Parameters

$Capa_{eg}$	available capacity per period and employee of employee group *eg*
$d_{k,t}$	demand per product *k* in period *t*
$f_{z,j,k}$	capacity load factors for lead-time period *z*, production segment *j* and product *k*
h_k	inventory holding costs per unit and period for product *k*

I_k^{Init}	initial inventory level for product *k*
I_k^{Max}	maximum inventory level for product *k*
m_{eg}^{Cost}	cost rate for hiring an employee from employee group *eg*
n_{eg}^{Cost}	cost rate for layoff an employee from employee group *eg*
R_j^{Max}	maximum permitted employee utilisation per production segment *j*
$Staff_{eg}^{Cost}$	cost rate per employee of employee group *eg*
$Staff_{eg,j}^{Init}$	initial number of employees per employee group *eg* and production segment *j*
$Staff_{eg,j}^{Max}$	maximum number of employees per employee group *eg* in production segment *j*
V	number of periods for overtime balancing
we_{eg}	lead-time periods for hiring employees of employee group *eg*
wf_{eg}	lead-time periods for employee turnover of employee group *eg*

Decision Variables

$a_{j,t}$	available capacity per production segment *j* in period *t*
$b_{j,t}$	capacity requirement per production segment *j* in period *t*
$I_{k,t}$	inventory level per product *k* in period *t*
$m_{eg,j,t}$	number of hired employees of employee group *eg* in production segment *j* and period *t*
$n_{eg,j,t}$	number of layoffs of employee group *eg* in production segment *j* and period *t*
$overtime_{j,t}$	used overtime per production segment *j* and period *t*
$Staff_{eg,j,t}$	number of employees of employee group *eg*, production segment *j* and period *t*
$x_{k,t}$	production quantity per product *k* in period *t*

Objective Function

The objective function minimizes the total costs from inventories, employees, and worker hiring as well as layoff (see equation (1) to equation (6)).

$$Objective\ Function: Minimize\ (TotalCosts) \tag{1}$$

$$TotalCosts = InventoryCosts + StaffingCost + HiringCosts + LayoffCosts \tag{2}$$

$$InventoryCosts = \sum_{t=1}^{T}\sum_{k=1}^{K} h_k \cdot I_{k,t} \tag{3}$$

$$StaffingCosts = \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{eg=1}^{EG} Staff_{eg}^{Cost} \cdot Staff_{eg,j,t} \tag{4}$$

$$HiringCosts = \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{eg=1}^{EG} m_{eg}^{Cost} \cdot m_{eg,j,t} \tag{5}$$

$$LayoffCosts = \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{eg=1}^{EG} n_{eg}^{Cost} \cdot n_{eg,j,t} \tag{6}$$

Constraints

First, as general constraints there are the inventory balance sheet (equation (7)), the definition of the initial and maximum inventory level (equation (8) and equation (9)) and equation (10) determine the capacity requirements.

$$x_{k,t} + I_{k,t-1} - I_{k,t} = d_{k,t} \quad \forall\ 1 \le k \le K;\ \forall\ 1 \le t \le T \tag{7}$$

$$I_{k,t=0} = I_k^{Init} \quad \forall\ 1 \le k \le K \tag{8}$$

$$I_{k,t} \le I_k^{Max} \quad \forall\ 1 \le k \le K;\ \forall\ 1 \le t \le T \tag{9}$$

$$\sum_{z=0}^{Z}\sum_{k=1}^{K} f_{z,j,k} \cdot x_{k,t+z} = b_{j,t} \quad \forall\ 1 \le j \le J;\ \forall\ 1 \le t \le (T-Z) \tag{10}$$

The aspects of human resource requirements planning are modelled as follows. The available capacity is integrated by equation (11), the employee hiring and layoff by the employee balance sheet (equation (12)) and the initial employee level by equation (13). Between the regular and temporary employees are distinguished by different employee groups (EG) and also different lead times for hiring (we_{eg}) and layoffs (wf_{eg}) are modelled. Equation (14) represents that the available number of (skilled) employees is limited on the labour market.

$$\sum_{eg=1}^{EG} Staff_{eg,j,t} \cdot Capa_{eg} = a_{j,t} \quad \forall\ 1 \le j \le J;\ \forall\ 1 \le t \le T \tag{11}$$

$$Staff_{eg,j,t} = Staff_{eg,j,t-1} + m_{eg,j,t-we_{eg}} - n_{eg,j,t-wf_{eg}} \quad \forall\ 1 \le eg \le EG;\ \forall\ 1 \le j \le J;\ \forall\ 1 \le t \le T \tag{12}$$

$$Staff_{eg,j,t=0} = Staff_{eg,j}^{Init} \quad \forall\ 1 \le eg \le EG;\ \forall\ 1 \le j \le J \tag{13}$$

$$Staff_{eg,j,t} \le Staff_{eg,j}^{Max} \quad \forall\ 1 \le eg \le EG;\ \forall\ 1 \le j \le J;\ \forall\ 1 \le t \le T \tag{14}$$

With regard to the consideration of overtime the maximum utilization of employees is modelled by equation (15). Overtime can occur if the maximum utilization (R_j^{Max}) is over 100 %. The control of overtime is achieved by equation (16) to equation (18). However, overtime do not result in additional costs because they have to be compensated within a specific time interval (by equation (17)) which meets legal restrictions. When the maximum utilization is less than 100% the equation (16) to equation (18) are not restrictive.

$$R_j^{Max} \cdot a_{j,t} \geq b_{j,t} \quad (15)$$
$$\forall\, 1 \leq j \leq J;\ \forall\, 1 \leq t \leq (T-Z)$$

$$b_{j,t} - a_{j,t} = overtime_{j,t} \quad (16)$$
$$\forall\, 1 \leq j \leq J;\ \forall\, 1 \leq t \leq (T-Z)$$

$$\sum_{t'=t-V}^{t} overtime_{j,t'} \leq 0 \quad (17)$$
$$\forall\, 1 \leq j \leq J;\ \forall\, 1 \leq t \leq (T-Z)$$

$$\sum_{t'=0-V}^{t=0} overtime_{j,\,t'} = 0 \qquad \forall\, 1 \leq j \leq J \quad (18)$$

Finally, the non-negative conditions and the integer conditions are defined in equation (19) and equantion (20).

$$a_{j,t}\,, b_{j,t}\,, I_{k,t}\,, m_{eg,j,t}\,, n_{eg,j,t}\,, Staff_{eg,j,t}\,, x_{k,t} \geq 0 \quad (19)$$
$$\forall\, 1 \leq eg \leq EG;\ \forall\, 1 \leq j \leq J;$$
$$\forall\, 1 \leq k \leq K;\ \forall\, 1 \leq t \leq T$$

$$Staff_{eg,j,t} \in \{\mathbb{Z}\} \quad (20)$$
$$\forall\, 1 \leq eg \leq EG;\ \forall\, 1 \leq j \leq J;\ \forall\, 1 \leq t \leq T$$

CASE STUDY AND FLEXIBILITY STRATEGIES

The case study considered here is based on Trost et al. (2019). At first, general parameters are presented in Table 1. The different employee groups (EG) represent the regular ($eg = 1$) and temporary employees ($eg = 2$).

Table 1: General Parameters

Parameter	Value
EG	2
J	2
K	2
W	3
Z	1

Further, Table 2 presents the employee related parameters for regular and temporary workers, which are based on a Saxon railway company with a IG Metal collective agreement for the metal and electrical industry. Due to the experience gap of temporary workers, they have a lower available capacity ($Capa_{eg}$ in seconds) than regular workers, which means that for given capacity load factors a lower productivity is depicted. However, the hiring and layoffs of temporary workers are outsourced to an external service provider, resulting in shorter lead times (we_{eg} and wf_{eg} in periods) and lower cost rates (m_{eg}^{Cost} and n_{eg}^{Cost}). But due to the agency fees, the cost rate per employee and period ($Staff_{eg}^{Cost}$) are higher for temporary workers than for regular workers.

Table 2: Employee parameters per worker class (eg)

Parameter	$eg = 1$	$eg = 2$
$Capa_{eg}$	524 400	393 300
m_{eg}^{Cost}	15 000	1 500
n_{eg}^{Cost}	60 000	100
we_{eg}	3	1
wf_{eg}	3	0
$Staff_{eg}^{Cost}$	3 671	5 435

Finally, Table 3 contains the inventory cost rate (h_k), the maximum inventory level (I_k^{Max} in quantity units) and the capacity load factors ($f_{z,j,k}$ in seconds). Note, that the capacity load only occur in lead-time period $z = 1$.

Table 3: Further parameters

Parameter		$k = 1$	$k = 2$
h_k		115	165
I_k^{Max}		30 000	37 500
$f_{z=1,j,k}$	$j = 1$	3 867	4 092
	$j = 2$	13 976	10 184

In order to investigate several required volume flexibility situations, different customer demands ($d_{k,t}$) are distinguished. A constant demand with 40 000 units of product one and 50 000 units of product two is the initial demand situation. Based on this, three normally distributed demand courses with a coefficient of variation from 5 %, 10 % and 20 % are regarded. To achieve this volume flexibility, the following four strategies are applied:

- **Strategy 1** enables the use of regular employees and temporary workers ($Staff_{eg,j=1}^{Max} = 1\,500$ and $Staff_{eg,j=2}^{Max} = 4\,500$), as well as 20 % overtime hours related to the regular working time ($R_j^{Max} = 1.2$). The overtime hours have to be compensated in accordance with the working time law § 3 (Germany) within an half a year ($V = 5$).
- Within **Strategy 2**, temporary workers cannot be employed ($R_j^{Max} = 1.2$, $Staff_{eg=1,j=1}^{Max} = 1\,500$, $Staff_{eg=1,j=2}^{Max} = 4\,500$ and $Staff_{eg=2,j}^{Max} = 0$).
- For **Strategy 3**, overtime cannot be used ($R_j^{Max} = 1.0$, $Staff_{eg,j=1}^{Max} = 1\,500$ and $Staff_{eg,j=2}^{Max} = 4\,500$).
- Finally, in **Strategy 4** neither overtime nor temporary workers are permitted ($R_j^{Max} = 1.0$, $Staff_{eg=1,j=1}^{Max} = 1\,500$, $Staff_{eg=1,j=2}^{Max} = 4\,500$ and $Staff_{eg=2,j}^{Max} = 0$).

RESULTS AND DISCUSSION

For this investigation, the results of the four strategies considered for achieving volume flexibility are compared. Strategy 1, which allows the use of temporary workers as well as overtime, serves as a benchmark. These strategies are applied to the four demand courses. In order to increase the statistical significance, five random demand series are realized for each normally distributed demand course. In total, 64 different planning problems are considered. Each planning problem regard a planning horizon from 84 month ($T = 84$). However, a 6-month warm up as well as run out phase are taken into account, so that the results from 72 months are analysed ($\hat{T} = 72$). The results were obtained using CPLEX 12.10 on a 3.30 GHz PC with 192 GByte RAM. Each problem could be solved within 12.44 seconds on average.

First, the monetary effects of the different strategies per demand course are considered. Table 4 presents the total costs for Strategy 1 as well as the relative deviations of the other strategies per demand course. Unrelated to the used flexibility strategy, the total costs increase with increasing required volume flexibility. These flexibility costs results from an increased pre-production, an increased number of employed regular as well as temporary workers and increased adjustments in the number of employees. Thus, an increase of all cost components (inventory costs, staffing costs, hiring costs and layoff costs) can be observed.

Table 4: Total costs for strategy 1 and relative deviations of the further strategies for each demand course

	Demand courses			
	Constant	5 % coefficient of variation	10 % coefficient of variation	20 % coefficient of variation
Strategy 1	719 607 417 MU	730 834 953 MU	746 430 404 MU	770 407 813 MU
Strategy 2	+ 0.04 %	+ 0.26 %	+ 1.19 %	+ 0.96 %
Strategy 3	+ 0.03 %	+ 0.87 %	+ 2.24 %	+ 3.68 %
Strategy 4	+ 0.04 %	+ 1.75 %	+ 4.10 %	+ 6.26 %

In more detail, it emerges that for a constant demand course the waiver of temporary workers and/or overtime hours have only a small monetary impact from maximum 0.04 %. Further, within Strategy 2 (no temporary workers) a moderate increase in costs for all demand courses from maximum 1.19 % occur. In comparison to this, Strategy 3 (no overtime) result in higher flexibility costs than Strategy 2. Accordingly, not using overtime is associated with higher flexibility costs than not using temporary workers. It is concluded that the use of overtime has a greater contribution for achieving volume flexibility. The waiver of overtime and temporary workers (Strategy 4) cause increased flexibility costs up to 6.26 %. Thus, the (partial) waiver of the considerd flexibility measures result in negative monetary effects. However, in some cases, the cost increase is low, especially when the required volume flexibility is low. With higher required volume flexibility, there is also a low increase in costs if only the the employment of temporary workers is not permitted.

Concerning the social impact, we consider the before mentioned deficits in human working conditions. For this, Table 5 reports the average worker utilization to assess the work intensity ($\overline{U}_j$) and the amplitude of worker utilization to assess the deviations of standard working hours ($U_j^{Max-Min}$). Table 6 present the use of overtime for Strategy 1 and Strategy 2 by the share of periods with used overtime ($\hat{T}_j^{OT}$) as well as the mean ($\overline{OT}_j$) and maximum (OT_j^{Max}) overtime within these periods related to the regular working time. For Strategy 3 and Strategy 4 overtime is excluded.

Table **7** reports the employment of temporary workers for Strategy 1 and Strategy 3 by the share of periods in which temporary workers are employed ($\hat{T}_j^{TW}$), the average share of temporary workers within these periodes ($\overline{TW}_j$) and the maximum share of temporary workers (TW_j^{Max}). For Strategy 2 and Strategy 4 temporary workers are excluded. All results refer to production segment one, note that production segment two contains analogous effects.

Table 5 to

Table **7** indicate that with higher required volume flexibility a higher deviations from regular working hours, use of overtime and employment of temporary workers occur. However, the average employee utilization decreases with increasing volume flexibility and with the absence of (single) flexibilty measures (Strategy 2 to Strategy 4) further reduction in average utilization occur.

Table 5: Mean utilization ($\overline{U}_j$) and amplitude of utilization ($U_j^{Max-Min}$) for production segment one

	Demand courses							
	Constant		5 % coefficient of variation		10 % coefficient of variation		20 % coefficient of variation	
	$\overline{U}_{j=1}$	$U_{j=1}^{Max-Min}$	$\overline{U}_{j=1}$	$U_{j=1}^{Max-Min}$	$\overline{U}_{j=1}$	$U_{j=1}^{Max-Min}$	$\overline{U}_{j=1}$	$U_{j=1}^{Max-Min}$
Strategy 1	100.00 %	0.14 %	99.04 %	14.28 %	98.26 %	31.75 %	96.76 %	51.06 %
Strategy 2	99.87 %	0.00 %	98.69 %	16.22 %	97.01 %	33.93 %	95.24 %	55.11 %
Strategy 3	99.87 %	0.03 %	98.84 %	7.84 %	97.71 %	17.17 %	95.69 %	29.34 %
Strategy 4	99.87 %	0.00 %	97.65 %	10.32 %	95.06 %	21.64 %	91.63 %	37.41 %

Table 6: Share of overtime periods ($\hat{T}_j^{OT}$) as well as mean ($\overline{OT}_j$) and maximum overtime (OT_j^{Max}) for production segment within these periods and related to the regular working time

	Demand courses											
	Constant			5 % coefficient of variation			10 % coefficient of variation			20 % coefficient of variation		
	$\hat{T}_{j=1}^{OT}$	$\overline{OT}_{j=1}$	$OT_{j=1}^{Max}$	$\hat{T}_{j=1}^{OT}$	$\overline{OT}_{j=1}$	$OT_{j=1}^{Max}$	$\hat{T}_{j=1}^{OT}$	$\overline{OT}_{j=1}$	$OT_{j=1}^{Max}$	$\hat{T}_{j=1}^{OT}$	$\overline{OT}_{j=1}$	$OT_{j=1}^{Max}$
Strategy 1	79.17 %	0.02 %	0.03 %	35.56 %	2.19 %	5.99 %	40.83 %	4.28 %	13.68 %	41.11 %	7.43 %	19.15 %
Strategy 2	0.00 %	0.00 %	0.00 %	33.89 %	2.34 %	6.92 %	33.89 %	4.41 %	13.81 %	36.39 %	7.39 %	19.79 %

Table 7: Share of periods with temporary workers ($\hat{T}_j^{TW}$) as well as mean ($\overline{TW}_j$) and maximum (TW_j^{Max}) share of temporary workers for production segment one within these periods and related to all employees

	Demand courses											
	Constant			5 % coefficient of variation			10 % coefficient of variation			20 % coefficient of variation		
	$\hat{T}_{j=1}^{TW}$	$\overline{TW}_{j=1}$	$TW_{j=1}^{Max}$	$\hat{T}_{j=1}^{TW}$	$\overline{TW}_{j=1}$	$TW_{j=1}^{Max}$	$\hat{T}_{j=1}^{TW}$	$\overline{TW}_{j=1}$	$TW_{j=1}^{Max}$	$\hat{T}_{j=1}^{TW}$	$\overline{TW}_{j=1}$	$TW_{j=1}^{Max}$
Strategy 1	20.83 %	0.15 %	0.15 %	30.56 %	1.82 %	6.63 %	33.33 %	4.08 %	10.57 %	36.11 %	6.01 %	17.65 %
Strategy 3	0.00 %	0.00 %	0.00 %	40.39 %	2.63 %	10.82 %	45.00 %	4.45 %	15.01 %	44.44 %	7.68 %	23.39 %

More in detail, with Strategy 1 and constant demand overtime and temporary workers are used. Because the available capacity from the optimal number of employees are not sufficient to satisfy the demand, a small amount of overtime is required. Since this has to be compensated within 6 months, the employment of a temporary worker is necessary in some periods. By not using (single) flexibility measures (Strategy 2 to Strategy 4) and a constant demand, the optimal number of employees is increased and no additional overtime or temporary workers are required. However, the average employee utilization is lower. With normally distributed demand courses, permitting overtime (strategy 1 and strategy 2) leads to significantly higher fluctuations in working hours and, in some cases, to an extensive use of overtime. If the use of temporary workers is not permitted in this context (strategy 2), working time fluctuations are even higher. For example, the maximum overtime of 19.79 % that occur at Strategy 2 and 20 % demand variation correspond to approximately 7.5 hours per week for a 38-hour work week. Accordingly, the fluctuations in working hours of 55.11 % correspond to varying weekly working hours of approximately 24.6 to 45.5 hours per week in relation to a standard working time of 38 hours per week. With the avoidance of overtime (Strategy 3 and Strategy 4) these fluctuations in working hours decrease. However, if the employment of temporary workers is permitted while overtime is avoided (Strategy 3), an increased employment of temporary workers occur as well. For this, even with low fluctuations in demand, the share of temporary workers is in some cases higher than 10 % and temporary workers are employed in more than 40 % of the periods. Strategy 4 excludes the use of overtime and the employment of temporary workers, which corresponds to a stronger social orientation and result, in some cases, in a significantly lower average employee utilization. In comparison to Strategy 1, which allows overtime and temporary workers, the fluctuations in working hours can be reduced by Strategy 4 as well. However, the reduction is not as strong as in Strategy 3, in which only overtime is avoided.

In summary, the use of overtime and temporary workers can reduce flexibility costs compared to not using these flexibility measures. However, in some cases, the achieved cost savings are small. But the social impact of these measures is negative. The avoidance of single flexibility measures does not lead to a comprehensive improvement of the social aspects, since restrictions of single social characteristics are compensated by the deterioration of other social aspects. Thus, we suggest that it might be more beneficial to limit for certain social aspects, e.g. fluctuations in working hours and the share of temporary workers, than to avoid it. The described monetary effects from avoiding a measure lead us to expect a corresponding potential for social improvements without a significant increase in costs.

CONCLUSION

The article demonstrated the monetary and social impact of the employment of temporary workers and the use of overtime. From the presented literature review it was pointed out that there are only a few approaches that consider production planning and personnel planning simultaneously. Further there are deficits in investigations regarding the impact on the use of overtime and temporary workers to archive volume flexibility. To address this gap, a linear optimization model for MPS was presented. The results indicate that ensuring the necessary volume flexibility impacts the human working conditions. Particularly in the case of higher fluctuations in demand, there are strong deviations from regular working hours, including frequent and, in some cases, extensive use of overtime. In addition, there is a frequent employment of temporary workers and, in some cases, a high share of temporary workers. The monetary impact of avoiding the flexibility measures demonstrate that this not necessarily cause a significant increase in costs even with higher fluctuations in demand. However, the use of overtime contributes more to achieving volume flexibility than the use of temporary workers, as indicated by higher flexibility costs for overtime avoidance than for temporary workers avoidance.

Finally, the working conditions might be improved by limiting specific social aspects without causing a significant increase in costs. The investigation of suitable limits is left for future work.

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