MASTER PRODUCTION SCHEDULING WITH INTEGRATED ASPECTS OF PERSONNEL PLANNING AND CONSIDERATION OF EMPLOYEE UTILIZATION SPECIFIC PROCESSING TIMES

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ABSTRACT

This article deals with the integration of social criterias into production planning and control. Firstly, it is emphasized, that working conditions for employees have barely improved and that production planning and control can achieve considerable progress in this field. The presented literature demonstrate, that only a few number of papers consider the social dimension at the context of production planning and control. Therefore this paper presents a linear optimization model for the Master Production Scheduling, which can be considered as a long-term employee utilization management system in order to reduce employee burdens. The special feature of this model is the link between aspects of personnel planning und production planning and control. The system consideres different employee utilization intervals and employee utilization specific processing times and it includes flexible capacities, so it is allowed to build and to reduce the available capacity. This model is used to examine a case study, with the aim to verify the need for the control of employee utilization. The results confirm previous results from short-term planning horizons, which underline, that maximizing the utilization of employees does not necessarily lead to optimal results. Finaly, further research questions can be derived from the analysis of the results.

INTRODUCTION

The development of sustainable models for production planning and control has received considerable attention in recent years. However, many papers ignore the social dimension. This is confirmed by the findings from Schmucker et al. (2014), which shows, that working conditions have hardly improved at all. In addition, the existing work, which takes the social dimension into account, concentrates primarily on optimizing the distribution of burdens. In this way, the overall burden on employees is not reduced, but only redistributed. Long-term load management is not known.

For this reason, the present work combines aspects of personnel planning with the Master Production Scheduling. In addition, different employee utilizations are assumed in order to take into account of employee utilization specific processing times, so that the exhaustion or recovery (hereinafter called exhaustion) of employees is also taken into account. In the area of personnel planning, the hiring and dismissal of personnel resources is integrated, whereby different qualifications and experiences as well as effects on shift models and labour market conditions are taken into account. Thus, the burden of employees can be reduced without restricting production capacity, because available capacity and capacity requirements are flexible.

The model presented here is an extension of the original model from Trost et al. (2017a and 2017b), which underlines the relevance of employee utilization specific processing times and demonstrate, that the most cost-effective production programme is not accompanied by maximum employee utilization. The current paper reviews these results for a long-term planning horizon and develops the model accordingly. The paper is divided into a brief review of the literature, an introduction to the linear optimization model, following by a case study and the results. A conclusion completes the article.

LITERATURE REVIEW

Considering the planning stages of the hierarchical production planning (Master Production Scheduling, Lot Sizing and Scheduling) presented by Drexl et al. (1993), it can be stated, that only a few papers exist, which take the social dimension into account. As already indicated in Trost et al. (2016), the social dimension is often overlooked in the development of sustainable models. Exceptions in the area of lot-sizing are, for example, the work of Arslan and Turkay (2013), in which personnel hours are to be minimized, and the work of Jaber and Bonney (2007), which integrates 2-phase learning and forgetting effects into a classic economic manufacture quantity model. In the scheduling area, for example, the

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work of Boysen and Fliedner (2011) is worth mentioning, in which the burden on the ground staff at an airport is minimised, which can be transferred to a production environment. Another work is that of Lai and Lee (2013), which integrates learning and forgetting effects into a scheduling model for a single-machine environment. It becomes clear, that many papers in this field mainly takes learning and forgetting effects into account and that no work is known, that takes social aspects into account in long-term planning models.

These findings are supported by the review of Grosse et al. (2017), who are looking for corresponding work and are setting up their own framework. The work classifies relevant papers in the areas of "inventory management and lot-sizing" (IM&LS), "production and assembly management" (P&AM) and "intra-logistics and warehouse management" (I&W). However, this does not apply to work that integrates learning effects into lot-sizing problems, since these have been researched more thoroughly, as mentioned before. As the work shows, although the number of corresponding papers has increased in recent years, there is still considerable potential for research. Relevant papers, mentioned by Grosse et al. (2017) for the IM&LS are, for example, the paper by Khan et al. (2014), which take cognitive human factors into account in lot-sizing and the paper by Andriolo et al. (2016), which determine an ergonomic lot size. In the area of P&AM, the paper by Otto and Scholl (2011) should be mentioned, which integrates a performance comparison with consideration of ergonomic risk factors in constraints. However, it could generally observed, that balancing problems are predominant in the foreground.

Especially physical effects have been less researched. The existing literature mainly deals with the improvement of social conditions by an optimized distribution of burden on different planning levels or tries to exploit learning and forgetting effects. However, the overall burden is not reduced, but merely redistributed. This paper therefore controls the overall burden in terms of keeping the employee utilization within a specific corridor, whereby the employee utilization reflects the quotient of available capacity and capacity requirement. Due to the possibility of building up and reducing capacities, there is also no impairment in the satisfaction of customer orders.

MATHEMATICAL NOTATIONS AND EQUATIONS

In order to reduce the previously outlined gaps in the integration of social criteria into production planning and control, the linear optimization model for Master Production Scheduling introduced in Trost et al. (2017a) and Trost et al. (2017b) was developed. To investigate a long planning horizon, this model was adapted with regard to the relevant requirements. Because of the resulting complexity, solutions cannot easily be achieved within an acceptable period of time. Therefore, the complete optimization problem has been broken down into a main problem and a subproblem. At the main problem, the decision variables are set to floating point numbers. After solving the main problem, the determined shift model is transferred to the subproblem. The subproblem determines the optimal results, whereby the number of employees is determined as an integer and the other variables remain floating point numbers.

Parameter

$CAPA_{ma}$	Available capacity per worker of a worker class *ma*
$d_{k,t}$	Product requirement per product *k* and time 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*
J	Number of production segments ($j = 1, 2, \ldots, J$)
K	Number of products ($k = 1, 2, \ldots, K$)
MA	Number of worker classes ($ma = 1, 2, \ldots, MA$)
$Mit_{ma,j}^{Cost}$	Cost rate per worker of class *ma* and production segment *j*
$Mit_{ma,j,s}^{Init}$	Initial number of worker per worker class *ma*, production segment *j* and shift *s*
$Mit_{ma,j}^{Max}$	Maximum number of worker per worker class *ma* and production segment *j*
$Mit_{ma,j}^{Min}$	Minimum number of worker per worker class *ma* and production segment *j*
$Mit_j^{TotalMax}$	Maximum number of worker per production segment *j*
$Mit_j^{TotalMin}$	Minimum number of worker per production segment *j*
m_{ma}^{Cost}	Cost rate for building capacity per worker class *ma*
n_{ma}^{Cost}	Cost rate for reducing capacity per worker class *ma*
$p_{j,s}^{Init}$	Initial shift model per production segment *j* and shift *s*
$Q_{j,s}^{Cost}$	Cost rate for shift model change per production segment *j* and shift *s*
R_j^{Max}	Maximum worker utilization per production segment *j*
R_j^{Min}	Minimum worker utilization per production segment *j*
S	Number of shifts ($s = 1, 2, \ldots, S$)

$S_{j,s}^{Above}$	Maximum limit for number of worker per production segment *j* and shift *s*
$S_{j,s}^{Bottom}$	Minimum limit for number of worker per production segment *j* and shift *s*
S_{s}^{Cost}	Cost factor for calculating shift bonuses per shift *s*
T	Planning horizon in time periods ($t = 1, 2, ..., T$)
W	Number of forerun periods for modifying available capacity ($w = 1, 2, ..., W$)
Z	Number of forerun periods for production ($z = 1, 2, ..., Z$)

Decision Variables

$a_{j,t}$	Available capacity per production segment *j* and time period *t*
$b_{j,t}$	Capacity requirement per production segment *j* and time period *t*
$I_{k,t}$	Inventory per product *k* and time period *t*
$m_{ma,j,t}$	Number of worker recruitments per worker class *ma*, production segment *j* and time period *t*
$Mit_{ma,j,s,t}$	Number of worker per worker class *ma*, production segment *j*, shift *s* and time period *t*
$n_{ma,j,t}$	Number of worker redundancies per worker class *ma*, production segment *j* and time period *t*
$p_{j,s,t}$	Boolean-Variable for calculating the number of shifts per production segment *j*, shift *s* and time period *t*
$q_{j,s,t}^{a}$	Boolean-Variable to determine shift changes per production segment *j*, shift *s* and time period *t* (no change)
$q_{j,s,t}^{b}$	Boolean-Variable to determine shift changes per production segment *j*, shift *s* and time period *t* (shift model becomes active)
$q_{j,s,t}^{ac}$	Boolean-Variable to determine shift changes per production segment *j*, shift *s* and time period *t* (shift model becomes inactive)
$x_{k,t}$	Produced quantity per product *k* and time period *t*

Main Problem

In the following the main problem is described, that determines the optimal shift model for each time period, wich is transferred to the subproblem.

The objective function (Equation 1) minimizes the total costs (Equation 2). These comprise the storage costs (Equation 3), employee costs (Equation 4), shift allowances (Equation 5), one-time costs for a possible shift model change (Equation 6), the costs for capacity building (Equation 7) and the costs for capacity reduction (Equation 8).

$$ObjectiveFunction = Minimize(TotalCost) \quad (1)$$

$$\begin{aligned} TotalCost &= StorageCost + MitCost \\ &+ ShiftCost + ShiftmodellCost \\ &+ BuildingCost + ReductionCost \end{aligned} \quad (2)$$

$$StorageCost = \sum_t^T \sum_k^K h_k \bullet I_{k,t} \quad (3)$$

$$MitCost = \sum_t^T \sum_s^S \sum_j^J \sum_{ma}^{MA} Mit_{ma,j}^{Cost} \bullet Mit_{ma,j,s,t} \quad (4)$$

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

$$ShiftmodelCost = \sum_t^T \sum_s^S \sum_j^J Q_{j,s}^{Cost} \bullet q_{j,s,t}^{b} \quad (6)$$

$$BuildingCost = \sum_t^T \sum_j^J \sum_{ma}^{MA} m_{ma}^{Cost} \bullet m_{ma,j,t} \quad (7)$$

$$ReductionCost = \sum_t^T \sum_j^J \sum_{ma}^{MA} n_{ma}^{Cost} \bullet n_{ma,j,t} \quad (8)$$

The constraints are shown next. First, the warehouse balance sheet (Equation 9) and the employee balance sheet (Equation 10) are determined. In addition, the warehouse and employee initial quantities (Equations 11 and 12) are determined. Further, the determination of capacity requirements (Equation 13) and available capacity (Equation 14) as well as restrictions on the minimum and maximum utilization of employees (Equations 15 and 16) are specified.

$$x_{k,t} + I_{k,t-1} - I_{k,t} = d_{k,t} \quad (9)$$

$$\sum_s^S Mit_{ma,j,s,t-1} + m_{ma,j,t-w} - n_{ma,j,t-w} = \sum_s^S Mit_{ma,j,s,t} \quad (10)$$

$$I_{k,0} = I_k^{Init} \quad (11)$$

$$Mit_{ma,j,s,0} = Mit_{ma,j,s}^{Init} \quad (12)$$

$$\sum_z^Z \sum_k^K f_{z,j,k} \bullet x_{k,t+z} = b_{j,t} \quad (13)$$

$$\sum_{ma}^{MA} \sum_s^S Mit_{ma,j,s,t} \bullet CAPA_{ma} = a_{j,t} \quad (14)$$

$$R_j^{Min} \bullet a_{j,t} \le b_{j,t} \quad (15)$$

$$R_j^{Max} \bullet a_{j,t} \ge b_{j,t} \quad (16)$$

The number of employees is limited below. To this end, the minimum and maximum number of employees per production segment (Equations 17 and 18) are determined in order to guarantee a permanent staff and not to exceed technical requirements (number of workplaces). In addition, the minimum and maximum number of employees per production segment and employee class (Equations 19 and 20) are defined as well, in order to reflect the structure of the core workforce and the supply of skilled workers available on the labour market.

$$\sum_{ma}^{MA} \sum_{s}^{S} Mit_{ma,j,s,t} \geq Mit_{j}^{TotalMin} \quad (17)$$

$$\sum_{ma}^{MA} \sum_{s}^{S} Mit_{ma,j,s,t} \leq Mit_{j}^{TotalMax} \quad (18)$$

$$\sum_{s}^{S} Mit_{ma,j,s,t} \geq Mit_{ma,j}^{Min} \quad (19)$$

$$\sum_{s}^{S} Mit_{ma,j,s,t} \leq Mit_{ma,j}^{Max} \quad (20)$$

The shift model is determined in the following constraints. For this purpose, lower and upper limits are determined for the number of employees per shift model (Equations 21 and 22) and the initial shift model (Equation 23) is specified. In addition, the Boolean variable for shift model determination (Equation 24) is limited. The change of the shift model (Equation 25) is also determined. It is possible that no change takes place (*qa=1*), a shift model becomes active (*qb=1*) or a shift model becomes inactive (*qc=1*). In addition, the Boolean variables have to be restricted (Equation 26).

$$\sum_{ma}^{MA} Mit_{ma,j,s,t} \geq p_{j,s,t} \bullet S_{j,s}^{Bottom} \quad (21)$$

$$\sum_{ma}^{MA} Mit_{ma,j,s,t} \leq p_{j,s,t} \bullet S_{j,s}^{Above} \quad (22)$$

$$p_{j,s,0} = p_{j,s}^{Init} \quad (23)$$

$$\sum_{s}^{S} p_{j,s,t} = 1 \quad (24)$$

$$p_{j,s,t} - p_{j,s,t-1} = 0 \bullet q_{j,s,t}^{a} + 1 \bullet q_{j,s,t}^{b} - 1 \bullet q_{j,s,t}^{c} \quad (25)$$

$$q_{j,s,t}^{a} + q_{j,s,t}^{b} + q_{j,s,t}^{c} = 1 \quad (26)$$

Subproblem

At the subproblem, the shift model from the main problem is used as a parameter. Compared to the main problem, the parameters p^{Init}, Q^{Cost}, S, S^{Cost}, S^{Above} and S^{Bottom} as well as the decision variables p, q^a, q^b and q^c are omitted. In addition, Equations 21 to 26 are no longer used. It should also be noted, that the omission of the shift parameter in all variables and equations means, that the s index is omitted.
The objective function (Equation 27) minimizes the total costs (Equation 28), which are composed of storage costs (Equation 29), employee costs (Equation 30) as well as the costs for building and reducing capacity (Equations 31 and 32). In addition, a *10 % GAP* to the upper bound is allowed for the optimal solution of the subproblem.

$$ObjectiveFunction = Minimize(TotalCostSub) \quad (27)$$

$$TotalCostSub = StorageCostSub + MitCostSub + BuildingCostSub + ReductionCostSub \quad (28)$$

$$StorageCostSub = \sum_{t}^{T} \sum_{k}^{K} h_k \bullet I_{k,t} \quad (29)$$

$$MitCostSub = \sum_{t}^{T} \sum_{j}^{J} \sum_{ma}^{MA} Mit_{ma,j}^{Cost} \bullet Mit_{ma,j,t} \quad (30)$$

$$BuildingCostSub = \sum_{t}^{T} \sum_{j}^{J} \sum_{ma}^{MA} m_{ma}^{Cost} \bullet m_{ma,j,t} \quad (31)$$

$$ReductionCostSub = \sum_{t}^{T} \sum_{j}^{J} \sum_{ma}^{MA} n_{ma}^{Cost} \bullet n_{ma,j,t} \quad (32)$$

EXAMINATION SCENARIO AND CASE STUDY

The 15 examination scenarios differentiate between 5 demand scenarios and 3 exhaustion courses (see Figure 1). It is assumed, that, because of the exhaustion, with lower employee utilization the processing times are also reduced. Therefore, *4* different employee utilization intervals are considered for each production segment: *80-85 %*, *85-90 %*, *90-95 %* and *95-100 %* ($R^{Min}(j)$ *to* $R^{Max}(j)$). Therefore (and due to the assumption of *2* production segments) each examination scenario has to been solved *16* times and the most cost-effective utilization interval is considered as the optimal solution for the examination scenario.

Figure 1: Worker utilization specific weighting factors for processing times per human exhaustion courses

The third exhaustion course corresponds to not-considering human exhaustion, so that the processing times for all employee utilization intervals are identical. All in all, the different exhaustion courses illustrate a wide range of possibilities that can occur in practice.

To determine the 5 different demand scenarios, the results from the Aggregated Production Planning are used as a basis. Thus, an average demand of *234 PCs* (pieces) per period is assumed for the product *k=1* and an average demand of *196 PCs* per period for the product *k=2*. Based on this mean values, the 5 demand scenarios are calculated under the assumption of a normal distribution with a standard deviation of *5 %* for *k=1* and *10 %* for *k=2*. This procedure ensures, that the demand scenarios are generated independently of the optimization model. In summary, under the given assumptions, a representative analysis is achieved for this problem class. The parameters of the case study are presented below, initially with the general parameters in Table 1.

Table 1: General parameters

Parameter	Value
J	*2*
K	*2*
MA	*2*
S	*3*
T	*90*
W	*1*
Z	*1*

Additional, there is no initial stock $I^{Init}(k) = 0$. The storage costs *h(k)* per period and piece amount to *160 MU* (monetary unit) for product *k=1* and *100 MU* for product *k=2*. The original processing times (*f(z)(j)(k)*), which are evaluated with the exhaustion factors mentioned above, are *2,794 TU/PC* (time units per piece) for product *k=1* in production segment *j=1*, *2,329 TU/PC* for product *k=2* in production segment *j=1*, *8,900 TU/PC* for product *k=1* in production segment *j=2* and *6,779 TU/PC* for product *k=2* in the production segment *j=2*, and it is assumed that the requirements must be available at the beginning of each period. Therefore, the processing times are already incurred in the preprocessing period *z=1*. However, it is taken into account, that the complete processing time is not carried out manually and is therefore influenced by exhaustion effects. It is assumed that *60 %* of the activities are carried out manually in production segment *j=1* and *50 %* of the activities in production segment *j=2*. The further parameters define the assumptions for planning personnel requirements. The following tables 2 to 5 show the relevant parameters. Each employee class represents different levels of experience and qualifications. In the case study, the employee class *ma=1* is interpreted as highly qualified and experienced internal personnel. Employee class *ma=2* represents external employees that are procured temporarily. The procurement and release for employee class *ma=2* is carried out by a service company, which is compensated by the employee costs. The initial number of employees (Mit^{Init}(ma)(j)(s)) is assumed to be *2* employees in the employee class *ma=1* and the production segment *j=1* as well as *7* employees in employee class *ma=1* and the production segment *j=2*. In the employee class *ma=2*, a number of *0* employees are accepted. Further in Table 5 the respective limits for the determination of the corresponding shift models are presented.

Table 2: Employee parameters for each production segment (j)

Parameter	j=1	j=2
$Mit^{TotalMax}(j)$	*9*	*15*
$Mit^{TotalMin}(j)$	*1*	*1*

Table 3: Employee parameters for each worker class (ma)

Parameter	ma=1	ma=2
CAPA(ma)	*576,000 TU*	*432,000 TU*
$m^{Cost}(ma)$	*6,000 MU*	*250 MU*
$n^{Cost}(ma)$	*20,000 MU*	*150 MU*

Table 4: Employee parameters for each worker class (ma) and production segment (j)

Parameter		j=1	j=2
$Mit^{Cost}(ma)(j)$	ma=1	*3,000 MU*	*3,000 MU*
	ma=2	*3,800 MU*	*3,800 MU*
$Mit^{Max}(ma)(j)$	ma=1	*3*	*10*
	ma=2	*9*	*15*
$Mit^{Min}(ma)(j)$	ma=1	*1*	*1*
	ma=2	*0*	*0*

Table 5: Limits for determination of the correct shift model for each production segment (j) and shift model (s)

Parameter		s=1	s=2	s=3
$S^{Above}(j)(s)$	j=1	*3*	*6*	*9*
	j=2	*5*	*10*	*15*
$S^{Bottom}(j)(s)$	j=1	*1*	*4*	*7*
	j=2	*1*	*6*	*11*

So the shift models *s=1* in the production segment *j=1* and *s=2* in the production segment *j=2* are active ($p^{Init}(j)(s)$). Shift allowances $S^{Cost}(s)$ are assumed to be *0 %* for *s=1*, *1.5 %* for *s=2* and *15 %* for *s=3* of the employee costs per period and in addition, one-time costs $Q^{Cost}(j)(s)$ for a shift model change of *1,500 MU* to activate shift model *s=1* and *2,500 MU* to activate shift model *s=2* are assumed for both production segments.

To activate shift model *s=3*, *5,000 MU* in the production segment *j=1* and *7,500 MU* in the production segment *j=2* are assumed.

RESULTS

The results of the examination scenarios are presented below. Table 6 shows the optimal results for each examination scenario. In comparison, Table 7 shows the results derived from a non-consideration of employee utilization. For this purpose, the results of the employee utilization interval of 95-100 % were used, since it is generally assumed, that maximizing utilization leads to optimal results.

Table 6: Optimal Solutions for each demand scenario and exhaustion course [MU]

Demand Scenarios	Exhaustion Course 1	Exhaustion Course 2	Exhaustion Course 3
Scenario 1	*2,477,865*	*2,529,101*	*2,649,707*
Scenario 2	*2,549,378*	*2,510,901*	*2,551,692*
Scenario 3	*2,493,051*	*2,520,922*	*2,637,919*
Scenario 4	*2,657,297*	*2,728,688*	*2,780,999*
Scenario 5	*2,525,665*	*2,392,793*	*2,538,531*

Table 7: Solutions without consideration of worker utilization [MU]

Demand Scenarios	Solution without worker utilization
Scenario 1	*2,649,707*
Scenario 2	*2,551,692*
Scenario 3	*2,637,919*
Scenario 4	*2,893,396*
Scenario 5	*2,538,531*

As can be seen, the costs resulting from Table 7 are higher than those for the first (by 4.45 %) and second (by 4.63 %) exhaustion course from Table 6 and they are identical for the third exhaustion course, with the exception of the demand scenario 4. As Table 6 shows the true optimal results per exhaustion course and Table 7 the results of a maximum employee utilization, it becomes clear, that irrespective of the extent of the exhaustion or a non-consideration of exhaustion, maximizing employee utilization does not necessarily lead to optimal results, so planning and controlling employee utilization is necessary. This finding is enhanced by Figure 2, which shows the optimal employee utilization interval for each exhaustion course and demand scenario for the production segment *j=1*. The upper interval values are displayed as legends. For example, the legend value *85 %* stands for the utilization interval *80-85 %*. Next to the findings before, it becomes clear, that in order to achieve optimal results, employee utilization should be lower, the stronger the exhaustion effects are. In addition to the cost advantages due to planning and controlling the employee utilization, it is also important, to emphasize the reduction of the burden on employees by taking exhaustion effects and utilization specific processing times into account. It can be stated, that the findings from the investigation of short-term planning horizons (see Trost et al. 2017a and 2017b) can also be confirmed for long-term planning horizons.
In addition, the results for the first and second exhaustion course from Table 6 are compared with the results of the third exhaustion course from Table 6. This illustrates the variations between the consideration and non-consideration of exhaustion effects. It becomes clear, that even with flatter exhaustion curves, considerable deviations of up to *7 %* occur. This suggests a considerable potential for improvement through the integration of exhaustion effects, whereby there is a need for concrete quantification of exhaustion effects, which Grosse et al. (2017) and Trost et al. (2016) also mentioned.

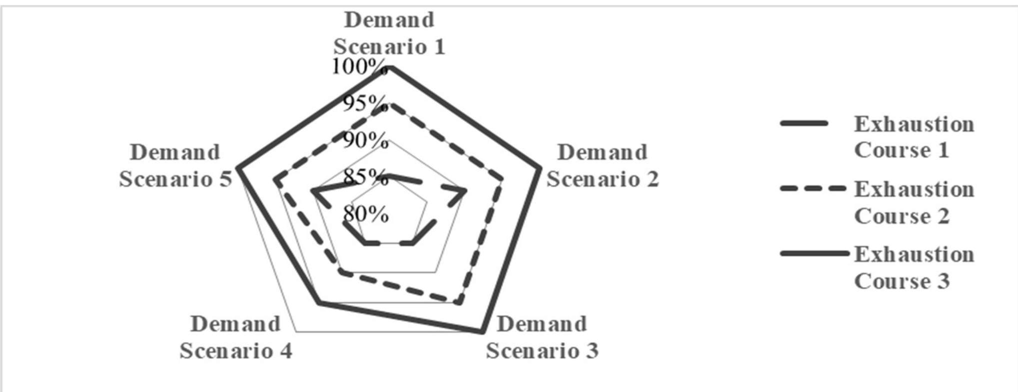

Figure 2: Optimal worker utilization for each demand scenario and exhaustion course

In addition, further research questions can be derived from a more detailed analysis of the results. The analysis of the shift models showed that no shift model changes were necessary, which can be explained by the demand scenarios. For further research, greater fluctuation in demand should also be investigated. These include, for example, the integration of seasonal effects and various scenarios of slumps in demand.

Another research question arises from the analysis of the number of employees per employee class (ma). It becomes clear, that, despite the rather stable demand scenarios, the flexibility of the available capacity is a decisive factor. For example, partly despite an increase in the total number of employees, some employees in employee class *ma=1*, which stands for highly qualified and experienced internal employees, are replaced by employees in employee class *ma=2*, which stands for less qualified and experienced external employees. This finding does not come as a surprise at first, but on the one hand, there is the research question of how this need for flexibility changes with increasing fluctuations in demand and which level of flexibility leads to optimal results. On the other hand, there is the question of how the need for flexibility in connection with the expected shortage of skilled workers will change. In view of the demographic change and the increased demand for skilled workers (for example due to job restructuring in the context of Industry 4.0), it could become problematic or more expensive to always procure the necessary number of employees (*ma=2*), so that an increase in internal personnel (*ma=1*) may be preferable.

Finally, it can be summarized that it has been proven, that the consideration of exhaustion effects and the planning and control of employee utilization in connection with production planning are necessary, since a maximum employee utilization, independent of the exhaustion courses, does not necessarily lead to optimal results. Further studies, which can be carried out with the presented optimization model, should deal with the effects of increasing demand fluctuations in connection with decreasing numbers of available employees.

CONCLUSION

This paper underlines the need for a link between production planning and personnel planning. The basis of this approach is the inadequate improvement of working conditions for employees and the potential of production planning and control confirmed by the literature. However, there are few papers in the context of hierarchical production planning, that integrate the social dimension. Especially in the area of long-term planning, no papers are known.

On this basis, the model presented above was developed, which controls employee utilization in a long-term planning environment without significantly restricting production capacities by integrating aspects of personnel planning into the Master Production Scheduling. In addition, social aspects in the form of employee utilization specific processing times are also taken into account. This makes it possible to reduce the burden of employees without endangering the fulfillment of customer orders.

On the one hand, the findings show, that the recognized results from short-term planning horizons are also reflected in long-term planning environments. Especialy, the finding, that maximizing employee utilization does not necessarily lead to optimal results should be emphasized. Consequently, taking into account employee utilization and the resulting processing times, a cost advantage can be achieved and the burden on employees can be reduced. On the other hand, the results show, that there is further research potential. Continued investigations should examine the effects of increasing demand fluctuations in connection with decreasing numbers of available employees.

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