SOCIAL AND ECOLOGICAL CAPABILITIES FOR A SUSTAINABLE HIERARCHICAL PRODUCTION PLANNING

Marco Trost
Prof. Dr. Thorsten Claus
Enrico Teich
Maximilian Selmair
Department of Business Science
Dresden Technical University
Markt 23, 02763 Zittau, Germany
E-mail: marco.trost@mailbox.tu-dresden.de

Prof. Dr. Frank Herrmann
Innovation and Competence Centre for Production
Logistics and Factory Planning (IPF)
Regensburg Technical University of Applied Sciences

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ABSTRACT

Production planning and production control mainly focus on optimising the entire production system of a company. On the basis of hierarchical planning as a suitable method for solving this task, this paper shows - besides the economic dimension taken into account so far - that there are also social and ecological effects which will have to be considered in the process of planning. For this purpose, we would like to indicate here which social and ecological parameters can be or have already been taken into account for master production scheduling, for lot sizing and resource scheduling. As a result, an overview has been created which presents the existing concepts of sustainable production planning and production control as well as the existing deficits regarding the sustainability perspective.

INTRODUCTION

The concepts of hierarchical planning, as put forward by Hax, and Meal (1975), represent the state of the art in research and industry. In this paper, we have looked at hierarchical planning considering the restricted capacities as suggested by Drexl et al. (1994), with respect to production planning and production control (PPC). We distinguish between three planning stages: Master production scheduling (1), lot sizing (2) and resource scheduling (3) (refer for figure 1).

The planning approaches applied so far mostly consider single stages of planning and forbear from considering an interrelationship in connection with a hierarchical approach. Because of ecological impacts emanating from a company's environment, such as an increased ecologically motivated demand behaviour, an increasing shortage of resources and growing waste disposal and energy costs as well as the rising average age of the economically active population and the ensuing aggravation of skill shortage, it will also have to be noted that the aspect of sustainability will gain a high significance in the future. In this paper, we have therefore examined existing concepts of sustainability for the various individual stages of hierarchical planning and analysed deficits regarding an integrative concept.

This paper has been structured as follows: Chapter 2 shows the relevance of sustainability. Subsequently, Chapter 3 looks into master production scheduling and shows which social and ecological aspects can be considered at this level of planning. Likewise, batch sizing and resource scheduling are examined in chapters 4 and 5. The concluding Chapter 6 presents our conclusions as well as a summary.

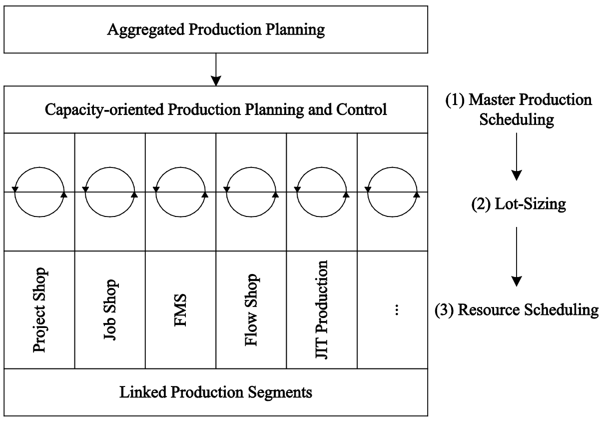

Fig. 1: The concept of hierarchical planning (based on Drexl et al. 1994)

RELEVANCE OF SUSTAINABLE VARIABLES

The idea of sustainability is a frequently discussed notion in science and practice (Andriolo et al. 2014). In the Brundtland report, this notion has been defined as "a development that meets the needs of the present without compromising the ability of future generations to meet

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their own needs“, (Brundtland 1987). Any industrial progress should consist of the elements “economy”, “ecology” and “social aspects” which need to form a triad of equivalent priorities since the equal balance of these elements will become a critical task of sustainable corporate governance in the future, particularly due to the aggravation of skill shortage and the rising average age of the economically active population. In industrial companies, this task will first and foremost have to be managed by PPC (Haasis 2008).

Any economic parameters such as storage costs or default charges are traditional parameters in the field of PPC. By considering these parameters, companies succeeded in minimising costs and improving their performance. Besides that, the global intertwinement of markets creates an enormous cost pressure for production companies, forcing them to become more and more flexible; as a result of this, methods of dynamic planning and optimization are required which have to take uncertainties of the market into account and which primarily permit a sufficient scope of action in terms of capacity. (Lanza and Peters 2011).

Due to the ongoing climate changes and the resulting political decisions and requirements, ecological parameters such as efficiency of energy and resources will however also constitute an important dimension in the future. In the framework of the climate and energy package, the EU committed to reduce greenhouse gas emissions by 20 per cent, to increase the percentage of renewable energies to 20 per cent of the total energy demand and to increase energy efficiency by 20 per cent, by the year 2020 in comparison with a development without further efforts to reduce energy consumption. In addition to this, the Paris Agreement concluded during the United Nations Climate Change Conference in 2015 provides to curb global warming to a value significantly below 2 degrees Celcius (if possible 1.5 degrees Celcius). As soon as ecological parameters are taken into account at all levels of hierarchical planning, this will provide an enormous potential for supporting the conformity with these requirements (Müller et al. 2008; Erlach and Westkämper 2009; Vorderwinkler and Heiß 2011). The Frauenhofer IPT estimated that the potential energy savings feasible in Germany in the medium run would range between 25 and 30 per cent (Drescher and Rohde 2009), where mainly cost savings would be a critical criterion, in addition to positive effects on the environment and the climate (Lanza and Peters 2011), a fact which will put even more emphasis on the intertwinement of ecological and economical parameters.

The third dimension to be considered here comprises social parameters which must always be considered as soon as human labour is involved. In spite of different models which are used for work shift planning, job rotation or staff scheduling, the working conditions do not improve (Schmucker 2014). Among others, the report: “DGB-Index Gute Arbeit 2013” (good work index of the German trade union confederation, 2013) classified the physical stress and work intensity as “poor” and even as “lower medium range” (Schmucker 2014). This report shows that 45 per cent of the work force do not assume to be able to exercise their profession until they will have reached the age of retirement (Schmucker 2014). The consequences of increased stress may be psychosomatic, psychological, or behavioural. As short-term reactions, an increased heart rate (psychosomatic), frustration (psychological), increased failure rate (behavioural & individual) or aggressive behaviour (behavioural & social) can be observed; these factors lead to increased durations of absence from work, resignation as well as psychosomatic diseases (Nerdinger et al. 2014). The general responsibility of companies for their employees urges them to improve working conditions; and the fact that the economically active population decreases, as forecast by the German Federal Ministry of Labour and Social Affairs, increasingly forces companies to boost the performance potential of their employees. A mutual solution to these tasks may for example consist in reducing physical and psychological overstress and in benefiting from learning effects. In addition to the improvements of the work environment and the development of carefully adapted production processes, PPC therefore offers lots of possibilities for improving their employees’ performance potential (Vorderwinkler and Heiß 2011).

MASTER PRODUCTION SCHEDULING

Master production scheduling as a central planning module captures all production segments of a given production site, as well as its main products and its aggregate capacity requirements. The task to be solved consists in preparing production programmes over several time periods and in coordinating these programmes between the various production segments. The starting points of master production scheduling are existing customer orders as well as short-term demand forecasts for end products. The resources needed are organised in groups and units having the same functions and necessitating the same amount of costs (cost centres). The objective is to minimize the relevant costs incurred in connection with production, storage and resources on the basis of the deadlines specified for the target to be reached (Günther and Tempelmeier 2012).

As a rule, the actual capacity needed per unit of quantity to be produced is considered as constant. In case of a purely machine-based production, this assumption is correct. However as soon as manual processes are used in a production system, besides the machine-based processes, the capacity needed for producing a certain unit of quantity of a product will also depend on the employee to whom the job is assigned. However because of the huge complexity and the generally prevailing aggregate approach, a detailed human resources planning is not expedient in the field of master production scheduling. The objective should rather consist in building up and maintaining a constant performance level of the employees, also against the background of social influences on the production system. This performance level is determined by the respective employee's qualification, experience and workload, however in the framework of master production scheduling, we need to consider employee groups. A possible clustering may for example be set up on the basis of various qualifications.

The nurse-scheduling method for instance considers social effects. In case of a planning horizon ranging between one and three months and a period length of one shift, further parameters are taken into account in addition to the necessity of covering the capacity requirements with the lowest possible number of employees. For instance it is imperative to comply with legal requirements. However any cyclical shift systems which can be set up easily, as suggested by Warner (1976), Warner and Prawda (1972) and Miller et al. (1976), are not sufficient to ensure this. However these models are characterised by a low flexibility towards fluctuating capacity requirements, so that dynamic planning alternatives such as the model created by Smith and Wiggins (1977) have to be given preference (Ozkarahan 1989). There, the individual preferences of employees are additionally taken into account. Human resources scheduling in general has been analysed by literature for a long time. The investigations made by Dantzig (1954) and Edie (1954) were the starting points. The fundamental objective is to cover the required capacities. Here, legal requirements of the Law on Working Hours and stochastic influences such as illness and vacation were also considered. However as a rule, these models assume given capacity requirements which can only be modified by means of advance production or subcontracting. Since the utilisation of learning effects and the reduction of employees' stress exposure have a direct impact on execution times and therefore on the capacity requirements, it is necessary to look at master production scheduling and human resources planning in an integrated manner. Here, it becomes apparent that there are various approaches which are based on a group-related consideration of employees' preferences, simultaneously ensuring the availability of required capacities. However particular approaches considering this explicitly for the PPC and simultaneously including the interdependencies between the employees assigned to the jobs on the one hand and the capacity requirements on the other hand, are still lacking.

Besides capacity requirements, production also generates a certain energy demand which in turn causes further costs. As a rule, the energy price to be considered is assumed to be constant. However in case of particularly energy-intensive (high-consumption) productions systems, it may be advantageous to procure energy on the basis of individual contracts or from the spot market. In the future, we will have to expect fluctuating energy prices. These fluctuations may be of the seasonal or the intra day type. Because of the change-over to regenerative sources of energy, we will have to expect that the amplitude of these fluctuations will keep on rising in the future as witnessed in the past. By planning energy intensive processes in low price periods, companies may benefit from the volatility of energy prices and thus save costs. In addition to variable energy prices, a restriction of energy supplies will have to be considered in the ecological dimension. In the future, it will not be possible to ensure constant energy supplies with the help of regenerative sources of energy (e.g. solar and wind energy) since sufficient energy storage capacities are still lacking (Laux 2013). If phases of low energy generation overlap with peaks of demand, bottle necks will be the result. The idea of integrating these aspects as early as at the moment of the preparation of the master production scheduling has not been considered so far, a fact which constitutes a respective research task.

LOT SIZING

As a result of the previous planning activities, the data of net quantities, as required in the specific periods of time are now available which are used as starting points of lot sizing. These net quantities may be produced on the basis of the "just in time" principle, which will however cause considerable set-up times and therefore set-up costs. Therefore, the task of lot sizing is to combine these required quantities in reasonable batches. The increased storage costs caused here lead to a batch size problem. In addition to this, it is imperative to take existing sequence relations between subordinate and superordinate products and the restricted resource capacities into account, and this will then give rise to a multi-tiered dynamic batch size problem with capacity restrictions. This can be represented in a simplified manner by means of the Multi-Level Capacitated Lot Sizing Problem (MLCLSP). Explanations in this respect may be found in Tempelmeier (2008), Tempelmeier (2012) and Herrmann (2009).

The major part of research work in the field of lot sizing, which is discussed in specialist literature focuses on optimising economic and ecological target parameters. In their economic dimension, the conventional target parameters such as costs of production, ordering, set-up work, storage and transport are looked at in the context of the decision to be taken about lot sizes. In their ecological dimension, a predominant part of research work focuses on different approaches aiming at minimising carbon dioxide emissions (CO_2-emissions) and on the ensuing costs. Here, the interrelation between batch size and CO_2-emissions, resulting from production, transport and storage of this batch size is used as the basis of batch sizing. For example the approaches suggested by Absi et al. (2013) and by Wahab et al. (2011) envisage minimising the costs of batch-size related

CO_2-emissions in connection with transport processes. Other works enlarged this approach even further by integrating the batch size-related CO_2-emission costs of storage (Battini et al. 2014, Bouchery et al. 2012). In case of perishable products, any decisions on batch sizes, which are based on an overestimation of the future product demand may result in the generation of waste. The disposal of these kinds of waste will also generate costs in the form of expenses for CO_2-emissions which need to be taken into account by batch sizing. Approaches in this respect have been provided by the works of Battini et al. (2014) as well as Bonney and Jaber (2011). Arslan and Turkay (2013), Benjaafar et al. (2013), Chen et al. (2013) and Hua et al. (2011) integrated aspects of CO_2-trading (compliance with emission limits, payment of penalties when emission limits are exceeded, prices of emission right trading) into their batch size models and therefore they also aim at minimizing the costs. Besides CO_2 emissions, there are further ecological target parameters which have not been taken into account yet by the research done in the field of batch sizing. As examples, those waste quantities may be referred to here which are brought about by batch packaging (discrepancy between batch size and transport size) or as a result of rejected parts produced in start-up phases after retrofitting processes initiated by batch changes. The energy demand depending on batch sizes in production, storage and transport processes should be included here as well.

The analysis of the state of science regarding the existence of methods which also take the social dimension into account leads us to the research work done by Arslan and Turkay (2013). In this approach, the man hours required for producing, transporting and storing batches are considered as a minimization target; or a limiting value is specified as a side condition of batch sizing. Battini et al. (2014) attributed an indirect significance to the minimisation of transport costs. Since any minimisation of transport costs mostly goes along with a reduction of the number of transports, it is possible to reduce the probability of the occurrence of accidents and traffic jams. The minimisation of emission costs also provides an indirect social contribution, since environmental pollution will thus be reduced and a contribution is made to the protection of the environment for the benefit of the generations to come. A further approach which has a social dimension besides the economic one is the work done by Jaber and Bonney (2007). There, a two-phase model of learning and forgetting is integrated in a classical EMQ-model (Economic manufacture quantity model), where effects of learning and forgetting are taken into account as a function of batch sizes. The two-phase model of learning and forgetting is based on the work submitted by Jaber and Kher (2002), which splits the process of learning and forgetting into a cognitive part and a motor skill part. Further significant social factors which are influenced by the decision on the batch size are in particular the aspects of work ergonomics. The bigger the size of the batch to be manufactured is, the higher the frequency of identical work steps will be which production workers will have to perform repeatedly. This monotony may have a negative impact on the employees' performance potential both in physical and a psychological terms, a fact which will in turn lead to an increase of stress. An approach aiming at illustrating the process of exhaustion was presented by the work of Jaber et al. (2013) which also considered aspects of exhaustion and recovery in addition to a one-phase process of learning and forgetting. However this model was not integrated into a batch size model.

In summary, we need to emphasise that there are different approaches which take the economic, ecological and social dimensions into account, independently to different degrees. However a combination of all these approaches aiming at establishing a really sustainable model has not been achieved yet. Besides that, these approaches partially assume unrestricted capacities, a problem which leads to production schedules that cannot be implemented in entrepreneurial practice. Therefore, an extension will be required here (e.g. including an MLCLSP-model) in addition to a combination of these approaches.

RESOURCE SCHEDULING

Batch sizing is followed by resource scheduling; here, the production orders prepared during batch sizing have to be released on the basis of the previously determined major deadlines and to be allocated to concrete work systems. This elucidates the respective interrelationship between the various planning stages. The length of a period is reduced to any smaller amount of time and any time-consuming processes have to be taken into account (Günther and Tempelmeier 2012). As a possible solution to this problem, we refer to the Resource Constrained Project Scheduling Problem model RCPSP-model presented by Günther and Tempelmeier (2012). The field of application of the RCPSP models is wide and not limited to the original domain of project scheduling (Hartmann and Briskorn 2010). Hartmann and Briskorn (2010) have put various versions of RCPSP together and classified them. Stadtler (2005) combined the MLCLSP and the RCPSP and developed an integrated model. However these studies put the focus on the economic dimension.

At a social level, Boysen and Fliedner (2011) showed exact and heuristic solutions aiming at reducing the stress exposure of an airport's ground. The workload the ground staff is exposed to depends on the arrival frequency of aeroplanes so that overwork may occur in case of a high arrival frequency of large aeroplanes. Here, the available time window for arrivals is limited by the earliest and the latest times which result from flight distances, speed and quantities of aviation fuels. This may for instance be compared to the planning of production orders. The equivalents of earliest and latest time are the major deadlines of batch sizing. As a result, the work pressure the employees are exposed to may be reduced by means of an adapted scheduling of the production orders. In addition to a possible reduction of work pressure, Peteghem and Vanhoucke (2015) referred to significant potentials which become available as soon as learning effects are considered regarding the discrete time/resource trade-off scheduling problem (DTRTP). Particularly the reduction of throughput time was presented as a significant result. Furthermore, the authors suggested to consider learning effects in stochastic terms in order to permit an approach that would be more realistic than deterministic methods. In parallel, effects of forgetting must also be considered in addition to learning effects. As regards resource planning, the consequence is that production orders can be planned in such a way that their sequence will generate the highest possible level of learning, that a maximum work load of the employees is not exceeded and that the production targets are achieved according to the time schedule. The available literature offers several approaches to this. However this approach is still lacking a concrete consideration of social parameters for resource scheduling.

In the ecological dimension, energy savings are possible when the modes of operation of machines are considered in resource scheduling (Selmair et al. 2015). Selmair et al. (2015) explained that energy demand and operation time, the latter one being based on resource scheduling, are not directly related which means that energy demand is not directly proportional to the total throughput time, a fact which unveils a considerable potential for optimization. For assessing the energy demand within the optimization process, a flexible energy price has to be chosen, as suggested by Selmair et al. (2015), since as a rule, companies conclude special contracts which stipulate individual energy prices. In addition to this, a possible restriction of the energy supply and of CO_2-emissions has to be considered for the entire planning horizon (for example one day) . In a future research task, a sustainable model will have to be developed (e.g an RCPSP-model) which will aim at a timely achievement of production targets by considering social effects for a more realistic ascertainment of process times and for a reduction of employees' exposure to work pressure as well as ecological effects for a reduction of energy costs.

CONCLUSION

This paper presented various possibilities which could generate an improvement both in the social and in the ecological dimension besides an efficient and timely achievement of production targets, along with a reduction of costs. Here; the tasks of PPC have to be fulfilled by means of hierarchical planning methods, since their application will avoid the disadvantages occurring in a simultaneous planning approach such as a lack of available data. By looking at the three different stages of hierarchical planning, we have pointed out that various models for solving the subproblems are presented in literature; however as a rule these are limited to the economic dimension.

In the section of master production scheduling we pointed out that a more sustainable approach could help obtaining more realistic results and various kinds of cost savings. In this context, cost savings benefit from fluctuations in energy prices and can also be achieved by reducing the work pressure employees are exposed to, since reduced work pressure contributes to reducing the frequency of work-related diseases, to increasing the motivation and therefore to achieving lower and more constant execution times. In the field of batch sizes, we have shown that some approaches taking the ecological dimension into account do exist. Furthermore it became however apparent that these approaches have not been combined yet in order to create a really sustainable approach. In addition to this, it will be necessary to convert a combined model into a model which is close to reality (e.g. MLCLSP). In resource scheduling, we referred to the RCPSP-model as a multifaceted solution model. In combination with the approaches suggested by Selmair et al. (2015) and Boysen and Fliedner (2011) this will permit reducing work pressure of employees as well as energy costs. Besides that, a significant reduction of throughput times can be achieved as soon as learning effects are taken into account, as demonstrated by Peteghem (2015).

In summary, it can be said that, based on the integration of the ecological and social dimension, hierarchical panning offers supplementary improvement potentials, which may yield additional cost savings and considerably contribute to protecting our resources (in social and ecological terms), besides a timely achievement of the production targets. However the scientific works presented here are exclusively approaches of a sustainable PPC which need to be combined at each level of planning. Besides that, the concrete interdependencies between the various planning stages will have to be analysed explicitly. We also have to point out that the possibilities indicated here are just mere options for the time being. The effects and integration possibilities of these options have to be investigated further.

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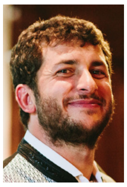
AUTHOR BIOGRAPHIES

MARCO TROST is doctoral student at the Department of Business Science at the Dresden Technical University and he is sponsored by the European Social Fund (ESF). His e-mail address is: Marco.Trost@mailbox.tu-dresden.de.

PROF. DR. THORSTEN CLAUS holds the professorship for Production and Information Technology at the International Institute (IHI) Zittau, a central academic unit of Dresden Technical University and he is the director of the International Institute (IHI) Zittau. His e-mail address is: Thorsten.Claus@tu-dresden.de.

PROF. DR. FRANK HERRMANN holds the professorship for operative production planning and control at the OTH Regensburg and he is the head of the Innovation and Competence Centre for Production Logistics and Factory Planning (IPF). His e-mail address is: Frank.Herrmann@OTH-Regensburg.de.

ENRICO TEICH is doctoral student at the Department of Business Science at the Dresden Technical University and he is research associate at the professorship for Production and Information Technology at the International Institute (IHI) Zittau, a central academic unit of Dresden Technical University. His e-mail address is: Enrico.Teich@tu-dresden.de.



MAXIMILIAN SELMAIR is doctoral student at the Department of Business Science at the Dresden Technical University. His e-mail address is: Maximilian.Selmair@mailbox.tu-dresden.de