3rd International Scientific Conference

Management of Technology Step to Sustainable Production

MOTSP 2011

8-10 June 2011, Bol, Island Brac, Croatia

Conference Proceedings

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Publisher:
Faculty of Mechanical Engineering and Naval Architecture Zagreb, Croatia

Organizer:
Faculty of Mechanical Engineering and Naval Architecture Zagreb, Croatia

Co-organizer:
University of Zagreb, Faculty of Graphic Arts
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University Ss. Cyril and Methodius, Skopje, Faculty of Mechanical Engineering
University of Maribor, Faculty for Mechanical Engineering
Politehnico di Torino, Engineering II

Printed in:
Printera grupa d.o.o. – 150 copies

Published categorized papers are peer-reviewed by two independent experts.

All papers are presented in the form which is delivered by authors. The Organizer is not responsible for statements advanced in papers or spelling and grammar irregularities.

A CIP catalogue record for this book is available from the National and University Library in Zagreb under 770482.

ISBN 978-953-7738-10-5

European Commission
TEMPUS

This project has been funded with support from the European Commission. This publication reflects the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Tempus Project
Master PLM
Product Lifecycle Management

Tempus IV Joint Project Curriculum Reform
MAS-PLM: Master Studies and Continuing Education Network for Product Lifecycle Management with Sustainable Production
No.144959-TEMPUS-2008-IT-JPCR (www.master-plm.net)

Management of Technology – Step to Sustainable Production

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TABLE OF CONTENTS

FUNCTIONAL MODEL FOR A CAPACITY ADAPTION SYSTEM USING FLEXIBILITY OPTIONS

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Abstract

The extensive fluctuations in demand during the past 2 years have challenged the flexibility of many companies to the limit. Furthermore, many experts believe that the demand will increasingly be volatile in the future. Companies have to adapt to these requirements by being more flexible and adapt their capacities faster and in a higher frequency. Within this paper, the functionality of a decision support system, based on the concept of capacity envelopes and methods of operations research, is shown. The system delivers a recommendation to the decision maker which flexibility options are to choose in order to adapt capacity to the actual demand causing minimal additional costs.

Keywords: flexibility options, capacity envelopes, decision support system, capacity adjustment

1. INTRODUCTION

High fluctuations in demand have been a major challenge for producing companies, especially over the last two years. These fluctuations will show a significant increase, according to many experts. A major driver for this development is in particular the globalization of the industrial production and the rising complexity due to customer specific products. Consequently, a higher frequency and a higher amplitude of market demand changes can be expected. Therefore, companies have to adapt their available capacity to capacity demand even more frequently and seriously in the future, while keeping competitive overall costs.

SMEs (=small and medium sized enterprises) in particular are especially challenged, since they are facing intense cost-pressure combined with their relatively small market-share [1]. In addition, they are limited in taking actions and adopting a different strategy, due to their lacking financial and human resources [2]. This hypothesis was confirmed through a survey, conducted and carried out by Gruber [3] in the mechanical engineering industry. As shown in Figure 1, fluctuations in demand are affecting SMEs not only stronger, they are also growing with a declining forecast horizon.

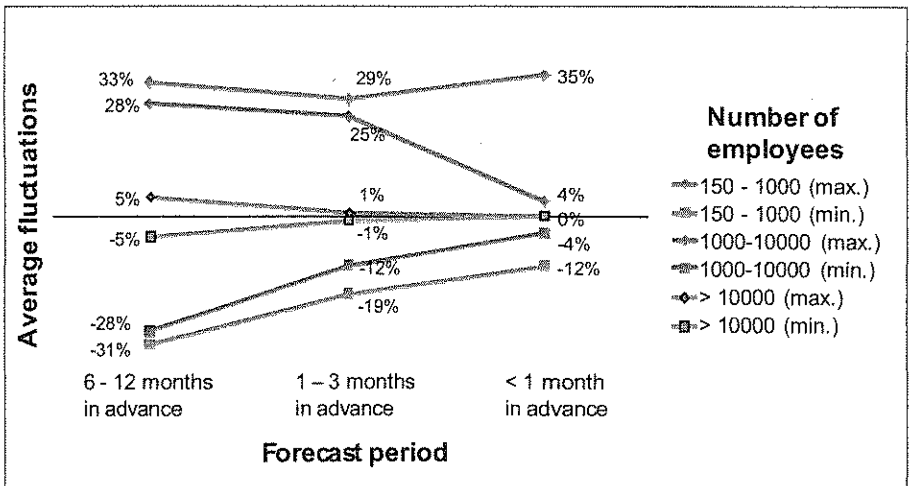

Figure 1 – characteristics of demand fluctuations by company size [3]

Since one can expect that a total leveling of customer demand fluctuations [4] is not possible, a company has to somehow cope with turbulences (see also at Wiendahl [5]). It is now obvious, that a continuous adaption of the output to the market demand is required, especially at SMEs. According to Single [6], three different adaption strategies, as shown in Figure 2, are feasible: Emancipation, Synchronization and Escalation.

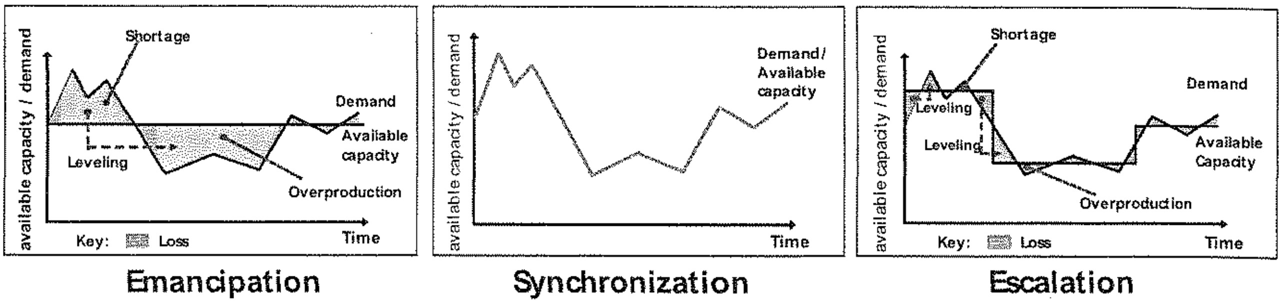

Figure 2 – Strategies to adapt the output to capacity demand [6]

Different factors and parameters, i.e. inventory costs, product shelf-life, reliability of demand forecasts, the company's liquidity and the amount of product-variations, are influencing the decision which model to choose. However, one may assume that in most cases the "Emancipation" strategy can be barred from a full implementation, mostly due to its great share of logistics costs. The same applies for the "Synchronization"-strategy. It causes high costs for capacity adaption and for the preservation of this capacity respectively. Therefore its use is mostly bounded to perishable products exclusively.

The Escalation-strategy remains as the preferred strategy in most industrial cases, where the available capacity is adapted to the demand in discrete steps. The challenge is now, to find the cost-related optimum in adapting the available capacity. Choosing the measures to adapt the capacity is usually a task for the short and medium term capacity planning.

2. CURRENT SITUATION AND STATE OF THE ART

Experiences of the authors in industrial projects certainly are showing considerable weaknesses in short- and midterm capacity planning, especially at SMEs. In practice, capacity demand planning is supported by ERP-systems, which are usually using a MRP II-Logic. Thereby, exceedings and shortfalls in capacity are displayed in order to be optimized by the operator in an iterative and manual process with support of the MRP-Systems [7]. Thus, the planning of the available short- and midterm capacities is done manually and therefore strongly depends on the experiences of the responsible employees.

The actual scientific literature offers only little support in this topic, because the short- and midterm capacity planning is treated only roughly in subject specific elaborations. When it comes to operative midterm capacity planning, Kurbel [8] only uses the idea of capacity corridors, where orders can be aligned to. However, this model does only work in theory.

The adjustment of capacity mainly deals with deciding- and planning problems. This becomes even more apparent, if the diverseness of the demand uncertainty regarding type and time horizon are considered as well. Different fluctuation events cannot be treated with the similar adjustment and configuration measures, but rather have to be treated with specific, tailor-made ones, especially when financial efforts for adjustments have to be considered. [9]

According to Buzacott [10], adjustments of capacity can be carried out by:

- Changing the intensity of production processes (adapting cycle time etc.)
- Extension / reduction of operating time (overtimes, extra shift, short-time work etc.)
- Increase / decrease number of employees and operating resources (Investment, Outsourcing, etc.)

In the actual scientific literature, selection criteria for the adjustment of available capacities are not specified explicitly. Buzacott [10], for example, explains that each measure for capacity adjustment depends on the one hand from the situational suitability for capacity leveling and on the other hand from the measures' occurring costs. Gottschalk [9] claims that a sufficient understanding for flexibility at all stages of production and a detailed capacity planning lay the foundation for successful capacity adjustments. However, both authors do not name any specific criteria and measures.

To find a capacity adjustment strategy at optimal cost, it is essential to know the company's capacity flexibility. Lödding [11] defined it as the capability to adapt its manufacturing capacities rapidly, cost-efficient and to a great extent. According to Wiendahl/Breithaupt [12] and Bornhäuser [13] capacity envelope curves help to visualise and describe different flexibility options. As shown in figure 3 the x-axis stays for reaction time and minimum installation time respectively. The y-axis represents the added or reduced capacity a system can facilitate, due to the conducted measurements.

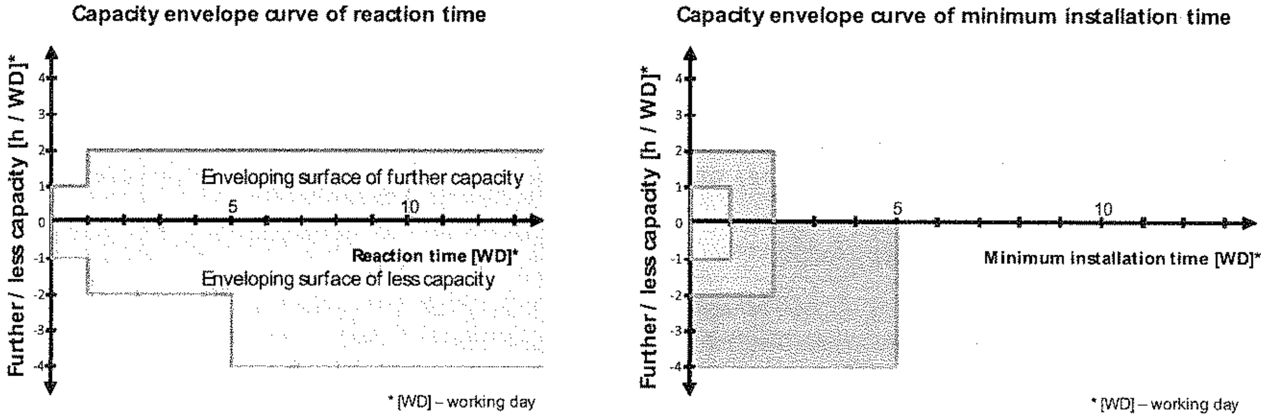

Figure 3 – Capacity envelope curve according to Wiendahl/Breithaupt [12]

According to Reinhart [14] human beings, technologies and organizational structures can be used as measures to adjust capacities. The capacity envelope curves of all measures to adjust the capacity of a work system are overlapped to establish a flexibility profile, which provides information about the maximum ability of the work system to adjust its flexibility, without informing about additional costs which will be incurred. [9], [15]

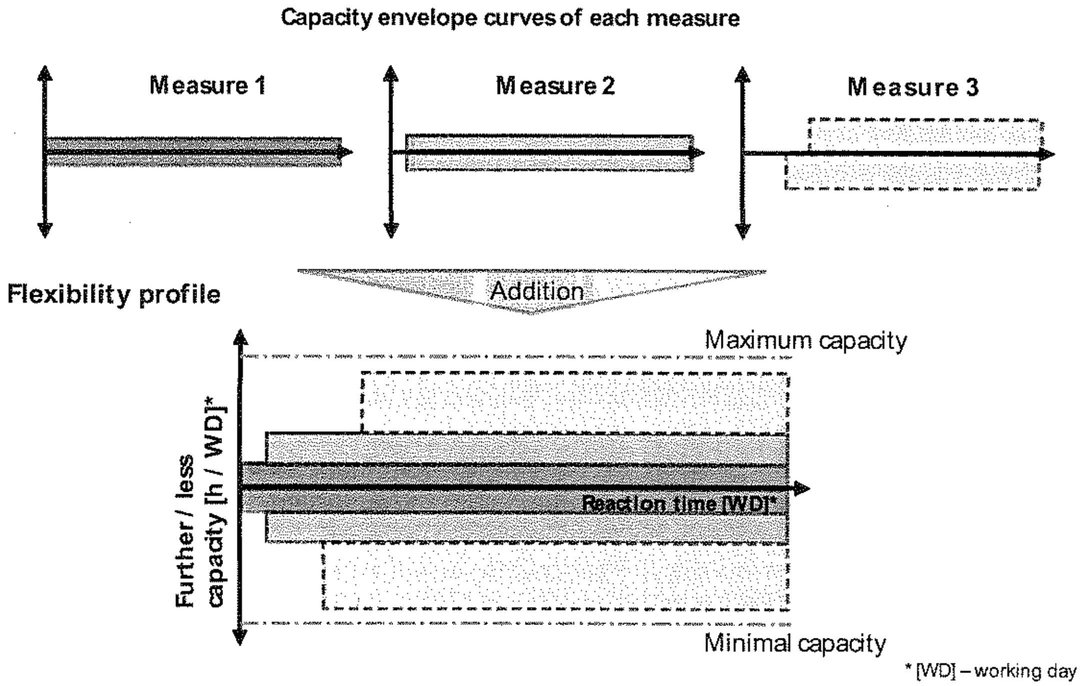

Figure 4 – Development of flexibility profile. [6], [11]

Lödding [11] recommends the generation of a capacity profile of all relevant resources to identify the need for action in the first place before the bottleneck resource is determined. Measures to adjust the capacities, regarding the bottleneck, have to be analysed and the planning needs to be adjusted respectively. But it is not illustrated how the adaption measures are chosen or evaluated. A consideration of costs lack completely. Single [6] also describes a methodology to identify company's future reactions or actions concerning customer related fluctuations in orders, which is organized in seven steps.

Similar to the solution of Lödding [11], step 5 tries to identify weaknesses and measures, reaction strategies are developed in step 6. This method neither considers cost aspects, nor supports the decision on the choice of measures.

There often exist two concrete weaknesses of the planning of the capacity adjustment in operational practice:

1. Lack of overview over all possible measures to adjust the capacities.
2. Planning of the supply of capacity offered without a holistic assessment of adjustment costs and thereby without a total cost management.

The first weakness can be mitigated by the previously described approaches, whereas the second weakness still exists and therefore needs to be resolved by an additional approach.

3. DEVELOPMENT OF A DECISION SUPPORT SYSTEM

3.1 Necessity of a decision support system

A functional model of a reaction system to define the capacity adjustment strategy at optimal cost, is presented within this paper. This functional model describes, among other things, the needed data base and structure, algorithms and assessments to choose a flexibility option at optimal cost and to define the system's output. Thereby, a tool is placed at the disposal, to support companies choosing the right strategy – at optimal total cost – to adapt to changing requirements on the market. The core idea is to provide the decision maker with a bunch of measures for the adjustment of capacities, both for the short-term and the middle-term capacity planning. Therefore the system can prevent discount of flexibility option by the planner on the one hand and on the other hand, all known flexibility option are assessed and compared, regarding occurring costs.

All companies, which face a fluctuation in demand, use cost-intense manufacturing technologies and which see significant potential within their strategies to adjust capacities are potential users of such a reaction system.

3.2 Description of the functional model

The functional model, see Figure 5, is based on the work of Lödding [11] and Single [6], whereas existing preparatory work was strongly adapted. The short-term and middle-term capacity planning is chosen to be the application area, whereas the strategic long-term capacity planning can be supported by this approach only on a limited basis. The focus can be chosen relatively free, the capacity adjustments of single user stations can be designed at optimal cost as well as the capacity adjustment of complete sites, regarding the grade of aggregation of the data.

Relevant fluctuations in demand are identified and analysed within the **first step**. These can be affected by internal and external primary production cycles on the one hand and by happenstances on the other hand. Numerous authors have developed methodologies and strategies to develop demand forecasts, exemplarily we refer to Morrell and Armstrong [16], [17].

Within the **second step** it is necessary to identify and assess flexibility options. A flexibility option is a capacity adjustment measurement, which is assessed, regarding all substantial criteria. Flexibility options can be of personal (adjustment of the number of employees, assignment of hired staff, etc.), organisational (adaption of working hours, modification of the number of shifts, external processing of orders, displacement of maintenance, etc.) or technical (adjustment of the machine efficiency, modification of the manufacturing method, etc.) kind. Reinhart [14] and Lödding [11] provide an overview of theoretically possible flexibility options.

Building up of stock of finished products is a flexibility option which isn't regarded in this phase yet, because it should remain an option within the calculation model for the capacity adjustment at optimal cost. Which flexibility option is relevant and possible for the observed (part of the) system needs to be assessed on a case-to-case basis. A creative process is needed within the company to develop a bunch of flexibility options, which is carried out as a rule within the scope of a moderated workshop. An exemplary assessment of a flexibility option, which contains the essential assessment criteria, can be found in Figure 6.

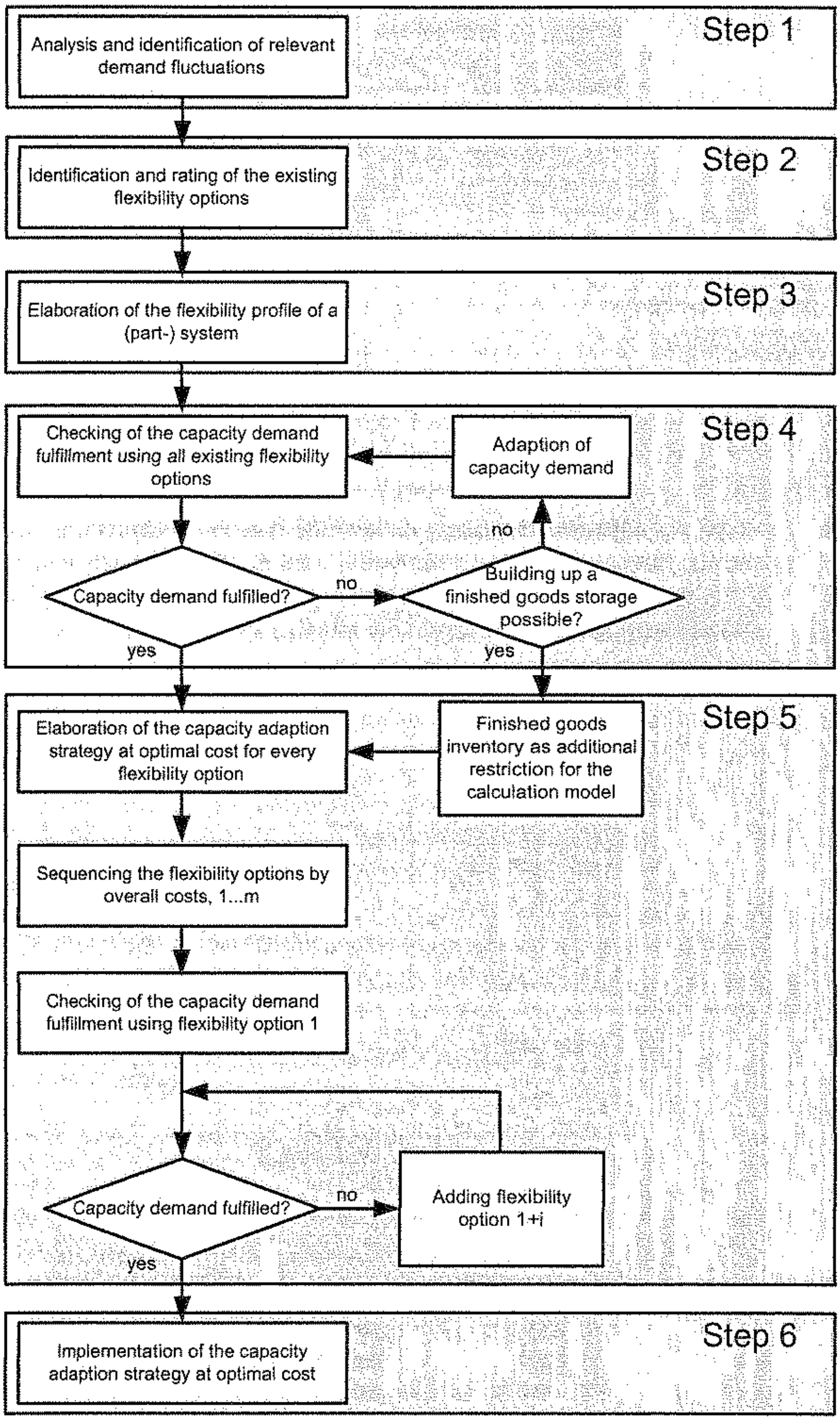

Figure 5 – Functional model of the response system

The **third step**, the establishment of flexibility profile of (a part of) the system, can be implemented based on the data gathered during step two and is carried out analogue to the approach shown in Figure 4, by overlapping single flexibility options, considering activation time and minimal and maximal operating time.

It has to be checked if the predicted fluctuation in capacity demand can be covered by the available capacity, using all possible flexibility options, during the **fourth step**. For this purpose the flexibility profile and the capacity profile are superposed, possible capacity bottlenecks can be identified (see Figure 7) and adequate counteractions have to be initiated. The only way to react on a still remaining capacity shortages is an postponement of quantities, since all flexibility options are taken into account. The capacity requirements for (a part of) the system has to be reduced, if it is not possible to postpone the quantities (for example when dealing with perishable goods or an unpredictable or not defined mix of products). If postponements are possible, it has to be regarded within the calculation model as an additional restriction.

Flexibility Option	Workplace		
flextime	xyz		
capacity change [h/wd]	+/- 1	+/- 2	+/- 3
activating time [wd]	0	1	3
min. duration of availability [wd]	0	0	0
max. duration of availability [wd]	-	-	30
adjustment costs [€/h]	0	0	20

wd ... working days

Figure 6 – Example for an evaluated flexibility option

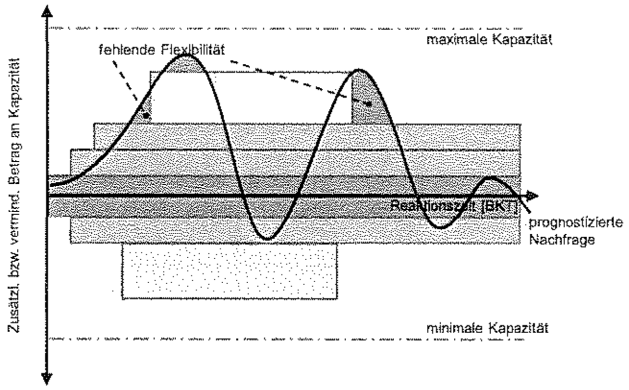

Figure 7 – Superposed flexibility profile and capacity profile

During the **fifth step** the capacity adjustment strategy at optimal cost is determined up to the barriers of the flexibility. The "production planning and warehousing model with adjustment costs when changing the level of production", presented by Stepan and Fischer [18], based on Bellman's principle of optimality, can be, slightly adapted, used to calculate the optimum operational strategy of a flexibility option, regarding possible make-to-stock strategies. In doing so the objective function is

$$minimise\, f = \sum_{n=1}^{N} C_n(s_{n-1}, u_{n+1}, u_n)$$

with

$N = number\ of\ considered\ periods$ $\qquad s_n = Stock\ during\ this\ period$

$n = Index\ of\ the\ period$ $\qquad u_n = Output\ during\ this\ period$

$C_n = Costs\ of\ the\ period$

further

$$C_n(s_{n-1}, u_{n+1}, u_n) = c_n(u_n) + h_n s_{n-1} + v_n(u_{n+1}, u_n)$$

with

$h_n = Factor\ for\ storage\ costs\ for\ each\ period\ and\ piece$

$v_n(u_{n+1}, u_n) = x_n |u_{n+1} - u_n|$ $\qquad$ with $x_n = Factor\ for\ adjustment\ costs$

and the restrictions

$0 \le s_n \le L_n$ $\qquad$ with $L_n = max.\ storage\ capacity\ during\ a\ period$

$0 \le u_n \le K_n$ $\qquad$ with $K_n = max.\ production\ capacity\ of\ a\ period$

the recursion formula to be used is

$$f_n(s_n, u_{n+1}) = \min_{u_n}\{C_n(s_{n-1}, u_{n+1}, u_n) + f_{n-1}(s_{n-1}, u_n)\}$$

with the constraint

$s_{n-1} = s_n + u_n - d_n$ $\qquad$ with $d_n = Demandzu\ during\ this\ period$

The restrictions for the minimal activating time and the minimal and maximal operation time have to be considered manually within the model.

Results of this calculation are the total costs of the capacity adjustment strategy at optimal cost for a flexibility option, regarding all given restrictions and constraints. To determine the optimum combination of all flexibility options, the following approach has to be implemented, as also described in Figure 5: After the assessment, concerning the possibility to cover the capacity requirements using the flexibility option at minimal total costs, the flexibility option with the next higher total costs has to be added. This will be continued until the available capacity satisfies at least the capacity requirements.

Afterwards, **step six** is performed and the gathered capacity adjustment strategy is implemented.

4. PRACTICAL EXAMPLE

The described approach was verified with the help of a concrete example. The observed company is an OEM electronic manufacturer, who produces products not related to a customer order. In step one, forecasts which already existed in the company, were analysed (see Figure 8) and in step 2 and 3 flexibility options were identified and assessed to establish the available flexibility options. The capacity check in step four revealed restrictions for the calculation in step five. The results of step five are shown in Figure 9 and 10 and indicated, as strategy at optimal cost, a combination of a flextime model for the permanent staff and the deployment of temporary staff to cover seasonal heights.

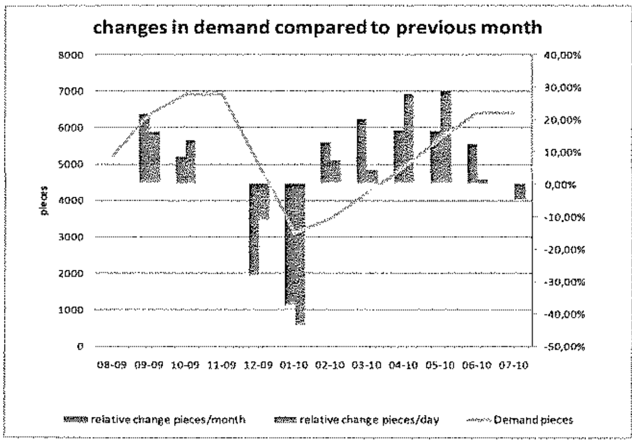

Figure 8 – Demand changes compared to previous month

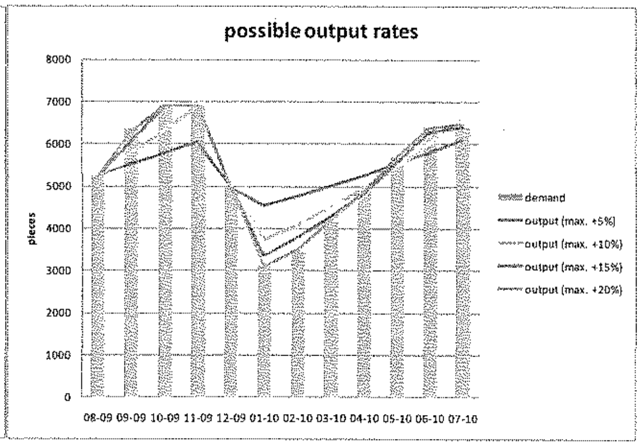

Figure 9 – Possible output rates at different flex time models

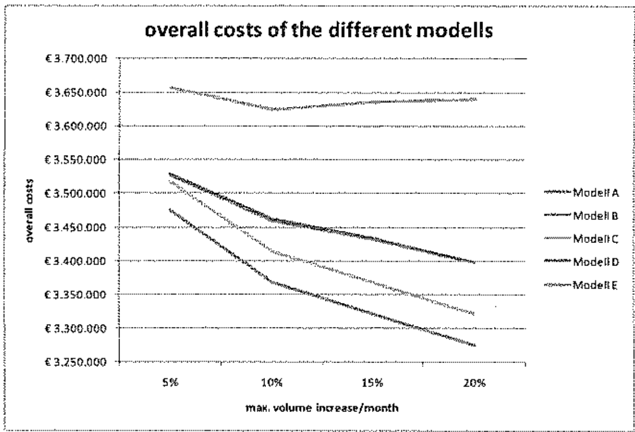

Figure 10 – Overall costs of different modells

5. CONCLUSION

The model, presented in chapter 3, contributes to mostly eliminate the weaknesses described in the beginning when selecting the capacity adjustment strategy at optimal cost. Nonetheless there is still need of further research. The presented model shows amongst others the following weaknesses:

1. The consideration of restrictions for minimal activating time as well as minimal and maximal operation time still need to be executed manually.

2. The step-by-step extension of capacities through adding of the next best flexibility option doesn't guarantee an optimum whole solution.
3. The model doesn't have an interface with existing ERP systems, the data transfer and integration has to be carried out manually and therefore is executed event-driven and not continually.
4. The monitoring of the capacity requirements isn't accomplished continuously and automated, therefore manual data transfer is still necessary.

Middle-term target of our further research therefore is the development of a reaction system to adjust and harmonise capacities at optimal cost, which can be used as a decision support system for short- and middle-term capacity planning and exceeds existing solutions of ERP and MES systems. With the help of automated interfaces it doesn't orientate to statically planned capacity borders, but continuously supervises the capacity requirement, which results from demanded or planned quantity and deduces capacity adjustment strategies at optimal cost.

6. REFERENCES

[1] Gómez Kempf, F. A.; Aurich, J. C.; Drews, O.: Implementation Strategy for a Flexibility Oriented Production System; in: Mitsuishi, M.; Kimura, F. (Hrsg.): Manufacturing Systems and Technologies for the New Frontier, Proceedings of the 41st CIRP Conference on Manufacturing Systems; Tokyo 2008; S. 315-318

[2] Abel, J.: Ganzheitliche Geschäftsmodelle in KMU; in: wt Werkstattstechnik online 97 (2007) Heft 4; S. 293-297

[3] Grundmann, S.; Reinsch, S.: Flexible Kapazitäten im Maschinen- und Anlagenbau; in: Industrie Management 22 (2006) Heft 5; S. 42-44

[4] Buhl, M.; Deuse, J.: Stufenmodell zur Nivellierung in der variantenreichen Kleinserienfertigung; in: PPS Management 14 (2009) Heft 2; S. 26-29

[5] Wiendahl, H.-H.: Situative Konfiguration des Auftragsmanagements im turbulenten Umfeld. Dissertation, Universität Stuttgart, 2002.

[6] Single, N.: Methodik zur Identifikation von Reaktions- und Handlungsmöglichkeiten auf kundenseitige Auftragsschwankungen, Diplomarbeit, Universität Karlsruhe, 2010; p. 28 ff.; p. 73 ff; p.86 ff

[7] Dickmann, P. (Hrsg.): Schlanker Materialfluss mit Lean Production, Kanban und Innovationen, Springer (2007); p.326

[8] Kurbel, K.: Produktionsplanung und -steuerung, methodische Grundlagen von PPS-Systemen und Erweiterungen, 4. Auflage, Oldenburg (1999), S. 159 ff.

[9] Gottschalk, L.: Flexibilitätsprofile: Analyse und Konfiguration von Strategien zur Kapazitätsanpassung in der industriellen Produktion. Dissertation, ETH Zürich, 2005.

[10] Buzacott, J.A., Corsten, H., Gössinger, R., Schneider, H.M.: Produktionsplanung und -steuerung, Grundlagen, Konzepte und integrative Entwicklungen, Oldenbourg (2010), S. 104 ff.

[11] Lödding, H.: Verfahren der Fertigungssteuerung, 2. Auflage; Springer (2008), p.467 – 478

[12] Wiendahl, H.-P., Breithaupt, J.-W.: Kapazitätshüllkurven – Darstellung flexibler Kapazitäten mit einem einfachen Beschreibungsmodell, in: Industrie Management 14 (1998) Heft 4, S. 34-37.

[13] Bornhäuser, M.: Reifegradbasierte Werkstattsteuerung. Dissertation, Universität Stuttgart, 2009, p. 87

[14] Reinhart, G.; Dürrschmidt, S.; Krüger, A.: Stückzahlflexible Montage- und Logistiksysteme; in: wt Werkstattstechnik 89 (1999) Heft 9; S. 413-418

[15] Reinhart, G., Schellmann, H.: Rahmenkonzept zur Ermittlung kundenspezifischer Mengenflexibilität, in: ZWF 104 (2009) Heft 7-8; S. 546-551.

[16] Morrell, J.: How to forecast – a guide for business, Gower Publishing, Ltd.;2001

[17] Armstrong, J.: Principles of Forecasting – a handbook for researchers and practicioners, Springer, 2001

[18] Stepan, A., Fischer, O.: Betriebswirtschaftliche Optimierung – Einführung in die quantitative Betriebswirtschaftslehre, Oldenbourg (2001), S. 216 – 222.