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Organized by:
Laboratory for Manufacturing Systems and Automation (LMS)
Director: Prof. George Chryssolouris

Conference Programme

Tuesday, 15 May, 2012				
17:00–19:00	**Onsite Registration**			
19:00–20:00	**Reception at "The MARGI" Hotel**			
Day 1: Wednesday, 16 May, 2012				
08:30-09:30	**Onsite Registration**			
09:30–10:00	**Opening Ceremony** Welcome by Prof. G. Chryssolouris CIRP President Address by Prof. A. Nee Conference Planning by Prof. D. Mourtzis			
10:00–10:30	**Plenary Session** **Keynote Paper: Manufacturing Skills and Competences for the Factories of the Future** D. Mourtzis, D. Mavrikios, N. Papakostas, G. Chryssolouris			
10:30–11:00	**Coffee Break**			
11:00–12:30	**Manufacturing Systems Design**	**Manufacturing Processes**	**Manufacturing Systems Planning & Control**	**Manufacturing Equipment Automation**
	Session A1	**Session B1**	**Session C1**	**Session D1**
	P01: Assessing Lean Systems Using Variability Mapping A. Deif	**P17: Analysis of Micro Burr Formation in Austenitic Stainless Steel X5CrNi18-10** D. Biermann, M. Steiner	**P04: Model of a decision support system for a least-cost and harmonized capacity adjustment in the short- and medium-term planning horizon** C. Morawetz, W. Sihn	**P24: Automated Driving by standardizing and scaling the manufacturing strategy** Z. Yang, P. Sachnik, D. Opritescu, R. Golle, W. Volk, H. Hoffmann, F. Schmiedl, M. Ritter, P. Gritzmann
	P03: A Simulation-Based Evaluation of Selective and Adaptive Production Systems (SAPS) Supporting Quality Strategy in Production J. Kayasa, C. Herrmann	**P15: Reduction of Burr Formation in Drilling using Cryogenic Process Cooling** D. Biermann, H. Hartmann	**P11: Operational planning of maintenance measures by means of event-driven simulation** B. Denkena, S. Kroening, K. Doreth	**P25: Online Evaluation Method of Machining Precision Based on Built-in Signal Testing Technology** F. Zhao, X. Mei, Z. Du, T. Tao, G. Jiang
	P36: A wed-based platform for customer integration in the decentralized manufacturing of personalized products D. Mourtzis, M. Doukas	**P34: Numerical Study on Shear Flow in Sliding Bearing with Partial Slip Surface** Q. Lin, Z. Wei, Y. Tang	**P27: A Reference Model For Collaborative Capacity Planning Between Automotive And Semiconductor Industry** M. Zapp, C. Forster, A. Verl, T. Bauernhansl	**P02: Defining Manufacturing Performance Indicators using Semantic Ontology Representation** G. Pintzos, M. Matsas, G. Chryssolouris

12:30–14:00	**Lunch Break**			
14:00–15:30	**Session A2**	**Session B2**	**Session C2**	**Session D2**
	P73: A case study on reuse of manufacturing knowledge within the defence industry with a comparison to automotive and aerospace practices L. Krogstie, P. Andersson	**P16: Size Effects in Micro Drilling Ferritic-Pearlitic Carbon Steels** M. Abouridouane, F. Klocke, D. Lung, O. Adams	**P110: Optimal Process Shift Design in Selective and Adaptive Production Systems** M. Colledani, D. Ebrahimi	**P54: Collaborative Factory Planning in Virtual Reality** N. Menck, X. Yang, C. Weidig, P. Winkes, C. Lauer, H. Hagen, B. Hamann, J.C. Aurich
	P19: The State of the Art and Prospects for the Future of Learning Factories U. Wagner, T. AlGeddawy, H. ElMaraghy, E. Müller	**P35: Numerical Simulation and Experimental Study on the Resist Filling Behaviour in UV-nanoimprint Lithography** J. Du, Z. Wei, Y. Tang	**P28: Benchmarking of Methods and Instruments for Self-Optimization in Future Production Systems** C. Wagels, R. Schmitt	**P18: Realistic Machine Simulation with Virtual Reality** R. Neugebauer, P. Klimant, M. Witt
	P108: Developing Competencies for Continuous Improvement Processes on the Shop Floor through Learning Factories – conceptual design and empirical validation J. Cachay, E. Abele	**P21: An Initial Study of the Effect of Using Liquid Nitrogen Coolant on the Surface Roughness of Inconel 718 Nickel-Based Alloy in CNC Milling** A. Shokrani, V. Dhokia, R. Imani-Asrai, S.T. Newman	**P93: A Model of Collaborative Enterprise Networks** H. Baum, J. Schuetze	**P32: Design and Development of an in situ Machining Simulation System using Augmented Reality Technology** J. Zhang, S.K. Ong, A.Y.C. Nee
15:30–16:00	**Coffee Break**			
16:00–18:00	**Session A3**	**Session B3**	**Session C3**	**Session D3**
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	P09: An integrated setup planning and pallet configuration approach for highly automated production systems with energy modelling of manufacturing operations S. Pellegrinelli, A. Valente, L.M. Tosatti	**P97: Knowledge Integration in a Collaborative Machining Process Planning Environment** M. Helgoson, V. Kalhori	**P37: Ontology based Intelligent assistance system to support manufacturing activities in a distributed manufacturing environment** S. Minhas, C. Juzek, U. Berger	**P55: Design methodology for mechatronic active fixtures with movable clamps** T.N. Papastathis, O.J. Bakker, S.M. Ratchev, A.A. Popov

	P26: Multiple-attribute decision making for an energy efficient facility layout design L. Yang, J. Deuse **P47: Distributed Optimization of Energy Portfolio and Production Planning for Multiple Companies under Resource Constraints** T. Nishi, E. Sekiya, S. Yin	**P56: Carbon Emission Assessment to Support the Planning and Operation of Low-Carbon Production System** X. Shi, H. Meier **P61: Suitability of the ISO 10303-207 Standard for Product Modelling of Line Linked Micro Parts** K. Tracht, F. Weikert, T. Hanke	**P43: Game Theoretic Approach for Global Manufacturing Planning under Risk and Uncertainty** S. Yin, T. Nishi **P53: Throughput time characteristics of rush orders and their impact on standard orders** D. Trzyna, A. Kuyumcu, H. Lödding	**P60: Robot Path Correction Using Stereo Vision System** G. Michalos, S. Makris, A. Eytan, S. Matthaiakis, G. Chryssolouris **P75: High Speed Vision based automatic Inspection and Path Planning for Processing conveyed Objects** M. Weyrich, Y. Wang, J. Winkel, M. Laurowski
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09:00–10:30	**Session A4**	**Session B4**	**Session C4**	**Session D4**
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10:30–11:00	**Coffee Break**			
	Session A5	**Session B5**	**Session C5**	**Session D5**
11:00–12:30	**P87: Manufacturing Complexity Review Challenges and Outlook** K. Efthymiou, A. Pagoropoulos, N. Papakostas, D. Mourtzis, G. Chryssolouris **P67: Testing Complexity Index - A Method for Measuring Perceived Production Complexity** S. Mattsson, P. Gullander, U. Harlin, G. Bäckstrand, Å. Fasth, A. Davidsson **P39: Structural Complexity Assessment: A Design and Management Tool for Supply Chain Optimization** V. Modrák, P. Semanco	**P57: Preliminary Study on Chemical Figuring and Finishing of Sintered SiC Substrate Using Atmospheric Pressure Plasma** K. Yamamura, Y. Yamamoto, H. Deng **P104: Forming Process Integrated Induction Brazing** J. Avemann, R. Willy, G. Zhao, P. Groche **P80: Investigation of the material removal efficiency during Femtosecond Laser machining** P. Stavropoulos, K. Efthymiou, G. Chryssolouris	**P50: Design and planning of decentralized production networks under high product variety demand** D. Mourtzis, M. Doukas, F. Psarommatis **P65: An evolutionary approach for global production network optimization** G. Schuh, T. Potente, D. Kupke, R. Varandani, C. Hausberg **P48: Computational Evaluation of Order Selection Methods in Dynamic Supply Chains** Y. Tanimizu, B. Orita, Y. Shimizu, C. Ozawa, Y. Maeda, K. Iwamura, N. Sugimura	**P106: Optimal Design of Machine Tool Bed by Load Bearing Topology Identification with Weight Distribution Criterion** B.T. Li, J. Hong, Z.L. Wang, W.W. Wu, Y.B. Chen **P13: A Cost Model for Determining an Optimal Automation Level in Discrete Batch Manufacturing** J.E. Staehl, P. Gabrielson, C. Stael, C. Andersson **P59: Cooperating machines for reconfigurable assembly operations, review and technological challenges** S. Makris, G. Michalos, A. Eytan, G. Chryssolouris
12:30–14:00	**Lunch Break**			
	Session A6	**Session B6**	**Session C6**	**Session D6**
14:00–15:30	**P46: Intelligent management of manufacturing knowledge: Foundations, motivation scenario and roadmap** M. Landherr, C. Constantinescu **P51: Software evaluation criteria for rapid factory layout planning, design and Simulation** N. Shariatzadeh, G. Sivard, D. Chen	**P81: An Empirical Study of the Energy Consumption in Automotive Assembly** A. Fysikopoulos, D. Anagnostakis, K. Salonitis, G. Chryssolouris **P86: Improved tribotesting for sheet metal forming** L. Kirkhorn, K. Frogner, M. Andersson, J.E. Staehl	**P77: Hybrid Production Strategy between Make-to-Order and Make-to-Stock – A Case Study at a Manufacturer of Agricultural Machinery with Volatile and Seasonal Demand** J. Koeber, G. Heinecke **P82: Efficient Scheduling Rule for Robotic Flexible Assembly Cells Based on Fuzzy Approach** K. Abd, K. Abhary, R. Marian	**P45: A function based approach on designing intelligent flexible automated manufacturing environments** M.S. Essers, T.H.J. Vaneker **P84: Modelling and Theoretical Analysis of Membership-type Services in Manufacturing Industries** K. Okuda, N. Nishino, K. Ueda

	P52: Product Design Leverage on the Changeability of Production Systems G. Schuh, J. Arnoscht, M. Völker	**P90: Measurement of Cutting Edge Temperature in Drilling** T. Beno, U. Hulling	**P89: Real–Virtual Fusion Production Scheduling Using Social Contract-based Approach – Effectiveness of Adjusting Virtual System Size** N. Fujii, Y. Qian, T. Kaihara	**P07: CAx Process Chain for Two Robots Based Incremental Sheet Metal Forming** H. Meier, J. Zhu, B. Buff, R. Laurischkat
15:30–16:00	**Coffee Break**			
	Session A7	**Session B7**	**Session C7**	**Session D7**
16:00–17:00	**P91: Enterprise Strategic Flexibility** A. Arafa, W.H. ElMaraghy	**P85: On the investigation of the structural behavior of robots while machining** C. Doukas, J. Pandremenos, P. Stavropoulos, P. Fotinopoulos, G. Chryssolouris	**P68: From task allocation towards resource allocation when optimising assembly systems** A. Fasth, J. Provost, M. Fabian, J. Stahre, B. Lennartson	**P101: Personalised Trachea Stent Designer, a Knowledge Feature** D. Ugarte, A. Izaguirre, A. Rosell
	P58: Organizational Comprehension of Manufacturing Strategy – A Case Study of a SMME N. Edh, M. Winroth, K. Säfsten	**P49: Experimental Investigation of the Plasma Arc Cutting Process** K. Salonitis, S. Vatousianos	**P74: Knowledge Management in Lean Production Systems** U. Dombrowski, T. Mielke, C. Engel	**P38: On a Predictive Maintenance Platform for Production Systems** K. Efthymiou, N. Papakostas, D. Mourtzis, G. Chryssolouris
20:30–23:00	**Banquet and Best Paper Award**			
Day 3: Friday, 18 May, 2012				
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	P66: A holistic view on design and development of manufacturing systems H. Nylund, P.H. Andersson	**P96: Social aspects of Process Monitoring in Manufacturing Systems** K. Martinsen, H. Holtskog, C.E. Larsson	**P20: Agent Oriented Construction of A Digital Factory for Validation of A Production Scenario** M. Matsuda, K. Kashiwase, Y. Sudo	**P30: A Function Block Enabled Robotic Assembly Planning and Control System with Enhanced Adaptability** L. Wang, M. Givehchi, B. Schmidt, G. Adamson

	P70: Methodology for the assessment of changeability of production systems based on ERP data G. Schuh, T. Potente, S. Fuchs, C. Hausberg **P14: The Role of Randomness of a Manual Assembly Line with Walking Workers on Model Validation** A. Al-Zuheri, L. Luong, K. Xing	**P99: Collaborative Digital Data Management for Design and Production** B.E. Biçici, C. Cangelir **P05: 3D Nesting of Complex Shaped Objects** D. Lutters, D.C. ten Dam, T. Faneker	**P100: Manufacturing Execution Through e-FACTORY System** A. Köksal, E. Tekin **P10: Integral Analysis of Labor Productivity** T. Czumanski, H. Loedding	**P95: Bionic Based Energy Efficient Machine Tool Design** R. Neugebauer, M. Wabner, S. Ihlenfeldt, U. Friess, F. Schneider **P94: Virtual Ergonomics and Time Optimization of a Railway Coach Assembly Line** A. Marzano, K. Agyapong-Kodua, S. Ratchev
10:30–11:00	**Coffee Break**			
11:00–12:30	**Session A9**	**Session B9**	**Session C9**	**Session D9**
	P69: Method for Multi-Scale Modelling and Simulation of Assembly Systems M. Neumann, C. Constantinescu, E. Westkaemper **P72: Intelligent Utilisation of Digital Databases for Assembly Time Determination in Early Phases of Product Emergence** O. Erohin, P. Kuhlang, J. Schallow, J. Deuse **P98: Matching Demand and System Structure in Reconfigurable Assembly Systems** D. Gyulai, Z. Vén, A. Pfeiffer, J. Váncza, L. Monostori	**P107: Designing for Additive Manufacturing** B. Vayre, F. Vignat, F. Villeneuve **P76: Design Architectures in Biology** J. Pandremenos, E. Vasiliadis, G. Chryssolouris	**P103: Planning of Reconfigurations on Manufacturing Resources** F. Karl, G. Reinhart, M.F. Zaeh **P102: Model for the valuation of a technology established in a manufacturing system** G. Schuh, J. Schubert, M. Wellensiek	**P22: Improvement potentials in Swedish electronics manufacturing industry – Analysis of five case studies** R. Sundkvist, R. Hedman, P. Almström, A. Kinnander **P88: Closed Loop Engineering – A relational model connecting activities of a product development process** L. Krogstie, K. Martinsen
12:30–13:00	**Closing of the 45th CIRP CMS 2012 in Plenary Session**			
13:00-14:00	**Quick Lunch**			

Model of a decision support system for a least-cost and harmonized capacity adjustment in the short- and medium-term planning horizon

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Abstract

Because fluctuations in demand will increase in future, producing companies will have to adapt their available capacity regularly, always taking the total production costs into account.

In practice, planning of available capacity is being realised without a comprehensive evaluation of changeover costs of total costs. The aim of the presented approach is to support companies in choosing an adequate strategy for a least-cost and harmonized capacity adjustment in the short- and medium-term planning horizon. This also represents a first step towards a new planning approach, enabling not only the systematic utilization of flexibilities of orders, but also of manufacturing resources.

Keywords: Capacity Adjustment, Decision-Support System, Flexibility-Options

1 INTRODUCTION

Over the last years, high fluctuation in demand forced companies to adjust their capacities gradually. According to many experts, this phenomenon will show a significant increase [1]. Due to increasing globalization of business competition and demand, companies will have to adapt their capacity level to the customer demand more often, while giving full thought to efficient cost structures.

SMEs (=small and medium sized enterprises) in particular are going to face greater challenges, since they are more vulnerable to “cost-pressure”, because of their relatively insignificant market-share [2]. In addition, they are strongly limited in taking actions and adjusting a different strategy, due to their narrowed and confined financial and human resources [3]. This hypothesis was confirmed through a survey in machinery and plant engineering industry, conducted and carried out by Grundmann und Reinisch [4].

Since one can expect that fluctuations in demand cannot be levelled totally (cf. [5]), those turbulences have to be handled somehow (cf. [6]). This shows that a continuous adaption of production volume and mix is necessary to fulfil the requirements of the international markets (cf. [7]).

2 PROBLEM STATEMENT

The capacity adjustment mainly deals with deciding and planning problems which have to consider different adaption strategies on given fluctuations in demand. In practice, capacity planning is supported by IT, whereby ERP-systems (=Enterprise Resource Planning systems) are the most used and common ones. ERP-systems use MRP II (= Manufacturing Resource Planning) Logic, in which under-utilized resources or unfulfilled customer orders are visualized and then manually and iteratively optimized [8]. Therefore, the short and medium term capacity planning strongly depends on the experience and ability of the responsible employees. Hence, the achievement of a global optimum is very unlikely. Furthermore the planning process takes place without the consideration of adjustment costs, and as a result without a total cost analysis. In addition, there is no outline of all possible capacity adjustment measures. To find an appropriate solution (a global optimum) under these general conditions, a decision support system for manufacturing companies will be developed.

3 STATE-OF-THE-ART

3.1 Adjustments related to demand fluctuation

How to react on fluctuations in demand is dependent from different parameters, e.g. storage costs, shelf life of products, accuracy of demand forecasts, liquidity of the company, quantity of product variants, and of course the flexibility of each resource (cf. [9]). Therefore, it is obvious that the flexibility of a company is not only a function of its ability to shift working hours, but is influenced by multiple parameters.

Buzacott has listed capacity adjustment measures and points out that each of those depends from its situational applicability for capacity levelling and likewise from the measures’ related costs (cf. [10]), but there is no assistance in choosing the right capacity measure. Other authors (cf. [11, 12]) define capacity adjustment measures more detailed, but they do not deliver selection criteria as well. In comparison to that, Asl and Ulsoy [13] have presented approaches to the capacity management problem based on Markov decision process and feedback control. In this approaches, the decision process itself is focussed, but neither the calculation of adaption costs and adjustment measures nor a practical application in a decision support system.

The concept of capacity envelopes, which is discussed by many different authors (cf. [14, 15, 16, 17, 18]) seems the most promising approach for defining the ideal capacity adaption strategy. In this concept, the x-axis represents the reaction time or the minimum installation time respectively. The y-axis represents the capacity level and shows especially additional or less capacity caused by a certain adaption measure. By interleaving envelope curves of all possible measures for capacity adjustment of a working system, flexibility profiles can be generated. They show the maximum capacity adjustment ability of a production system, but do not factor the related costs.

The existing scientific literature does not deal with operative short and medium term capacity planning in detail; therefore there is no support for identifying the adaption strategy which causes the lowest overall costs.

Although an interesting modelling approach for evaluating capacity flexibilities in uncertain markets was presented by Zaeh and Mueller [19]. This approach focusses on evaluating the configuration of Value Streams by their ability to handle the expected market volatility. Furthermore it calculates which changes in fixed costs or profit occurs if different investment strategies or process changes are applied. Therefore, it can be used as a decision support system in long term capacity planning.

Currently, the medium term capacity planning gets along with capacity corridors. The capacity of a resource can be adjusted within such a corridor; exceeding manufacturing orders are shifted (cf. [20]). Furthermore, general selection criteria to adapt capacities to the demand cannot be found. However, Gottschalk [15] claims that a sufficient understanding for flexibility at all production stages and a detailed capacity planning lay a foundation for successful capacity adjustments.

In order to identify the need for capacity adaption, Lödding [16] suggests developing capacity profiles for all relevant resources in a first step. In a second step, the bottleneck-resource can be identified, for which specific measures have to be elaborated and proofed. These measures adapt the previous plan and should finally improve the performance of the total system. Nevertheless, Lödding does not discuss how to choose and evaluate adjustment measures and related costs remain again disregarded. Single [21] describes reaction and action methods for companies as well, which struggle with demand fluctuations. Similar to the bottleneck-search at Lödding (cf. [16]) he looks for weaknesses, and establishes counter-measures and reaction strategies respectively.

In operational practice, capacity planning is generally done with capacity and PPS (= Production Planning and Scheduling) -software's. They are used for staff planning and complete resource planning and are usually integrated in ERP-systems. Generally, they support the flexibility of companies by considering costs in planning. However, adjustment costs are not observed. Some examples are:

- Production von abas (cf. [22]).
- Fast/pro (cf. [23]).
- enviso optiCAP (cf. [24]).
- GANTTPLAN (cf. [25]).
- WINLine PROD (cf. [26]).

SAP APO (Advanced Planning and Optimizer) is the production planning component within the mySAP SCM solution. It is probably the most used planning and optimization tool for customer order processing and therefore a closer look is appropriate. It contains 7 modules, whereby Production Planning and Detailed Scheduling (PP/DS) has the biggest relevance for the topic of this paper. Generally, it delivers feasible schedules, optimizes order sequences under consideration of resource capacities, set-up and delay costs, and also matches customer demand with free capacities along the supply chain. However, capacities are treated as fixed constraints and are only adaptable manually.

4 AIM OF THIS PAPER

As mentioned in the introduction, increase in demand fluctuations force manufacturing companies to adjust their capacities on a day to day basis. Based on this challenge it is aimed to support companies by developing a decision support system that recommends an appropriate capacity adjustment strategy at optimal cost. This strategy consists of a package of measurements to adjust capacities in the short and medium term planning horizon. In this way it is ensured that the user considers all possible adjustment measures and all flexibility measures are evaluated and compared under total cost aspects. The selection of the appropriate mix of measures is supported by an optimization algorithm.

In the scientific literature capacity balancing is divided into capacity levelling and capacity adjustment. Capacity levelling takes place, at least in the short term planning, prior to capacity adjustments. It represents a first try to adapt the demand to the available production capacity in terms of time, technology and quantity (cf. [27, 28, 29]).

In the following, the solution only concentrates on capacity adjustments and assumes that all possibilities of capacity leveling have been used to full extend. Furthermore, the idea bases on the "new perspective in PPS" [6], while the question is: "What do we have to do in operations – regarding capacities and material availability – to fulfil each order in time?" Hence, the actuating variable in order management is not the order release, but rather the variable level of capacity (cf. [30]).

5 SOLUTION

Within an internally financed research project, a functional model of a reaction system for capacity adjustment at optimal cost was developed (see fig. 1). The fundamental elements of this system are the following:

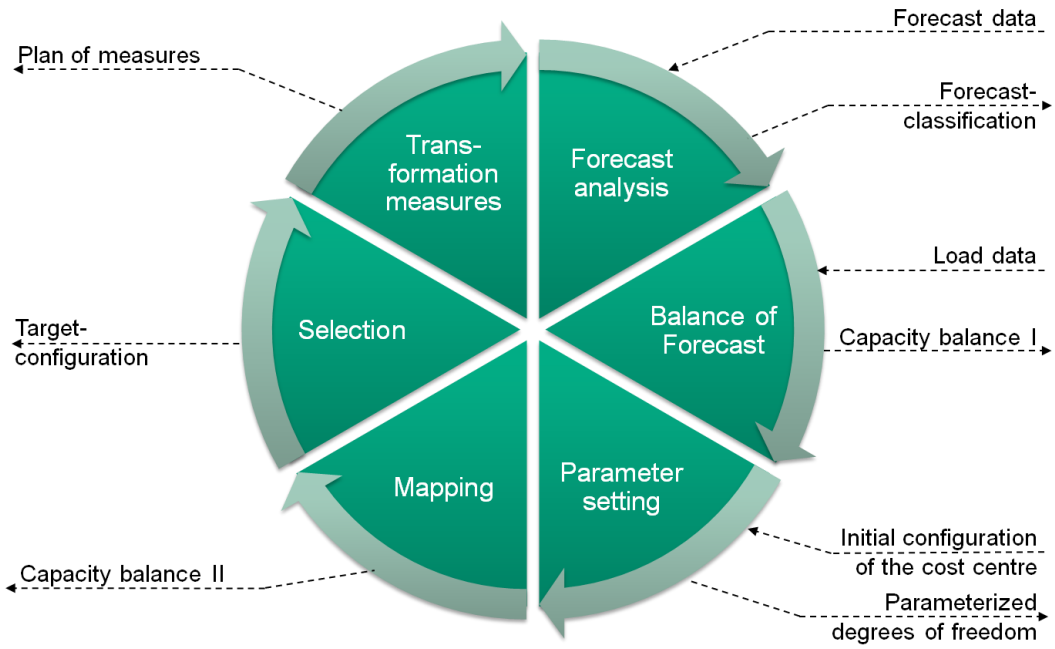

Figure 1: Model of the reaction system.

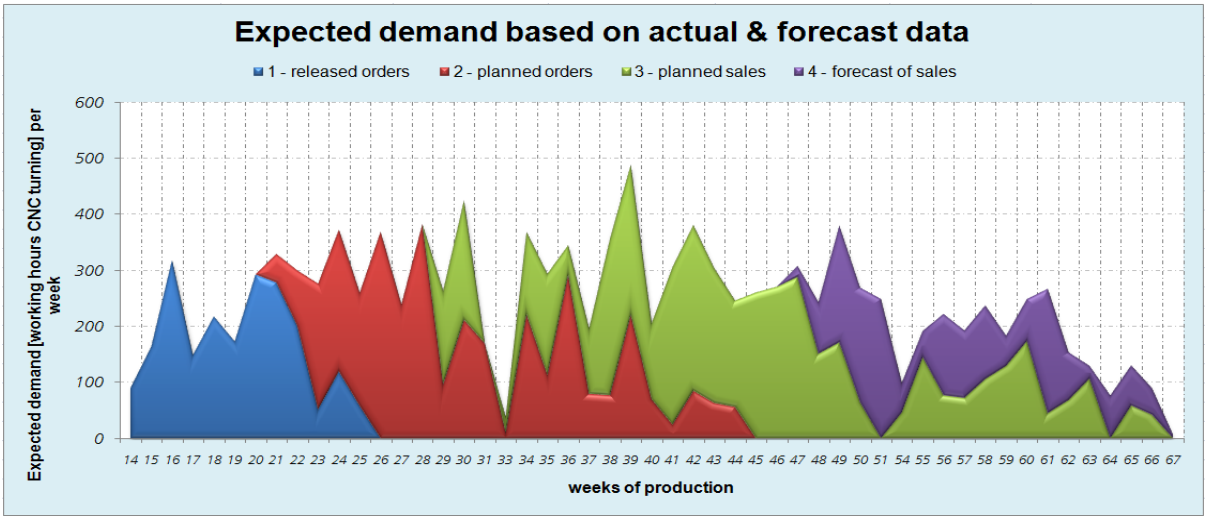

Figure 2: Overlapping of different types of data-sources.

5.1 Analysing forecast data to identify fluctuation type

At first, forecast data is analyzed and classified in terms of fluctuation. In general, accurate demand forecasts provide the basis for developing a cost-efficient capacity adjustment strategy. It is essential to forecast the trend of demand, but likewise the uncertainty of demand. In literature, forecasting methods are sufficiently discussed (cf. [31, 32, 33]). To get a valid forecast, it is crucial to use data from different sources, e.g. as cleared and not-cleared production orders, planned orders and long-term forecasts (see Figure 2:). Demand trends can be classified based on its character (e.g. seasonal fluctuations or peaks) and are relevant indicators for strategic and long term capacity adjustments. (cf. [34]).

5.2 Comparison of forecast and actual load data with the initial configuration

The comparison of forecast and actual load data with the initial configuration serves as a position check. If there is no deviation between capacity demand and available capacity in the initial configuration, no further measures have to be implemented. If there is deviation in capacity, the next step has to be executed.

5.3 Define and parameterize the degrees of freedom

To conceive and illustrate the flexibility of a resource, it helps to classify the degrees of freedom of a resource in terms of feasible capacity adjustments (see Figure 3:).

Methods to increase capacity	E 1	Temporary overtime	Methods to reduce capacity	R 1	Temporary reduction of working hours
	E 2	Temporary additional shift		R 2	Shift off / closure days
	E 3	Permanent additional shift		R 3	Reduction of employees (direct/indirect)
	E 4	Purchase new production facility		R 4	Permanent reduction of shifts
	E 5	Increase of working hours in production facility or in administration		R 5	Disinvestment of production facilities
	E 6	Increase of efficiency/performance rate of production facilities		R 6	Reduction of efficiency/performance rate of production facilities
	E 7	Temporary outsourcing		R 7	Re-insourcing
	E 8	Permanent outsourcing		R 8	Adjustment of production processes to reduce capacities
	E 9	Adjustment of production processes to support capacities		R 9	Insourcing
	E 10	Fully automated shift		R 10	Closing down production facility

Figure 3: Degrees of freedom in terms of capacity adjustments.

In case of application, possible measures for capacity adjustment have to be determined and parameterized appropriately. The relevant parameters are:

Cost aspects	Implementation costs
	Fixed costs per time unit
	Costs per capacity unit
	Costs of capacity reduction
Time aspects	Duration to first employment
	Duration until 100% workload
	max. workload
	min. workload
	Retreat duration to starting level
	Recovery Time
Scale aspects	Max. increase of capacity [total]
	Max. increase of capacity [unit]
	Min. increase of capacity [unit]

Table 1: Relevant parameters for a cost-optimal capacity adjustment.

The parameter setting follows an analysis of business and technical company data. The input and further processing are done in preconfigured charts. The aspects of time are used as restrictions in the following optimization problem. The scale aspects and cost aspects define a cost function of the available capacity for each degree of freedom (cf. Figure 4).

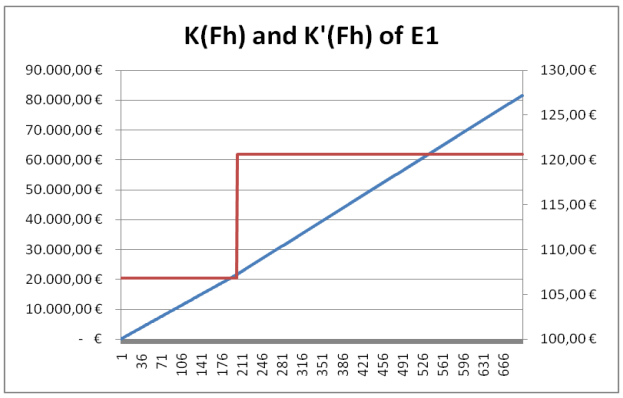

Figure 4: Cost function and first derivative of the cost function of measure E1 (temporary overtime) in response to the available manufacturing capacity.

The overall costs for a production process, depending on the number of working hours (x-axis), are represented by the blue line. Whereas the red line represents the overall production costs per working hour, which are as well dependent from the total number of planned working hours, due to overtime premium in example. If interactions of measures exist, they have to be conceived and finally defined in addition.

5.4 Mapping of demanded and available capacity under consideration of degrees of freedom

The parameters of the previous step can be used for the illustration of capacity envelope curves (cf. [14, 15, 16, 17, 18]). By overlapping these envelope curves, one can identify a maximum capacity corridor, which outlines the flexibility of this (sub-) system. In this step, capacity is inspected in terms of fulfilment of demand. If the maximum capacity corridor is exceeded or undercut, further measures for capacity adjustments have to be defined. A repetition of step 3 is recommended, to find new or alternative measures for capacity adjustments with a higher impact.

5.5 Selection of the appropriate level of capacity and profile

To reduce costs, an appropriate capacity level will be chosen, whereby a valid measure mix leads to fulfilment in demand. Similar problems have been already solved (cf. [35]). However, the larger amount of degrees of freedom requires a new and specific model. For finding a solution, discretisation was executed and all occurring values have been set as steady within a time range. The basic approach is described in the following: For every interval in time $T_i, i = 1,\ldots,N$ and every capacity adaption measure $M_k, k = 1,\ldots,R$ we define a decision variable $\boldsymbol{X}$ $M_{ki}, i = 1,\ldots,N;\ k = 1,\ldots,R$, which states, in which amount the measure M_k in the interval T_i will be started. The definition area D_{ki} of $\boldsymbol{X}$ M_{ki} (e.g. $\boldsymbol{X}$ $M_{ki} \in \{0,1\}$ or $\boldsymbol{X}$ $M_{ki} \in \{0,1,2,\ldots\}$ or $\boldsymbol{X}$ $M_{ki} \in \mathbb{R}$) results from the nature of the capacity adaption measure M_k.
We combine the variables $\boldsymbol{X}$ $M_{ki}, i = 1,\ldots,N;\ k = 1,\ldots,R$ to a matrix $\boldsymbol{X}$. By introducing additional auxiliary variables, we can formulate a linear optimization problem:

Find $\boldsymbol{X}$ in the area D with

$$\mathbf{c} * \boldsymbol{X} = \min \boldsymbol{X} \text{ within } D\ \mathbf{c} * \boldsymbol{X} \quad (1)$$

$$\mathbf{A} * \boldsymbol{X} \leq b \quad (2)$$

$$\mathbf{A}\text{eq} * \boldsymbol{X} = beq. \quad (3)$$

The entries of the matrix $\boldsymbol{X}$ evoke certain measures in certain intensity to a certain point of time. **c** is a cost vector whose values represent the costs for a single capacity unit for each measure. **A** and **A**eq are matrices. The (in)equations (2) and (3) define the acceptable area of the minimizing problem, which results from the restrictions given. Due to the fact that some variables have to be integer, it is a mixed integer linear programming problem.

5.6 Definition of transformation measures

The optimal solution defines the capacity adjustment strategy at optimal cost and delivers a package of capacity adaption measures for each period and resource. Finally, a corresponding action plan has to be worked out and implemented by the responsible.

6 APPLICATION EXAMPLE

In order to evaluate the approach, the cost center milling of a mechanical engineering company was chosen. According to the approach, described in chapter 5, the forecast-data was analyzed and compared with the initial situation. As no basic trend in the demand has been identified, the possible adjustment measures, the so called degrees of freedom, have been identified and parameterized based on machine hour rate calculations, governmental regulations (maximum overtime and shift models) and outsourcing contracts. The adjustment measures, chosen for further calculations, have been overtime, alternative shift models and outsourcing.

By applying the optimization method as described in chapter 5.5, an capacity adaption strategy was derived. The final level of capacity, which was elaborated considering all given restrictions, is illustrated in **Error! Reference source not found.**The green dashed line represents the available capacity as a result of the planning process. Due to the given restrictions, many phases with over-capacity occur. It can be assumed, that there is still room for improvement and further adjustment measures have to be considered to be able to adapt to the demand need optimally. These could be under-time or eventually finished goods storage.

7 SUMMARY AND PROSPECT

Results so far provide a standardised procedure, including related tools to conceive, to parameterize and to visualize degrees of freedom in terms of capacity adjustments, and consequently a procedure to find a cost-optimal capacity adjustment strategy. The existing weaknesses in the results will be eliminated in the on-going work.

Funding for a research project, in which a fully ERP-integrated decision support system for capacity adjustment will be developed, has just been granted. This decision support system will surpass existing solutions in ERP and MES (=Manufacturing Execution Systems) - systems and improve short and medium term capacity planning.

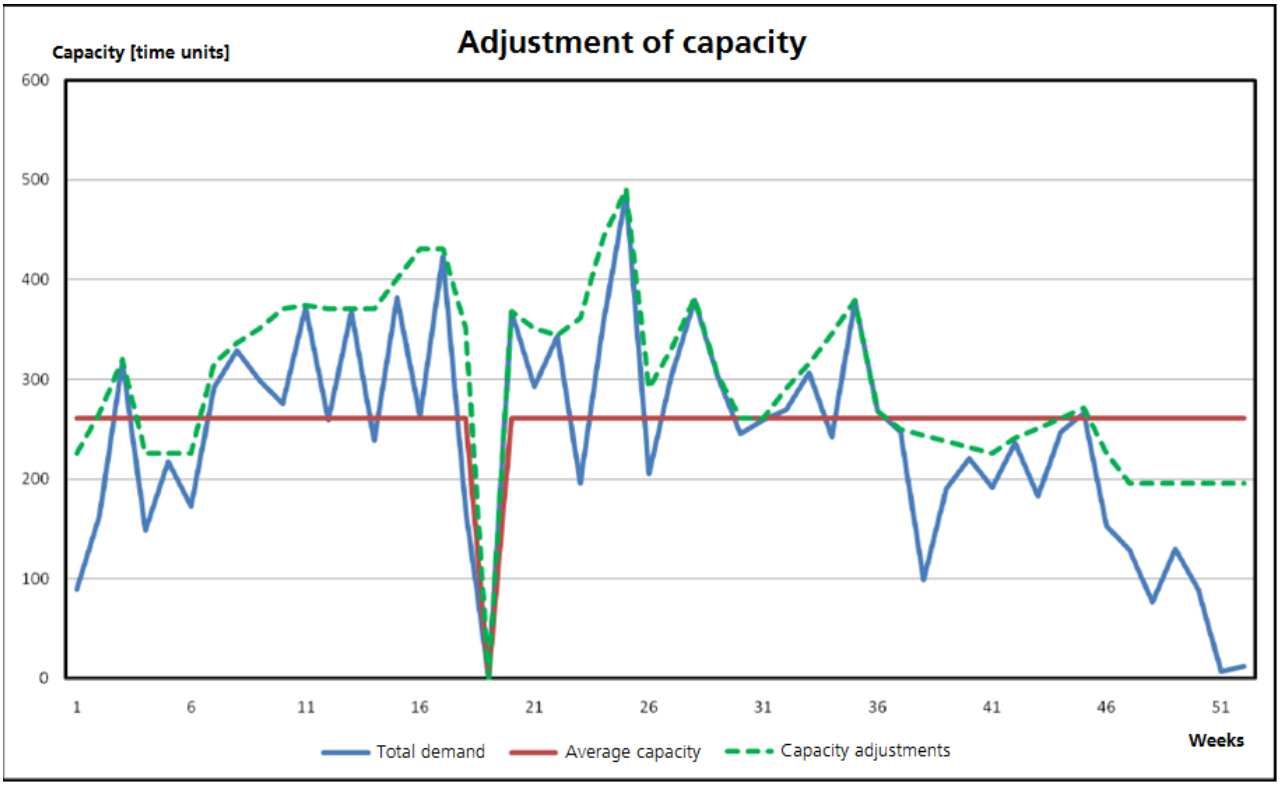

Figure 5: Level of capacity at minimized costs in the cost centre milling

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