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Production Planning and Scheduling and SME

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***Abstract*—**Small and medium-sized enterprises (SME) are the backbone of central Europe's economies and have a significant contribution to the gross domestic product. Production planning and scheduling (PPS) is still a crucial element in manufacturing industries of the 21st century even though this area of research is more than a century old. The topic of PPS is well researched especially in the context of large enterprises in the manufacturing industry. However the implementation of PPS methodologies within SME is mostly unobserved. This work analyzes how PPS is implemented in SME with the geographical focus on Switzerland and its vicinity. Based on restricted resources compared to large enterprises, SME have to face different challenges. The real problem areas of selected enterprises in regards of PPS are identified and evaluated. For the identified real-life problem areas of SME clear and detailed recommendations are created, covering concepts and best practices and the efficient usage of PPS. Furthermore the economic and entrepreneurial value for companies is lined out and why the implementation of the introduced recommendations is advised.

***Keywords*—**Central Europe, PPS, Production Planning, SME.

I. Introduction

PÁNTA rhei – everything flows. This statement of the Greek philosopher Heraclitus (535-475 BC) emphasizes that everything on this planet is subject to change. Especially for enterprises and entrepreneurs this aphorism is more than true. Since the industrial revolution in the second half of the 18th century the global economics have changed and evolved radically. Companies have to develop new markets, increase their productivity and strengthen the collaboration with their suppliers and customers. Long-term and sustainable economic success demands constant adaption to change for enterprises.

The topic of production planning and scheduling is well researched especially in the context of large enterprises in the manufacturing industry. However the implementation of PPS methodologies in small and medium-sized enterprises is mostly unobserved. Unique entrepreneurial side condition and resource constraints exist in this sector. SME are the backbone of central Europe's economies and have a significant contribution to the gross domestic product. Based on that PPS is still a crucial element in manufacturing industries of the 21st century even though this area of research is more than a century old.

The target of this work is to analyze how PPS is implemented in SME with geographical focus on the Swiss Rhine Valley, Liechtenstein, and the southern part of Germany. The real problem areas of selected SME in regards of PPS are identified and evaluated. Based on restricted resources compared to large enterprises, small and medium-sized companies have to face totally different challenges. These side conditions are taken into account when solution strategies are developed. Clear and structured recommendations for efficient and effective usage of PPS methodologies for SME are proposed. The focus lies on realistic and pragmatic, as well as entrepreneurial worthwhile recommendations that can be applied by production leads.

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II. Problem Description

The main problem that is evaluated within this work is located in the area of production planning and scheduling in context with the industry sector of small and medium-sized enterprises. The focus lies on the challenges that these companies have to face in regards of production planning. These challenges are not limited to the operational production process only, however they reside within the whole range of the supply chain. Production planning and scheduling is not an isolated process within a company. These strong dependencies of different disciplines within an enterprise can lead to negative side effects and problems if not properly managed, monitored and controlled.

Every company has its unique requirements as well as business and production setups. In the following an overview of potential problem areas is listed and the main questions are explained that are examined and evaluated in this work:

A. Production Planning

How is production planning executed within the company? Which tools are used and which information is used for it? Can an optimal production plan be ensured, or what prevents it from being generated? What is the impact of the generated production plan to manufacturing? Who is responsible for production planning and are full authorities given?

B. Manufacturing Process

How do manufacturing processes look like? Which interdependencies to the overall supply chain exist? Which constraining factors prevent machinery from operating at peak performance? Which logistic approach is applied in order to operate machinery? How are parts and intermediate goods pulled from storage and delivered to manufacturing?

C. ERP-System

Is an ERP-system used at all? Which parts of the ERP-system are used for production planning if applicable? How deep is the integration into the production planning and manufacturing process? Which data represents the input for production planning? Does media discontinuity exist within the IT-landscape? To which degree is production planning

actively supported by software solutions?

D. Business Processes

How are business processes managed within the company? Are processes documented? Is there a structured approach for process optimization or re-engineering? Are business processes of different departments connected to the supply chain, in particular manufacturing? Who has the authority to define new processes or adjustments within the company?

III. Theoretical Basics of PPS and SME

A. PPS and ERP-Systems

Production Planning and Scheduling (PPS) and PPS-systems as parts of the logistics are after decades of research and development still of high interest. They represent the economic backbone of information processing within manufacturing industries. PPS-Systems are mostly replaced and integrated into advanced Enterprise Resource Planning Systems (ERP).

The development of ERP marked a milestone within the evolution of PPS-systems. Within an ERP *all* resources that are necessary for the business activities of an enterprise are considered [1]. Their most important functional areas that are:

- PPS, Materials Logistics
- Acquisition, Maintenance, Quality Assurance
- Marketing, Sales and Distribution, Route Planning and Scheduling
- Financial Accounting, Liquidity Planning, Controlling

B. Production Methodologies

Production Planning and Scheduling is more than talking about ERP-systems. It covers all aspects within the supply chain, however with a focus on manufacturing and all supporting and stabilizing processes around it. In the course of this work four PPS methodologies have been selected. The selection is based on economic potential and applicability:

- Just-in-Time
- Kanban Scheduling System
- Lean Production
- Constraint Oriented Production

These methodologies represent contemporary approaches in PPS that are applied on an international level within the manufacturing industries. Properly applied, these four offers the chance of significant added value throughout a company's supply chain:

1) *Just-In-Time* (JIT) defines itself as having the right material available, at the right time, in the right quality, in the right quantities, and at the right place. Part of this philosophy is to optimize production flows in a holistic way, not only parts of the production processes such as logistics [1]. JIT-production is the core element of the JIT-philosophy; however it is not as widespread as JIT-logistics. Reason is that compared to logistics, the production demands a fundamental paradigm shift in companies, especially SME. This paradigm shift starts with the change from *Push* to *Pull*. This means, the focus lies on the customer demand where a customer purchase order triggers the production start. The best example is flow shop or assembly line production with small lot sizes. Whereas within *Push* the downstream production step delivers material upstream causing overflow or shortage, within *Pull* the upstream production step pulls a product as soon as it is idle. Within JIT-production the produced good moves from work station to work station without stops. This reduces lead times significantly as well as minimizing work in process [2].
2) *Kanban* is the Japanese word for "ticket" or "signal". The Kanban Scheduling System was developed in Japan around 1970 and got applied at that time in the production scheduling of Toyota. It was developed with the target to reduce stock in order the reduce capital commitment. The basic principle of Kanban is a system of self-regulating closed loop controls intended to adjust and balance between production steps. It is a scheduling system for manufacturing and industrial production [1]. When a sales order is placed and goods are shipped from central storage to customer, this information triggers a re-order at the last production stage upstream. Every production stage has a dedicated buffer stock with a defined minimum stock level. Each production stage has therefore access to stock with a specific amount of intermediate goods. A re-order triggers a production activity up-stream. If the re-order falls below the minimum stock level, an additional re-order is triggered by the next production stage up-stream. This chain of triggering production activities and re-ordering goes up-stream till purchasing is reached. If a product is delivered to the customer and hence leaving the system for good, the Kanban ticket is returned. The Kanban Scheduling System realizes the so-called *pull-principle*. This means that work orders with production activities are pulled from a final product point of view through the system.
3) *Lean Production* or more widely known as Toyota Production System (TPS) represents the elementary basis for efficient, competitive and modern flow of materials. It is successfully applied in industries such as automotive, mechanical engineering, building sector, medical engineering or bio-chemistry. An interesting fact is that it is applied in high- as well as low-wage-countries. The basic element of lean thinking is the understanding and elimination of *muda*, which means "waste" in Japanese. Waste or *muda* are all processes or things that add no value to the product or end customer. This covers mainly human activities that absorb resources but create no value. Based on Womack and Jones [3] supported by Rother [4] the 5 principles of lean thinking are the following:

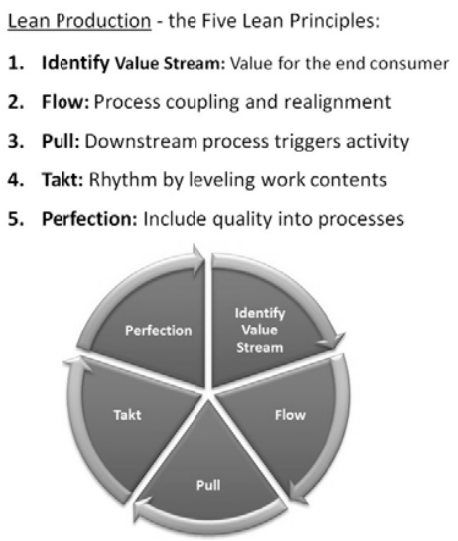

Fig. 1 The Five Lean Principles

Identify Value Stream: the value stream is a set of specific actions, required to bring a specific product to the customer. This covers the creative problem-solving task (design and engineering), the information management task (order-taking, scheduling, and delivery), and the physical transformation task (proceeding from raw material to a finished product).

Flow: all value-creating steps have to flow. In its ideal one-piece flow means that parts move from one value-adding processing step directly to the next one, and finally to the customer without any waiting time or batching between those steps [4]. The goal of the flow principle is to reduce throughput time. This is realized by aligning and coupling of adjacent process steps and the reduction batch sizes and buffers.

Takt: the customer takt is the frequency of the JIT production system, which is set by the average customer demand. The takt time is calculated by dividing the effective operating time of a process by the quantity of items customers require from the process in that time period [4]. With that information the average number of products requested by customer per time period can be identified. This is the basis for redistributing and leveling of production processes.

Pull: the pull principle regulates production processes. This means a production stage gets active only, if material is requested (or pulled) from it. Material is pulled up-stream and goods are transported down-stream within manufacturing. The supplying processes then produce in order to replenish what was pulled from them. This creates a tight customer-supplier relationship. In addition it avoids overproduction. In the end the customer sends the signal to start production. There is no production without an explicit signal by the customer.

Perfection: Perfection means to strive for a zero-defect approach. With tight coupling of process steps, high quality of each intermediate product is required. This can be supported by quality control loops for early defect detection. The ultimate goal is fault prevention instead of reactive maintenance within production.

4) *Constraint Oriented Production* is based on the Theory of Constraints (TOC), developed 1984 by the Israeli physicist Eliyahu M. Goldratt [5]. It is an overall management philosophy that is based on the premise that the rate of goal achievement in a system is limited by at least one constraining factor. This constraint or constraining factor limits the performance of the whole system. TOC targets these constraints or bottlenecks and eliminates or at least reduces them. Key elements are the *Five Focusing Steps* that aim to ensure ongoing improvement efforts that are centered on the system's constraints and where buffers are placed before the key constraint. Constraints are identified and eliminated, resulting in an overall increase in efficiency and an improvement in organizations competitiveness. In addition it optimizes the performance or throughput of the whole system, as it is a collection of interacting components. It involves methods for identifying and removing barriers that block progress and reduces effort, time, costs, and mistakes. Similar to the *Lean* approach, TOC provides a continuous improvement process as well.

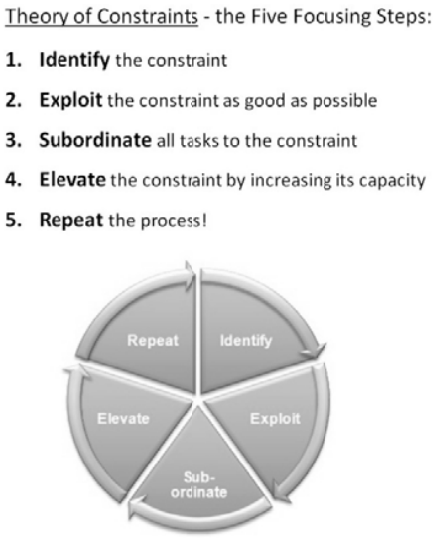

Fig. 2 The Five Focusing Steps of TOC

Identify the constraint that is limiting the performance of the system. This helps to determine areas in which productivity needs to be increased in order to increase overall performance. To find the constraint the output of each component in the process has to be determined and the component with the lowest capacity is the constraint that needs to be focused on.

Exploit the constraint that is limiting the overall process or project. The goal is to get the constraint operating at normal productivity. This is done by finding ways to improve effectiveness and efficiency within existing limitations, and without additional investments. Considering operational modifications to maximize the constraint's productivity is often a good starting point.

Subordinate the non-constraint resources to the constraint so that the constraint is not limited by anything outside of its

control. This is achieved by placing the non-constraints in second place to the constraint, and focusing of all available resources on the identified constraint.

Elevate the constraint by increasing the output (or capacity) of the constraint. This is achieved by additional machinery, employing more people, or using alternative methods that don't involve the constraint.

Repeat the process to address any new constraint that may result from the improvement of the original constraint. This is done by readdressing the system from step one to identify the new constraint that may have arisen. This enables a process of continuous improvement.

C. Small and Medium-Sized Enterprises

From bakeries and trust companies to precision parts manufacturers operating on the international market, 99.7% of Swiss companies employ fewer than 250 staff. These small and medium-sized enterprises are a vital element of the Swiss economy. They account for the vast majority of Swiss firms.

A more sound and holistic definition of SME is available when switching the perspective from Switzerland to the European level. The European Commission [6] gives the following definition:

"*The category of micro, small and medium-sized enterprises is made up of enterprises which employ fewer than 250 persons and which have an annual turnover not exceeding 50 million euro, and/or an annual balance sheet total not exceeding 43 million euro*."

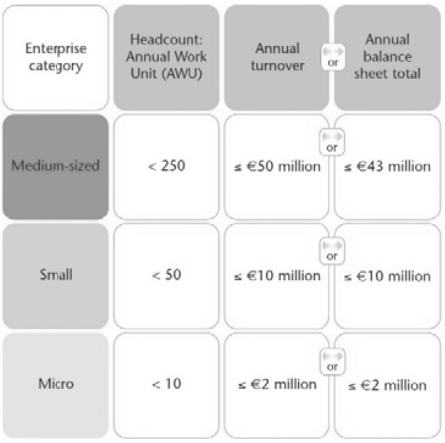

Fig. 3 Threshold values of SME categories

Micro, small and medium-sized enterprises play a central role in the European economy. They are a major source of entrepreneurial skills, innovation and employment. In the enlarged European Union of more than 25 countries, some 23 million SME provide around 75 million jobs and represent 99% of all enterprises. Parallels to the economic importance of SME in Switzerland are obvious.

Small and medium-sized enterprises are often confronted with market imperfections as well as the increasing pressure of globalization. They have to face faster process and product innovations, shorter product and development lifecycles, an increase of complexity and variety, as well as fluctuations in supply and demand. Especially the shortage in raw materials and primary energy carriers leads to rising prices.

SME experience these changes more intensively than large enterprises, as they react more sensitively on minor price increases, for example in the area of resource purchasing. The lack of quick and flexible reactions in entrepreneurial activities can lead to significant competitive disadvantages. However the challenges of changing markets are not always a downside for SME. Especially in the area where customers demand a degree of individualization, SME can adapt much faster on customer focus than large enterprises. High flexibility and lean structures paired with short communication channels are the strengths of SME [7].

As SME can't influence external market changes, the focus has to be shifted to the areas that can be controlled. SME frequently have difficulties in obtaining capital or credit, particularly in the early start-up phase. Access to skilled and well educated employees can be a critical factor for growth. Their restricted resources may also reduce access to new technologies or innovations.

IV. Empirical Foundation

A. Initial Position

The methodology to address the research question is based on a questionnaire survey. This is the selected methodology for this research. Furthermore the questionnaire survey is conducted via personal interviews with experts in the area of production planning and scheduling. The initial position of the empirical part covers three examination areas:

- Geographical location
- Industrial sector
- Entrepreneurial setting

In the *first* phase of the empirical research the *geographical location* is determined. For the current research this covers the areas of Liechtenstein, Switzerland (especially the Swiss Rhine Valley), and the southern part of Germany.

In the *second* part the *industrial sector* is selected. The current work focuses on manufacturing industries with production facilities on site. Additional restrictions are not made, as this allows to analyze different industrial areas such as automotive, engineering, food, and similar. Business areas such as banking or gastronomy are out of scope.

In the *third* part of the *entrepreneurial setting* is chosen. As small and medium-sized enterprises dominate the selected geographical location in regards of quantity, this has been chosen as examination range. However a couple of large enterprises are included in the empirical part of this work, in order to determine reference values.

B. Questionnaire

In the following the details of the questionnaire are lined out. It covers seven questions with focus on PPS and its implementation within enterprises. As each company is unique in its internal processes, implementation of standards and concepts, as well as setting up their production lines, the

questionnaire has to be quite generic.

The following seven questions cover the main topics of the interview which are drilled down via adaptable on-demand questions based on the feedback of the interviewed person:

1) Describe the production process in your company. How does the supply chain looks like end-to-end?
2) What are the challenges within production? Where are the biggest problems?
3) How does the operational production planning looks like within manufacturing and who is involved?
4) Which tools are applied during production planning (e.g. ERP-system, etc.)?
5) Are you familiar with one or more of the following PPS methodologies? JIT delivery, Kanban scheduling system, lean production, or constraint oriented production?
6) If YES, which of the named PPS methodologies are applied within the company?
7) How does the future of production planning in your company look like?

C. Interview Realization

The interview realization in course of this scientific research covers two different approaches. On the one side telephone interviews are conducted, on the other side personal interviews are performed including the inspection of the manufacturing facilities.

Telephone interviews have an excellent cost-benefit ratio. The logistic costs are nearly zero and when performed right, a lot of usable and valuable information can be obtained with low effort.

Personal interviews including the inspection of the manufacturing facilities represent the other type of interview technique applied in this work. The logistic costs in that case are significant. Travel time and expenses have to be taken into account and based on the distance this can be time consuming. However these efforts allow excellent information acquisition. Whereas the personal interviews based on the questionnaire takes comparable time as the telephone interview, it allows better and more intense discussions as a face-to-face dialogue is possible.

V. Analysis & Evaluation

Within this research 50% of the interviews were phone-based, whereas 50% were performed at the manufacturing site including the inspection of the production facilities.

The conducted questionnaire-based survey research focuses on identifying the unique challenges and problem areas that SME have to face. As each company that is part of the survey has a different level of maturity it is not trivial to create a common basis for assessment. In order to achieve this goal, subject areas have to be defined that need to suit young companies in start-up phase, small enterprises with several years of experience, as well as mature companies with decades of market presence.

In the course of the interviews and the analysis of the content, the obtained insights can be clustered in four different subject areas:

- Execution of Production Planning
- Usage of ERP-Systems & IT
- Adoption of PPS methodologies
- Business Process Management

A. Execution of Production Planning

This section covers all activities how the interviewed companies perform their production planning in order to manufacture goods for the end-customer. Target is to identify and evaluate areas of the production planning process.

Starting at the initial input sign that triggers production planning – the customer request – it is interesting to note that more than 83% of the companies face high deadline pressures. This manifests in low lead times in more than 67%. Background is a volatile market with constantly changing customer demands. In very few cases (17%) even regular customers are unable to communicate clear demand quantities per period, confirming volatile markets.

Increased market dynamics and uncertainty of production forecast confirm that this is a serious challenge for SME. The consequences of high pressure on deadlines and low lead times are a decrease in the scope for production planning itself. This means that production capabilities can't be used efficiently as time pressure is the predominant factor. This leads to an increase in priority production jobs, which invalidate already existing production plans. Therefore a balancing of production capabilities is nearly impossible, leading to an inefficient usage of resources for SME.

When analyzing the produced products itself it comes to notice that in more than 50% the complexity is high. In these cases the product structure – the bill of materials – is stated as very high, ranging from 400 to 1600 materials. In 83% the product has a multi-level structure.

Facing a comparable product complexity as large enterprises leads to the consequence that SME have a comparable complexity in manufacturing processes. The result is that the requirements of production planning and the related manual steps included, are independent to company size.

Furthermore it is interesting to state that the majority (83%) rates the degree of capacity utilization as bad. To be more specific, the efficiency of manufacturing capabilities is not constant or balanced. Analogues to the bullwhip effect in supply chain management, periods of high machine utilization are followed by periods of low machine utilization. This is enhanced with time consuming setup costs that are named by 50% of the interviewed SME as significant factor affecting production planning. Whereas setup costs are treated very strictly when generating lot sizes in production planning, inventory costs are treated differently. In classic PPS literature setup and inventory costs are the backbone of optimization algorithms and are treated more or less equally. In the reality of SME this is different as more than 67% have stated that they ignore inventory costs. Whereas they take fixed capital in storehouses into account, the costs for storage itself are not regarded as important.

Focusing on the planning part of PPS itself it was observed that 50% of the companies perform a continuous planning,

whereas the others rely on forecasts based on average historical data.

The resource constraints of SME limit their capabilities of an accurate strategic planning. Compared to large enterprises, this is a significant disadvantage, as these are able to use complex BI analysis (Business Intelligence) on customer data as well as holistic market research on customer demand and trends. Such resource intense analysis and planning is not feasible for SME due to capacity constraints. This increases their difficulty to react fast and efficient on volatile markets and customer demand. Furthermore this can lead in worst case to a kind of vicious circle as SME might get pushed in a reactive mode where they are purely dominated by external factors, instead of aligning production capabilities and manufacturing processes based on forward-looking planning. Anticipating customer and market behavior is key to entrepreneurial success, especially for SME.

The most important aspect in the execution of production planning that was observed is that a surprisingly large amount of more than 50% of SME performs their production planning without an ERP-system or similar IT support. The tool of choice was either pen-and-paper or in most cases a spread-sheet application such as Microsoft Excel. Even for those companies that have an ERP-system installed, a significant amount is not using the full PPS spectrum of software systems.

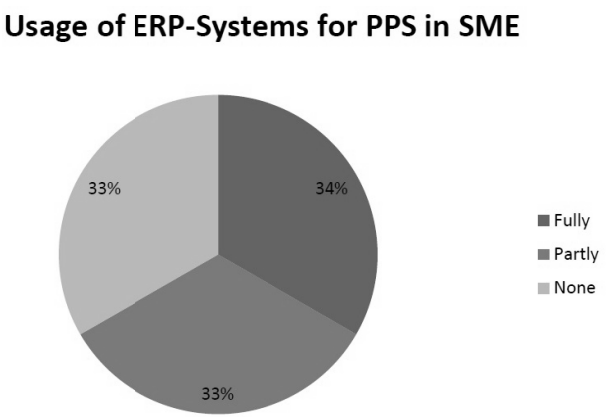

Fig. 4 Usage of ERP-Systems for PPS in SME

As the figure indicates 33% of SME are not using an ERP-system at all for production planning and scheduling. The remaining 67% have such a system installed and use it, however 33% use it only partly for production planning. The identified key message is that in the end 67% of SME create their production plan without the full and integrated support of an ERP-system.

B. Usage of ERP-Systems & IT

Compared to large enterprises the variety of ERP-systems and vendors in the SME sector is very large. Within this study none of the named ERP-systems appears twice throughout all conducted interviews. An interesting aspect that could be identified is that the largest SME of the survey uses an ERP-System from SAP. ERP-systems from large and international vendors such as SAP, Oracle or Microsoft are widespread in the large enterprise sector but not within small and medium sized enterprises.

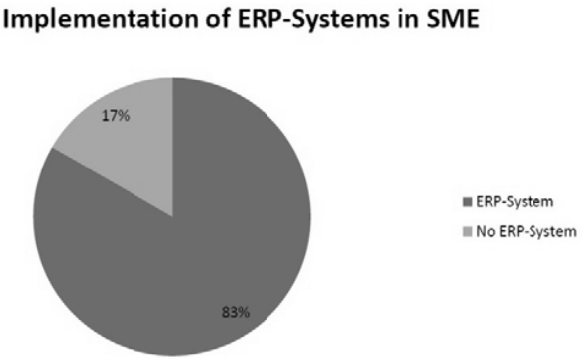

Fig. 5 Implementation of ERP-Systems in SME

The usage of several IT-landscapes in parallel to an ERP-system within the enterprise is reported as significant issue by SME. The following figure gives an overview on this mixed setup of IT-landscapes:

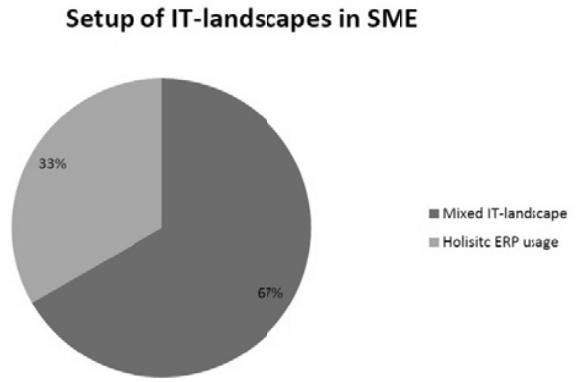

Fig. 6 Setup of IT-landscapes in SME

As shown in the figure the majority of SME (67%) have a mixed IT-landscape installed, whereas the remaining companies use their ERP-systems for all business processes around production planning and scheduling. The biggest reported pain point that results from an inhomogeneous IT-landscape is the need for data harmonization and consolidation. Master data is stored in several systems, preventing production planning in a single system. Here various consistency checks are needed in order to ensure that master data records are up-to-date and complete. The consequence is a prolonged production planning process.

The evaluation of the IT-landscape setup confirms an unpleasant situation that is valid throughout SME as well as large enterprises. The unsatisfactory management of master data leads to additional expenses in time and effort that is agreed upon by the majority of production leads. Especially the loss of time that is caused by manually consolidating master data from various IT-systems is impacting the process

of production planning significantly. Furthermore features such as data cleansing, enrichment or normalizing are not supported and demand additional manual activity. This strengthens the need for a centralized repository where data from heterogeneous sources are collected and stored. Thereby the flow of consistent information throughout the company is ensured supporting both the production planning as well as all internal business processes. Faster and more accurate production planning, based on proper master data management, increases production flow and therefore creates value for the company and customer.

An additional finding of high interest is the reported PPS capabilities of ERP-systems. By definition an ERP-system supports all major business process within an enterprise, covering production planning and scheduling as well. With more than 80% the vast majority of SME of this study report that the used ERP-system does not support all their requirements in regards of PPS. To be more precise the technical features of the software for production planning are stated both too complex and time consuming for SME or are simply not available. More than 50% of the interviewed companies with an ERP-system use it only partly for their production planning.

The evaluation of the findings in regards of used PPS capabilities of the implemented ERP-systems is alarming. Only 34% of the interviewed SME are able to use the full PPS capabilities for their production planning, the resultant problem areas are the following:

Optimized production plans not ensured: Advanced algorithms for generating optimized lot sizes demand sophisticated tool support. Pragmatic approaches such as using spreadsheets provide valid plans, however far from an optimal solution. Especially when multi-level product structures exist, advanced PPS software solutions are mandatory.

Manual selection of PPS input data: Generating production plans demand data consistency. This can be ensured, if all master data for production is available in the system. Manual data selection is both time consuming and endangers data consistency, due to export and import to the target system.

Additional operational effort: The described manual steps for creating production plans, if not supported by PPS software, lead to significant time consuming manual steps. On the one side it allocates workforces, on the other side it has to be double-checked if the calculations are correct and accurate.

PPS functionality does not fit to production setup: The worst case that can occur is that the production processes and setup cannot be mapped and customized to the ERP-system. Hence all planning activities around manufacturing have to be executed outside the central system, which is error-prone. Here either the ERP-system has to be adjusted to fit into the company, or the company's processes have to be modified to fit to the software solution.

C. Adoption of PPS Methodologies

This section gives an overview how the production planning approaches are available in SME. Focus lies in the analysis and evaluation if and why specific PPS methodologies such as JIT or Kanban are implemented.

Existing knowledge on the selected methodologies JIT, Kanban, lean production, and constraint oriented production is following: Whereas JIT and Kanban were fully known throughout all companies without exceptions; knowledge on lean production and constraint oriented production was relatively low. Only 50% of the companies within the survey were familiar with the two latter concepts.

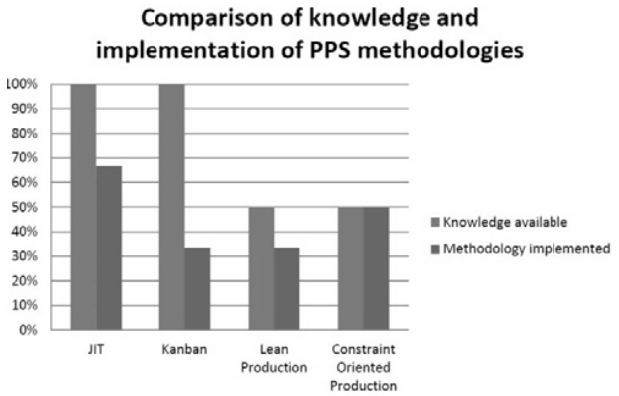

Fig. 7 Comparison of knowledge and implementation of PPS methodologies

The evaluation of the level of knowledge and degree of implementation provides interesting insights for the SME sector. However it has to be taken into account that each SME has its unique production setup, impacting or even limiting the implementation of one or more of the named PPS methodologies.

The area of *JIT* shows capacities for development. It is fully known within SME and the limit has not been reached yet. The positive impact of JIT on warehousing, keeping stock levels low, should stimulate SME to implement it. The feasibility is given, as JIT is relatively independent on the unique production setup of an enterprise.

The field of *Kanban* implementation compared to JIT is mature. An increase of implementing Kanban within production facilities of SME is unlikely, as first-hand feedback states the opposite. All interviewed production leads confirm that they would implement Kanban, if it would fit into their production setup. Similar to JIT the target is to reduce stock levels and therefore reduce capital commitment.

The evaluation shows that the concepts of *Lean Production* are not widespread in SME, yet. However the degree of implementation is surprisingly high. The knowledge gap on lean production can easily be closed with appropriate training and technical literature. All SME that implement lean methodologies within their production facilities report that they were able to realize significant improvements. This emphasizes that lean production has considerable potential for SME. An additional advantage is that some lean methodologies are less resource intense than others, allowing SME to start with small improvements.

The area of *Constraint Oriented Production* shows great potential for SME in manufacturing industries. All companies that are aware of constraint orientation apply it within their production processes. This emphasizes that it is a powerful methodology, providing value to an enterprise. However every company applies its own type of constraint orientation. A structured and methodic approach is missing in the majority of cases. In general common sense and pragmatism are widely used to solve constraints within SME and real root cause analysis is seldom performed. Nevertheless the observed constraint orientation proved to be very efficient. The implementation of constraint oriented production within SME can be extended and additional value for the company, especially the production processes, realized. Background is that constraint orientation focuses on the whole value and supply chain of a company. The key for realizing additional value lies in a structured and methodic approach how this PPS methodology shall be applied. Here investments in training and pilot projects are strongly recommended.

D.Business Process Management

This section analyses and evaluates all business processes that are executed within SME with focus on production planning. Business Process Management (BPM) is a necessity for every organization and key for entrepreneurial and sustainable success. It allows aligning the company's processes in order to provide value to the customer. It is essential to ensure long-term business success based on flexible, market-responsive structures that simultaneously promote efficiency [8].

The analysis and evaluation have shown that nearly none of the companies performs a holistic business process management or structured process documentation. This finding is not surprising as the need for proper and structured business process management, increases with the size of an enterprise. SME see these disciplines and activities as additional bureaucratic efforts with low or even negative effects on short-term cash flows or day-to-day business. In the following figure an overview on the degree of BPM implementation within SME is given:

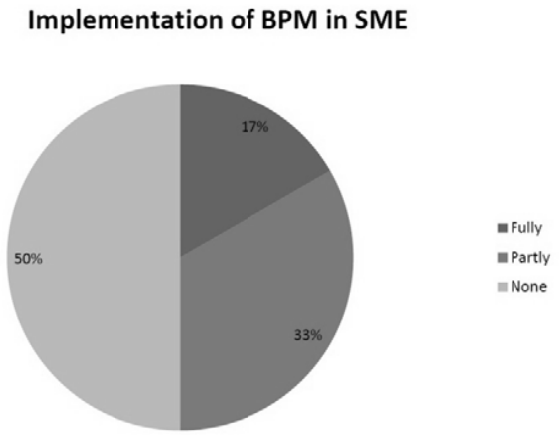

Fig. 8 Implementation of BPM in SME

The interviewed SME report that they are confronted with a set of various market requirements when asked about their core business processes and how they are structured. The most pressing challenges are shorter product lifecycles, increased decline in prices, increased cost pressure, higher quality demands from customers, as well as new regulatory requirement and industry norms. Key for success is the velocity how these market requirements can be realized. Furthermore efficiency is named as key differentiator on the market as well as for internal process. All SME name that efficiency improvements within manufacturing and supporting processes around are essential and critical for their business success. The reasons for not applying BPM within SME are surprisingly unexceptional.

On the one side the lack of professional business process management is a major statement. A sound scientific knowledge on BPM is still exotic in SME within manufacturing industries. Here mechanical engineering or more technical educations are predominant. It is important to realize and accept that the scale of academic degrees is much lower in SME than in large enterprises. This demands in general, in regards of BPM implementations, to hire external expertise such as management consultants.

On the other side the demand of external resources leads to the second reason why BPM is rarely implemented in SME, which are resource constraints. First of all it was stated that it is not possible to assign employees to perform BPM activities without endangering daily businesses. Each employee owns a dedicated part in the supply chain and reducing this resource by assigning additional tasks puts sales and customer orders at risk. Staff departments that take care of such topics in large enterprises exist only seldom in SME. Further arguments were that no additional financial resources or time can be spent on BPM activities. Neither on external consultants (the most expensive option) nor additional trainings, BPM tools, and IT support. Even though the necessity of BPM is agreed upon in general, the scarce resources of SME have higher priorities for executing and stabilizing the day-to-day business.

Several interviewed parties in this research conclude, that they see no direct added value on short-term financial KPI such as cash flow or revenue, if BPM is implemented. This is the main reason why BPM is not widely spread in SME. Central argument is that process knowledge is in the heads of the employees and that everyone knows what he is doing within manufacturing and production. Additional activities in managing or documenting processes are seen as non-essential. This attitude however is more predominant in small than medium enterprises. The larger the company the higher the need and demand of BPM.

The reluctant attitude towards BPM is reflected in the characteristic structures of SME: Flat organization structures, business management by the owner, small range of products and division of work, as well as specialized knowledge and permanent shortage of resources characterize SME. Especially the more centralized and often patriarchic management style within small companies compared to large enterprises is the cause of low BPM adoption. Flat organization structure paired

with task accumulation leads to low degree of formalism such as process documentation or job guidelines. Consequence is that knowledge transfer is performed via direct communication and personal exchange by the employees. This means the knowledge is with the employees rather than in a central accessible database or similar storage facility.

VI. Recommendations

Based in the previous analysis and evaluation the basis for recommended activities for SME is given. The insights that were obtained allowed identifying the real problem areas small and medium-sized enterprises are confronted with. This allows the expression of clear and precise recommendations. The following recommendations have been identified:

- Methodic ERP-system selection and implementation approach
- Structured approach for constraint oriented production
- Holistic Business Process Management

A. Methodic ERP-System Selection and Implementation

The most popular problem situation in the context of production planning is that companies have selected or even badly implemented the wrong ERP solution. Especially the area of production planning has an insufficient usage of software solutions within small and medium-sized companies.

Solving this unsatisfying situation demands a methodic and systematic approach for selecting and implementing an ERP-system. An enterprise has to select an ERP solution that fits to the company and fully supports its core business processes. Key element is that the future ERP-system to be acquired has to fit to the company and its requirements *and* in addition it has to be implemented in a proper manner. If one of these two steps is not done correctly, the consequence is entrepreneurial failure. Therefore this recommendation covers both, the *selection* as well as the *implementation process*. In the following the software selection process as well as the critical success factors (CSF) for the implementation of an ERP-system is lined out in detail:

The *selection process* of a potential ERP-system covers three types of evaluations that are needed to identify the software solution that shall be acquired:

- The software vendor
- The functional scope
- The technical requirements

The *evaluation of the software vendor* is part of the early stages of the software selection process. It can be compared to an initial screening in order to create a first and relatively long list of potential software vendors. This first selection focuses mainly on knock-out criteria with the target to create an initial list of software vendors. Popular and widely used parameters for selecting potential vendors are:

- Minimum of 100 installations by the software vendor
- Minimum of 10 reference customers of the software vendor
- System integrator shall have at least 10 employees
- System integrator shall have performed minimum 30 installations

The *evaluation of the functional scope* is the dominant and in general prime consideration factor. Target is to determine if the software can do what it claims. Based on *Verville* [9] two different approaches are recommended: (1) The company develops demonstration scripts that can be sent to the vendor. They are used to verify the content of the request for proposal (RFP), simulate tasks (simple to complex), and clarify open questions that were unclear or not ad-dressed in the RFP. These scripts are the basis for the demonstrations of the software vendors and should be sent a couple of weeks prior the functional demonstrations. (2) The company invites the software vendors in-house in order to let them perform simulations of their software.

The *evaluation of the technical requirements* covers technological aspects such as performance (benchmarks), operating systems, or databases. In addition to that it has to be verified if specific product standards are followed. This means the compliance with state-of-the-art software requirements in the area of Security, Usability, or Accessibility have to be ensured. Main target is to get live and physical evidence of the ERP-systems abilities. Furthermore this allows identifying technological gaps in the existing IT-landscape of the company and answers the question if it can be integrated into the existing landscape. Here additional requirements on hardware and software purchases can be derived.

The *critical success factors* of ERP-system implementations are based on experience of various successful and failed projects. Fortunately the topic of ERP implementation can build upon an abundance of research articles within the last 20 years. In the following a summarized representation of CSF for ERP implementation projects is given, focusing on the needs and unique requirements of SME. The CSF cover the characteristics of success and failure supporting a deeper understanding and gives guidance on how these factors of success can be considered and implemented. In the following eight CSF for successful ERP-system implementation projects, based on the works of Sammon [10], Hanafizadeh [11], and Muscatello [12] are lined out:

- *Business Need & Project Objectives*: The strategic business need of the planned ERP implementation has to be stated. This is essential for convincing stakeholders and employees.
- *Management Commitment*: Top management commitment is essential for project success. Especially for fundamental and resource-intensive endeavors such as ERP implementations. It is imperative that top management monitors the progress of the project and provides direction.
- *Prioritized Business Requirements*: One of the key elements is the transformation and translation of business needs into prioritized activities. This allows recognizing the importance of the various business processes and sets them into con-text with each other.
- *Allocation of Internal Personnel*: Each project needs staffing. Besides the project lead, all departments that are touched by the planned ERP-system have to be represented in the core project team. To ensure that this

CSF is a success internal personnel has to be dedicated full-time to the project. In general these are the best employees in the company.

- *Effective Communication*: As a planned ERP-system implementation affects the whole organization, it is important that this message is transported. Here top management has to communicate the shared vision of the ERP implementation project and the value and consequences of the new business software.
- *Clear Project Scope*: The most important CSF is the definition of a clear project scope. It is vital that the project scope is clearly defined, understood and controlled. This CSF can be considered as successful, if a project charter covering the project scope is created.
- *Accurate Project Planning*: The implementation of an ERP-system within a company can be regarded as classical project with the need of proper project management. This involves accurate planning as well as a sound and stable timeframe.
- *Organizational Support*: Projects can only succeed if they are supported by the organization. It is essential that a cross-organizational coordination exists where stakeholders and their business needs are involved. Target is to achieve a buy-in from all involved parties, supporting constructive collaboration.

B. Structured Approach for Constraint Oriented Production

Constraints exist in every system, especially in process intensive areas such as production and manufacturing. The problem situation that SME have to face is that on the one side constraint orientation does not exist, on the other side constraint orientation is implemented poorly or in an unstructured and inconsequent manner.

Target of this recommendation is to provide a structured and methodic guideline how the theory of constraints can be applied within SME. Furthermore SME shall be enabled to utilize the full potential and understand the thinking process of TOC. The guideline for implementing TOC in SME covers three phases:

- *Analysis*: What shall be changed?
- *Evaluation*: What shall be changed to?
- *Implementation*: How can this change be realized?

The *Analysis phase* targets to identify the underlying and root-cause problems of problem areas within a system. This identified core problem prevents the system from performing as planned or with a higher efficiency. This problem is called *Core Conflict* and causes the negative effects to the system. These negative effects are called within TOC *Undesirable Effects* (UDE) and describe some-thing negative that exists in reality and cause penalties if continued exist. In order to make this core conflict visible that cause the UDE, the so called *Core Conflict Cloud* is created. It describes the objective with its requirements and pre-requisites. The core conflict cloud describes the decision conflict between two needed but obviously contradictory actions. It describes the objective with two different requirements and pre-requisites that cause a dilemma, as both arguments are opposite. The schema always follows the same structure: "*in order to achieve the objective, we have to fulfill a requirement and its pre-requisite.*" A speaking example is: "*In order to reduce the costs per unit, we have to reduce the setup costs per unit with the batching of large lot sizes.*"

After the core conflict is identified the so called *Current Reality Tree* has to be created. It validates the identification of the core conflict and helps to understand existing cause-and-effect relationships within the system. The current reality tree is crucial in order to understand the root causes and additional effects that lead to a specific UDE. With this in place, the question of "*What shall be changed?*" can be answered. However it is essential that all undesirable effects are identified.

The *Evaluation phase* is based on the results of the analysis phase. Here the core conflict cloud and the current reality tree are used as input factors. The target is to challenge and question the assumptions of the core conflict. This is crucial in order identify a solution. Background is that both pre-requisites in the core conflict cloud are opposite at first sight only and might be invalid. The injected assumptions create the basis for a solution, which means to achieve so called *desirable effects* (DE). The concept of a DE is the opposite of an UDE; it describes a positive and valuable status that shall be achieved in order to solve the core conflict. In order to develop this solution a strategy has to be developed. This strategy must be made next to the solution to the core conflict to ensure that the solution works and the system is improved to the desirable result. Such a solution strategy is lined out with a so called *Future Reality Tree*. It identifies what changes in system must be made to ensure the UDE are resolved, based on an injected assumption or idea. With this in place, the question of "*What shall be changed to?*" can be answered. However it is essential that no negative branches in the future reality tree remain unresolved.

The *Implementation phase* focuses on transitioning a system from its current to the target status. This means an operational plan for implementing the solution strategy has to be created. In order to define which part in the system has to perform which activity, and in parallel determining obstacles or blocking elements, a so called *Pre-Requisite Tree* has to be created. The prerequisite tree consists of two elements: an *Obstacle* (Obs) and an *Intermediate Objective* (IO). The intermediate objective is an action that has to be performed in order to solve the obstacle. Several independent obstacles can exist in a pre-requisite tree. Obstacles can be either a situation or problem that has to be solved, or situation or status that has to be achieved. The pre-requisite tree is the most important artifact within TOC as it provides full transparency on the obstacles that prevent the solution strategy to be implemented. It states the problems that have to be solved. With the pre-requisite tree in place, the interdependent tasks needed to implement the pre-requisite tree can be created. This is called the *Transition Tree*. Following the actions and requirements defined in the transition tree leads to the successful implementation of the solution strategy, as all intermediate objectives up to the final target objective are addressed. The

target objectives are synonymous to the sum of desired effects lined out in the future reality tree.

Applying the *theory of constraints* within an organization or system can lead to significant improvements. However for SME in particular additional success factors and best practices are recommended to support a successful implementation of TOC. This lies mainly in the flat hierarchies and the shortage of resources that are predominant in small and medium-sized enterprises. These additional factors are the following:

- Top management commitment is crucial
- TOC project lead released from work at least by 50%
- TOC project lead must be authorized to access all areas and information of the company
- Resistance of employees has to be reduced with convincing arguments
- Department managers have to be convinced that TOC targets global optimization

Especially the overcoming of resistance for change is crucial in implementing TOC within an enterprise. Buy-in and support from both parties is needed, the people that implement the changes and those who are affected by the changes, in order to succeed.

C. Holistic Business Process Management

The majority of SME lack a holistic business process management. This prevents them from performing a continuous process optimization, resulting in inefficient or out-dated workflows as well as an unnecessary waste of resources. Especially companies that evolve from small to medium-size are affected here. The possibility of having coordinated, cost-effective, and high-quality processes demands the implementation of holistic business process management. This means to model processes, optimize them, and make them measurable.

A successful implementation of BPM leads to significant improvements as business processes can be adjusted to meet specific market needs. Furthermore it allows improving existing processes throughout the supply chain, increasing efficiency and therefore the output of manufacturing itself. The most interesting aspect however is, that BPM supports the implementation of ERP-system projects. Reason is that optimized business processes are easier to be adopted into an ERP-system. An ERP-implementation project has a higher chance of success and can be performed smoother if lean and optimized processes exist.

Based on *Becker* [13] the structured and methodic approach of a process-oriented reorganization project covers the following phases:

- Preparation of Modeling
- Development of Strategy and Business Process Framework
- Execution of As-is-Modeling and As-is-Analysis
- Execution of To-be-Modeling and Process Optimization
- Development of Process-oriented Organizational Structure
- Introduction of New Organizations and Implementation
- Continuous Process Management

Preparation of Modeling: Target of the preparation phase is to determine three elements: *modeling subject*, *perspective*, and *modeling method and tools*. The *modeling subject* defines "what" shall be modeled. This can be the whole enterprise or just a single department, such as manufacturing or logistics. The *perspective* defines "why" a modeling project shall be initiated. It determines the reason, such as certification or organizational re-design. Finally the *modeling method and tool* defines "how" the business process modeling shall be done. The last item of the modeling preparation is the decision on the degree of detailing, which is most adequate to the perspective.

Development of Strategy and Business Process Framework: Process modeling with a top-down approach starts with deriving the business strategy into a framework. This business framework covers all major functions and tasks of an enterprise on a high level. It is used as basis and allows navigating through all process models. It can be seen as a high-level overview allowing to access specific subordinate processes.

Execution of As-is-Modeling and As-is-Analysis: Target is to collect and model the currently existing processes within the company. They are documented and made transparent with the chosen tools as they are the basis for identifying process weaknesses and analyzing improvement areas. As-is-modeling allows the project team to get familiar with methods and tools of the business process modeling project.

Execution of To-be-Modeling and Process Optimization: Here the results of the As-is-Analysis are used as input. It uses the identified process improvements of the previous phase and develops and models new processes. Several iterations are needed in order to model target processes. Furthermore different types of to-be-models can be created based on restricted resources. Examples are the to-be-model and the ideal model. Whereas the to-be-model can be achieved in limited time using existing resources, the ideal model describes the target process in its theoretically best implementation on a mid-term or long-term basis.

Development of Process-oriented Organizational Structure: An essential step is to derive the organizational structure based on the to-be-model. This is needed as process improvements or re-engineering activities result generally in adjustments of the area of responsibility within an organization. This task has to be handled with care, as it involves the shift of power within the company, which can result in resistance of stakeholders. To be more precise the responsibility of certain processes might be shifted within departments.

Introduction of New Organizations and Implementation: The implementation phase converts the process improvements and processes based on the to-be-model into real business processes. Based on the defined modeling subject this can lead to different results. For example in case of a lean-production project, the machine positioning and layout of the manufacturing facilities is adjusted. Or in the case of an ERP-implementation, the software is introduced and customized to fit to the companies' processes and needs.

Continuous Process Management: After project close of the process-oriented reorganization project, the elaborated processes have to stay in focus. Target is to implement a continuous process management. This means the process of process improvement has to be seen as a process itself. The new processes have to be reviewed and analyzed, as well as compared to changes in the markets and customer demand. With that in place sustainable and long-term competitive advantages can be supported and realized.

In addition to the described methodic approach the unique requirements of SME demand additional success factors in order to perform holistic business process management. In the following additional recommendations for BPM projects for SME are listed:

- Employ external consultants if BPM know-how is not available internally
- Minimize man-days of consultants and efforts of project team members
- Integrate project work into daily work of employees, especially for process analysis and improvements
- Improve motivation of employees and project team with initial workshops, including top management
- To-be processes shall be evaluated by the affected departments and not by management only
- Establish a committee that meets regularly and discusses and reviews existing processes in order to ensure continuous process management

Taken these recommendations of a structured business process-oriented reorganization project as well as the additional best practices for SME into account, support of the transformation into a process-oriented organization is ensured. This is a crucial element for the growth and sustainable business success of an enterprise

VII. Conclusion

The target of this research is to identify the unique challenges of small and medium-sized enterprises in the area of production planning and scheduling as well as to recommend clear and realistic solution strategies. This has been realized by the analysis of SME and their manufacturing processes as well as the interviews with production leads and experts in the area of SME, PPS and ERP. These results have been evaluated and the gained insights formed the basis for deriving solution strategies that can be implemented by the target group of small and medium-sized enterprises in manufacturing industries.

This work provides a set of recommendations for small and medium-sized enterprises to approach their challenges within production planning. Nevertheless this topic of production planning combined with the small enterprises has to be critically examined. The introduced recommendations are tailored to be compatible to the resource constraints of SME. Real-life examples and personal experiences of production planning within SME are essential in order to propose improvements. However it can't be ensured that every company is able to execute these recommended approaches. There is still a huge potential in scientific research in the area of small and medium-sized enterprises. This lies in the fact that each SME is unique and has its individual requirements and constraints. Therefore it is questionable if the problem area of SME and PPS can be mitigated or even solved in the near future. The market of ERP-systems for SME is consolidating and evolving, leading to new opportunities and challenges for small enterprises. Even process orientation will change as state of to today more and more small and medium-sized companies follow the example of large enterprises where lean processes or the lean methodology itself are introduced. In addition the question has to be raised, to which degree the implementation of lean methodologies with-in SME is reasonable and can be justified. The strength of SME lies in their flat hierarchies and short communication channels paired with pragmatic processes. Theoretical constructs, technologies or methodologies should not be implemented blindly without a very thorough and sophisticated examination of applicability. No question, optimization algorithms for generating the optimal production plan are great, however is the benefit of a perfect production plan worth the investments for its realization such as new business software for example? Without doubt an ERP-system is essential for managing all processes within an enterprise. But is a large ERP-system worth its tens of thousands of Euros, or is a SME not better equipped with small and specialized business software? It has been verified by countless enterprises that lean processes outperform historically evolved practices. However shortsighted changes of existing best practices within a small enterprise towards lean are dangerous and can even disrupt businesses. Therefore it is a key and critical element for SME to ensure that the surrounding conditions and general requirements for changes are met, if they want to apply and implement the recommendations lined out in this research.

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