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AN INSTRUMENT FOR REDUCING UNCERTAINTY IN THE EARLY PHASE OF PRODUCTION PLANNING

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Abstract: The early production planning phase requires that all involved planning departments cope with different kinds of uncertainty. Especially contract manufacturing companies providing complex products face the challenge of having to cooperate with product design companies during the whole product development process. This paper introduces a practical instrument for production planners during the quotation process with the goal of detecting and reducing both uncertainty and risk during planning, with limited access to product data, production requirements and premises. This instrument was developed on the basis of a concrete use case of a contract manufacturing company in the automobile industry.
Keywords: Uncertainty reduction, production planning, product development

1. INTRODUCTION AND MOTIVATION

Production planning engineers face many challenges in early planning phases, for example handling of weak product data, vague formulation of assumptions and uncertain market forecasts. Corporate strategy, specific competencies, prices and operating efficiencies in particular must all be considered already in the early planning phase. Dimensioning production and factory systems is generally beset with uncertainties due to market dynamics and consequences attributable to changes of the production program. Besides the basic aspects of flexibility and mutability in the production system, there is also a need to plan redundancy and reserves for changes in production facility utilization and quantity [1]. These planned reserves are currently considered as a surcharge on the resource demand in the early production planning phase. However, there is presently a lack of information that defines the basis of the calculation of the surcharges by each department, and also there is no definition of the riskiness of the choice of the resource demand without the surcharge.

In scientific literature, the concept of 'production planning' is subdivided into several phases [2,1, 3]. Grundig [1] roughly structures production planning into preparation, structure planning, detailed planning, execution planning and operation. In this paper we define the concept of the 'early phase of production' as all of the steps prior to detailed production planning, as outlined in figure 1.

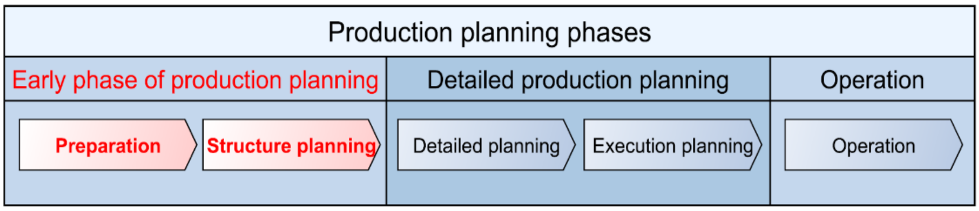

Figure 1 – Production planning phases: The early phase of production planning includes preparation and structure planning [1]

If we take a look at these phases, we can outline that the planning activities in the automobile industry take place during the early phase of production planning in order to determine the required production resources, and in case of a contract manufacturer to submit substantiated quotations. Outsourcing offers numerous advantages for original equipment manufacturers (OEMs), especially in today's highly fragmented and competitive automobile industry producing a higher number of car types than ever before. Products continue to proliferate every year. Indeed, OEMs are more and more focusing on niche segments and platforms [4].

In this volatile and rapidly changing market, the quotation process, i.e. the early phase of production planning for new contracts, is particularly difficult and very time-consuming, especially for a contract manufacturer, if it is considered that many of the requests for quotation are used for the OEM's internal benchmarking only. Quotations should offer a mature level of detail, though only rough specifications are provided by the OEM in many cases. The quality of input data for quotations can range from a one-pager in drastic cases (e.g. a rough hand-drawn sketch of a vehicle) up to a full catalogue of requirements and additional assumptions.

Production planning departments do benefit from a continuous flow of information between product design departments and product planning departments to manufacture complex products successfully in practice. Hence production planners require data, information and knowledge from different stages of the product design phase so that they are able to cope with uncertainty in product planning at the earliest possible stage. Active knowledge sharing between all stakeholders can contribute even more to reducing uncertainty, but will be hampered if product designers and production planners work in different enterprises, which is the usual case in today's supply-chain based economy.

This paper presents a practicable instrument to detect and subsequently reduce uncertainties in the early phase of production planning. Production systems have many different planning levels, and each level needs a specification to state economic and technical applicability. But all planning phases rely on more or less uncertain information. Therefore successful planning instruments have to shed light on the planning uncertainty and finally help to reduce it from the beginning.

After this introduction and motivation of our research topic, the paper is structured as follows:

- ✓ Section 2 presents the method to develop the instrument.
- ✓ Section 3 explains the results of the research work.
- ✓ Section 4 discusses these results.
- ✓ Section 5 contributes a conclusion and perspective.

2. A METHOD TO DEVELOP MEASUREABLE RISK MANAGEMENT FOR UNCERTAINTY

The cost of each department involved in the planning process is based on different uncertainties. These uncertainties differ in their cause, dependencies, values and shapes. The research challenge is to aggregate all the costs with information about the uncertainty in order to calculate a final quotation price.

During project estimation two approaches are practiced to determine costs: If sufficient information is available, the planer will be able to estimate single-values based on a deterministic approach. Historical data or experts' knowledge form the basis for this approach. For projects with a lack of detailed information and considerable uncertainties, a probabilistic approach is chosen [5]. This probabilistic approach provides potential possibilities for the case of the early phase of production planning. Markowitz has already used probabilistic methods to select portfolios of financial instruments in the late fifties of the last century [6]. The idea of risk analysis based on probabilistic is now state-of-the-art in finance mathematics [7]. Meanwhile it has been transferred to other domains including project management, decision theory, construction engineering and risk management [8, 9, 10, 11]. In this regard the Monte-Carlo-Simulation is shown as an adequate method to simulate more complex problems [8]. Though current research has explored several details and specific challenges, the probabilistic approach to determine costs for quotations has remained unexploited in production planning although the planner faces several uncertainties [1, 12, 13].

Since the problem of uncertainty during production planning is similar to the problems within the above mentioned domains, the existing mathematical solution statement can be transferred, if the problem can be described in an abstract way. The TRIZ approach provides a standardized procedure to identify solutions for specific problems via an abstract problem description. The potential of TRIZ applications lies in the utilization of general solution principals [14], a method shown in figure 2.

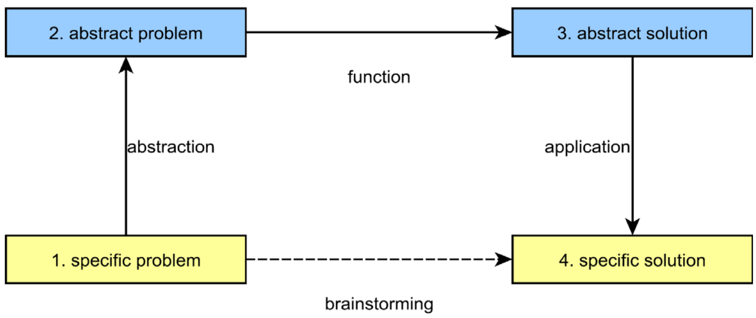

Figure 2 – TRIZ approach: Starting from the specific problem and coming via the abstraction of the problem and its abstract solution to the specific solution [14]

In a first step of the TRIZ approach, it is necessary to understand the current situation in planning. The following questions have to be answered:

- ✓ Is uncertainty part of the current planning process?
- ✓ What types of uncertainties do exist in the planning process?
- ✓ Is the current consideration suitable for the requirements of the planning process?

Furthermore the elements inside the considered planning system and outside this system need to be defined in a proper way. The output of this working step is a system description of the problem within the use case. On the one hand there are components inside the system with their correlation description, and on the other hand there are components outside the system and neglected conjunctions.

In the second step the problem of uncertainty is detached from the use case of the contract manufacturing company in the automobile industry. It is analyzed in the broader context: What does the concept of uncertainty mean in abstract terms, and how can the aligned phenomena be described mathematically. This working step defines the basis for an abstract problem-solving method, and the challenge is to describe the problem mathematically.

A solution will be elaborated in the third step on the basis of the abstract problem description. Possible solutions are the application of a purely theoretical mathematical approach, or the transfer of a solution from a different research field. These techniques are analyzed in the context of the abstract problem description.

Finally the developed technique is applied to the real case. An evaluation must be conducted, whether the technique is applicable in precisely this real use case, and also if the requirements of the planning challenges are met. In addition to this, an analysis is made to determine whether a new planning process needs to be elaborated and implemented. A new solution technique may even demand the implementation of new collaborative working methods and require a cultural change process in the company. This may lead to new possibilities in the planning phase, which should be taken advantage of.

3. INSTRUMENT FOR EARLY PHASE OF PRODUCTION PLANNING: FROM UNCERTAINTY TO MEASUREABLE RISK MANAGEMENT

During the early phase of production in particular, planning is influenced, among other things, by uncertainties caused by various environmental effects. As already mentioned in the introduction, the uncertainties are based on weak product information and production requirements, on weak projectable production details due to a lack of time and a limited planning budget. Furthermore they are also based on future prices for the means of production that are not fixed. Figure 3 visualized all elements, which are considered in the developed instrument.

The output of the production planning system consists of a demand plus surcharge for all kinds of resources in line with the product information and production requirements. Whether internal surcharges are transparent, partly transparent or not transparent is part of the particular corporate culture. Even if a best-case situation emerges, having the surcharges of each demand and department transparent, it is still difficult to establish on what basis these surcharges are calculated and how these surcharges cover uncertainties. It is precisely this information that is crucial in markets with pricing pressure and fierce competition. Thereby profits tend to be low and several negotiation loops will take place until the final offer is accepted or rejected by the customer. The negotiator of the contract manufacturer lacks key information in the described uncertainty system. Hence the following question arises: Does the actual negotiated price still cover costs or not?

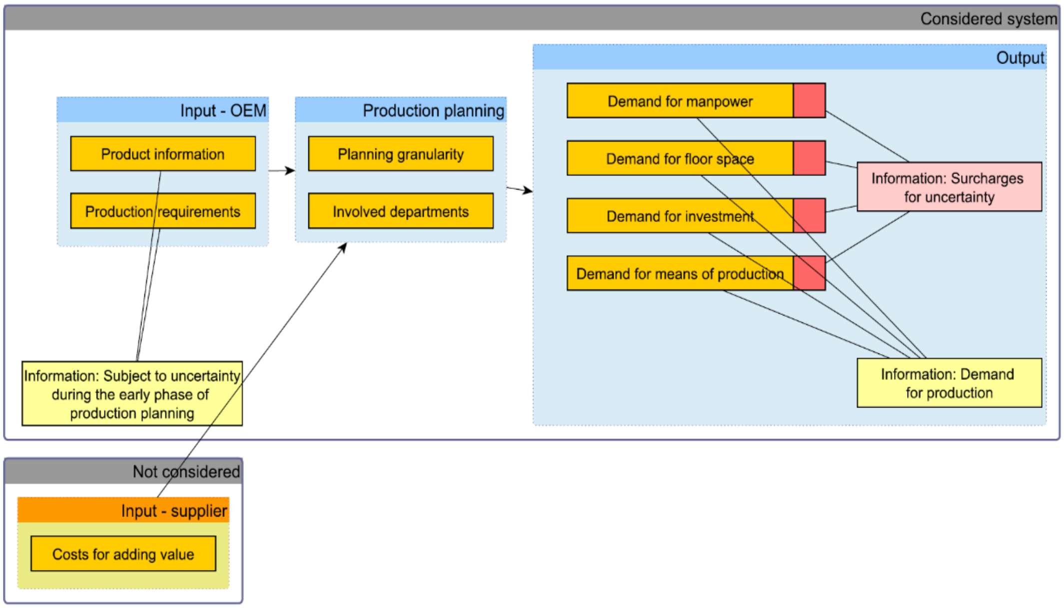

Figure 3 – System description: Production planning system elements and their links for a consideration of uncertainties during production planning

On the other hand there is the interface between product development and production planning. The product information is transmitted to the production planning departments, but in many cases not all the required information is provided. This is because of the lack of knowledge about which key information is required in the early production planning phase with its special requirements regarding the high aggregation planning level. In this case important information is missing, namely what types of uncertainties regarding the product have the biggest influence on production planning and need to be figured out.

In general, uncertainties cause risks in planning and finally in the output. Moreover a calculation with point estimations does not provide a suitable system for handling uncertainty and risk. Point estimation is a suitable instrument for handling exact input and exact requirements. Uncertainty demands an instrument which is able to cope with ranges. These ranges have an influence on each other or on output parameters. The instrument thus needs to be able to calculate the aggregated ranges, to combine different kinds of ranges and help to analyze which uncertainties have the biggest influence on the aggregated ranges.

As a first step assumptions are helpful to calculate exact values, where detailed information and product data is missing. But the information about which possibilities exist beyond the assumptions is still missing. The second step of the solution is the definition of the minimum and maximum levels, which should be considered for each parameter that has an uncertainty. In many cases an expected value between the minimum and maximum can be defined. A definition in the standard Enterprise Risk Management - Integrated Framework fits the described solution steps. An event that occurs can have negative impacts, which are referred to as risks, and positive impacts, which are referred to as opportunities [15]. The probability of the occurrence between minimum and maximum has to be defined to conclude this process. Several probability distributions including normal distribution and uniform distribution can be appropriate to cope with different uncertainties.

Instruments of probability theory and statistics are implemented for the solution of the specific problem. The application level is one aggregation level below the final output parameters of each planning department. This level was set based on the minimum effort in defining the probability and the minimum necessity of information about the probability. These departments determine the minimum, the maximum and the probability distribution for each detailed output parameter. Numerically the distributions are aggregated with a Monte-Carlo Simulation. In this way, every possible combination of distributions according to their defined occurrence is aggregated in several predefined iterations. A simple aggregation of distributions is only mathematically possible under a boundary condition – the combined parameters are independent [16]. Although this is a simplification of the real situation, the information gain for the production planner regarding uncertainty will still be tremendous. A distribution curve is calculated representing the aggregated probability distribution of the costs for a specific project as a result. In most cases this curve can be approximated with a function of normal distribution. The maximum level represents the costs where the real costs will be lower with a probability of 97.75 percent; the minimum level represents the costs where the real costs will be higher with a probability of 97.75 percent. In between these extremes, it is possible to determine the probability that the real costs will exceed the chosen costs.

An example of the uncertainty consideration is described below: Several input parameters are necessary for the determination of demand for a specific joining machine of a car body:

1. calculation of cycle time
2. determination of processing time
3. determination of numbers of joining machines and
4. calculation of demand for joining machines

Information about the annual production volume, the annual working days, shifts per day, working hours per day and shift is needed first. It will likely happen that the volume of cars produced varies (this means the volume of cars is uncertain), while the other parameters are most likely fixed.

Second we need to know for how long the joining machine runs to complete the joining process for each car. At this point information is required about the number of joining locations, the accessibility of the joining locations with standard joining equipment, the duration to execute the joining task, to change the joining tool, to cover traverse distances, the loading and unloading and dead time of the machine, etc. All of these parameters can be determined in detail by simulation during the production planning process or are information inherent to the product design. But in the early production phase, in-depth production planning requires too many resources and too much time. Therefore the durations are standardized and calculated by detailed reference processes. As a matter of fact there always exist variations from the standard values based on the specified uncertainty. This can again be described by means of probability functions based on experiments in the specific technology departments.

Thirdly the number of joining machines is obtained by dividing the processing time by the cycle time. Since the processing time and the cycle time are described with probability functions, the result will again be a probability function due to the considered uncertainties. The production planner receives the information of the minimum number of joining machines, the maximum number, the expected number and the probability function combining these values.

Finally the quantity of joining machines is multiplied with the costs of a joining machine. The subsequent figure shows the distribution of costs of joining machines – aggregated with Monte-Carlo-Simulation in blue and the costs of the aggregation approximated with a function of normal distribution in orange. The approximated curve has a mean value of € 13.5 millions and ~95.5 percent of the cost are between the minimum of € 12.04m and the maximum of € 14.95m.

The expected outcome of an uncertain event is defined exactly as the expected outcome of a random variable, except that assumed probabilities are used instead of objective probabilities [6]. The output is an approximated cost function of the demand for joining machines described by a probability function (Figure 4). This probability function is based on information about the product itself and production requirements

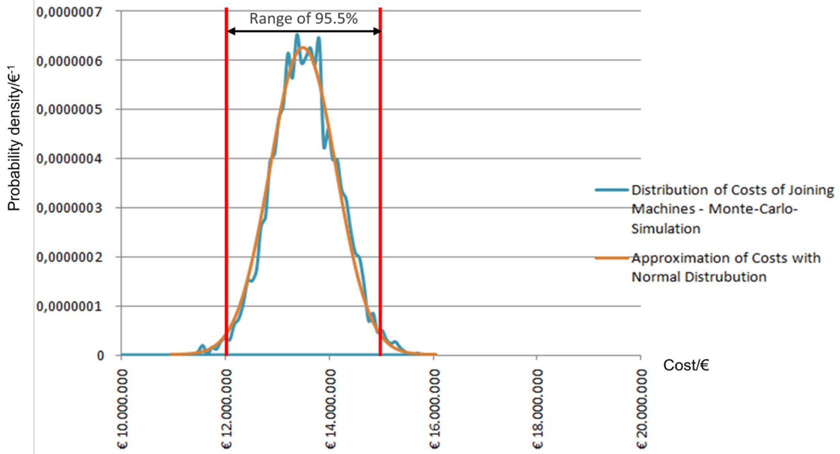

Figure 4 – Cost function of joining machines, example for demand of investment

4. DISCUSSION OF THE RESULTS

The user can proceed in two ways based on the information gained from the probability distribution: The first is to analyze the parameters that have the widest distribution curves with the highest cost influence in his production model. The information quality on which production planning is based can be improved by these parameters. If the production planner gets more detailed product and production information for planning variables, he will be able to determine the production costs with a narrower distribution curve. Secondly, the distribution information is forwarded to the team that negotiates with the customer. During the negotiations the team has access to the information about the risk the company is taking if it offers a certain price for the given conditions. An increase of the risk is transparent for every step of price reduction. All-in-all the instrument provides a transparent view of the risks considered in the early phase of production planning by means of the distribution curves of the costs in each technology department and at different aggregation levels. This instrument helps to analyze which uncertainties finally force the contractor to present proposals with a higher price level. As a final step processes can be implemented in the enterprise to reduce the amount of uncertainties and reduce the calculated demand for resources as a result of the implementation of a more detailed calculation basis.

We generally foresee a big challenge to determine the probability distribution for all relevant planning variables. Enterprises need to invest more time and effort as it is not enough to determine the demand using one value. It is also necessary to calculate the minimum, the maximum and the probability function in between. Nevertheless enterprises need to improve their knowledge in determining uncertainties and transferring to risk considerations. Each industry and production facility has its own specific influences, which must be further investigated.

A critical success factor for the implementation of such advanced methodologies is the social factor, especially the gaining of acceptance by the employees [17]. The individual expert is forced to share his or her personal knowledge and experience to make it available to an information system and to other co-works. Knowledge and experience are often considered as a unique selling proposition and therefore a competitive advantage over peers. This was often a reason why so-called knowledge management systems did not have the desired effect in enterprises in the past [18]. We argue the education of the team members as well as the moderation of the quotation process to be crucial for the success of our presented method. A constructive way to guide a quotation team along that path might be SCRUM [19]. This iterative and incremental method based on software engineering will guarantee a flexible and holistic approach, and limit the degree of freedom for the individual expert to conceal his or her personal knowledge. Applying flexible methods development teams have found a better way of producing high-quality software and meet the demands without extraordinary effort [20]. Ideally such a team consists of tandems of subject matter experts pairing up with process agents who understand the methodology of uncertainties and probabilities.

5. CONCLUSION AND OUTLOOK

Uncertainty in the early phase of production planning is a big challenge for the planning team. The following instrument for handling uncertainty has been presented in this paper: Transfer of uncertainty into measureable risk management. Each of the production planning parameters is influenced by uncertainties based on different and inadequately detailed information. It is proposed to consider these uncertainties during the demand calculation as probability functions with a minimum and a maximum value plus a distribution curve in between in the output. The aggregation of the demands of each production technology including the resulting distribution curve variables is numerically solved under the boundary condition of independencies of these variables. The possibility to analyze the main influences on the quotation uncertainty becomes available with our presented instrument. It makes the main risk drivers. What is more risk information is then made available during negotiation of the quotation. The probability that actual costs will be higher than the price discussed is expressed as percentage. The link from production planning to product design is stimulated by a precise definition of the lack of information of the production planners.

On a technical basis PLM systems aim at facilitating a continuous information flow across the whole product lifecycle including design and production. Basically successful production planning relies on a phenomenon, which can be called integrated information in practice. In the best possible case, the early phase of production planning has good access to data, information and knowledge from the early phases of product design and vice versa, and potential pitfalls can be discussed and particular solutions agreed. This will reduce uncertainty to a minimum level. In the worst case production planning has no direct access to data, information and knowledge from product design.

The instruments have been developed together with a specific contract manufacturer. Our paper does not claim generalization in manufacturing domains other than automobile. We suspect limited modification to be required.

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