World Academy of Science, Engineering and Technology
International Journal of Industrial and Manufacturing Engineering
Vol:9, No:11, 2015

Determination of the Economic Planning Depth for Assembly Process Planning

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***Abstract*—**In order to be competitive, companies have to reduce their production costs while meeting increasing quality requirements. Therefore, companies try to plan their assembly processes as detailed as possible. However, increasing product individualization leading to a higher number of variants, smaller batch sizes and shorter product life cycles raise the question to what extent the effort of detailed planning is still justified. An important approach in this field of research is the concept of determining the economic planning depth for assembly process planning based on production specific influencing factors. In this paper first solution hypotheses as well as a first draft of the resulting method will be presented.

***Keywords*—**Assembly process planning, economic planning depth, planning benefit, planning effort.

I. Introduction

IN an age of increasing globalization and competition, today's markets are ruled by the goals of quality, time and cost. To meet the customers' expectations, companies need to raise the quality of their products while reducing product costs and time to market simultaneously. Thus, they have to improve process quality as well as process flow and they have to decrease production costs. To encounter these challenges and enhance efficiency, companies plan their assembly processes as detailed as possible [1]-[3].

At the same time, the development from a provider market to a buyers' market leads to the change of a former small product spectrum to an expanded range of products with numerous variants, shorter life cycles and smaller batch-sizes. As variance is chiefly created at the end of the value chain and thus in the assembly, this individualization increases the amount and frequency of assembly process planning drastically [1], [4], [5]. These accrued planning efforts can best be reduced by lowering the level of detail for assembly process planning. Trapped between both trends, companies are confronted with the question where the line is between over- and under-planning. Respectively what should be given through planning and what should be self-organized within the assembly so that savings, achieved through assembly planning, are not outperformed by planning costs. To solve the described practical problem, a method to determine the economic planning depth of assembly process planning is being developed at the WZL (Laboratory for Machine Tools and Production Engineering) of RWTH Aachen University. Before outlining the methodology, the relevance of this topic and its status quo will be investigated in this paper so that solution hypotheses and requirements for the methodology can be deduced.

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II. Purpose

A. Need for Action in Practice

To validate the relevance of the described topic in practice, a preliminary study has been conducted at the WZL of RWTH Aachen University [6]. Lately, this study has been expanded to 43 companies, mainly belonging to the sectors of machine and plant engineering, automotive industry and machine tool building. These companies predominantly offer individually customized solutions.

In this study, the companies have been asked how they determine the planning depth, respectively the level of detail, for their assembly planning. A constant planning depth is used by 56% of these companies. 32% ascertain the level of detail based on the individual experience of the planner in charge, whereas only 12% of the companies determine the level of detail for every planning case specifically (Fig. 1 (a)).

The results as well as further expert interviews show that companies currently do not know how to determine and justify the planning depth for a specific planning case due to the lack of a suitable method. According to them, another reason is the difficulty in determining the benefits and efforts of planning. Therefore, they often use a constant planning depth. Since companies plan assembly processes frequently for similar planning cases - e.g. in the case of a new product generation, a facelift or a new variant - it can be expected that they approximate the economic planning depth for their assembly planning iteratively through the continuous repetition of the planning task. However, this iterative approximation is only possible if the products to be planned and the conditions of the planning case remain almost constant over a longer period. However, if the planning situation changes fundamentally, it will be a major problem probably leading to over- or under-planning [6]. For instance, the automotive industry is currently being confronted with electro mobility as a completely new planning situation since electric vehicles are presently not produced in high volumes but with small batches and completely new product and production technologies [7].

The resulting hypothesis, namely that the economic planning depth depends on the planning situation and case, has been verified with a two-third majority in a further part of the survey (Fig. 1 (b)). Due to those facts, an approach is needed which allows determining the specific planning depth about the planning case. Such an approach holds great potential for use in practice, as confirmed by the vast majority of all respondents (8 %) (Fig. 1 (c)).

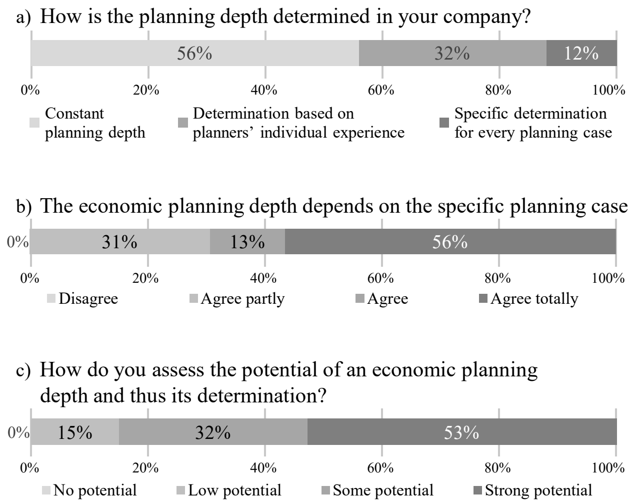

Fig. 1 Results of the study

B. Need for Action in Theory

One reason why companies do not determine the level of planning detail is the difficulty in determining its benefits and efforts. When planning assembly processes, an increase in the detail of planning leads not only to more benefits, e.g. shortened lead-time or avoidance of bottlenecks, but also to more planning costs. Fig. 2 shows that a specific planning depth is economic when the difference between the benefits of planning and its efforts is maximized. Whereas planning efforts can easily be calculated relatively by means of planning costs (in terms of among others planning time, personnel costs and planning tools), the benefit of a specific planning depth is hard to determine due to the complexity of correlations in assembly systems. For instance, it is ambiguous whether a benefit is generated by an explicit planning step, a specific planning depth or by environmental influences. Furthermore, benefits can barely be quantified as not only reduced assembly costs have to be considered but also other targets of planning, e.g. quality, time and flexibility. A further problem in determining an absolute benefit of planning is its lacking zero point. As a situation without any planning is not imaginable, the benefits of planning can be only estimated relatively. Thus, it is difficult to determine the profitability when choosing a particular planning depth for assembly process planning [8], [9]. This deficiency leads to fact that several approaches in literature determine the economic planning depth only based on planning efforts and reduced assembly costs considering other benefits qualitatively at most [10]-[13]. In contrast, other approaches focus on a planning depth based on an analysis of parameters describing the planning situation. However, these approaches do not explain the correlation between influencing factors and the planning depth precisely. Instead, they mainly make use of experiences with the planning situation and existing data so that a sufficient number of representative and similar products need to be accessed [10]. Due to this fact, these approaches cannot be used in profoundly new and unfamiliar planning situations. Besides, most of them are limited to specific industries or company types [11]-[13].

One very promising approach has been developed by Höth and Wienand. In this method, a specific planning depth for manufacturing and assembly planning is determined by means of an assessment scheme describing the assembly system respectively the planning situation. In particular, ten influencing factors regarding the product, process, organization and personnel are considered within this assessment scheme. These influencing factors are subdivided into five categories/ attributes with respect to planning depth: e.g. the qualification of workers is divided into specialists, skilled workers with experience, skilled workers, unskilled workers with experience and unskilled workers. By evaluating these influencing factors, the company can determine a suitable planning depth [14]. However, this approach is limited to single and small series in the metal working industry as the method is based on studies of companies in this industry and this company type. Furthermore, it strongly focuses on the manufacturing planning so that advised planning activities do not apply to assembly processes and the explanation of the correlation between the influencing factors and the planning depth is not completely suitable for the assembly process planning.

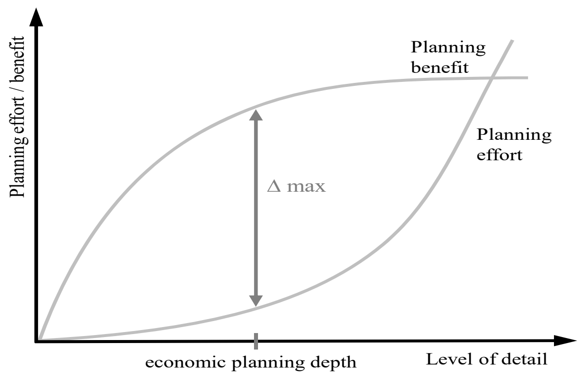

Fig. 2 Economic planning depth

Due to the difficulty of identifying benefits and efforts of planning and due to the deficiencies of existing approaches, a method to determine the economic planning depth for assembly process planning based on factors describing the specific planning case has to be developed.

C. Interim Conclusion

Companies need to position themselves between the conflicting priorities of maximizing productivity by detailed planning and minimizing planning efforts. Thus, they are confronted with the question which level of detail is economic for their assembly process planning. Especially in new and unfamiliar planning situations, this is a major problem as experiences and iterative approximation cannot be applied. A study shows that companies currently do not determine the level of detail for each particular planning case – however they see great potential for an approach to combat this deficiency. Therefore, a method to support assembly planners in the determination of a case specific economic planning depth is required.

Existing approaches can be divided into two different types. One category relies on a company-specific estimation of planning efforts and planning benefits based on experience so that these approaches are not suitable for new and unknown planning situations. The other category allows the determination of the planning depth based on influencing factors of the production system. Although these approaches have aged and influencing factors need to be adapted to modern planning situations and challenges as well as assembly systems, their concept can be well transferred to a new method dealing with assembly process planning. In contrast to the existing approaches, the method to be developed should put special focus on the explanation of correlations to enable a well-founded decision. Therefore, a method based on influencing factors – and thus on the planning situation - is useful, relevant and can work.

III. Introduction of the Concept

Before explaining the methodology in detail, the basic requirements for it will be discussed and a general overview of the method is given.

A. Requirements

For a target-oriented development of a methodology, it is necessary to define the basic requirements it has to fulfill. Four basic requirements can be identified:

- The methodology must fit to the individual company and its planning situation. At the same time, it is should be applicable to all industries and company types.
- The methodology should be especially designed for the application in new and unfamiliar planning situations.
- The methodology should consider the correlation between influencing factors and the planning depth as well as between the planning depth and the specific planning task or method.
- The methodology must offer a specific recommendation of action regarding the level of planning detail.

B. Introduction of the Methodology

To develop the required methodology, three types of models are used: a description model, an explanatory model and a decision model. First, the influencing factors and the tasks of assembly process planning, also considering the definition of planning depth for each task, are identified and described with the help of description models. At this stage, no analysis of correlation is carried out as factors and planning tasks, respectively planning depth, are observed separately. In the next step, an explanatory model helps to display the correlation between influencing factors and planning depth as well as the different planning depths of the investigated planning methods for carrying out the planning tasks. Therefore, it is possible to match the different attributes of the influencing factors to the particular kind of planning method based on planning depth. In a final step, the methodology can be developed by generating clusters, which contain specific attributes of the influencing factors. Each cluster is linked to a recommendation of action regarding the level of planning detail for assembly processes. Thereby, the connection between the cluster and the recommendation of action is based on the examined relations between factors and planning tasks or planning depth. Fig. 3 presents an overview on the development of the methodology.

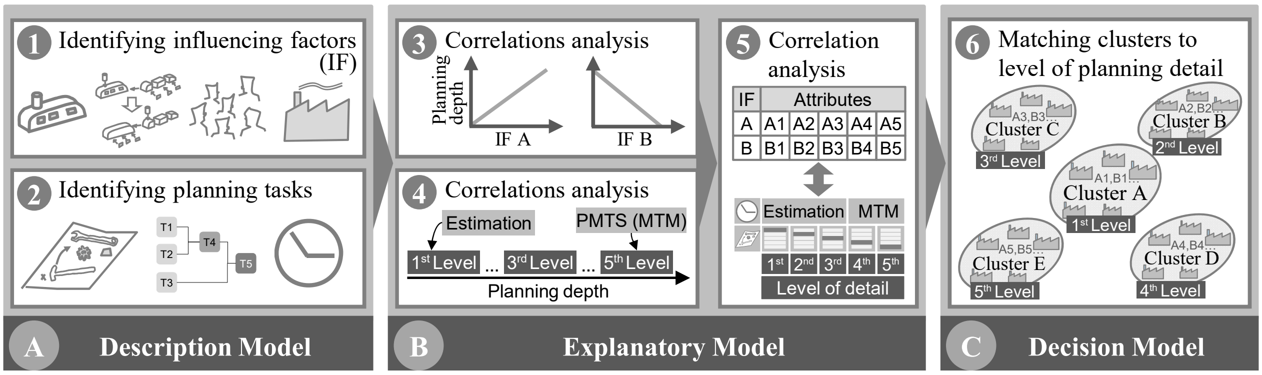

Fig. 3 Methodology

IV. Methodology

To present the development of the introduced methodology, each individual model will precisely be explained in this chapter.

A. Description Model

In the first step, the factors influencing the planning depth are identified. Based on literature research and expert interviews, thirteen influencing factors have been determined so far to describe the planning situation. Those can be assigned to four categories: product, process, organization and personnel. Each category with its particular factors will be introduced below.

The category product encompasses quality requirements, product variety, the degree of product novelty and the dynamics of product change. Quality requirements include the dimensions accuracy requirements of a product (tolerances) [13], [16], requirements due to product liability and obligatory documentation requirements. The number of product variants [10], [17] and the variety of parts (number of different parts to be assembled) [15], [17] belong to the subcategory product variety. The degree of product novelty contains factors such as the novelty of the components, of the product structure and of the materials [17], [18]. Dimensions such as the product life cycle time and the degree of novelty of the successor product are counted among the dynamics of product change [14].

The category process contains five subcategories. The subcategory degree of process complexity includes factors such as process diversity (regarding the content of the process), technical process diversity (number of different joining technologies and assembly tools) and technological process diversity (number of potential assembly sequences) [17]. The degree of process novelty comprises the degree of novelty of assembly methods and of production facilities [13], [17]. The amount of assembly steps and workstations belong to the subcategory size of assembly process [13], [15]. The subcategory process influences and disturbances includes effects of customer changes, fluctuant order receipts or rush orders. The last subcategory is the level of automation [14].

TABLE I
RELEVANCE OF INFLUENCING FACTORS

Influencing factor	$\bar{x}$	Normalized Value
Degree of product novelty	4,00	5
Quality requirements	3,90	5
Dynamics of product change	3,90	5
Product variety	3,85	4
Degree of process complexity	3,78	4
Process influences and disturbances	3,73	4
Qualification	3,64	4
Productions-specific conditions	3,50	3
Degree of process novelty	3,49	3
Size of assembly process	3,27	2
Level of automation	3,23	2
Information requirements for other systems/departments	2,97	1
Culture	2,88	1

The category organization covers only two subcategories. The subcategory production-specific conditions comprises the assembly organization (e.g. assembly line) [15] and effects of the organizational design (e.g. bottlenecks caused by a limited number of employees, assembly tools or work stations [10], [14]. The information requirements for other systems/ departments are determined by the type, amount and level of information detail, whereby information might be needed for operational safety, ergonomics and the wage system [19]. Two further subcategories are counted among the category personnel. The subcategory qualification includes the professional qualification (e.g. technical expertise) [8] as well as interdisciplinary qualification (e.g. ability to work in a team) [20], [21]. Expectations and needs of the personnel as well as their willingness for responsibility and self-organization are considered within the factor culture [17].

Within the study mentioned in chapter II, those thirteen factors have been evaluated regarding their relevance for the level of detail for assembly process planning based on a scale from 0 (not relevant) to 5 (very relevant) (Table I). By means of the determined average value, these influencing factors are ranked and given, a normalized value from 1 to 5. The three most important factors are the degree of product novelty, quality requirements and the dynamics of product change. In contrast, information requirements and culture are of minor significance for the determination of planning depth.

Looking at the results from each industry separately (Fig. 4), it can be noticed that the degree of product novelty is most important for all industries. Ranking product variety second and dynamics of product change third, the sectors of machine and plant engineering and machine tool building share the top three influencing factors whereas the automotive industry attaches importance to quality requirements and the degree of process novelty. This shows that the importance of influencing factors may vary depending on the industry or company type. Therefore, an individual ranking should be considered in the method.

Automotive	Machine and plant engineering	Machine tool building
1. Degree of product novelty 2. Quality requirements 3. Degree of process novelty	1. Degree of product novelty 2. Product variety 3. Dynamics of product change	1. Degree of product novelty 2. Product variety 3. Dynamics of product change

Fig. 4 Top three influencing factors of each industry

Apart from the influencing factors, the tasks for planning assembly processes have to be identified in a second description model. To enable a smooth interaction between workers, operating resources and work pieces, assembly operations and their sequences need to be planned. Thus, assembly process planning determines which product is assembled out of which components as well as how, in which sequence and in what time this is done. Finally, it has to be planned which assembly operation is done at which assembly station and by whom [22]. The resulting four planning tasks will be described precisely below.

The first step of planning is to generate an assembly-oriented product structure out of the engineering bill of materials (BOM). Whereas the engineering BOM describes the product from a functional perspective, the assembly BOM demonstrates which part is assembled out of which component. Although both part, lists are quite similar, this transformation has to be done to raise the efficiency of assembly [22], [23]. A different level of planning detail would be achieved by not considering standard parts or single components but whole assembly units.

Composing assembly operations and their logical sequence is the second planning step, which can be deduced from the product structure. The assembly sequence is visualized by means of an assembly priority chart, which is similar to a network plan. A result of this planning step is the work instruction, which informs assemblers about the operations to be carried out, as they might not have the required knowledge or skills [22]-[24]. When composing assembly operations, the whole assembly task has to be divided into smaller segments whereby the level of breakdown is determined by the planning depth. Hence, the definition of planning depth is based on the underlying breakdown structure of assembly operations.

To calculate capacity requirements, delivery dates or production costs, the determination of a standard time, in which the worker has to complete his task, is necessary. Due to the diversity of requirements, many different methods exist to predetermine the motion time [23]. Hence, this work focuses on the methods of comparison and estimation, predetermined motion time systems (PMTS, e.g. MTM) and catalogues of standard time (e.g. REFA time study). Thereby, the method for the determination of standard time depends on the level of breakdown structure. MTM, for instance, regards single work elements and has thus a higher level of detail [23].

Finally, line balancing can be performed by means of the calculated standard times for all assembly operations. Operations will be equally allocated to the assembly stations so that waiting times and thus lead-time can be reduced. Thereby, the priority chart and other assembly-related product features (e.g. immovable operation resources) have to be considered [22]. The planning depth likewise depends on the level of the breakdown structure of the assembly operations. When balancing smaller operation segments, the amount of planning would be increased while the allocation is becoming more accurate. Although it is possible to generate a product structure with different levels of detail, interviewing industry experts has exposed that a rough product structure is not common. This is because even standard parts are needed for planning material supply and describing assembly processes. Furthermore, its planning efforts are negligible as the existing engineering BOM only needs to be converted regarding its structure but not its content. Thus, a product structure should be generated with the highest planning depth, as it is essential for all further planning steps. Furthermore, the planning depth of line balancing results from the planning depth of the work break down structure and the standard time determination so that it does not have to be determined on its own but it will be deduced automatically. Therefore, out of these four planning tasks, generating assembly operations/priority charts as well as the determination of standard time will be focused in the methodology as they mainly determine the planning depth of the whole planning process.

B. Explanatory Model

After describing influencing factors and planning tasks, they will be analyzed regarding the planning depth. Looking at the factors, it has to be figured out whether the correlation between the factor and the planning depth is negative or positive. For example, the correlation between the degree of product novelty and the planning depth is positive, i.e. the higher the degree of novelty, the higher the detail of planning which is required [25]. In contrast, the correlation between qualification and planning depth is negative, i.e. the higher the qualification, the lower the detail of planning, as the workers have enough knowledge, skills and experience to assemble products with little guidance [14]. In order to confirm these correlations, a hypothesis will be developed for each factor and validated in further studies, expert interviews and experiments. Then these influencing factors will be subdivided into five classes of attributes. For example, the degree of product novelty in terms of components is divided into solely known components, a few, several and many new components as well as completely new components [17]. With regards to the kind of correlation, these attributes will be put on a scale from lowest to highest planning depth, e.g. solely known components will be at the lowest point on the left whereas completely new components will be on the right requiring a more detailed planning. These attributes will also be checked within studies, expert interviews and experiments. By applying this procedure to all influencing factors, a morphological box can be generated which will be needed for the method in the decision model.

When generating assembly operations and priority charts, the level of detail is expressed through the breakdown structure of assembly work. Hence, they will also be subdivided into five levels according to their planning depth: the whole assembly work (e.g. assembling a gearbox), assembly sections (e.g. assembling a drive shaft), assembly operations (e.g. shrinking on the gear wheel), specific assembly actions (e.g. adjusting the shrinkage temperature) and single work elements (e.g. press a button). When determining standard times, the method as well as the breakdown structure is considered for classifying five different levels of detail. The first two levels of planning depth include comparison and estimation or catalogues of standard time regarding the whole assembly work (first level) or assembly sections (second level). Besides these two methods, the third level of planning depth will also contain systems of predetermined times based on assembly operations. The fourth and fifth level will comprise catalogues of standard time or systems of predetermined times regarding specific assembly actions (fourth level) or single work elements (fifth level). Because of this analysis, we have an action plan with five levels of planning detail whereby planning efforts and the level of detail increase with every step. This action plan also needs to be validated within studies and expert interviews.

As the attributes of influencing factors and the methods of planning will be analyzed and sorted according to the planning depth, both dimensions can be linked successfully. In order to achieve a realistic connection between them, studies and expert interviews as well as experiments will be carried out.

C. Decision Model

In a final step, the required method - to be used by the company - can be developed. This method consists of a pairwise comparison, a morphological box, which is used to create different clusters and an action plan with five recommendations. With the method of pairwise comparison, the company will be able to evaluate the importance of the influencing factors individually. The outcome of this comparison will be a normalized value for each factor, which is needed for further evaluations within the morphological box. This box contains influencing factors with five attributes each. The company will evaluate its planning situation by means of this morphological box getting a profile of planning depth. Depending on this profile and the importance of the individual influencing factors, the company will be assigned to a cluster, which represents it mostly. This cluster will be linked to a specific recommendation of action from the action plan. This recommendation tells the assembly planner how precisely he has to plan the assembly process. If a company´s profile cannot be assigned to one specific cluster but lies in between two clusters, the planner will have to examine efforts and benefits of planning for both levels based on his experience.

V. Conclusion

In this paper, an approach to develop a method to determine the economic planning depth for assembly process planning has been presented. This method is based on a morphological box containing influencing factors to describe the current planning situation of a company. Depending on the respective attributes of each factor, the company will be assigned to a cluster, which recommends a specific planning depth. This recommendation covers the planning tasks of establishing assembly operations/ priority charts and determining standard times.

As the connection between influencing factors, in form of clusters, and planning methods, in form of a recommendation of action, is most important for the function of this method, it needs to be further investigated with the help of studies, expert interviews and experiments. Moreover, this method needs to be verified by analyzing several companies and their assembly process planning.

Acknowledgment

The research work has been conducted by the Laboratory of Machine Tools and Production Engineering (WZL) of the RWTH Aachen University.

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