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"Engineered Hours per Product for Simultaneous Engineering"

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Abstract

Modern Cooperative Engineering approaches suggest a transparent tracking of production costs during development stages. The traditional concept of Engineered Hours per Product, originally developed for the automotive industry, focusses on specific production and assembly times. Necessary but auxiliary tasks are ignored since their reduction is within the domain of production departments. Thereby this approach promotes the decrease of production time but does not give an adequate measure to compare design alternatives. This paper presents a complementary approach based on the assumption that the production system has reached a stable status and remains relatively constant for new variants. Based on existing products core time drivers based on features are successively identified until an adequate approximation of the time for the current product is achieved. Those time drivers thereby include the total time to perform the task, including auxiliary task and can be used during the development stage. The paper concludes with an industrial case study to illustrate the benefits.

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1. Introduction

Cooperation between different departments involved in the product development process have been widely accepted to be crucial for manufacturing companies [1]. Simultaneous Engineering [2], Concurrent Engineering [3] and Integrated Product Development [4] differ in process specific aspects but follow the same overarching goal of increased cooperation. Despite the general agreement for the benefits, improvements concerning the methods are still necessary [5]. One of the key challenges for an efficient cooperation is the evaluation of products and transparent product costs prediction in early development stages [6]. This paper addresses those evaluations from a manufacturing perspective and presents an Engineered Hours per Product approach capable of supporting the early phases.

Starting with a brief introduction to Cooperative Engineering and product cost tracking approaches, this paper refelects shortcomings identified in recent literature. The concept of Engineered Hours per Vehicle (EHPV) is presented and evaluated according to those shortcomings. Section 4 presents an approach for Engineered Hours Per Product including the process of data acquisition as well as the optimization model required for the approach. A sanitized industrial case study is presented in Section 5 and benefits are illustrated. This paper concludes with a summary and outlook for further research.

2. Cooperative Engineering and Product Cost Tracking

2.1. Cooperative Engineering

Cooperative Engineering has been known since the early 1960s [7] as Simultaneous Engineering [8], Concurrent Engineering [9] and Integrated Product Development [10]. While all approaches differ in details they all require the participants to work on preliminary data [11] and trace product costs along the entire process [12]. Development of the product has to be conducted parallelel to the development of the functions within other departments. Those include but are not limited to the development of production-systems, logistic networks as well as sourcing strategies. If implemented successfully time-to-

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market as well as development and product costs can be significantly reduced [13]. Additionally an increased customer focus is found to be a result of closer cooperation between the departments [14]. Early publications introducing approaches of collaborative product development highlighted the expected benefits [15] and were supported by reports of successful implementations in industry [16]. More recent publications confirm the potential but also focus on the challenges and short-comings [17]. Beside others demand for fast methods to evaluate early product concepts from a production perspective is articulated [18].

2.2. Product Cost Tracking

Evaluating product concepts always requires cost evaluation besides the evaluation of requirements [19]. Even though the costs are largely determined by the design, they are realized within other departments like sourcing, after-sales and production. Therefore the costs can only be evaluated interdisciplinary. The approach of target costing [20] includes primarily a top-down approach. Allowed costs are defined for components and parts. Therefor it is primarily a management tool which requires methods for product cost evaluation [21].

3. Engineered Hours per Vehicle

Especially in automotive assembly lines, costs are very closely related to the time required to complete the task of assembly. Therefore the target costing approach as well as the cost tracking approach were simplified to focus on assembly time rather than complete costs [22]. Even though no unique understanding of Engineered Hours per Vehicle (EHPV) exist [23], regarding solely the time of actual assembly process or using arbitrary values is common practice [24]. Thereby EHPV is capable of being a valuable management tool to set development targets. A product concept may not exceed a defined sum of assembly hours in an ideal case where only active productive time is evaluated. In this regards only the time to tighten a screw is accounted for, auxiliary tasks are neglected. Therefore production planning has the target of coming as close as possible to the EHPV.
The concept is very well suited for defining targets as well as comparing similar concepts relative to each other. Reducing the number of screws from four to three results in an equivalent reduction in EHPV. However it gives no indication if this reduction covers for an increase in sourcing costs resulting from higher strength screws.

4. Engineered Hours per Product for Cooperative development

4.1. General Concept

In order to overcome those shortcomings in the illustrated context of Cooperative Engineering, it is necessary to give a cost indication while still focusing on product features which are present at early design stages.
Using the close relation between time and costs present especially in assembly lines, the requirement is to give an indication for the complete effect a change in concept has on the assembly time, not only the directly productive time. The second assumption used is the fact that an already existing production system for a similar product has reached a stable level of efficiency. Thirdly, it is assumed that the product under development will be manufactured in a production system to similar to a system available for observation at present.

The underlying idea of the approach is to identify groups of product features which are most relevant time drivers and generate factors which include all auxiliary tasks (which are not known to the developer or the team at that stage). While the number of feature groups can be in the range from 1 to the total number of individual assembly tasks, it is important to summarize tasks in groups to allow for an easy evaluation of a concept. For example giving a time demand of two minutes for each screw allows the developer to easily evaluate how much time the reduction of one screw yields within the production, including task like material handling and tool preparation. Defining those groups it is important to keeping the number low enough for quick evaluation while reducing the error to an acceptable level. Summarizing every screw as a one product feature would neglect, that larger screws in general connect heavier parts and therefore need more positioning time for those parts. In order to allow for a viable implementation it is required that those groups can be generated by the user.

4.2. Defining relevant Product Features

The following section describes an iterative process for the definition of relevant product features.

Initially the first expected product feature is defined for a production line. This can be, in order to stick to the example, the number of screws. The total number of screws assembled within a certain time period is calculated for each station via the bill of material or assembly documentation. The total available workforce in this time is divided through this number. Therefore the duration for each of this product feature is approximated. However there is no indication of the quality of this approximation. The selected feature might as well be insufficient. In the second step the number of performed product features (assembled screws) for each assembly station (s) is multiplied by the identified factor from step one and compared to the workforce available at that station during the time period (w_s). The difference gives an error indicator whether the approximation was sufficient for this station. Combining the error at each station, using for example an absolute value, gives an overall error of this approximation. If the error is not sufficiently low for the user, a new feature (f) is added to the list of product features (F). This feature can be identified by investigating the stations with the largest error. In

an assembly context this might be the stations where wires and pipes are assembled and an indicator might be the length of assembled pipes in meter.
The number or amount of the feature is identified for each station while the total available workforce at the workstation is known from the previous step.
Therefore an optimization problem is defined in step four which tries to minimize the error (using the function from step two) by selecting the factors for each feature. Each factor has to be non-negative. Steps three and the following are repeated until an accepted level of error is achieved or the number of features has exceeded a predefined threshold. Features are not necessarily base on processes (e.g. screwing) but may include additional parameters as diameter. One group may be screws below a diameter of 14mm and another one those above. It is however mandatory that the number or amount of this feature is acquirable for each assembly station and that the feature is available to the developer during early concept stages.

Figure 1 depicts the complete process including the initialization as well as the iterative steps and the stop conditions.

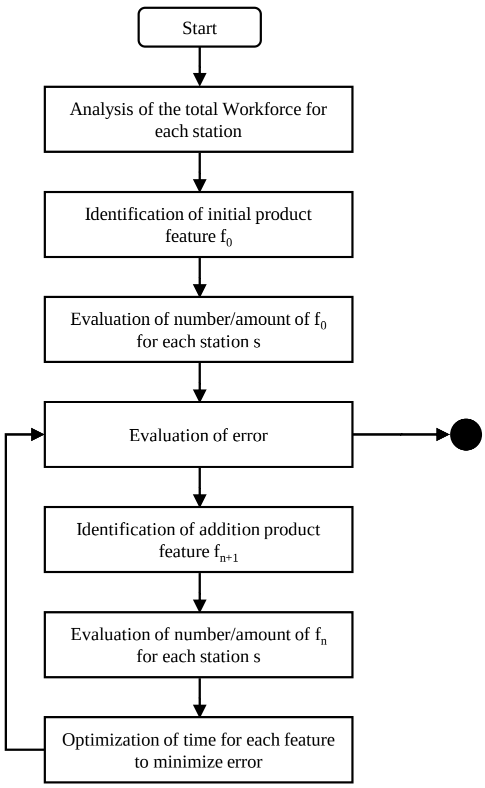

Fig. 1. Iterative Process

Equations (1) and (2) illustrate the target function as well as the constraints. Depending on the error function the optimization problem may be solved with simple office tools.

$$\min \sum_{s}^{Stations} \left| \left(\sum_{f}^{Feature} x_{s,f} \times t_f \right) - w_s \right| \quad (1)$$

$$t_f \geq 0 : f \in F \quad (2)$$

If different variants (V) are produced at the same line with significant differences in work time required, the target function has to be extended. The additions are reflected in Equation (3).

$$\min \sum_{v}^{Variant} \sum_{s}^{Stations} \left| \left(\sum_{f}^{Feature} x_{s,f,v} \times t_f \right) - w_s \right| \quad (3)$$

The amount or number ($x_{s,f,v}$) of Feature f has to be analyzed for each variant v separately. Figure 2 illustrates the general concept using a simplified example. The features added during an iteration are highlighted.

Initial Step

	Feature	Station 1	Station 2	Station 3
Worktime [min]		200	300	100
screws [-]		50	3	1
time screws [min]	4,0	200,0	12,0	4,0
Calculated Time [min]		200,0	12,0	4,0
Error [min]	384,0	0,0	288,0	96,0

Iteration 1

	Feature	Station 1	Station 2	Station 3
Worktime [min]		200	300	100
screws [-]		50	3	1
rivets [-]		2	15	0
time screws [min]	3,2	161,3	9,7	3,2
time rivets [min]	19,4	38,7	290,3	0,0
Calculated Time [min]		200,0	300,0	3,2
Error [min]	96,8	0,0	0,0	96,8

Iteration 2

	Feature	Station 1	Station 2	Station 3
Worktime [min]		200	300	100
screws [-]		50	3	1
rivets [-]		2	15	0
pipes [m]		0,0	0,0	20,0
time screws [min]	3,2	161,3	9,7	3,2
time rivets [min]	19,4	38,7	290,3	0,0
time pipes [min]	4,8	0,0	0,0	96,8
Calculated Time [min]		200,0	300,0	100,0
Error [min]	0,0	0,0	0,0	0,0

Fig. 2. Example

5. Application

Despite of the simplicity of this optimization the generation of a list of features (F) with the corresponding time for each feature (t_f) allows for a quick evaluation of product concept since all auxiliary tasks are included. In contrast to the traditional EHPV approach, changes in product design reflect time savings more accurate. The illustrated concept was implemented with an industrial partner producing goods on a manual assembly line. For evaluation purposes a line segment of 21 stations was selected including screwing as well as piping operations. The initial step included screwing operations and led to an error of 95%. Including riveting reduced the error to approximately 91%. Large deviation was identified within the screwing operation as some stations assembled heavy components with significant time for aligning the product parts prior to assembly. Other stations however assembled interior components with a high number of small screws requiring very limited alignment effort. Therefore screwing operations were divided to reflect those differences. The total error significantly decreased to 65%.

Largest deviation was identified at stations assembling particular heavy parts with very large screws exceeding M20. The screwing operations were further divided and a total error of 55% was achieved. Additionally information about the part weight was used to define two groups as a feature. This led to an error of 17%. Including the length of assembled piping reduced the error to 8% and including the number of piping connectors reduced it further to 3% which was within acceptable range for the user.

The selected seven features where used to quickly evaluate different product concepts from an assembly perspective. In order to reflect performance increases within the assembly line, the process was repeated quarterly and extended to the complete production line. Different sections as the milling and drilling section gave different sets of features with similar quantities. It is to be noted that the optimization model was implemented using standard office tools and no additional software or expertise was required leading to a very low entry barrier.

4. Summary

This paper has illustrated the benefits of cooperative engineering and given a brief insight into the short comings of existing approaches. The necessity for product cost tracking was illustrated and the concept of Engineered Hours per Vehicle was evaluated. Based on the need an approach was developed which includes the total work time and distributes it to a limited list of product features. Finally the approach was evaluated in an industrial case and the usability was confirmed.

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