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Leveling of low volume and high mix production based on a Group Technology approach

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ABSTRACT

Application of conventional leveling approaches in industry is constrained by the requested product diversity. Therefore, leveling is predominantly used in high volume production. However, it can be utilized in low volume and high mix production by means of an adapted leveling approach presented in this paper. This approach primarily uses clustering techniques to group product types into families. After that, a family-based leveling pattern is generated. The paper focuses on the formation of product families for leveling and describes in detail the usage of a so-called desirability index for cluster validation. It also provides an example of actual application.

1. Introduction

Production leveling, also referred to as production smoothing or heijunka, is an essential element of the Toyota Production System and lean production respectively [14]. It aims at balancing production volume as well as production mix and enhancing production efficiency by means of reducing waste, unevenness, and overburden of people or equipment [6,14]. When using standard methods, leveling is only implementable in repetitive production environments with limited product diversity, i.e. large scale production [9,20]. This paper presents an adapted approach that can be used to apply leveling in low volume and high mix production.

This approach is based on the principles and methods of Group Technology. The fundamental idea of Group Technology is to subsume items (e.g. parts, processes, equipment or tools) into families according to their similarity and to take advantage of these groups in order to increase productivity in manufacturing [19]. In context of the leveling approach presented in this paper, Group Technology is utilized to group product types into a manageable number of product families according to their similarity in required manufacturing operations. Based on these families, production is leveled into a family-oriented leveling pattern. This pattern is generated by applying a systematic procedure that is adapted from high volume production.

This paper first gives some facts about production leveling in general (Section 2). After that it describes a systematic procedure for leveling in low volume and high mix production (Section 3). This section also focuses on formation of product families for leveling purposes. Section 4 gives a practical example of how product families are formed for production leveling. A brief summary is given in Section 5.

2. Production leveling

The objective of production leveling is to balance production volume as well as production mix by decoupling production orders and customer demand [14]. In contrast to tayloristic large scale production, leveling allocates production volume and mix to even, short periods [22,25]. The sequence of these periods defines a periodic manufacturing frequency, i.e. a repetitive pattern. According to this leveling pattern, every product type is manufactured within a periodic interval, for example a day or a shift [15]. The so-called EPEI-value (every part every interval) denotes this interval's duration. The general objective is to reduce the EPEI-value to a cost-effective minimum. This leads to a balanced work load in production and logistic processes as well [14,12,18].

2.1. Effects of a Leveled Production

By decoupling production and customer demand, leveling reduces waste, overburden, and unevenness which are the three main loss factors for productivity [14]. It avoids variability in the production schedule caused by fluctuation in customer demand. Without leveling, this fluctuation leads to waste in form of worker and machine idle times (in case of under utilized capacities) or quality problems, breakdowns, and defects (in case of overburdened capacities) [14]. Leveling enables production to meet customer demand without holding large volumes of inventory or

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spare capacities [15]. Hence, the risk of holding unsold goods is reduced [14]. Inventories are limited to a controlled standard, the bullwhip-effect is diminished or even avoided, and lead times are shortened [5,17].

Despite these positive effects, leveling is not synonymous with waste-free built-to-order production [17]. On the contrary, implementing leveling successfully often requires a controlled inventory of finished goods [14]. In this case, a determined degree of waste that is counterbalanced by reducing unevenness and overburden along the whole value stream is accepted [21]. Furthermore, leveling leads to a certain degree of stability in production processes that facilitates implementing other lean production methods like standardized work [18]. Leveling can also be used to specify a target condition for continuous improvement processes (CIPs). Comparing a target condition to a current situation highlights variability that represents an initial point for continuous improvement and problem solving [17].

2.2. Requirements for production leveling

To decouple production from customer demand and implement production leveling successfully, a controlled level of inventory is needed [14]. In general, leveling goes along with mixed-model manufacturing in small lots and high changeover frequency. Thus, minimal setup times for changeover are essential [22]. Additionally, leveling requires utilizing general-purpose machinery and equipment on the one hand [16] and flexible and multi-skilled workers on the other hand [5,25].

3. Leveling of low volume and high mix production

Application of conventional leveling (i.e. manufacturing every product type within a periodic interval) is limited to repetitive production environments characterized by limited product diversity combined with stable and predictable demand [9,12,20]. Nevertheless, it can be implemented in low volume and high mix production by means of a systematic procedure which is adapted from conventional leveling approaches (Fig. 1). This procedure consists of four fundamental steps which are described in the following subsections.

3.1. Analysis and constitution of the leveling model

The systematic procedure starts with a detailed analysis using value stream mapping, enhanced by customer demand analysis if required. Thus, material and information flow get visualized transparently and bottlenecks can be identified. These bottlenecks are possible pace maker processes which can be used to trigger production orders according to the leveling pattern.

Based on these analyses, the so-called leveling model is built. It consists of four elements which have to be concretized to adapt leveling from high volume production to constraints of low volume and high mix production [4]. The leveling model describes the relative amount of production volume that is included in the leveling pattern, e.g. 80% (first element), and the degree of aggregation, e.g. leveling based on product families or single product types (second element). The third element of the model indicates the time periods for production scheduling, e.g. one day or one shift. The fourth element of the model depicts the specific characteristics of leveling, e.g. smoothing production volume only or volume as well as mix. Buhl et al. [4] describe this leveling model in detail.

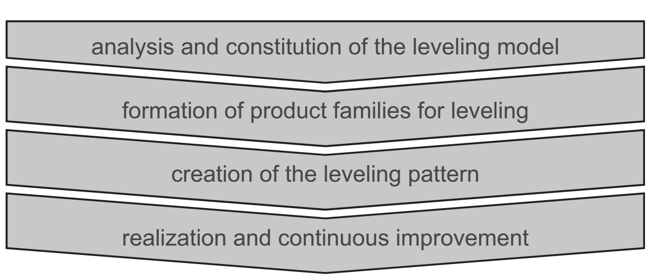

Fig. 1. Systematic procedure for production leveling in low volume and high mix production.

3.2. Formation of product families

In order to implement leveling in spite of high product diversity, product types are grouped into a manageable number of families according to their manufacturing similarity. In common practical cases, a large amount of product types can be expected. These have to be grouped according to a large number of attributes representing a specification of the selected grouping criteria. Additionally, a predetermined number of families and pre-classified objects does not exist in most cases. Hence, on a more abstract level, product family formation for leveling can be classified as an unsupervised (machine) learning task [10]. For this learning task, different clustering algorithms are applied which generate a large number of different grouping results. These results are compared and validated using a so-called desirability index. This index considers formal aspects as well as aspects deduced from the case of application. The product family formation process for leveling is described in detail in the following subsections.

3.2.1. Selection of grouping criteria

Product family formation bases on the identification of similarities. These similarities are reflected in different grouping criteria. In general, design- and manufacturing-oriented attributes represent the two categories of grouping criteria applicable for product family formation [13]. Whereas design-oriented criteria describe products with respect to their geometrical and physical attributes, manufacturing-oriented criteria denote similarities concerning production sequence and requirements. The latter similarities are required to manufacture products of one family in a sequence without or with minimal losses (e.g. caused by changeovers). Consequently, manufacturing-oriented criteria are chosen to form product families for leveling.

Adequate grouping criteria for forming product families for leveling are operation sequences, required equipment and staff, process times, setup times for changeover and share of identical components, parts, or raw material [2]. This hypothesis has been confirmed by an online survey conducted by the Chair of Industrial Engineering at TU Dortmund University. In sum, 106 company representatives from different industry sectors participated in this survey. Amongst others, they were asked to assess which grouping criteria they would choose to form product families for leveling considering manufacturing similarities. The results are shown in Fig. 2. Selection of grouping criteria essentially depends on the concrete case of application.

3.2.2. Application of different clustering algorithms

As described above, product family formation can be classified as an unsupervised learning task. The concrete learning task is to group a set $\mathbf{X} = \{X_1, X_2, X_n\}$ of n p-dimensional objects (i.e. product types) into the most adequate partition $C^{(k)} = \{C_1, C_2, C_k\}$, $k \leq n$. Thereby, the objects within each group C_i, $1 \leq i \leq k$ (i.e. product types within each product family) should be as similar as possible and the different groups should be as inhomogeneous as possible. An optimal partition size (i.e. the optimal number of product