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Using Process Design to Overcome Undesirable Consequences of Increased Product Complexity

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Abstract

This work closes a knowledge gap, which hindered the exploration of the relationships between complexity and quality in full. Recent decades are characterized by rapid technological progress, which has been followed by elevated product complexity. Many repercussions of this growing complexity have already been considered, but the work has not yet been completed and this study adds a significant contribution. While not the sole, the most straight-forward expression of product's complexity level is the number of components, which are assembled to make this product – the more components, the higher the complexity.

In serial manufacturing processes, each item moves individually, but items are joined together, serially or in parallel, in assemblies. There, mutual effects exist – a single defective component suffices to disqualify a whole assembled unit! Surprisingly, few studies have considered the effects of defective items on the production process. Particularly, there appears to be no study that quantifies these mutual effects among components which arrive from different sources with different defect rates. Thus, this study appears to be a first attempt to analyze and quantify these effects. Evidently, the mutual effects among their components amplify assemblies' defect rates dramatically, to the extent that defects due to common or random causes become significant. This hypothesis is supported by both the result of this study and field data from the industry.

This is a price of advanced products – increased complexity which sets hurdles on the preservation of quality; a price that should be considered in the course of product design. However, the present analysis reveals that setting quality assurance activities just prior to assembly operations reduces the mutual effects among components. Consequently, process design can be used to overcome undesirable repercussions of increased product complexity, thereby increase the yield of the production process.

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Keywords: Assembly; defect rate; process design; product design; product structure; quality; yield.

1. Introduction

Recent decades faced rapid increase in product complexity due to, even faster technological progress. While not the sole, the most straightforward expression of products' complexity level is the number of components, which are assembled to make this product – the more components the higher the complexity. Some repercussions of this factor are studied here.

The subject of this study is the effects of the existence of defective items on assemblies. No process is perfect and the existence of defective items is unavoidable. A defective item is an item that as produced cannot be used as intended to because it does not conform to specifications. A product or subassembly is conforming only if all its components are conforming. This requirement creates dependencies and mutual effects among components – a single defective component suffices to disqualify a whole assembled unit. Consequently, the efficiency of the process deteriorates as its yield decrease, dramatically. Furthermore, if the existence of defect(s) is detected at late stages, it might be impossible or very hard and extremely expensive to disassemble the defective unit and use the conforming components elsewhere. Therefore, the distribution of quality assurance (QA) activities in the production process is a central issue in process design.

This study aims to quantify the mutual effects of defective components in assemblies and develop strategies to reduce them. The methods and tools used for the analyses are quite simple and straightforward and yet produce results with significant implications. Thus, it is rather surprising to find no previous similar study. Further, in a recent survey, Hu, Ko,

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Weyand, ElMaraghy, Lien, Koren, Bley, Chryssolouris, Nasr, and Shpitalni [1] have noted that "very limited work exists in analyzing assembly system quality when multiple products are produced in the same system." The methods used herein are readily applicable to multi-product environment.

1.1. Assumptions and nomenclature

Often there are several components of the same type in a product; e.g., 4 wheels in a car, 2 processors in a computer, etc. Let k denotes the type of the component, m_k denote the number of components type k in an assembly – the assembly coefficient of components type k, and d_k denotes the average defect rate and Y_k=(1-d_k) the average yield of that components type. Since their manufacturing processes are different, it is reasonable to approximate reality by assuming independence among component types. Also, a classical distinction in quality theory is between common or random causes for defects and quality deterioration due to assignable causes; e.g., [2], [3]. Here, the first defect type – due to random causes is considered. This makes independence between items of the same type a reasonable approximation, too. (A study of quality deterioration due to assignable causes can be found in e.g., [4].) Finally, in repetitive production, long term averages are proper performance measures to use, rather than first time quality as in [5].

Nomenclature

d_k	average defect rate of component type k
K	number of component types in an assembly
m_k	assembly coefficient of components type k
Y_k	average yield – average number of conforming units of component type k
Y^a_k	actual average yield of component type k

2. Mutual effects and actual yield

Consider, first, a single item, which is manufactured in isolation and whose defect rate is d. Then, on average, only (1-d)·Q =YQ unit are conforming, out of Q units that are processed. In practice however, target sales are aimed at. Hence, the number of units that should be processed, in order for Q units to come out conforming, is required and is given by the inverse calculation: Q/Y.

Next, consider an assembly and its direct components, which may include sub-assemblies. Each component has its own defect rate d_k and yield Y_k. That is, some units of each component may arrive defective. In addition, defects may be created during the assembly itself; e.g. [6]. Accordingly, the actual yield of an assembly is given by Eq. (1) and for this matter, the type of assembly - serial or parallel is irrelevant:

$$Y_A^a = Y_A \cdot \prod_{k=1}^{K} Y_k^{m_k} \qquad (1)$$

Consider, for example, a product which consists of three component types, K = 3: m_1 = 4, m_2 = 2, m_3 = 1, d_1 = d_2 = d_3 = 1%, and the defect rate of the assembly operation is 0.1%. The actual yield of this assembly is just about 93%, which implies that if no QA activity is taken, 1,074 units should be assembled to yield an average of 1,000 conforming units. This requires 4,296 units of the first component, 2,148 units of the second component and 1,074 of the third. However, with defect rates of 1%, only 42.96 units of component 1 are defective, on average. The other extra 253 units will be assembled with defective units of other component, or the assembly will fail. Similarly, only 21.48 of component 2 and 10.74 units of component 3 are defective, on average. These are the mutual effects among the components.

Moreover, products are seldom assembled in one step. More often, the assembly is performed in a hierarchical manner; e.g., [6], again – first, elementary components are assembled into sub-assemblies, then these subassemblies are joined together and other component are added and so on. This complicates the mutual effects and the calculations of actual yield. To assist, the product's hierarchy can be portrayed graphically by the, so called product structure, as in Figure 1. Notice the difference between Figure 1, which describes a product, and the study in [7] where manufacturing systems are considered. Consequently, each box in Figure 1 represents a component, while boxes represent a work stations in [7]. The component's number appears next to the # sign and its assembly coefficient appears next to the 'x' below. For convenience, component numbers follow the hierarchy – the first digit in the number is the hierarchy level. The process proceeds as directed – from bottom to top, where item #0 is the 'end' product.

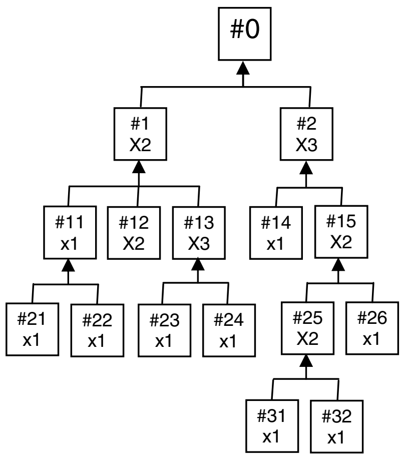

Fig. 1. A product structure.

To clarify, a unit of item #31 and a unit of item #32 are assembled to form a unit of item #25. Two units of this item are assembled with a unit of item #26 to form item #15, etc. This implies that there are 4 units of components #31 and of component #32 in each subassembly #2 and 12 units of each of these components (#31, #32) in a unit of the end product.

Product structures are heavily used for material requirement planning (MRP; e.g., [8]). A target quantity is set for each end product in the master production plan, from