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Optimization–simulation–optimization based approach for proactive variation reduction in assembly

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ABSTRACT

This paper addresses the economic benefits of selectively assigning a batch of subassemblies to each other after inspecting and correcting them as needed. Our work is based on optimizing the collective cost of subassembly inspection, rework, scrap, final assembly failure, and the act of subassembly mating. The expected value for the cost is estimated using Monte Carlo Simulation and optimized using a metaheuristic. After each simulation replication where we simulate a batch of subassemblies, we assign the inspected subassembly parts so that the rolled yield throughput is maximized. The complexity of this work is attributed to the fact that we solve an optimization problem for an objective that is estimated using simulation, and in each simulation replication there is another optimization problem to be solved for selective assembly. Significant improvements in assembly lines are predicted to be accomplished when this work is integrated in a real production environment.

1. Introduction and literature review

Often times, we hear the slogan of "doing things right the first time!" This slogan was taken into account during our work on this research. A successful manufacturing firm—in nowadays highly competitive manufacturing environments—is the one that implements agile production concepts, with cost minimization and variation reduction. We aim to achieve the cost reduction by minimizing the inspection and assembly costs. We also reduce the variation by integrating inspection planning with subassembly mating so that we can produce the least possible failed final assemblies. Finally, we seek to do-things-right-first-time by using simulated data when historical data are not available to develop the inspection plans.

1.1. Background

We will interchangeably refer to an *assembly* as a *product* in this article. Each assembly is made of *M subassembly groups* and each group is made of φ *parts*. Fig. 1 depicts a hitch ball assembly that is made of 3 subassembly groups ($M=3$) and 2 subassembly parts ($\varphi=2$). One part is needed from each subassembly group to assemble the final product (hitch ball), therefore the number of subassembly parts is equal to the number of final assemblies (τ) in this example. First, the ball is inserted into the shank with the appropriate positioning. Then, a locking pin is pressed into place to secure the ball.

Quality characteristic concept is used frequently in this article, which refers to a quantitative measure of a physical property. Examples are diameter of a hole, length of a rod, etc. We also use the terms: *assembly function* and *assembly system*. Assembly function is the mapping function between the subassembly quality characteristics (x's) and a final assembly quality characteristic (y's). Fig. 2 presents three examples for three assembly functions (linear and nonlinear). In the first example, the assembly function is linear since it is a result of adding two quality characteristics together as follows: $y=x_1+x_2$. Similarly, the second example is linear because the function is linear itself: $\delta=(D_0-D_i/2)$. In the third example, the assembly functions are clearly nonlinear. Assembly system is a collection of Q assembly functions: $y_1=f_1(x_1,\ x_2,\ldots,x_G)$, $y_2=f_2(x_1,\ x_2,\ldots,x_G),\ldots,\ y_3=f_3(x_1,\ x_2,\ldots,x_G)$. We also repeatedly use the term Rolled-yield throughput (in short; throughput) which refers to the probability for all products' quality characteristics to lie within the specified tolerance limits (lower and upper acceptable limits).

1.2. Literature review

In a previous publication [1,16], the authors proposed models to achieve optimal inspection plans by solving for the optimal

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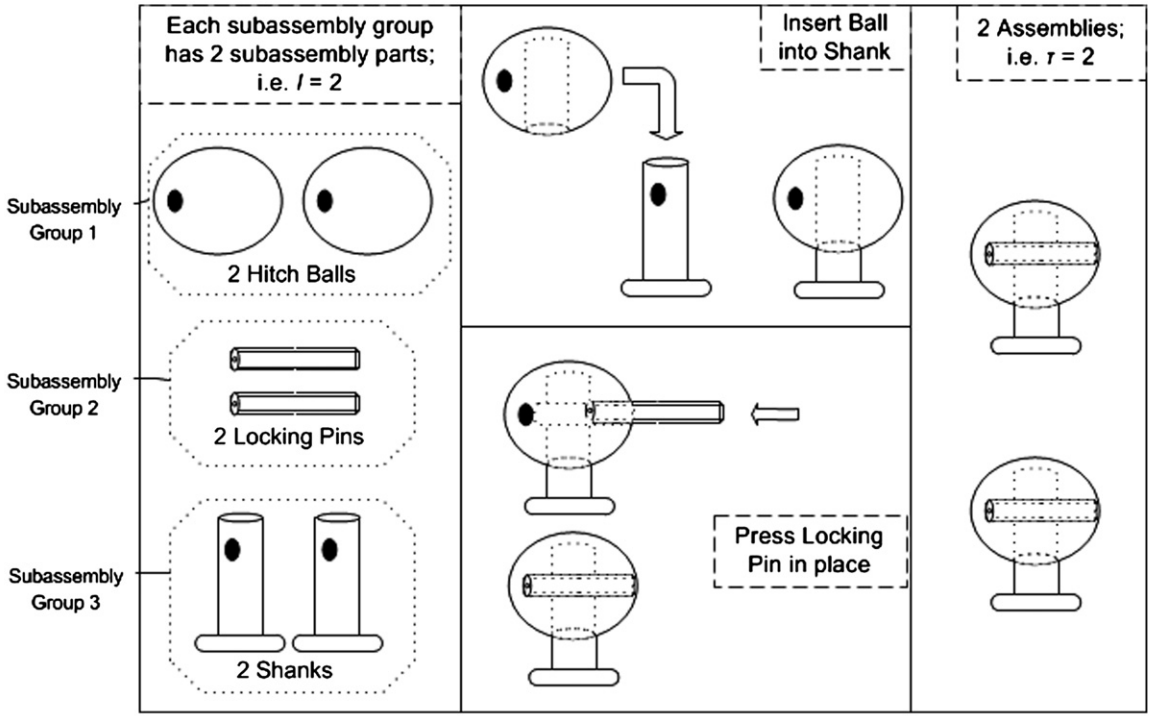

Fig. 1. Example of an assembly (product) of 3 subassembly groups ($M=3$) and 2 subassembly parts ($I=2$) to make 2 final assemblies ($\tau=2$).

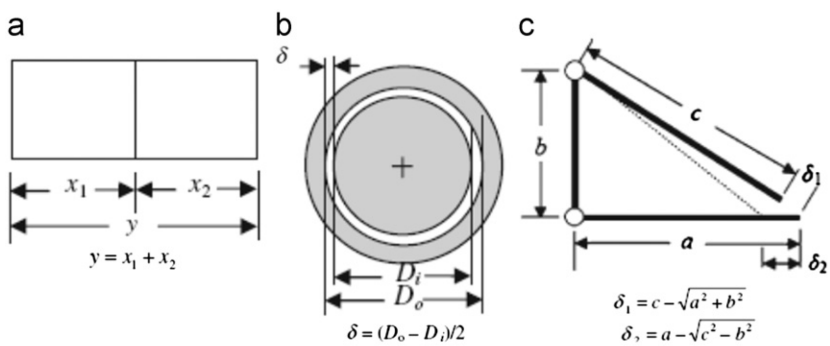

Fig. 2. Examples of assembly functions.

frequencies of inspection for subassemblies and corrective plan if the inspected subassembly item is found to be out-of-tolerance. This model was inspired by a work from Chen and Thornton [2]. We modified their approach by introducing the frequency of inspection as a decision variable, and a more general corrective plan than their model. After performing the inspection for a batch of subassemblies, we have the choice to either assemble items *arbitrarily* or *selectively*. In this work, we study the opportunity of further reducing the cost of the inspection plans by dynamically and selectively mating subassembly items to achieve the least possible failed final assemblies. This is a novel approach that was not introduced in the aforementioned research works. This is expected to reduce the failure cost and therefore the total cost. We do not consider here the sensor allocation problem that aims at reducing product variation by inspecting the process items that make the parts, such as fixtures, etc. Rather, we look into what subassembly items need to be inspected in order to minimize the total cost. Different studies [1,5–8,12,13] investigated the sensor allocation problem. On the other hand, Greenstein and Rabinowitz [9] solved the problem statistically in two stages. The objective was to fully inspect $K<n$ components in the first stage that "explain" the whole behavior of the n components. Their objective function was to minimize the cost of accepting a "bad" product, the cost of rejecting a "good" product and the cost of inspection. After that, they determine whether it is cheaper to inspect the rest of the batch or not. They assumed that the joint probability distribution function is known as a priori and that it is normally distributed. Moreover, they did not consider in the model any possible rework or scrap actions and the specification limits were input information rather than being decision variables. Chen and Chung [3] introduced a model to determine the inspection precision and the optimal number of *repeated* measurements in order to maximize the net expected profit per item. The model is specifically applicable for the lower specification-limit quality characteristic; i.e. the specification has unbounded upper limit. The profit is modeled as the difference between the selling price and the following costs: inspection, production, and dissatisfying the customer. There is an assumption that all measurements are normally distributed and all items are completely inspected at least once because of inspection inaccuracy. Their model is mostly appropriate for industries where there is a need for repeated measurements because of known measurement errors and where the production is at a late stage of producing an item in the supply chain. Most recently, Mandroli et al. [14]