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Allocation of the equipment path in a multi-stage manufacturing process

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ABSTRACT

The allocation of equipment in a multi-stage process is discussed in this article. In most of the multi-stage manufacturing processes, multiple equipment are operated to minimize the waiting times between stages. Thus, the allocation of the equipment path becomes an issue in choosing the equipment for the next stage. In solving the allocation problem of the multi-stage process, it is assumed that main effects and two-way interaction effects for the two adjacent stages are significant. The efficient allocation problem for the multi-stage process for a given historical data is solved by the general linear model approach, and then the predicted responses are ordered to choose the subsequently optimal equipment paths. The effectiveness of the proposed allocation strategy is evaluated in terms of the probabilities for detecting all true effects and detecting optimal equipment path for three cases of precisions: baseline, precise errors and noisy errors. It turns out that the noisy error case is less efficient than the others. When it is possible to use pilot experiments, the efficiency of the product design of orthogonal arrays for two-level and three-level fractional factorial designs is compared to that of the random selection of factorial design points. It is shown that the former is more efficient than the latter in a case study.

1. Introduction

There have been numerous statistical process control (SPC) methods for quality and productivity improvement. Examples of such activities are the control charting methods and gauge R & R, etc. Most of such methods are designed for single-stage processes. In modern manufacturing processes, such as semiconductor manufacturing, electric device assembly, and so on, it is quite common that multi-stage processes are used for the production of the item. A multi-stage process is referred as a manufacturing process where multiples of unit processes are serially connected and final products can be manufactured when materials pass all the unit processes. A famous example of the multi-stage process is the manufacturing process of IC chips that involves hundreds of operations being executed layer by layer onto a silicon wafer. The whole IC chip making process includes several group processes such as insulating, placing, patterning, and so on. The SPC methods for multi-stage processes have also been studied recently, but not as much as the single-stage processes. The SPC of the multi-stage process is complicated and difficult since it requires understanding of the effects of the current process to adjacent processes in consideration of the serially connected processes.

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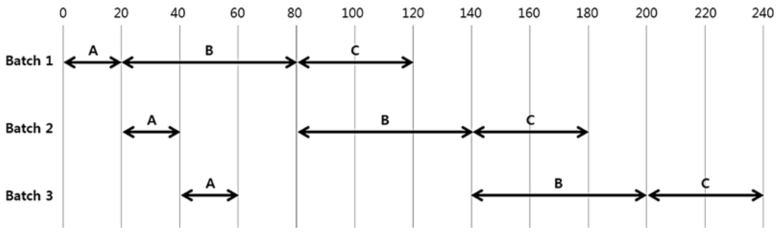

Fig. 1. The flow of three batches for case 1.

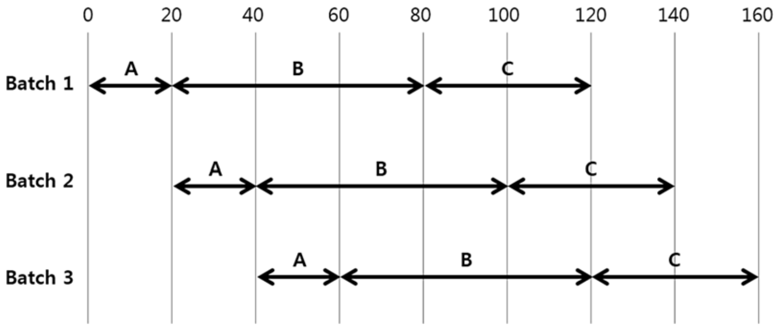

Fig. 2. The flow of three batches for case 2.

Besides the SPC, another problem occurring in the multi-stage process is the allocation of equipment at each stage of the whole process. Equipment in a stage is defined here as a tangible property that is used to accomplish the same operations of the manufacturing. Examples of equipment in a stage of a multi-stage process include devices, machines, and tools used for manufacturing in each stage.

In most of the multi-stage processes, there are multiple of equipment at most of the stages, and the raw materials are fed to each stage by the dispatching rule. The dispatching rule of the manufacturing process is to keep operating the process by minimizing the dead time, the waiting time between unit processes. Such dispatching rule makes the raw materials flow smoothly through the whole process, and thus maximize the productivity. Consider a multi-stage process with three batch processes (say, A, B, and C) whose lead times, times required to pass through the process, are 20, 60, and 40 min, respectively. Consider case 1 where there is only a single equipment at each process. The flow of three batches for case 1 is described in Fig. 1. In case 1, batch 1 passed through process A can be put into process B at 20 min, and put into process C at 1 h and 20 min without any waiting time. On the other hand, batch 2 will be out from process A at 40 min, but should wait 40 min to be put into process B. Moreover, batch 3 should wait 80 min to be put into process B. The total lead time of case 1 is 240 min. Consider case 2 where there are 1, 3, and 2 equipment for process A, B, and C, respectively. Then the flow of three batches for case 2 is described in Fig. 2. In case 2, it can be easily seen that there is no waiting time between processes and the total lead time is only 160 min.

As an example of the multi-stage process with multiple equipment, the layer process of the PCB manufacturing process can be considered. In the layer process, four processing units, such as PCB preprocessing process, D/F lamination process, D/F exposure, and DES process (circuit development, PCB etching, D/F stripping), are connected in serial. Equipment for the layer process are typically very expensive, for example, D/F exposure machine costs around couple of million dollars or more. Despite the high price, several equipment are provided to satisfy the dispatching rule. Fig. 3 shows the operation of multi-equipment in the layer process. In Fig. 3, there is a single equipment for preprocessing and lamination process, while there are three and two equipment for exposure process and DES process, respectively. All the final products, the manufactured PCBs, are inspected and accessed as pass (conforming) and fail (nonconforming) through several inspection procedures such as AOI (automatic optical inspection) and E-check, and then the yield of the manufacturing process is calculated.

If some equipment is occupied at a certain stage during the material flow, then one of the remaining equipment can be used for the operation of the stage. An unexpected problem occurred in such multiple equipment situations is that equipment between stages may have significantly related effects to the quality of the final product. That is, some specific allocations of equipment produce products with better quality than the other allocations of equipment. It has been reported by engineers that certain equipment combinations produce high yield, whereas some others low yield. Such harmonious and disharmonious equipment combinations can be revealed through the study of the equipment allocation. Although the optimal equipment combination is most preferable, the equipment corresponding to the current stage of the optimal equipment combination may not be available because it is still being operated for previously allocated materials. In such cases, the subsequent best equipment combinations will be considered. For such allocation of subsequent equipment combinations, all the possible equipment combination will be ordered according to the estimated yield. Then the materials