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Production process changes: A dynamic programming approach to manage effective capacity and experience

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Abstract

The introduction of process changes is often used by management to invest in production competencies. However, implementing process changes causes disturbances in production learning. This work describes a process change strategy to increase the effective capacity of a production system when unit costs are subject to a learning curve. It is found that the optimal process change level is decreasing in the effective capacity level and increasing in the accumulated knowledge level and production learning rate. Conditions are provided under which the optimal process change level is larger/smaller than the myopic process change level.

Keywords: Process changes; Learning; Knowledge management; Dynamic programming

1. Introduction

1.1. Problem environment

Manufacturing departments of electronics firms deal with complex and knowledge-intensive production processes. In these environments frequent introductions of changes to the process recipe can be observed. Examples of incremental process changes are equipment changes, implementation of software to support manufacturing, procedural changes, etc. Empirical research shows that such process change implementations are responsible for important jumps backward on the learning curve. Adler and Clark (1991) show that process changes caused by changes of the product have a disruptive effect on learning through sustained production activities. Marcie and Hauptman (1992) worked on the idea that the introduction of important process changes such as a new technology, is a source of uncertainty and as such disturbances. The two problematic attributes identified from the implementation and usage of new technology: the technical complexity and the shift in production approaches and organizing principles involved in using the new technology. Hatch and Mowery (1998) find that the disruptive

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effects of the introduction of process innovations on learning for the existing process in the semiconductor industry are significant. Lapre et al. (2000) report that process changes due to quality improvement projects without preparation of the work force, disturb the process of waste reduction in production. Terwiesch and Xu (2004) argue that if process specifications are changed and introduced in the production environment, line workers have to adjust to the new situation: behavioural patterns have to be adjusted and new operating procedures have to be developed to cope with the new environment. As indicated by these authors, the implementation of a process change makes some of the accumulated production knowledge such as operating procedures obsolete. New operating procedures have to be developed to handle the modified process recipe. The more significant a process change is, the larger the decrease of the accumulated production knowledge.

1.2. Decision problem

Although empirical evidence shows the negative effect of process changes on learning in production, managements often uses the introduction of process changes to invest in production competencies to boost profits from operating a production system, but face a dilemma: if investment in process change is too low, performance improvement opportunities due to scientific or technological progress will be forgone; on the contrary, a too large investment in process change is responsible for a serious disruption of the production department, which causes losses difficult to earn back.

1.3. Literature review

In the normative operations management literature, Carrillo and Gaimon (2000) present an optimal control model that uses the process change level and the level of training and preparation for process change as variables under control of management. The production environment is parameterised with the level of effective capacity of the production system and the level of knowledge present in the production environment. In the dynamics of the model, they consider a short-term loss and a long-term gain in effective capacity of a production system due to process change activities. Further, the level of knowledge present in the production environment increases with the level of process change. The level of knowledge increases the performance of the production system. The authors describe the optimal process change policy and the optimal preparation and training policy. The optimal amount of process change over the production horizon is larger if the amount of cumulative knowledge is larger. The optimal preparation and training policy is decreasing in time.

Terwiesch and Xu (2004) include explicitly the loss of knowledge due to process change in an optimal control model. They use production rate, process change rate and learning effort as decision variables to optimise the profit from cumulative process changes and the stock of knowledge. In the law of motion of the stock of knowledge, the level of process change has a negative impact. The optimal learning policy is monotone decreasing in the knowledge level and the optimal process change level is larger for larger amounts of cumulative knowledge.

Comparing the assumptions on the dynamics of both models leads to an interesting result: in the Carrillo model, the level of knowledge increases with the level of process change whereas in the Terwiesch model, the level of knowledge decreases with the level of process change. Carrillo explains the increase through a learning-by-doing effect: while implementing the new process recipe, operators and engineers learn how to do it.

Terwiesch explains his assumption differently: due to the change of the process recipe, a part of the accumulated production experience becomes obsolete which clarifies the empirically established jump backward on the learning curve. One way to interpret the difference between both models is that Carrillo does not consider knowledge generated through sustained production but focuses on knowledge generated through training, preparation for implementation of process changes. The phenomenon described in Terwiesch occurs for knowledge generated through sustained