# MANAGING ENGINEERING CHANGES ALONG WITH NEW PRODUCT DEVELOPMENT

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Abstract: This proposed research is to develop a process model for managing Engineering Changes (ECs) while other New Product Development (NPD) activities are being carried out in a company. The discrete-event simulation model incorporates Engineering Change Management (ECM) into an NPD environment by allowing ECs to compete for limited resources with regular NPD activities. The goal is to examine how the *size* and *frequency* of NPD as well as ECM, *NPD process structure* (in terms of overlapping and department interaction), and the *policies* one organization employs (such as resource using priority and project cancellation policy) affect lead time and productivity of both NPD and ECM. Decision-making suggestions for minimum EC impact are drawn from an overall enterprise system level perspective based on the simulation results.

## 1 PROBLEM DEFINITION

New product development is defined as the complete process from idea generation, product design, to detail manufacturing until bringing a product to market. It is the whole process beginning with the perception of a market opportunity and ending in production. There are several important characteristics of NPD. First, a product design and development company usually launches certain number of new products according to a relatively strict schedule. Second, although scarce engineering capacity has always been a huge problem faced by most organizations, the resources provided for NPD projects are relatively placed and fixed firmly. That is to say, there are always certain amounts of resources to be dedicated to each NPD project. Third, though the NPD process tends to become more and more complex attributable to the increasing volume of information involved, it has some repeatable structure due to fact that design is something of an art but with many consistent patterns (Browning, 2007).

Engineering change management, on the other hand, is defined as a collection of procedures, tools, and guidelines for handling modifications and changes to a product that has been released to the market (Terwiesch and Loch, 1999; Bhuiyan 2006). Unlike the iterations within NPD process, engineering change is the rework after production. It occurs in far more random pattern compared with regular NPD projects. The amount of time and effort required for each ECM also varies from case to case. As an industry norm, ECM usually doesn’t have its own specified resources. It shares the same pool of engineering capacity with NPD projects. That is to say, NPD and ECM activities normally compete for limited resources available.

ECM is a major competitive component in product design and development process that should not be neglected. It plays a critical role in finally realizing actual profits from new product development efforts. Companies benefit from ECM by correcting design faults; solving safety or functionality problems; providing better customers’ satisfaction; reflecting technology improvements. However, on the other hand, ECM consumes considerable amount of resource, which in turns affects the lead time and productivity of regular NPD projects significantly. It also accounts for high EC costs with regards to manufacturing tool costs, engineering rework, inventory obsolescence, and possible downstream EC propagation. (Loch, 1999; Balakrishnan, 1996).



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## 2 RESEARCH QUESTIONS

The objective of this research is to fully model the ECM process within a multi-project environment to provide insightful decision-making suggestions for companies regarding how engineering changes should be implemented with minimal adverse effects on normal NPD activities. To be more specific, this research intends to answer the following questions.

1) How important is ECM for a firm that is engaged in developing new products?

2) What are the key contributors to long lead times in NPD in relation with ECM? And vice versa.

3) How will the occurrence of an ECM influence regular NPD activities? Within which activity during which phase in the NPD process will the impact be the most tremendous?

4) What are the key contributors to low production rates in ECM in relation with NPD? And vice versa.

5) What is an optimal way of allocating limited resources between NPD and ECM?

6) Is there a generic guideline for incomplete NPD/ ECM cancellation when engineering capacity is overloaded?

## 3 METHODOLOGY

This research focuses on the "flow of information" standpoint of an NPD process (Krishinan, Eqqinger, and Whitney 1997). From this information processing point of view, an NPD project can be treated as evolving product information that travels through time (total development cycle time) and space (all the departments involved), seizing and releasing engineering capacity. However, we are not interested in the way how the input information of an NPD activity from its previous one evolves gradually into the eventual output information, but the separated points in time when entities arriving and leaving an NPD activity and change of the state of system. By doing this, we can check the duration of each NPD/ECM activity and resource utilization. Also, the repeatable nature of an NPD process structure provides validation for decomposing an NPD process into successive design and development phases, each enclosing several sequentially repeated activities. Nevertheless, NPD is also an iterative process rather than a purely linear one with unforeseen uncertainty and ambiguity (Terwiesch and Loch 1999). This feature can be represented by both NPD iteration and variation of activity duration.

Among various kinds of mathematical and computer models, a stochastic discrete-event simulation are adopted as the modeling approach for the following reasons: 1) it is more suitable to represent such a complex and dynamic system; 2) allows for more detailed analysis; 3) matches the nature of problem well as discussed above; 4) several sophisticated software packages available.

## 4 STATE OF THE ART

While NPD is an area that attracts lots of investigations by huge amounts of researchers over the past decades, ECM, particularly, how ECM affects general NPD activities and vice versa, is overlooked in the past.

The review of papers until 1995 was done by Wright. (Wright, 1997) The author categorized the EC related papers into two main topics, computer-based "tools" for the analysis of EC problems and "methods" to reduce the impact of ECs on manufacturing and inventory control. We can find that most of the publications in that time period predominantly focused on the EC control mechanisms and systems. An important observation by Wright is that understanding of the positive effect EC can provide for product improvement and enhanced market performance is long omitted by EC research.

Terwiesch and Loch presented a process-based view of ECM. (Terwiesch and Loch, 1999) They showed by an industrial case study that a complicated and congested administrative support process is one of the root causes of long lead time and high cost. Based on the field study, they identified five key contributors to lengthy ECO lead time: complex ECO approval process, scarce capacity and congestions, setups and batching, snowballing changes, and organizational issues.

In another paper they wrote, an analytical framework that explains the extreme ratio between theoretical processing time and actual lead time was developed. (Loch and Terwiesch, 1999) They showed how congestion and batching influence engineering processes at a more detailed level.

Based on the processing network framework, they suggested improvement strategies such as flexible work times, the grouping of several tasks, workload batching, the pooling of resources, and the reduction of setup times.

Krishnan presented a model-based framework to manage the overlapping of coupled product development activities. (Krishnan, 1997) The author studied the overlapping problem based on two properties, upstream information evolution and downstream iteration sensitivity, of the information exchanged between product design phases. The mathematical model and conceptual framework of the overlapped process were illustrated with industrial examples to provide managerial insights.

The most related work to this research is done by Bhuiyan and her co-workers. They built a stochastic computer model to examine how overlapping and functional interaction affect the performance measures of development time and effort under varying conditions of uncertainty. (Bhuiyan, 2004) It is the first comprehensive model using a discrete event simulation for the entire NPD process by taking into account functional interaction at different values of overlapping under different uncertainty conditions. Development effort was also introduced, in the form of total person-days for a project, as a measure of NPD performance that was neglected by earlier researchers. A number of conclusions were drawn from the model, however, their model assumed an unlimited amount of resources, which is unrealistic in practice.

Bhuiyan's research group has also expanded this framework to compare two methods for managing Engineering Change Requests (ECRs): immediate individual processing as issued and batch processing after accumulation. (Bhuiyan, 2006) They evaluated the effects of the methods in terms of development time and effort. The model they developed, though, has a couple of limitations: (i) the research scope only on immediate or batch processing is too simplified compared with a large amount of ECM problems; (ii) treating all ECRs similarly is acceptable only for comparative analysis. Despite of these limitations, Bhuiyan's model is the only study on ECM using the discrete-event simulation. Thus it inspired our model.

Another important work is the comprehensive heuristic for a stochastic, resource-constrained project scheduling problem in an iterative project network. (Cho and Eppinger 2005) Their model uses a parallel discrete event simulation methodology to compute the distribution of lead time of engineering design processes for project scheduling analysis. Many important characteristics of complex design process, such as overlapping, iteration of tasks, rework concurrency, task priority, are incorporated in this model. Design Structure Matrix (DSM) is employed to capture the information flows between tasks.

Browning presented a thorough literature survey on the topic of activity network-based models for NPD project management. (Browning, 2007) The paper is based upon four major categories: visualization, planning, execution and control, and project development. And he highlighted five research directions for future study: activity interactions, global process improvements, process models as an organizing structure for knowledge management, modeling in cases of uncertainty and ambiguity, and determining the optimum amount of process prescription and structure for an innovative project.

Insufficient resource allocation always remains as one of the important questions faced by NPD organizations. At the same time, discovery of major problems is so often identified in final stages of the development cycle, which will require significant additional resources from other projects, especially those ones still in early phases, thus further detriment the problem of dysfunctional resource allocation. Black and Repenning propose a simulation framework to analyze different policies organizations may adopt for earlier problem resolution, better quality and performance in a multi-projects environment. This paper concludes with the following two main insights: 1) the importance of realistic schedules and appropriate amounts of resources at the early phases of NPD projects; 2) a strict and inflexible version of cancellation policy offers the highest potential to produce effective improvement in NPD projects.

# 5 STATE OF THE RESEARCH

In this part, the first model version is introduced by the illustration of both model screenshots and word explanation. Arena simulation package is used for the project.

## 5.1 Model Configuration

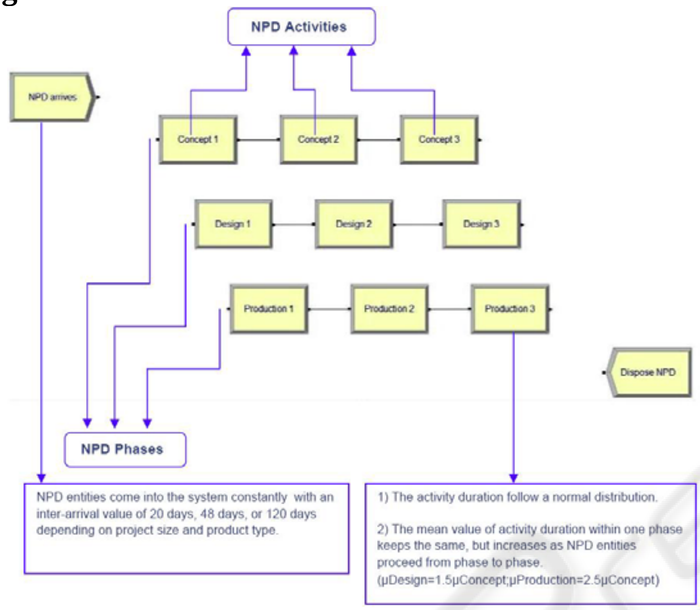


Figure 1: 3 phase and 3 activity framework for NP.

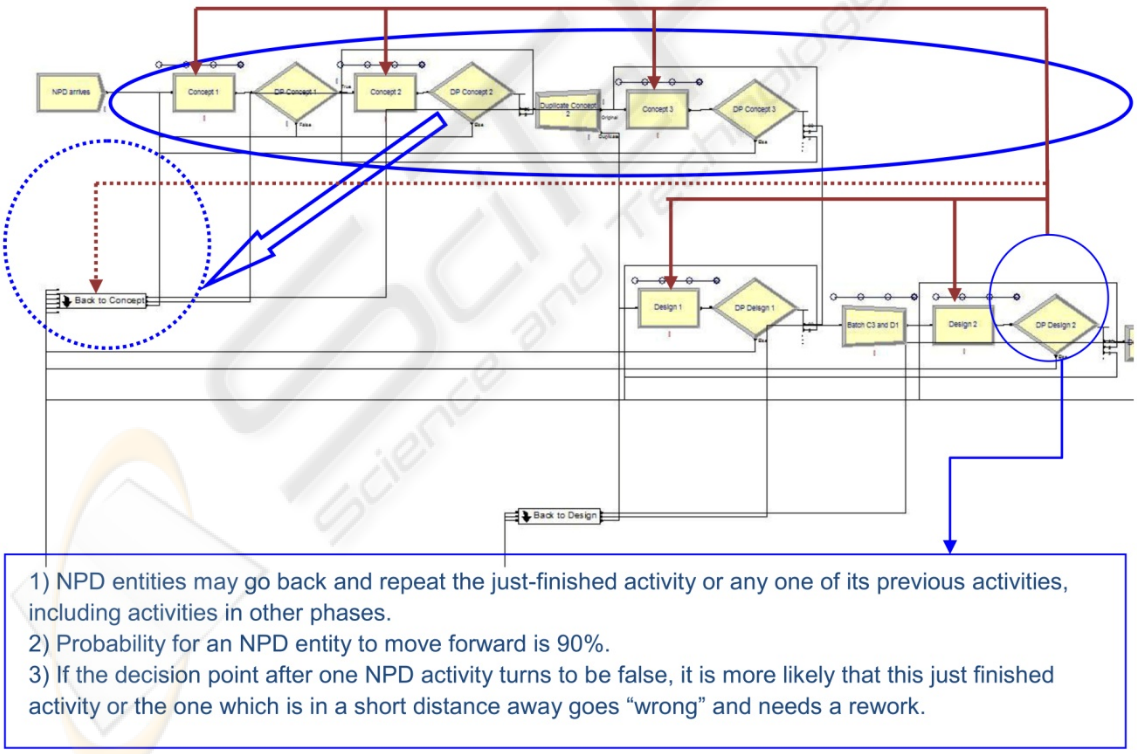


Figure 2 : Model overview of the NPD part.

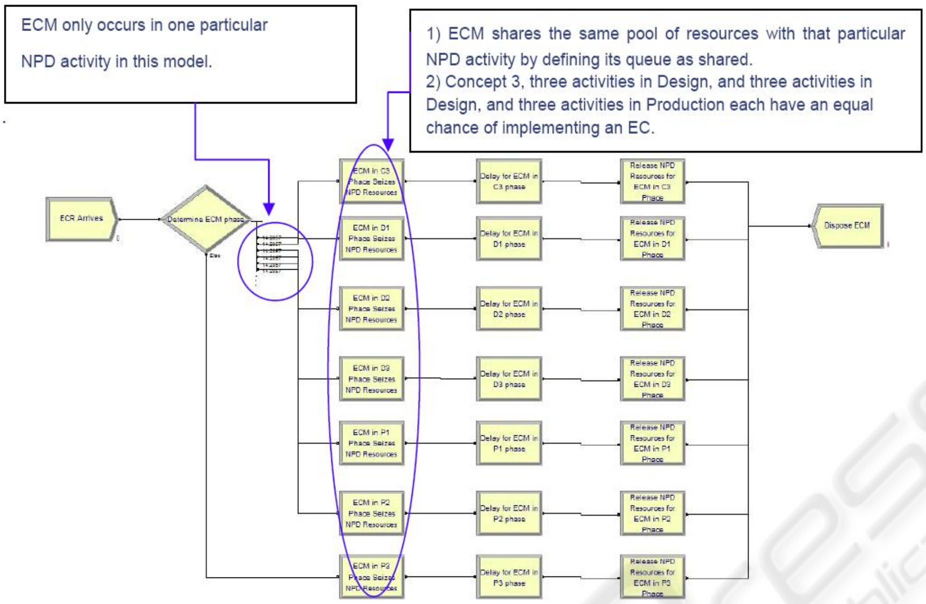


Figure 3: Model overview of the ECM part.

## 5.2 Preliminary Results

For the model described above, we analyzed the influence of resource constraint, resource using priority, overlapping, NPD departmental interaction, ECM effort, on both NPD and ECM lead time and productivity under different NPD and ECM arrival rates. Three levels of NPD and ECM arrival rates are combined in pairs according to their value. That is, high NPD arrival rate is studied with high ECM arrival rate, and low NPD arrival rate with low ECM arrival rate.

Partial results are presented in this poster due to space limitation. The following two charts show the impacts of overlapping, NPD departmental interaction, and ECM effort on NPD Total Time and Productivity under resource constraint of 60 units from each department.

The NPD and ECM model framework introduced above address several issues that earlier models didn't. In this model, we capture important new product design and development characteristics such as iteration and overlapping of NPD process, interaction among different functional areas, resource constraints and its using priority. We also take into account the size of NPD projects and ECRs in terms of their arrival rates and processing effort. From the simulation results, a number of conclusions can be drawn:

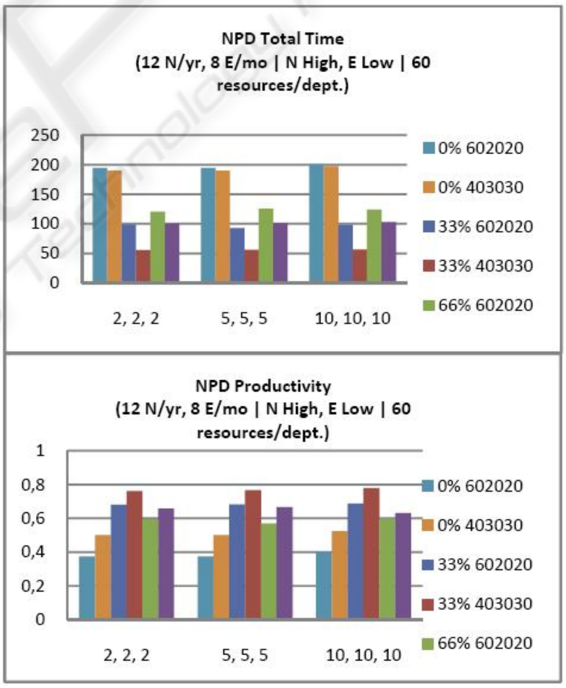


Figure 4: Simulation Results.

1) ECM is an important aspect to the success of an NPD project. On one hand, it solves safety or critical functionality problems of a product. And it reflects customer requirements or technology developments. On the other hand, it also consumes a considerable amount of product development resources which in turns affects the lead time and productivity of regular NPD activities significantly.

2) While each of the six model variables, overlapping, NPD departmental interaction, ECM effort, resource constraints, arrival rate, and resource using priority, affects the overall lead time and productivity of both NPD and ECM by some extent, the effect of resource constraints is most significant.
3) This model addresses decision-making suggestions for firms under different organization environment and resource constraint condition.

Specifically, when the resource capacity is limited, a medium level of overlapping and high departmental interaction is suggested to optimize system resource utilization.

# 6 FUTURE WORK

## 6.1 Model Extention

There are several aspects of this model that need further investigation.

1) The assumption that one EC is confined in one NPD activity is not always true. An EC that requires rework in a design activity may propagate to other activities in design or production phase. Future study should include engineering change propagation as one feature of the ECM process.

2) In the current model, probabilities for feedback iterations are assigned to an NPD project. However, when a new product project needs to go back to earlier NPD activities for a rework, subsequent activities need to be followed again no matter how many times these activities are repeated. In other words, an NPD entity has to go through again all the downstream activities after being sent back to the iteration starting point. Feed-forward flexibility and learning effects for iteration need to be considered in future work.
3) In this model, it is assumed that NPD and ECM share the same pool of resources with using priority. I could let NPD and ECM have their own dedicated resources. Or, NPD and ECM still use the same pool of resources. But ECM requests for outsourcing when resources are not available. In this case, different utility costs can be set for using resources within a department, cross departments, and for outsourcing.

4) Besides lead time and productivity, other critical criteria such as resource utilization, total cost, and customer satisfaction, can be adopted to review and evaluate the impact of ECM throughout NPD process.

5) As we can see from the preliminary running results of the first model version, production of NPD and ECM keeps to be less than 1 and is far less when the resource level is low (with a number of 60 per department). Black found out from her policy analysis model that the policy cancellation of the work that falls behind schedule well in advance of its launch date can ensure consistently high performance and recovering productive capability. (Black and Repenning 2001) Effective cancellation of incomplete NPD/ECM is also one direction of this research.

## 6.2 Model Validation and Verification

1) Use output analysis as the first step of model validation, and check to see if the simulation output is reasonable.
2) Comparison of this model and related studies provides another way of validation.

3) Apply the *correlated inspection approach*. That is, compare real-world observation and simulation output with historical system input data. For example, given input parameter from industry (actual observed inter-arrival time of NPD projects and EC Requests; actual observed activity duration in different NPD phases; etc.), we can determine the accuracy of the model by comparing the model output data and the inspection from company).

## 6.3 Model Validation and Verification

1) Use animation to enhance the credibility of this model.

2) Run the model under simplifying assumptions for which its true characteristics are known, and then gradually add details into the simulation project.

3) Run the model under a variety of settings of the input parameters, especially in those extreme conditions, and check to see if the output is reasonable.

## 6.4 Experimental Design

From the preliminary running of the first model version, we have already got some ideas about which model variables, such as inter-arrival rates of NPD and ECM, NPD departmental interaction, ECM effort, are likely to be important. However, carefully designed experiments should be carried out for efficient experimentation in determining which factors are most important and joint effect of the factors on a response as well. Table 1 shows possible model factors and responses.

### 6.5 Data Collection from Industry

Some of the parameter setting and input data for the first model version are hypotheses based on relevant results from similar studies or the modeler's experience. These may be obsolete due to time concerns but still realistic when this simulation study is initiated. We can replace them by real inspection from industry in later stages of this research.

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