A DEA Benchmarking Methodology for New Product Development Process Optimization

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Abstract. Developing new products on time within budget constraints is a crucial issue to survive in today's competitive marketplace. However, unpredictable incidents occur during new product development (NPD) processes, which often cause expenses, resources and schedule overruns. Traditional project management tools lack of efficient and effective methods to solve these problems and challenges. Hence, this study applies the data envelopment analysis (DEA) concept to develop a novel project planning and management decision support methodology for NPD that can optimally allocate resources and dynamically response to unexpected delays and budget overruns. The research adopts the methodology to a mobile phone NPD project case to demonstrate the method's real-world application and illustrate the effectiveness of the proposed methodology in-depth.

Keywords. New product development, DEA, resources and schedule overruns

1 Introduction

Introducing new products on time within resource and budget constraints is a key to success in today's competitive market place. Thus, distributed and collaborative product development paradigms are emerged considering time-to-market and cost efficiency for the complexity of modern product design. However, unpredictable incidents usually occur during new product development (NPD) processes, which cause expenses, resources and schedule overruns. Conventional project planning methods, estimating time, budgets and resources of NPD activities,

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are often based on project managers' expertise and subjective judgment. The NPD project managers lack objective benchmarking models to gain valuable insights into the relations between various resource allocations and activity times in order to support NPD engineers in the best collaborative practices, especially for the planning and execution phase. During the planning phase of NPD, the proposed schedule may not satisfy the due day. Thus, the project managers need to alter the plan accordingly. In addition, during the execution phase, the initially proposed schedule may become infeasible due to the unexpected delay of NPD activities. Therefore, modification of the project plan, while the project is being executed, is needed. However, traditional project management tools cannot provide mechanisms to dynamically modify NPD projects to avoid schedule and cost overruns. This research is to develop a novel project planning and management decision support methodology and tool for NPD process. In order to demonstrate the method's real-world application, a mobile-phone development project scenario is used as a case study to illustrate the effectiveness of the proposed methodology.

2 Literature Review

Many published papers on NPD management have put forward a wide variety of models related NPD planning and performance evaluation. By using a simulation model, Yang and Sum [8] investigate the performance of due date, resource allocation and activity scheduling rules in a multi project environment. The results show when due day nervousness is not mitigated, first in system first served (FISFS) resource allocation rule performs better than the due day sensitive resource allocation rules. Sicotte and Langley [5] examine the efficacy of five types of integration mechanisms for project performance in a sample of 121 R&D projects. This study shows the managers adjusted their use of horizontal structures, planning and process specification, and informal leadership to project uncertainty. In order to identify the key determinants that affect the project performance, artificial neural network (ANN) technique is used to check whether these performance metrics can reasonably predict design-build project performance [4]. Vandevoorde and Vanhoucke [7] compare three different methods to forecast the duration of a project. By using real-life project data, they find the planned value rate [1] and the earned duration [3] are unreliable. Instead, the earned schedule method [2] seems to provide reliable results through the project lifecycle.

3 The Methodology for NPD Process Optimization

Figure 1 shows the architecture of the proposed benchmarking methodology for NPD process optimization. There are includes six modules into the framework, i.e., (1) the process modification, (2) the estimation of project completion time, (3) the resource allocation given most-likely time spent, (4) the time estimation given resource allocation, (5) the time estimation with added resource allocation and (6) relative economical efficiency for the NPD processes within a product portfolio.

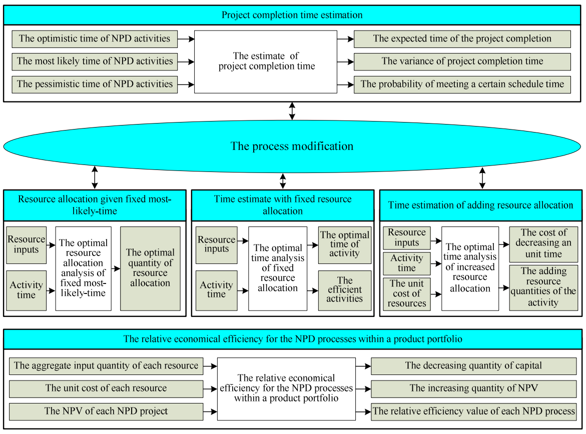

Figure 1. The architecture of the benchmarking methodology for NPD process optimization

In the planning phase, the feed-forward modification mechanism (FFMM), first, applies the module of project completion time estimation to calculate the probability of project time set by customer. If the estimation satisfies the customer's requirement, the FFMM, then, employs the resource allocation given most-likely time to benchmark and adjust all resource allocations of activities. On the other hand, if the time estimation cannot satisfy the customer's requirement, the FFMM utilizes the modules of the time estimation given resource allocation and added resource allocation to reduce the expected NPD process time. Figure 2 displays the feed-forward modification mechanism (FFMM).

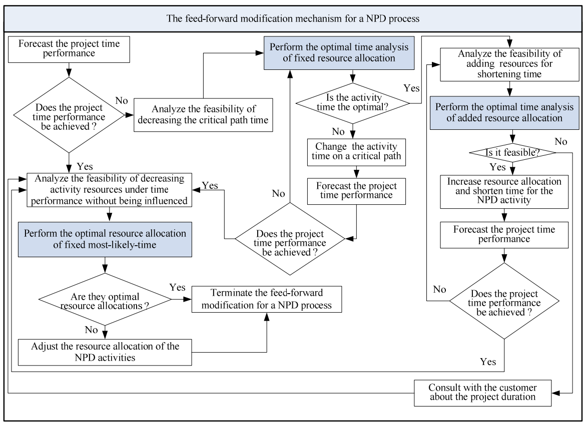

Figure 2. The process architecture of the FFMM.

During the execution phase, if a certain NPD activity delays, the feed-back modification mechanism (FBMM) is activated to assess whether the subsequent

NPD activities need to be modified by applying the time estimation with added resource allocation. Figure 3 shows the process architecture of the FBMM.

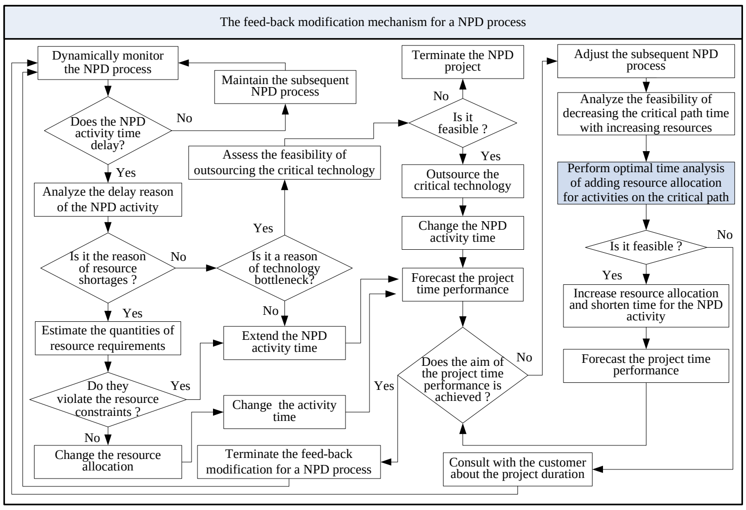

Figure 3. The process architecture of the FBMM.

3.1 Estimation of project completion time

In this functional module, the PERT/CPM approach is adopted to calculate the expected value and variance of the NPD completion time and the probability of meeting the specified project deadline. First of all, a project manager defines a "project network" diagram based on the logical sequence of NPD activities. Then, the NPD manager and participants jointly define the three time estimates of the optimistic time, the most likely time and the pessimistic time of each activity respectively under different executive conditions. The expected value and variance of a NPD activity time can be obtained. This research shortens the expected activity time by adjusting the most likely time. The expected time of a path are given by summing up the expected activity durations along the path. And, a path with the largest expected path time is called the critical path. Furthermore, the variance of a project completion time is the sum of variances of the activity times on the critical path.

3.2 Resource allocation given the most likely completion time

This model investigates the feasibility of reducing the NPD resource allocation given the most likely time. Resource allocation given the most likely time is represented as follows.

$$Min\ \theta_f - \varepsilon\left(\sum_{\forall e \in E} fs_e + \sum_{\forall m \in M} hs_m\right) \quad (1)$$

s.t. $\sum_{j=1}^{n} \lambda_j\ ht_j = t_f$, (j=1, 2, …, f, …, n), $\sum_{j=1}^{n} \lambda_j\ if_{ej} + fs_e = \theta_t\ if_{ef} \quad \forall e \in E$,

$\sum_{j=1}^{n} \lambda_j\ ih_{mj} + hs_m = \theta_f\ ih_{mf} \quad \forall m \in M$, $\sum_{j=1}^{n} \lambda_j = 1$, $\lambda_j \geq 0$, where

θ_f is the output-technical efficiency of the NPD activity f,

t_j is the time of the past similar NPD activity j,

t_f is the most-likely-time of the present activity f,

if_{ej} is the input time of the facility e for the activity j,

ih_{mj} is the input time of the human resource m for the activity j,

fs_e and hs_m are slack variables.

If $1/\theta_f < 1$, then it represents the facility and human inputs of the activity f can be reduced without being influencing the most-likely-time. Equation (2) and Equation (3) show the decreasing input quantities of facilities and human resources.

$$\Delta if_{ef} = if_{ef} - \left(\theta_f^*\ if_{ef} - fs_f^*\right) \quad (2) \qquad \Delta ih_{mf} = ih_{mf} - \left(\theta_f^*\ ih_{mf} - hs_m^*\right) \quad (3)$$

3.3 Time estimation with fixed resource allocation

This model analyzes the feasibility of shortening a NPD project time without adding resources as shown in Model (4).

$$Min\ \phi_f \quad (4)$$

s.t. $\sum_{j=1}^{n} \lambda_j\ t_j \leq \phi_f\ t_f$, (j=1, 2, …, f, …, n),

$\sum_{j=1}^{N} \lambda_j\ if_{ej} \leq if_{ef} \quad \forall e \in E$, $\sum_{j=1}^{N} \lambda_j\ ih_{mj} \leq ih_{mf} \quad \forall m \in M$, $\sum_{j=1}^{N} \lambda_j = 1$

If $1/\ \phi_f < 1$, it shows the time of the activity f can be diminished without adding the resource inputs of the activity f. The decreasing time of the activity f, $\Delta \mathrm{T}_f$, can be obtained by using Equation (5).

$$\Delta t_f = t_f \text{ - } \mathrm{t}_f \times \phi_f^* \quad (5)$$

3.4 Time estimation with added resource allocation

This model further analyzes the feasibility of shortening NPD time through adding activity resources. First, we calculate the decreasing activity time and the increasing resource quantities of the activity j, and then the project manager confirms whether the increasing resource quantities violate the resource constraints. If these resource requirements do not exceed the resource limits, we can obtain the CTP value using Equation (6).

$$ctp_f = \frac{\sum_{e\in E} \Delta if_{ef} \times cr_e + \sum_{m\in M} \Delta ih_{mf} \times ch_m}{\Delta t_f}, \text{ where} \qquad (6)$$

fc_e is the input cost of the facility e per unit time,

hc_m is the input time of the human resource m per unit time.

3.5 The relative economical efficiency for the NPD processes within a product portfolio

The completion-and-review phase analyzes the relative economical efficiency on the market for the NPD processes with a product portfolio by employing the VRS-DEA approach as shown in (7) . If $1/\gamma_k < 1$, then it represents the kth NPD project should increase the NPV amount $\Delta npv_k = \gamma_k \ npv_k - npv_k$.

$$\text{Max } \gamma_k \qquad (7)$$

$$\text{s.t. } \sum_{p=1}^{n} \lambda_p \ npv_p - npvs \geq \gamma_k \ npv_k \ , \ p = 1,\cdots,k,\cdots,n$$

$$\sum_{p=1}^{k} \lambda_p \left[\left(tif_{ep} \ fc_e\right) + \left(tih_{mp} \ hc_m\right)\right] \leq \left[\left(tif_{ek} \ fc_e\right) + \left(tih_{mk} \ hc_m\right)\right], \ \sum_{p=1}^{n} \lambda_p = 1, \ \lambda_p \geq 0, \text{ where}$$

tif_{ep} is the total input time of the facility e of the project p,

tih_{mp} is the total input time of the human resource m of the project p,

npv_p is the net present revenue of the NPD project p.

4 Case Study

Figure 4 shows the network diagram of a new product development (NPD) process for a music mobile phone (MMP) project. In order to evaluate the completion time performance of a MMP project, the project manager and NPD engineers provide the optimistic, pessimistic and most likely time estimations for each activity within the MMP NPD process. By using the PERT/CPM approach, we can obtain the expected value and variance of each MMP development activity time.In this case, we can understand that the network diagram for the MMP development project has four paths. The longest expected time path A-D-E-F-G-M-O is the critical path. Thus, the expected MMP project time is approximately the sum of the expected activity time on the critical path, i.e., 197 days. Furthermore, the variance of the MMP project time is 56.

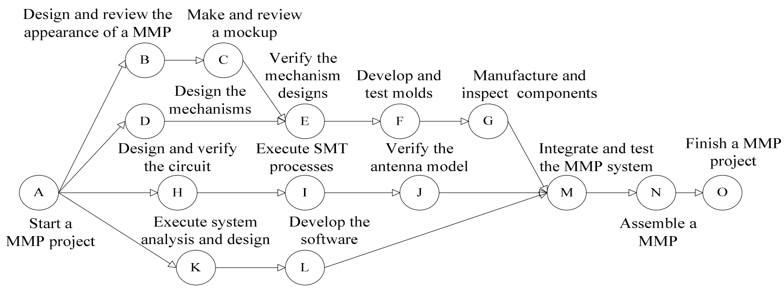

Figure 4. The network diagram of the MMP development process.

In this case, the customer requires that the probability of meeting the MMP project deadline (within 200 days) is 98%. The expected deadline is unlikely to be met because the estimated probability of meeting that deadline is only 64%.

Firstly, the FFMM analyzes the feasibility of diminishing the activity times on the critical path without adding resources by employing the time estimation with fixed resource allocation. Except the activity of mechanism verification, the output oriented technology efficiency of other activities is less than one. Therefore, the FFMM employs Model (4) to optimally shorten the most-likely-times of these activities without adding resources. The expected project time and the probability of meeting the deadline are adjusted to 191 days and 97% respectively. It cannot achieve the time-performance goal of the MMP project. Further, the FFMM analyzes the feasibility of increasing resources for shortening the time of critical path. Through using the time estimation of added resource allocation, the FFMM calculates the CTP values of critical path activities for optimally reducing the critical path time. The CTP value of the mechanism verification is the largest. Hence, the FFMM increases the activity resources of the mechanism verification. The expected project time and the probability of meeting the due day change to 185 days and 98% respectively. Because the mechanism-verification activity has no other benchmarking activities, the FFMM selects the best CTP, i.e., development and test of the molds. The probability of meeting the project's completion day changes to 99%, which satisfies the customer's requirement.

Then, the FFMM analyzes the feasibility of decreasing the resource allocations of non-critical path activities under time performance without being influenced. From the analytical results, we can see the efficiencies of the design and verification of the circuit, the verification of the antenna module, and the system analysis and design are less than one. By employing resource allocation given most likely time, the FFMM adjusts resource allocations of these activities. Finally, the FFMM achieves the MMP development process optimization in the planning phase.

In execution phase, the FBMM detects the delays of development and test of the molds of the MMP project. By understanding the reason of the delay, the project manager decides to maintain the resource allocation and modify the three time estimates for this activity. The probability of meeting the deadline is changed into 96%. Hence, the FBMM is activated to adjust the following activities of the MMP project. By increasing the working time 208 hours of testing engineers, the most likely time of the integration and test of the system and the probability of meeting the project schedule change into 32 days and 98% respectively, which achieve the customer's requirement level.

The third phase evaluates the performance of NPD processes with a product portfolio of 3 NPD projects, i.e., MMP, smart mobile-phone (SMP), and multimedia mobile-phone (MMP2) projects [6]. By employing Model (7), we obtain the performance assessment values of these projects. Because the efficiencies of SMP and MMP2 projects are less than one, this research further analyzes and provides the improvement directions for both projects. The output-oriented efficiency analyses suggest the NPD strategies and improve the expected profits of SMP and MMP2 projects to US$2,457,000 and $2,457,770 (increasing US$910,000 and US$660,000) respectively.

5 Conclusion

Currently, most performance evaluation methods, which focus mostly on the planning and completion phases of a project, cannot utilize the assessment results to further support the feasibility of NPD process improvement by providing consistent and quantitative comments and suggestions. From the entire process lifecycle point of view, this research develops a novel DEA benchmarking methodology, which consists of modification mechanisms to optimize NPD processes and avoid unexpected delays and budget overruns (during the planning, execution and completion phases). By applying the DEA methodology to a real product development project, this research shows that the methodology can be adopted to generalized NPD applications with significant advantages.

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