Time And Resource Characteristics Of Radical New Product Development (NPD) Projects And their Dynamic Control

Track: Product and Process Design

In many industries the innovation rate increased while the control of the timing of new product introductions become crucial for the success of the new product in the market place.
Using recent studies from the high-tech industry, we formulate a scientific model of the control process needed for managing the NPD projects under tight time constraints. Considering given the delivery time of the project, and the resources, the project and its control are organised to solve the uncertainty in the functional characteristics of the new product through repeated internal adjustments and interactions with customers.

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Introduction. Problem Description.

During the last decades in many industries the innovation rate has increased while at the same time the control of the timing of new product introductions has become crucial for the success of the new product in the market place. Concurrent engineering has been developed as a way to organize the activities in the new product development process such that the project duration is reduced while using information technology for keeping the risks of miscommunication and rework under control.

These developments have dramatically changed the nature of the new product development processes. Firms operating under a strict time to market regime seem to take the delivery time of the project as a given, and organize the project and its control such that, given the resources available the functional characteristics of the new product are in maximal agreement with the functional specification initially given. The project must be organized in such a way that frequent evaluation of the progress leads to optimal adjustment of functional specifications, given the resources remaining and the time remaining until the delivery date. Recent research in the operational characteristics of time constrained radical new product development projects has produced much new knowledge and insights regarding the nature of radical NPD processes and their control. However up to now this new knowledge has not been combined yet in order to get in one consistent mathematical formulation of the radical NPD process, and the various hierarchically ordered decision functions that are needed to control it. We have combined all scientific knowledge available to us to find the simplest possible formulation of the process and its control that still accounts for all characteristics of the process. Moreover, the process control system is formulated in terms of well-known mathematical process models.

Recent investigations (Eisenhardt and Tabrizi, 1995) emphasize that the time-constrained radical new product development consists of uncertain, ill-defined, and unstable design tasks. At the start of the project it is uncertain which design tasks are really necessary for realizing the functional specifications and it is even uncertain which (or the extent to which) functional specifications can be realized at a certain deadline. In these kinds of development processes, the design tasks are often reorganized during execution and the functional specifications of the product are gradually reconsidered, fact sustained by numerous researchers as (McDermott, 1999), (Turner and Cochrane, 1993), (Bourgeois and

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Eisenhard, 1988). This necessitates a flexible product-development process where designers can continue to change and to shape products even after their implementation has been initiated.

Although, various researchers have made an attempt to incorporate uncertainty in their project planning and control techniques most of the papers address the issue of uncertainty in the duration or flow of the design tasks, assuming no explicit trade-offs in the product definition process in terms of design tasks to be performed, or even an early complete product definition. Also, each design task is viewed as a unity, while its content (the number of planned activities) may differ significantly during the attempt to solve it. Formalized trade-offs underlying the new product definition process can be found in (Bhattacharya, Krishnan, and Mahjan, 1998). The authors present a model of achieving dynamically the product definition in the high technology industry with highly dynamic market environment. They found that the early definition was optimal only in a limited set of situations. However, the paper does not model the technological uncertainty appearing inside the firm as the result of its own innovation process.

To explain the consequences of the technological uncertainty in radical product development, (Oorschot, Bertrand, and Rutte, 2000) distinguish planned and unplanned design tasks. In an empirical investigation of two software development projects in a semi-conductor equipment manufacturer, they found that even about 50% of the planned design tasks lasted much more than foreseen in the beginning of the design process. Uncertainty not only results in the emergence of unplanned design tasks, but also has an impact on the content and the operation time of design tasks. According to the cognitive psychology literature (Reed, 1998), (Best, 1995) the innovation process can be seen as a cumulative series of problem solving activities, starting with a flash of insight which is mainly characterized by its suddenness. This makes the solving time of some of the design tasks in radical new product development highly uncertain and difficult to predict, and supports our assumption that the solving time of their activities are exponential distributed and as a result the solving times of those design tasks have a long tail distribution function.

The empirical research of (Oorschot, Bertrand, and Rutte, 2000), (Oorschot, 2001) shows that the radical new product development (NPD) can not be planned and controlled with traditional techniques, like PERT or GERT since we do not know at the start of the process the design tasks of which the project consists and their interrelationships, we cannot use probability distributions on a finite domain for the operation times of design tasks, since some of the problems may turn out to be even unsolvable within the time frame given. This level of uncertainty is far beyond what can be modelled by for instance Beta probability density functions for the duration of design tasks (PERT) and what can be modelled by probabilities that design tasks will have to be redone (GERT). The conjectures they verified experimentally emphasize two other characteristics of NPD processes not modelled in traditional project planning and control techniques: as the optimistic evaluation of the operation time of design tasks in the lack of an objective estimation method available, and the curvilinear dependency of the efficiency of engineers on the time pressure they experience. Well-known topic in cognitive psychology, this last real life characteristic of NPD projects has, to the best of our knowledge, completely overlooked in the project planning and control models.

Multi-Stage Hierarchical Control Structure Of An NPD Process

We will consider for the design process the same definition as in (Doumeingts, Girard, and Eynard, 1996). Namely, it translates the functional specifications (customer/market requirements/specifications) into product definition and manufacturing process definition. The already existing knowledge from existing products will help us to establish a level of ambition for the parameter values of the new product we want. We will distinguish two phases in it: the system design, which is based on research in the specific field and considers the possible interactions, and the detailed design phase, which consists of design tasks most of the time concurrently executed. Those are allocated to design teams, such that individual engineers will be associated to each transformation of a functional specification into technical ones. The first phase is too problem related to be able to model it mathematically, but a different situation holds for the detailed design where a dynamic method for control is needed for the management of functional specifications over the planning horizon.

As input in the detailed design phase we have as a result of the system design phase, some technical specifications and more detailed functional specifications, which are translated in a set of design tasks in order to be assigned to the team of engineers. During the system design phase the interactions between design tasks were considered which means that for a small period of time the work of the engineers on the design tasks can be viewed as independent. At later control points more interactions have to be considered since the concurrent engineering means also exchange of information, and the system design does not decompose perfectly due to the uncertainty in both the own technological process and in the market.

Opposed to the traditional off-line control models, we develop a control model of the detailed design phase that performs a series of on-line decision/planning/execution cycles, each time taking into account the new surroundings it is facing. At the end of each stage, before a new decision/planning/execution cycle starts, the state of the system is updated by observing the technological knowledge accumulated at the engineering level, and by using new information about the functional specifications of the product from the markets and consequently updating. Thus, the uncertainty in the new product definition is decreased stage by stage. We also assume that the progress of the project can only be inspected and measured at preset inspection points since it is too costly to measure it continuously. On-line controlling is an attractive solution for problems involving uncertainty or dynamics, as it allows the controller to adapt its decisions to changing situations in a way that is never possible off-line. Another reason for this model is the fact that the off-line planning models they construct a complete action sequence even before the engineers start their first design tasks. Not only that such a construction often results in exhaustive computations, but also requires an available precise model of the problem before taking any action.

The planning and control problem at each stage is approached hierarchically. This dis-aggregation in the analysis of NPD processes is supported also by recent research in organization design (Haque, Pawar, and Barson, 2000). We will assume in this paper similar process and resource levels (Figure 1), but for their internal structure for these levels will use the conceptual control model for a N.P.D. process developed by (Oorschot, 2001) which enable us to formulate mathematically the control problem of each of those levels. We will also consider the execution of a design task is as a problem solving activity, and we assume that a resource (engineer) will solve the problem defined in the design task, by breaking it down into a series of smaller, more manageable subproblems called activities (Best, 1995).

See Figure 1

The proposed production control structure consists of three hierarchical levels: scheduling, artificial due dates setting, and aggregate planning. This control structure is given in Figure 2 and Figure 3 and has a total number T of stages for NPD project (stages are numbered from 1 to T). Stage t starts at time instant t-1 and ends at time instant t, and we will consider T as being the deadline of the N.P.D. project.

See Figure 2
See Figure 3

Further in this paper, the different levels in the hierarchy of each stage and their roles are discussed, starting with the description of engineering process.

Engineering Process

The description on the engineering process, and hence our basic assumptions start from the empirical research of (Oorschot, Bertrand, Rutte, 2000), (Best, 1995) and (Reed, 1998). In the time interval (t-1,t] of the stage t, at the shop floor the M engineers work concurrently, each on its corresponding sequence of design tasks determined at the beginning of stage t at the detailed planning level. The engineers are considered the only resources needed for solving the design tasks, and a design task has been allocated to only one engineer. Each design task can be performed at different levels of performance, which will imply different stochastic durations for their completion time. For each engineer to solve a design task in its sequence, means that he has to solve sequentially the list of activities predicted at the beginning of the stage t, for each level up to the level established by the product management. In this paper we assume that for each allocated design task there is a due date given during the detailed planning phase. The due dates are assigned to each design task such that an overall optimal work pressure level is achieved for each engineer. Under this work pressure level the solving times of all the activities included in the design tasks allocated to each of them have independent identical exponentially distributed solving times. Then, as a consequence of the sequentiallity in performing the list of predicted activities for a design task, the solving time of any design task is a random variable distributed Erlang.

The decision of an engineer in choosing or not a specific design task to work on is not really something that can be modelled due to the large variety of variables implied and due to the lack of empirical data to support theories. Reasonably will be to consider that the engineer will work on its each design task with a probability equal to the normalized work pressure level perceived for that design task, and that the solutions will arrive for the activities of the design tasks on which the engineer is working on. We can compute the work pressure level perceived for each design task as its weighted expected tardiness.

During the solving process of the design tasks several disturbances may occur. Besides the sequence of predicted activities, there is a set of unpredicted activities that is unforeseen at the beginning of the process and discovered solving predicted activities. Moreover, even new design tasks may emerge as a result of a high technological uncertainty. Gradually, as more activities are solved, more knowledge about the problem is gained, and less predicted activities remain to be solved, the probability that new activities will be discovered becomes smaller. The estimation of the required amount of time and resources will then become more accurate. The decision of an engineer on working on a certain design task, the unpredicted activities arrival for the design task currently in the solving process, the stochasticity of the solving times for the predicted activities, all influence the execution of the schedule. Therefore, the scheduling model will take into consideration the current shop status (the position in the respective sequences of new design tasks, the number of predicted activities per level for each design task including the just emerged ones) at the time t, at the end of the stage t, fact consistent with the real life situations where each engineer measures on a weekly basis how much time was spent on solving each design task, what activities were solved, and what activities were added.

Detailed Planning Level

At the beginning of each stage t, (t-1,t], a set of new design tasks that can be solved in parallel is allocated to the team of engineers, and the set design tasks in progress from previous stages is updated. The two sets of design tasks are subject to precedence constraints inherited from the finite stage network of design tasks, which describes the entire project.

First a re-scheduling decision is taken for the design tasks assigned to the engineers in previous stages, then the scheduling takes place for the team of engineers, while afterwards the design tasks due dates setting is done for each engineer on an individual basis. The scheduling problem considers a set of design tasks subject to precedence constraints to be solved by the M engineers working in parallel. We assume that for each design task to be scheduled all its activities predicted at the beginning of the stage t have independent identical distributed solving times, independent of the engineer who performs the design task. But as mentioned earlier this assumption holds only if each engineer works at its optimal work pressure level. So, after obtaining at the beginning of the stage t a schedule under this assumption, we will achieve by due dates setting for any engineer, its optimal work pressure level.

The design tasks on progress from previous control periods, which have the performance levels unchanged at the beginning of the stage t preserve their previous due dates, even if the design task are already late. This apparent inconsistency is related to the different function of the due dates setting in the NPD case, where the due dates are given to build pressure and ensure the effectiveness of the engineers, not to be met. By detailed planning we do not intend to obtain a schedule minimizing the lateness of the design tasks, but to construct a model in the framework of which we can measure the work pressure perceived by the engineers. The scheduling part gives the possibility of computing the completion times of the design tasks, while the due dates setting part establishes the desired level for the weighted expected tardiness which is the estimate used to compute the work pressure level perceived by the engineers.

Aggregate Decision Level

The highest decision level distinguished in our control structure is the aggregate one, which at the beginning of each stage will provide targets on design tasks realization for the lower planning and decision levels. The first modelling assumption is that for each design task we have a utility function giving at any level of performance of a design task, its importance in the whole NPD, as perceived by the management. The second one is that a safety margin is required for the probability of completion before the deadline of the NPD project defined by the desired performance levels of the design tasks.

At this level the controller sees at the beginning of the NPD process as a T-partite directed acyclic graph of design tasks, reflecting the precedence relations among design tasks. In this graph a design task that is in progress at moment t will start with the next activity not performed yet. Decisions on allocating design tasks to resources (engineers) are not considered here. The objective of the aggregate decision level is to ensure at the beginning of each stage t, the achievement of an optimal utility realization at the end of the NPD project with a probability higher than the safety margin, and a high efficiency of the engineers for a medium term horizon, by balancing the expected capacity requirements.

We construct vectors giving for each functional specification the cumulative utility of the design tasks transforming that functional specification into to technical ones. By varying the desired performance levels for the design tasks we aim to find the cumulative utility vector maximizing the distance with respect to the cumulated utility vector achievable at the minimal performance levels of the design tasks. Those minimal levels define the minimal ambition level for the NPD project.

Conclusions

Controlling the radical NPD processes is a complex managerial task. In contrast to most of the existing literature that starts with an early definition of the product functional specifications, we have modelled rigorously the trade-offs underlying the new product definition process using the knowledge accumulated in time at the engineering level. This model enables a solvable mathematical formulation of the decision/planning problems at each control level, and is based on recent empirical studies in the field of NPD processes.

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Figure 1

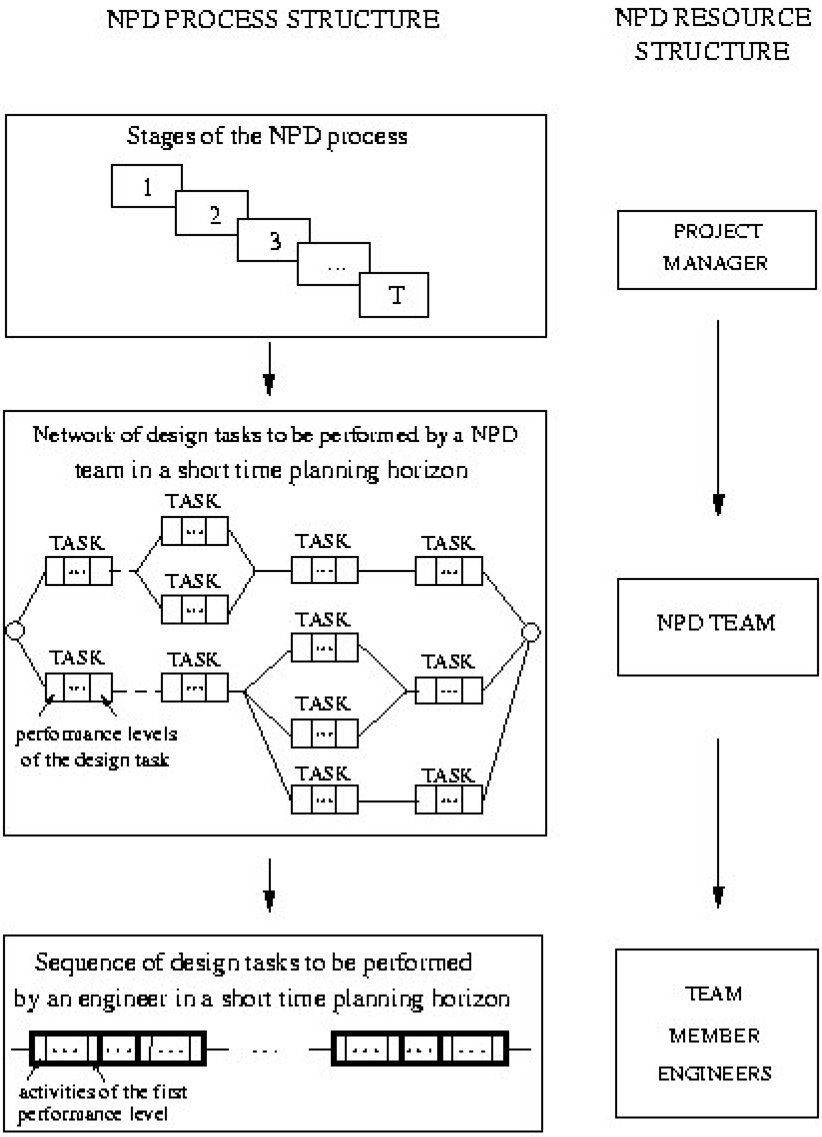
NPD PROCESS STRUCTURE
NPD RESOURCE STRUCTURE
Stages of the NPD process
1
2
3
...
T
Network of design tasks to be performed by a NPD team in a short time planning horizon
TASK
performance levels of the design task
Sequence of design tasks to be performed by an engineer in a short time planning horizon
activities of the first performance level
PROJECT MANAGER
NPD TEAM
TEAM MEMBER ENGINEERS

Figure 2

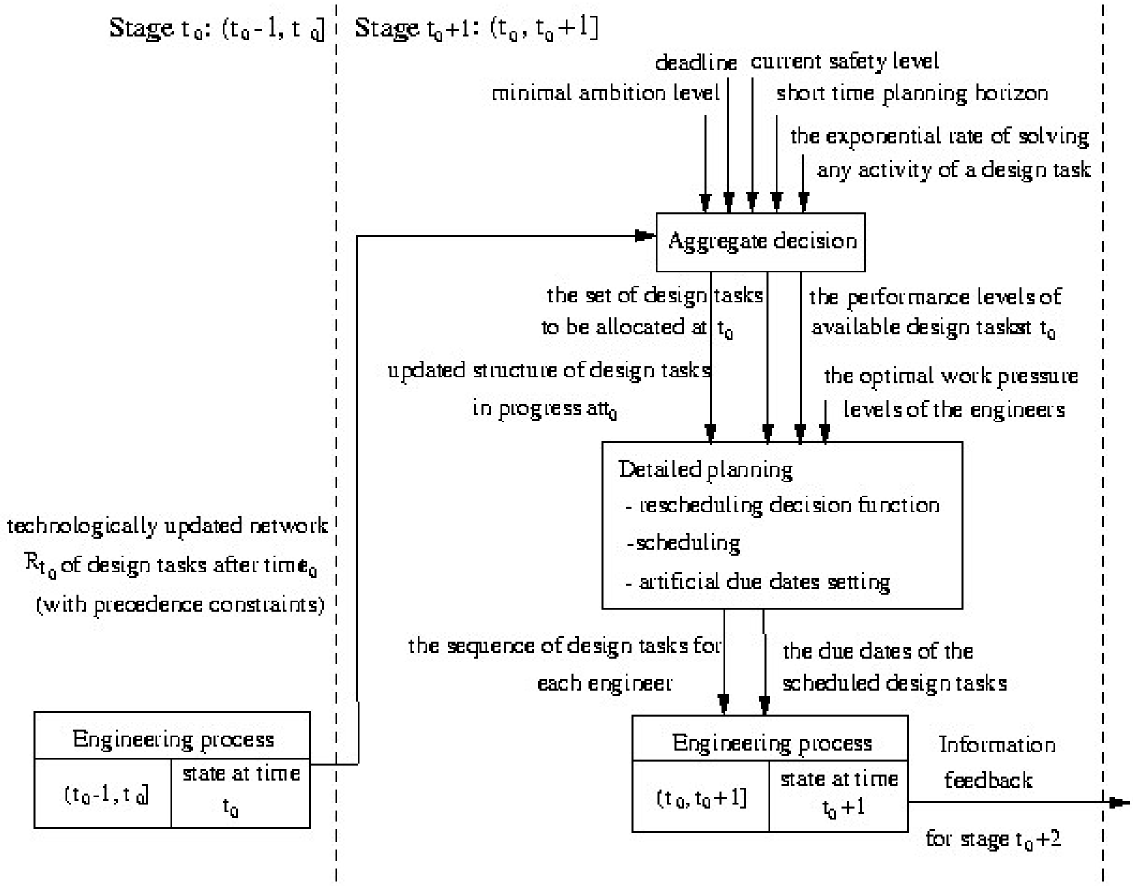

Figure 3