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Simulation based process design: Modeling and applications

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ABSTRACT

Business process management has been a hot topic for both management and enterprise modeling communities. Conventional training based approaches expect managers capable of apply their knowledge and experience when they make decisions in designing their business processes. The technology advancement in the past decades has made it possible to provide technological decision-support for both executives and in the trench managers. How one can create technologies that are both generally applicable to a wide range of domains and still powerful enough to provide specific solutions for specific problems has been a challenge for the research community. In our research, we take a simulation based approach to business design and management. In this paper, an enterprise simulation model, called PMT (Process Management Tool), is introduced and a case study of design and management of automotive engineering design processes using PMT was presented. The PMT based case study demonstrated the effectiveness of our simulation based approach and the PMT model by clearly identifying the fragility of product based design processes and the tolerance of function based design processes to overload situations.

1. Introduction

Business processes, including both managerial processes and engineering processes, are complex and mostly multidisciplinary. Almost everywhere organizations are undergoing rapid and significant changes driven by such pressures as customer expectations, new technologies, and growing global competition. As a result, many business processes must be dynamic and constantly changing. In order to survive in such environments, practitioners are forced to continually revise their business processes to respond quickly to changes. Typically three kinds of scenario can happen in an enterprise. First, an enterprise may look into achieving *drastic advance* of its current performance in terms of cost, service quality, and speed. If the business environmental change is drastic, then they need to develop complete new processes to deal with the change. Lack of experience with the new environment forces them to adopt a trial-and-error approach, which can be highly risky and costly. In the middle of 1990s, Business Process Reengineering (BPR) [18] was introduced as a solution to keep enterprises competitive in the changing environment. BPR helps enterprises link its strategic goals to its key processes and targets drastic changes in business processes by focusing on arrangement of processes to improve the efficiency, product quality and reduce cost. There are some methods and tools available to help enterprises improve their processes with BPR techniques; however, none of these adequately support the practitioner through all stages in the enterprise evaluation and reengineering. Especially, the current BPR practice pays little attention to the market or client environment in which the enterprise operates. In our research, we attempt to help businesses make drastic moves in the changing market environment based on organizational theories and computer simulations instead of merely "experience" and "luck".

Secondly, there are always *bottlenecks* in different parts of businesses and detecting these bottlenecks is of high importance. Usually managers are left with no support in analyzing processes and detecting bottlenecks and they completely rely on their own experience. In these cases, managers need to make local changes and they need to predict the change and factor in the impact of the change in the original process planning phase. A computational enterprise model can provide needed support for managers in terms of providing quantitative and qualitative evaluation of enterprise operations. Business managers also need to do quick "fire fighting" once the change or problem is identified. In these cases, managers must quickly find ways to respond to the problem, such as relocating resources, re-routing certain activities or flows of work, and adding new process components. Computational tools

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are needed to provide process and organization design and analysis support for these managerial activities. In addition such tools can be further developed to provide process monitoring capabilities to track the processes and provide guidance to react to the problems.

Lastly, the business environment change can also manifest itself as shrinking profit margin and higher labor and technology costs. In these cases, while the business remains the same, companies still have to strive for higher efficiency and effectiveness by upgrading their current practice to a higher level. Again an enterprise management tool is needed to provide process design and management guidelines for managers to analyze the reasons behind shrinking profit margin and react to them.

Our research deals with the above mentioned problems through computer based *modeling and simulation* and introduces a computer model called PMT (a Process Modeling Technology). In the course of this research, the two research questions that we must address are "*what are the key concepts and relations in business processes?" and "how can we maintain a balance between generality and powerfulness of a business process model when developing such a model*?" The major challenge that we face in this research is the lack of sound and complete foundation for the way business processes should be modeled and analyzed. To address this challenge, we follow the theoretical insights found in the social science and organizational behavior literatures [46,14,27,5], making our model to reflect the organizational behavior of business work and managerial decision making processes. In addition, we extend the Action Workflow model [29] to capture client-service relations generally found in the business processes. To ensure that our model is powerful enough to model the details of various managerial and engineering process found in business companies, we treat our model as a computational representation of the structure, activities, processes, information, resources, people, behavior, goals, and constraints of a business, government, or other enterprises [12]. The major contributions of this research include 1) a service based computational model of business organizations and processes that not only identifies key concepts and operations but also allows trade-off studies by comparing different organization and process designs along three dimensions of market situation, enterprise setting, and performance, and 2) a proven useful methodology for modeling specific business situations for the purposes of analysis and design. The case studies presented in this paper demonstrate the effectiveness of our proposed model and methodology.

In the rest of this paper, we first review the existing methods and technologies applied to the area of business process design and innovation. In the Section 3, our proposed PMT model [48,44] and associated modeling methodology are introduced. In Sections 4–7 we describe and discuss in detail a case study of applying our modeling technology to design an automotive press-forming-dies design process. Finally conclusions are drawn in Section 8.

2. Related work

There have been various methods for improving business processes performances [2] and support business decision making [3]. Quality Control [11] and the related methods [10,20,22] are the most popular and have been applied to various industries [33]. PDCA cycle is an application of QC (Quality Control) execution and searches process design solution based on "trial and error" by repeating a cyclic chain of four activities, "Plan", "Do", "Check", and "Action". It has contributed to the process improvement [32] remarkably. However, it is time consuming and cannot meet the requirement of the rapid changes in the current business because of the time and cost spent for "trial and error".

Since early 1990s, with the accelerative development of IT technology, various IT systems have been introduced to assist the enterprise management. Especially after BPR (business process re-engineering) was introduced [18], they have been applied to the enterprise process innovation. ERP (Enterprise Resource Planning) (Wylie, 1990) is one of the typical and practical examples of BPR technologies. ARIS [39] introduced by IDS Sheer AG intends to provide a complete package for process innovation. It includes not only the technologies such as modeling and visualizing business processes but also the necessary methods such as how to model with ARIS. EAI (enterprise application integration) [13] integrates the various IT applications existing in the enterprises for the effective IT uses. The currently applied IT technologies have enabled automating or semi-automating the process operations but the strict treatment on specific processes has limited their effectiveness for enterprise design. As a result, considerable numbers of the process innovations and improvements have resulted in failure [19].

From an organizational decision making perspective [30], the existing technologies are effective when the business environment doesn't change or changes slowly. They alert the managers what the current bottlenecks and problems are, however, they cannot predict what could be the potential risks, which operation or position could be the potential bottleneck, and how much impact the risk would give on the process performance when the surrounding business environment changes in future. Furthermore, it cannot help explore the optimum business process to the possible environment changes in future.

In many fields, computer based simulation is a popular and effective method to evaluate potential issues and future risks for a given system. For instance, in engineering design, FEM simulation (Finite Element Method) [35] is very popular and effective for analyzing the designed structure regarding the force interactions, heat transfer, and fluid dynamics. In meteorology, the risk and impact of industrial activities to the global warming can be examined with the help of the simulation technology [38]. In addition, the simulation based approach has been applied to the business development and management. Monte Carlo Simulation [16] is one of the simulation technologies applied in finance, quality control, and investment for managing and making decisions. Multi agent simulation [7,31] is another example that is applied into the complex system such as urban traffic system and stock exchange market. One of the benefits of the simulation approach is the time and cost reduction. As long as the new business process is designed and executed virtually, the time and cost spent for the process innovation is much smaller than the actual trials.

Modeling of organizations and their processes has been dominated by qualitative approaches based on descriptive and artistic qualities [2]. There has been research on process representation [17,34], process knowledge acquisition [37], processes for collaboration [36,4], integration [25,8,23]. In order to identify best processes for product development, Eppinger and his colleagues have developed various DSM (design structure matrix) based analytical models to optimize processes based on sequential and technical relationships among tasks (Epingger et al., 1994; [47]. To develop the effective simulation based approaches to the enterprise business process design, two critical issues shall be addressed. The first issue is related to the impact of coordination on the process performances. Especially in knowledge application processes such as engineering design, designers need to not only process the actual design work but also actively coordinate with each other through communications, reports, and waiting for decisions and/or replies from others. Few existing methods take coordination into consideration. The second issue has to do with the complex relations between clients and corresponding processes and with the impact of these relations on the process performance.

For instance, predicting the performance of a design process of five car models should be more complex than that of a design process of one model. Although VDT (Virtual Design Team) [21,24,45] method explicitly addresses the coordination work, it does not consider the relation complexity between changing clients in the market and the business processes of an enterprise partly due to its focus on project management.

In this research, we took a simulation based approach to enterprise business process design and developed a computational model called PMT [48,44]. PMT has a graphical modeling editor for designing an enterprise business process, a discrete event driven simulation engine for predicting the process performance, and a graphical reporter to display the simulation results of various performance measures. In the following, we introduce the PMT model, the method for applying the model, and discuss in detail a case study based on the model and the method.

3. PMT: A model of business organizations and processes

It has been pointed out that enterprises benefit from business process models in three different categories namely *design*, *analysis* and *operation* [12]. A business process model should be capable of benefiting each of these categories. From a design perspective, a business process model should provide essential concepts to define the whole business. Business designer should be able to reason about different designs of the business by exploring alternative models. From an analysis point of view, a business process model should provide the essential means for business analyzers to predict the effect of particular changes on all parts of the business. Finally from an operation perspective, the business process model must be able to represent what is planned, what might happen, and what has happened [12]. It must provide the information and knowledge necessary to support the operations of a business. Our goal of business process modeling in this research is to develop a computer simulation system that allows business managers to perform various "what-if" simulation studies in order to identify managerial risks in the current enterprise settings and evaluate or predict performances of new business process designs. To achieve this goal, our business process model must be useful—i.e., covering sufficient level of enterprise operation details—and truthful—i.e., providing real-world or close-to real world simulation results. To satisfy these requirements, we introduce following assumptions.

A business organization is a "bounded rational system". A bounded rational system is a system that strives to make rational decisions but is limited due to the finite information resources available for making them [42]. We view an enterprise organization as a "bounded rational system". Organizational actors have clearly defined goals and consensus on the "the most efficient means to achieve these goals" [14]. Therefore the appropriate description of organizational action will be one of the purposeful and goal-oriented searches for solutions trying to "satisfy" rather than "optimize" [43].

Most of the tasks in a business organization are routine and repeated Business operations are dominated by conservatism and incremental improvement. Therefore, the nature of tasks does not involve intrinsic innovation and creativity, but rather consist of routinized and repeated daily problem solving.

A business organization adapts and responds to external environment as an open system We view organizations as open systems [40] whose performance is highly dependent of external forces in the environment. More specifically, we attempt to directly model business environment for companies and capture political and economical environment factors indirectly through the business environment.

3.1. A client-service model of enterprises

Traditionally, researchers look at business processes as an "information factory" [26] with a focus on flow of information content. Workflow management systems using this approach are referred to as activity based. They tend to neglect human actors and their action and co-action within organizations [26]. Theories of speech acts and communicative action [1,41] inspired researchers toward a method with a focus on human actors. The fundamental idea of a speech act theory is that a statement consists of both a "propositional content" (describing the world) and an "illocutionary force" (action mode). The illocution used expresses the action performed through speech and thus the type of relationship established between speaker and listener [26].

One of the well recognized communication-based workflow methods is "action workflow" proposed by Winograd and his colleagues [29]. Action workflow was first introduced to address information systems, but the idea also breaks through the area of Business Process Reengineering. BPR software tools such as "Action Technologies" have been developed based on the idea of action workflow. This framework describes the interaction of two individuals as *customer* and *performer* which construct the flow of work in organizations. Action workflow claims that any workflow consists of two actors and four phases. Two actors are "Customer" and "Performer" and four phases are: *Proposal*, *Agreement*, *Performance*, and *Satisfaction*, as shown in Fig. 1.

The main idea of this framework is that upon a customer's request, the performer makes a commitment to perform the work. The first phase of the cycle starts when customer requests (i.e., proposal) a work from performer. In the second phase performer agrees (i.e., agreement) to perform the job. In this phase customer and performer may go into a negotiation process. In the third phase which is the main phase of the cycle, performer performs (i.e., performance) the actual job. Finally in the last phase, performer delivers the result of the job to customer for evaluation (i.e., satisfaction).

In our PMT model of business processes, we extend the idea of action workflow by enlarging the interactions between two individuals to those between an *enterprise* and its *market*, as shown in Fig. 2a. Furthermore, at a more detailed level, we view a pair of *client* in the market and a *service* provided by enterprise as a pair of *customer* and *performer* indicated in the Action Workflow model, as shown in Fig. 2b. One client can pair with multiple services, and one service with multiple clients. In modern enterprises, clients and enterprises are involved in everyday's business transactions. We call an activity *business transaction* if it generates revenue for an enterprise. Following Action Workflow model, four phases have been introduced in our framework to model enterprise business transactions. A business transaction starts with a client sending a *request* to a service of an enterprise. In the second phase, the enterprise *agrees* with the client in providing the requested service. In the third phase, the enterprise *performs* the service and delivers the service results. Finally in the last phase, the client evaluates the service results and sends back *satisfaction* feedback to the

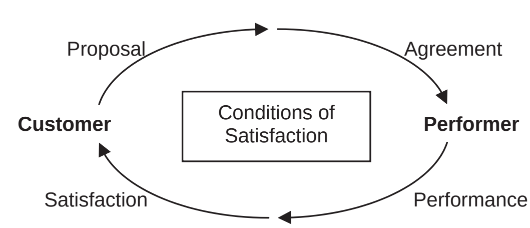

Fig. 1. Action workflow model [29].

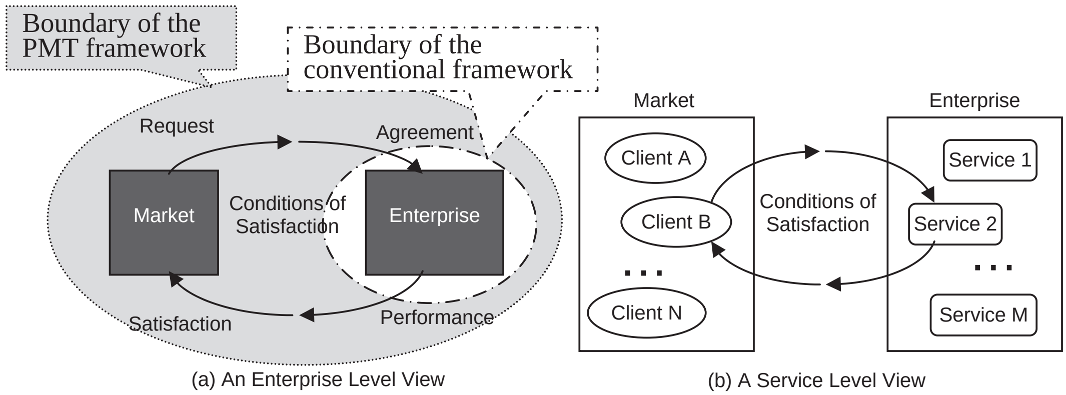

Fig. 2. A client-service model of PMT.

enterprise. The service quality is determined by the satisfaction feedback from the clients.

In the PMT framework, we aim to analyze the response of an enterprise in terms of their capacity in meeting market demands. Market demand is modeled by the number of clients together with their request generation patterns. Enterprise capacity is captured by explicitly modeling human *organization*, service *processes*, and the *resources* used by the organization to perform their services.

3.2. The PMT conceptual model

We view an enterprise as an "operating system" in which various applications (i.e., services) are running to serve users' (i.e., clients') requests and these applications use available and needed human resources as well as other non-human resources. This view provides a suitable structure for our computational enterprise model. According to this view, we model an enterprise together with its market environment in terms of four models, namely, Client Model, Organization Model, Process Model, and Resource Model, as shown in Fig. 3.

Each model has its own boundary, but has multiple interdependencies with other models. Clients function as market demands by sending requests to an enterprise that require applications of human or non-human resources of the enterprise. On the other hand, the enterprise needs to efficiently use their capacity composed of its organization (i.e., human resources), service processes, and resources to effectively fulfill its clients' requests.

A *client* is modeled as a source of work for an enterprise. It has its own operations (COP: Client Operation) and sends service requests (SRI: Service Request Item) to the enterprise. A *service* of an enterprise is a procedure for processing SRIs. It is composed of a set of required operations (SOP: Service Operation). An organizational *position* is assigned to one or more SOPs and processes SRIs sent to these SOPs. Positions form an organization through "report-to" relations. When a position processes a SRI, a coordination work such as communication and exception might be generated. A *communication* is sent to and processed by a task-related position, while an *exception* is sent to a supervising position for guidance or decision. In this way, a position processes not only the direct work from clients but also the coordination work generated from co-workers. In this information-processing view [21,24,28,15], a position is considered as an information processor and the requests (SRI) from clients, communications and exceptions from other positions, as well as decisions regarding the exceptions, are considered as the information to be processed by the positions, as shown in Fig. 4.

3.3. The PMT model structure

Fig. 5 briefly describes a UML class diagram of the PMT conceptual model. In our model, an enterprise can have multiple numbers

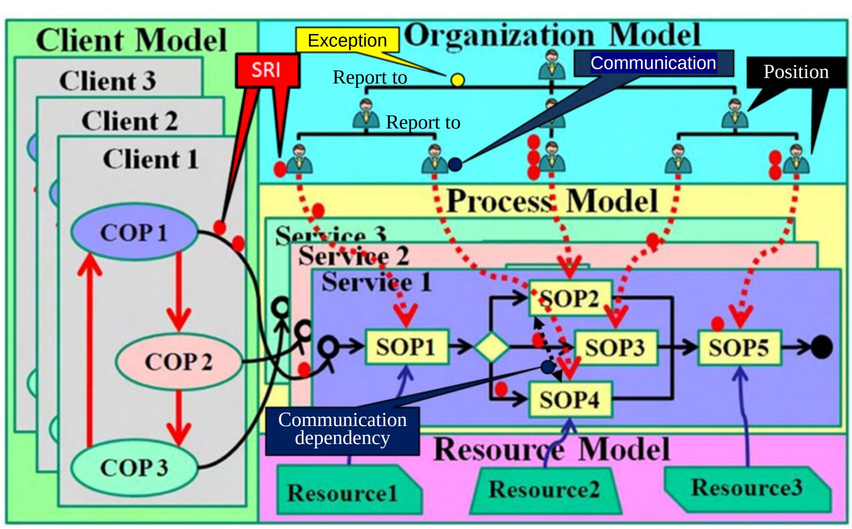

Fig. 3. The PMT client, process, organization, resources.

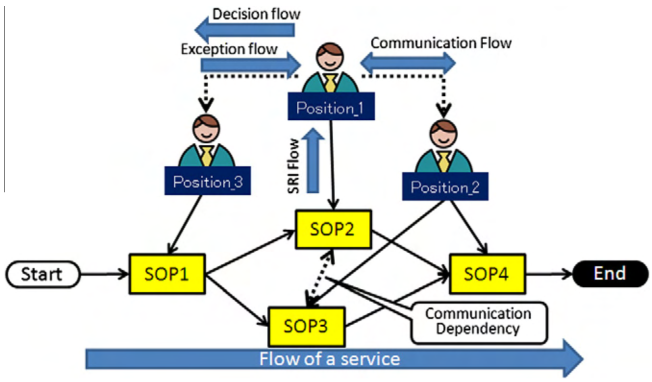

Fig. 4. Model behavior in the information-processing view.

of business cases depending on the market situations being studied, the business strategy, and the enterprise designs. Each case allows us to describe a possible business process for the enterprise as a set of clients and corresponding services.

Fig. 6 shows a UML class diagram of a *Client*. A *Client* is defined as a set of *Client Operations (COPs)*. Each *COP* is associated with a corresponding *Service*. A *COP* generates *Service Request Items (SRIs)* and sends them to its corresponding *Service* based on the predefined probability distribution. Typically, the distribution is characterized by the frequency (mean time between SRIs) and its variance which define how often the SRIs are generated and by what variety the interval may change.

Fig. 7 shows a UML class diagram of *Work Items*. In our model, there are three types of *work items* processed in an *enterprise*. A *SRI* represents the origin work requested its corresponding client. Its values of *work volume*, *priority*, *complexity*, and *required skill* are determined by the *SOP* to which the *SRI* is sent. *Exceptions* and *Communication Requests* are the added work due to organizational issues and task dependencies. They are generated based on a probability when a *SRI* is processed. The exception probability is defined by the complexity of the *SOP*, the skill level of the assigned *position*, and the exception probability of the *Service*. The communication probability is defined by the information uncertainty of the *SOP* and the communication probability of the *Service*. A *Communication Request* has a life time and if the *Communication Request* is not processed within the time, the *Communication Request* evaporates. This evaporation signifies a failure of a communication. PMT counts the number of the generated communication requests and their failures in order to evaluate the communication quality as a process performance measure.

Fig. 8 shows a UML class diagram of a *Service*. A *Service* is composed of the work item, resource, process, and organization and defined by centralization, formalization, matrix strength, exception rate, and communication probability. The centralization influences to the level of the decision maker in an organization. The higher the centralization is, the more probable a manager makes a decision. The formalization influences to the probability a communication request is generated when a SRI is processed. The higher the formalization is, the more probable a communication request is generated. The matrix strength influences to the attitude of a position in respect to a communication request. The lower matrix strength is, the more probable a position ignores (does not process) the communication request. As described above, the attributes of the service influences to the probability of the exception and communication, and how to process the exception and the communication.

Fig. 9 shows a UML class diagram of a *Service Process*. The *service process* is a set of the *Service Operations (SOPs)* that define how to

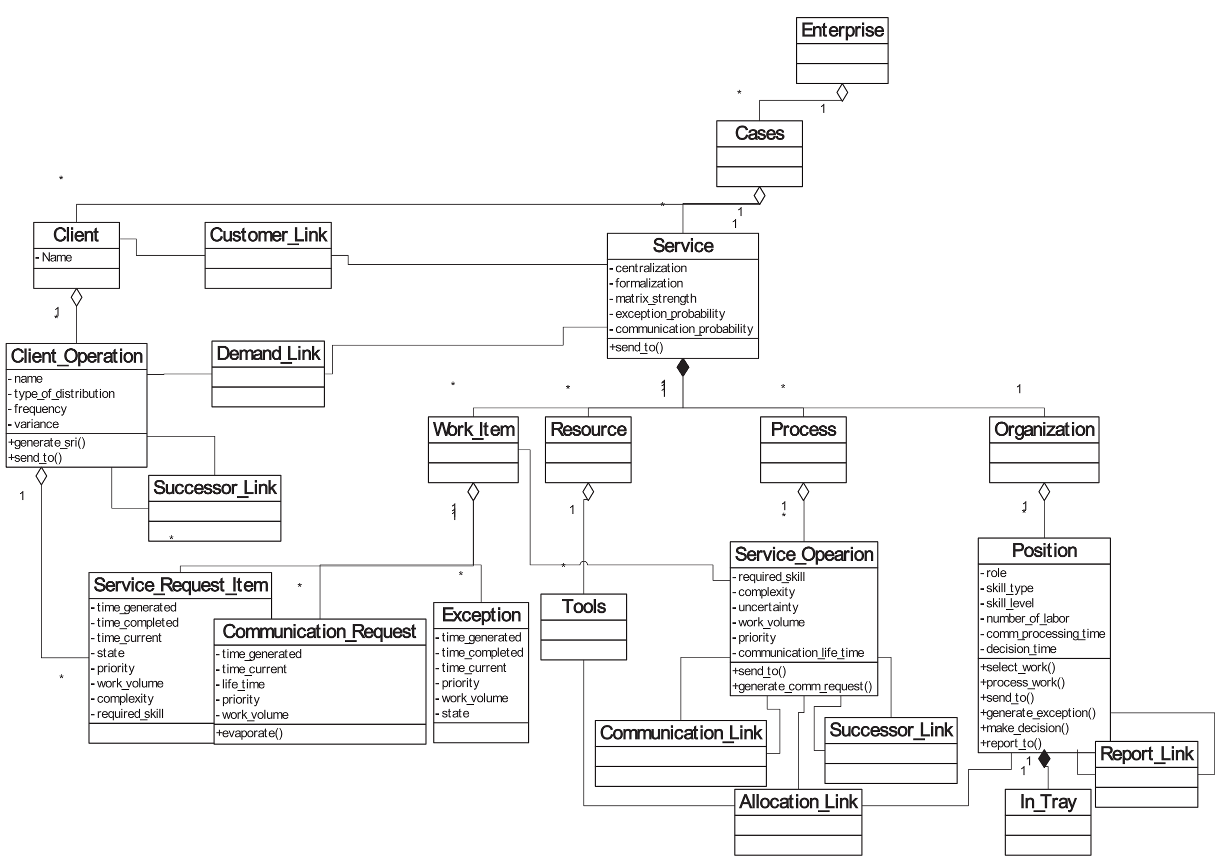

Fig. 5. The PMT model structure (UML class diagram).

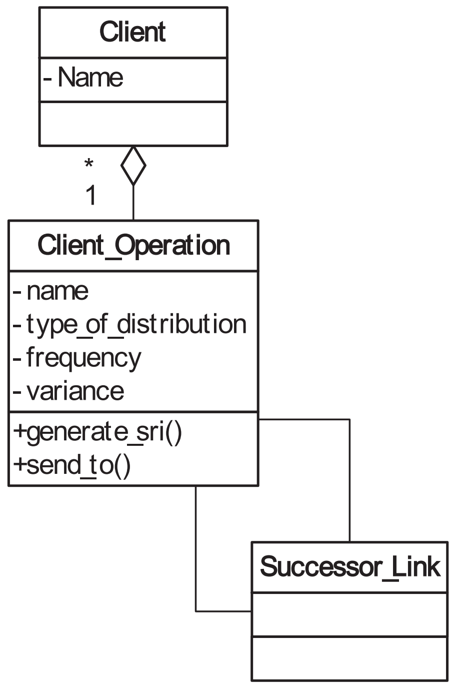

Fig. 6. Client data model (UML class diagram).

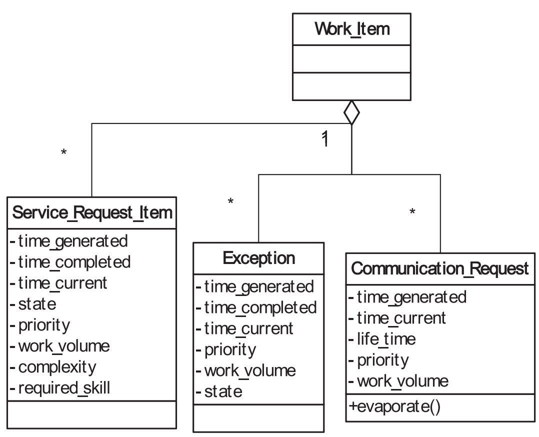

Fig. 7. Work item data model (UML class diagram).

process the SRIs. A *SOP* is an operation to be executed for fulfilling the SRI and defined by the *required skill*, *complexity*, *uncertainty, work volume, priority*, and *communication life time*. The *required skill* defines the necessary skill to execute the *SOP* for the assigned *position*. The *complexity* defines how complex the operation is to execute. The *uncertainty* defines the information dependency of the *SOP* to the other SOPs. When it is linked to another *SOP* by the *communication link*, it generates a *communication request* depending on the *uncertainty* of the *SOP* and the *formalization* of the *service*. The *work volume* defines the average time to complete the *SOP* on a *SRI* by a medium skilled person. The *priority* defines the importance of the *SOP* to the others. The higher the priority is, the more probable the *SOP* is executed. The *communication life time* defines the time to the deadline for processing the request and the value is given to a *communication request* when it is generated.

Fig. 10 shows a UML class diagram of an *Organization*. The *organization* is a network of the coordination relationship between "*Positions*". The relationship between the *positions* is defined by the "*Report Link*". An exception is reported to the decision makers and the decision to the exception is sent to its executors through the link. A *position* is represented by the role, the skill type and level, the number of labors, the communication processing time, and the decision time. The role defines the role of the position in its belonging *organization* and categorized into "staff" and "manager". The value influences to the decision type such as how to process the exception. In general, managers might prefer the thoroughly rework but the staffs might prefer the partial amendment or ignorance. The skill type and the skill level define the types of skills the *position* has and their skill level. The number of labors defines how many human resources are assigned into the position. The communication processing time defines the time spent when the *position* processes a *communication request*. The decision time defines the time spent when the *position* processes an exception for making a decision.

The position processes the work items, such as the SRI, the exception, and the *communication request*. A *position* has an in-tray and the all work items are sent to the in tray. When there are any items in the in-tray, the *position* selects a next item to be processed based on the selecting strategies such as FIFO (first in first out), LIFO (last in first out), random, and priority. The strategy the *position* might follow for the next item is varied and depending on the characteristics of the *organization*. When a *SRI* is selected as the next item, the time spent for processing it is defined by the skill level of the *position*, complexity of the executed *SOP*, the work volume of the *SRI*, and the number of labors of the *position*.

$$T\_sri(i) = \frac{WV\_sop(j)}{N(k) \times Eff\_sk(j,k)} \quad (1)$$

where *T_sri(i)*: the spent time for processing a *sri(i)*
WV_sop(j): expected work volume for completing the *sop(j)*
N(k): the number of the labors assigned into the *position (k)*
Eff_sk(j,k): the coefficient of skill matching between the *sop(j)* and the *position (k)*

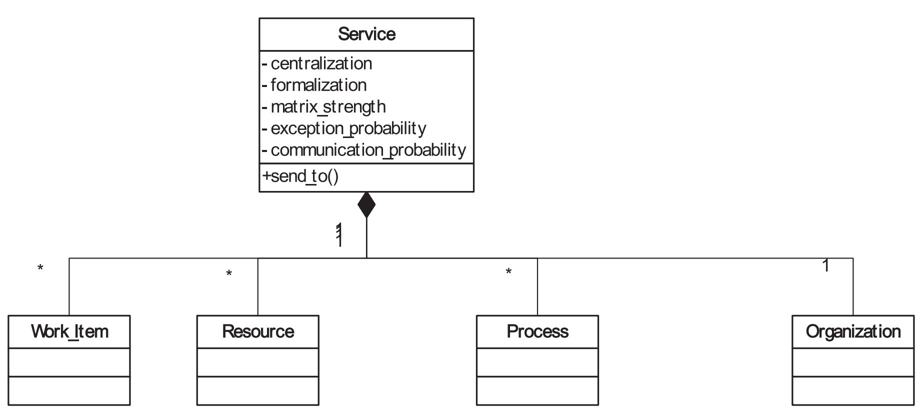

Fig. 8. Service data model (UML class diagram).

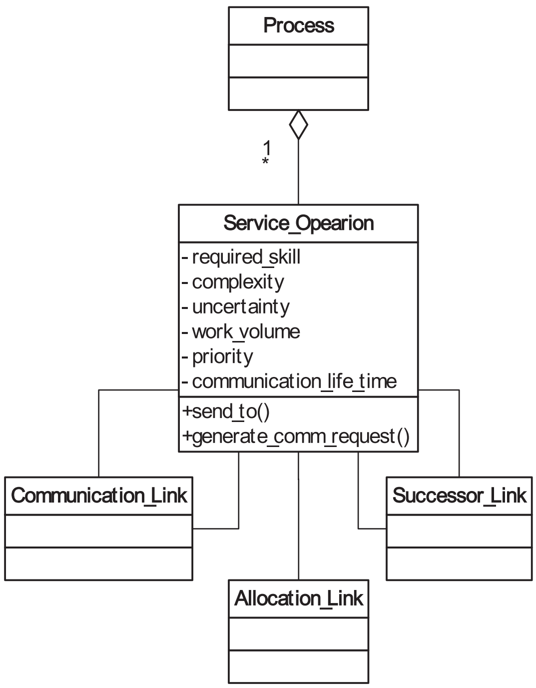

Fig. 9. Process data model (UML class diagram).

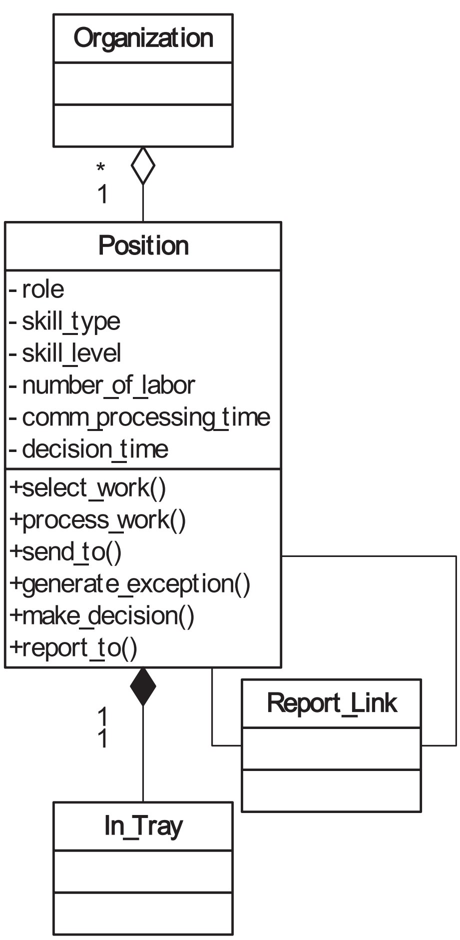

Fig. 10. Organization data model (UML class diagram).

After a *SRI* is processed, it is verified and might be determined as an *exception*. When an *exception* is generated, the *position* decides whether or not report to its supervising *position* linked by the *report link*. The probability of reporting to its higher *position* is influenced by the value of the centralization.

The PMT model described above brings two benefits for designing business processes. First, modeling an enterprise business process with its clients allows us to examine the impact of market changes to the performance of business processes. For instance, the changes of demand volume can be modeled by changing the number of clients or the frequency of the requests from the clients. In another example, the impact of legal change or obligation can be modeled by adding the laws or obligations as the new clients into the baseline model. Second, the information-processing view allows us to model the complex interactions between the objects forming the business processes. For instance, the unpredictable events such as exceptions and communications can be identified as a risk for a certain business process when the market demand increases. In the following sections, we present a case study in which PMT is applied to design an engineering process in an automobile company.

4. Case description: Automotive press-forming-dies design

In this case study, an automotive press-forming-dies design process was examined. A press – forming – dies is used for forming the car bodies from a metal sheet (Fig. 11) by pressing the sheet metal into the dies. In general, the quality of dies design has crucial impact on productivity because poor dies designs result in the burr and low yield rate. Furthermore, the problems influence to the subsequent operations such as welding and assembling. Although the press-forming-dies design is very important as described above, it is always forced to reduce its design schedule due to the delay of proceeding design phase "clay design" and the fixed release date. As a result, the daily load on the design team is occasionally higher than the planned schedule. In this case study, 6 models of cars were designed concurrently.

4.1. Motives of this process innovation case

Due to the high demand from the market and the delay of the clay model design, which was the predecessor of the press-forming-dies design, the design organization was required to process the more design work in a day than the planned schedule. Even if the design work exceeded the capacity of the design process, a constant design throughput had to be kept. This was a crucial requirement that the design organization must satisfy. However, it was obvious that the throughput might decline if the design organization would become busier. In addition to this critical situ-

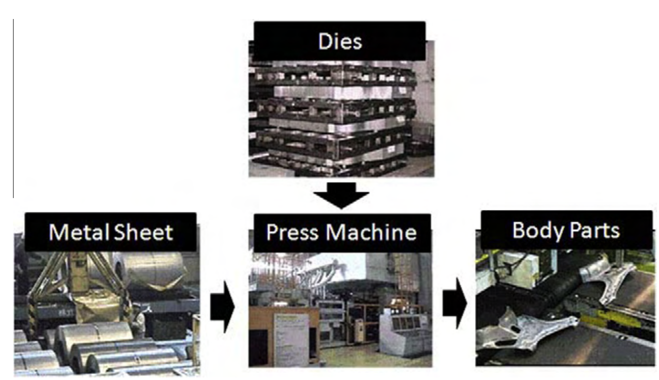

Fig. 11. Press forming process.

ation, a large number of new unskilled designers who just graduated from colleges were allocated into the design organization and this allocation drastically accelerated the declining of the design throughput. Finally, the responsible manager started to consider reforming the current design process from the product based process (Fig. 12) to the function based process by re-grouping the operations (Fig. 13). One of the most crucial differences between the product based process and the function based process is how to form and assign the design teams to the designing operations. The examples of the product based process and function based process are shown in Figs. 12 and 13 respectively. Supposing three operations, Op1 to 3, are required for designing three types of products, Model-1 to 3. In the product based process (Fig. 12), each team is assigned to an entire process for designing a specific Model. In other words, they are required to perform the all operations for a specific product model. On the contrary, in the function based process (Fig. 13), each team is assigned to a specific type of operations for all product models. In other words, they are required to perform a specific type of operations for the all product models.

The manager intuitively considered that the current process architecture would be the cause of the problems and that another better process would be able to solve the problem. However, the manager's intuition could not be evaluated, it was not clear what "another better process" should be, and there was no sufficient evidence for the manager to be convinced to make any informed decision. The only thing that was clear to the manager was the demand: i.e., the new process must satisfy the two requirements, "tolerance to the overload" and "accommodation for OJT (On Job Training) for unskilled designers".

Based on the case situation described above, the problems to be addressed prior to the process re-designing were identified (Table 1). The answers to these problems used to solely depend on the manager's experience. In this case study, it is also provided how our proposing approach assists the decision makings for the appropriate process design.

4.2. Information gathering

To build a simulation model for the design process of the press-forming-dies, the necessary information was collected as follows (Fig. 14).

- Press-forming-dies were designed with respect to 6 model types.
- The Press-forming-dies design required four major operations, i.e., "Prototype Design", "Prototype Try", "Product Design", and "Product Try".
- The operations were becoming more complex from "Product Try" (last operation) to "Prototype Design" (first operation).
- 50 designers, including managers, were assigned into the process.

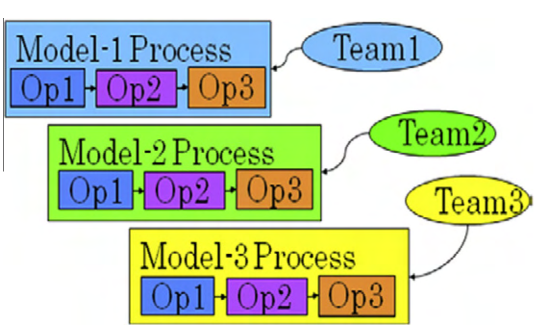

Fig. 12. Product based process.

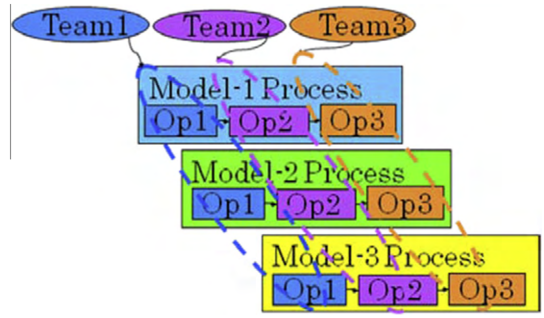

Fig. 13. Function based process.

To examine the process with respect to "allocation of human resources", the skills and the skill levels of the 50 designers were defined with respect to the four operations in the design process as shown on Table 2. This assumption is based on the interview to the responsible manager. The number of high-skilled designers in "Prototype Design" is less than the other operations because, as described above, it is most complex and requires more experience to be skilled than the others. Contrary to the prototype design operation, the number of high-skilled designers in "Product Try" is more than the others due to its less complexity. Persons 41–50 are the unskilled designer assigned to the process lately. They are low-skilled in all operations through the design process. In the current "product based process", all designers were assigned to the 6 teams corresponding to the 6 model types so that all team levels were equal to each other.

5. Modeling the design process

The information gathered in the previous section is visualized based on the PMT model. PMT has a hierarchical modeling structure. Top modeling layer defines Clients, Service, and their relations. Second modeling layer defines the structures of each Client and Service. A Client is described as a set of COPs (Client Operations) with the relations to the corresponding services. A Service, which is a mechanism processing the SRIs (Service Request Items) sent from Clients, is defined as a set of SOPs (Service Operations), Positions, and their relations. The detailed modeling procedures are described as follows.

5.1. Modeling client and service relations

First of all, Clients and corresponding Services are identified. Fig. 15 shows the top layer model of the press-forming-dies design process on PMT modeler. When this case was examined, there were 6 car models requiring the press-forming-dies design respectively. In this case, therefore, the each car model is considered as a source of the design work for the design process. Then, the 6 car models are modeled as Clients. On the other hand, the design process is modeled as a service to the each car model.

Each car model is developed as an aggregation of various parts of designs such as the engine, the chassis, the interior, and the shape. In our conceptual model, each operation is identified as a COP (Client Operation), which is a necessary activity or a demand for a Client. For instance, *developing an engine*, *defining car concept*, and *designing shape*, are the COPs for a car model. In this case study, "forming body" is identified as a "COP" that requires "designing press-forming-dies" as a "Service" (Fig. 16). When a simulation is executed, design work items are generated in the COP and sent to the related Service with certain frequency. By changing the frequency, we can virtually realize various market demands and loads

Table 1
Problems to be predicted.

Problems	Predictions	
	Product based process	Function based process
Tolerance to the overload Where to allocate the unskilled designer	*"Analysis by the simulation based approach"*	

Fig. 14. Press forming dies design process.

on the design team due to the reduced schedule from high to low for the design process.

Table 3 shows the attributes setting of a COP on the PMT. The attribute values were varied by the load of daily works on the designing-dies-service. The load 100% means the current daily work load onto the designing-dies-service and it is 20% more than the planned schedule due to the delay of the clay model design. In other words, the design team must process 20% more design works in a day than planned schedule in order to complete all design works by the fixed release date. So, if they could have longer schedule, the percent (%) of the work load on a day would decrease. In the planned schedule, the COP "forming-body" generates a SRI as a daily work every 8 h (8 h work per a working day in this simulation). In the current schedule, however, the COP generates 1.2 SRIs in a working day, which means that a SRI is generated every 6.7 h in order to reduce the planned schedule due to the delay of the clay model design. In this case study, only the frequency of generating the SRIs was varied to examine the tolerance of the process to the overload. As an example of the attributes setting of a COP, Fig. 17 shows a screenshot of modeling a COP.

5.2. Modeling service process

Again, the six models are the sources of requests (design work) for the design process. In this case study, two types of the process, i.e., product based process and function based process, were examined as the target design process. The modeling procedures of the two processes are described in Figs. 18 and 19, respectively.

First, the operation flow for processing the requests from each car model is defined. Each operation flow comprises three types of operations, which are "Designing Operations", "Directing Operation", and "Control Process Operation". The designing operations are "Prototype Design", "Prototype Try", "Product Design", and "Product Try". They directly contribute to completing the design work. Directing Operation monitors the designing operations and directs the designers. Control Operation integrates the all team managers from a management perspective. Both the Designing and Control Operations are information-dependent on the Directing Operation. For instance, a Designing Operation may request needed information from its relating Directing Operation when it is executed, and vice versa. In PMT simulation, when an information request is generated from an operation, it is sent to its dependent operation and processed by its responsible position.

Second, the responsible organizational positions are defined with respect to the operations defined above. The four designing operations are assigned to the design teams. The Directing Operations and the Control Operations are assigned to the Team Manager and the General Manager, respectively. In PMT simulation, a posi-

Table 2
Properties of human resources.

Staff ID	Skills and Levels			
	Prototype design	Prototype try	Product design	Product try
Person 1–10	**High**	**High**	**High**	**High**
Person 11–15	Medium	**High**	**High**	**High**
Person 16–20	*Medium*	*Medium*	**High**	**High**
Person 21–25	*Medium*	*Medium*	*Medium*	**High**
Person 26–30	Low	*Medium*	*Medium*	*Medium*
Person 31–35	Low	Low	*Medium*	*Medium*
Person 36–40	Low	Low	Low	*Medium*
Person 41–50	Low	Low	Low	Low

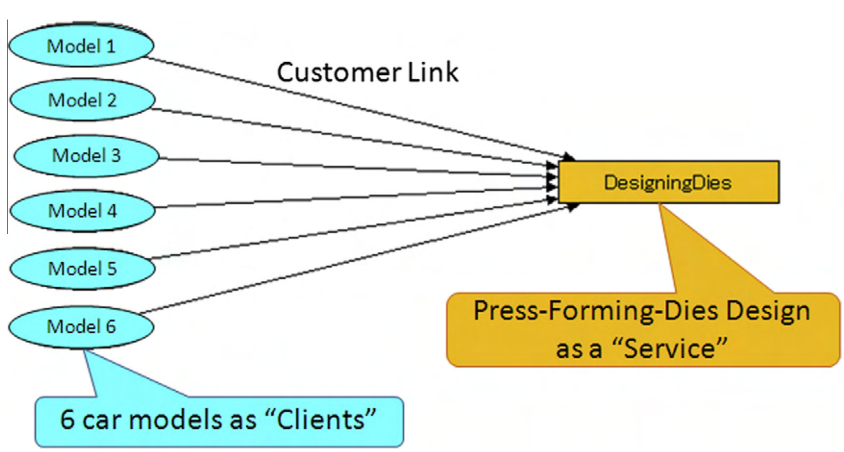

Fig. 15. The top layer PMT model of the dies design process.

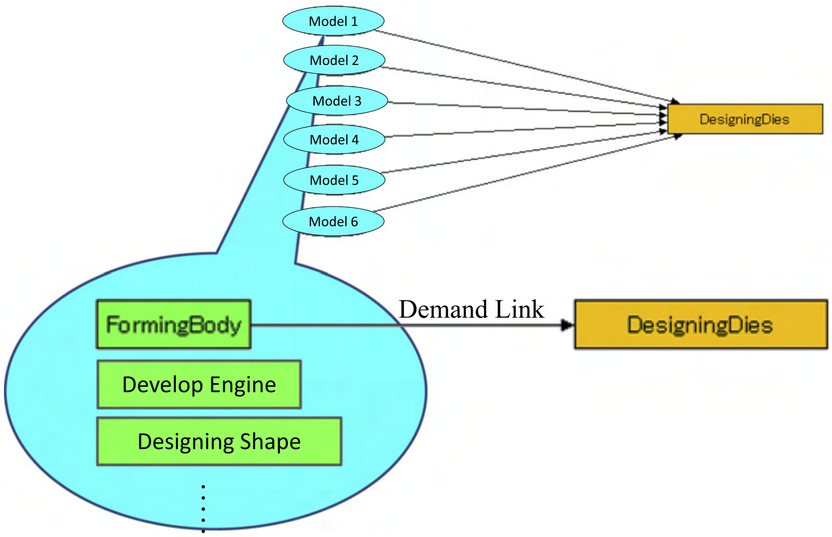

Fig. 16. A client as a set of COPs.

Table 3
The loads and attributes setting of a COP.

Attributes	Load setting					
	50%	60%	70%	80% Planned load	90%	100% Current load
Mean hrs (frequency)	13.3	11.1	9.5	8.0	7.3	6.7
Variance: hrs	0.1	0.1	0.1	0.1	0.1	0.1
Distribution type	Standard	Standard	Standard	Standard	Standard	Standard

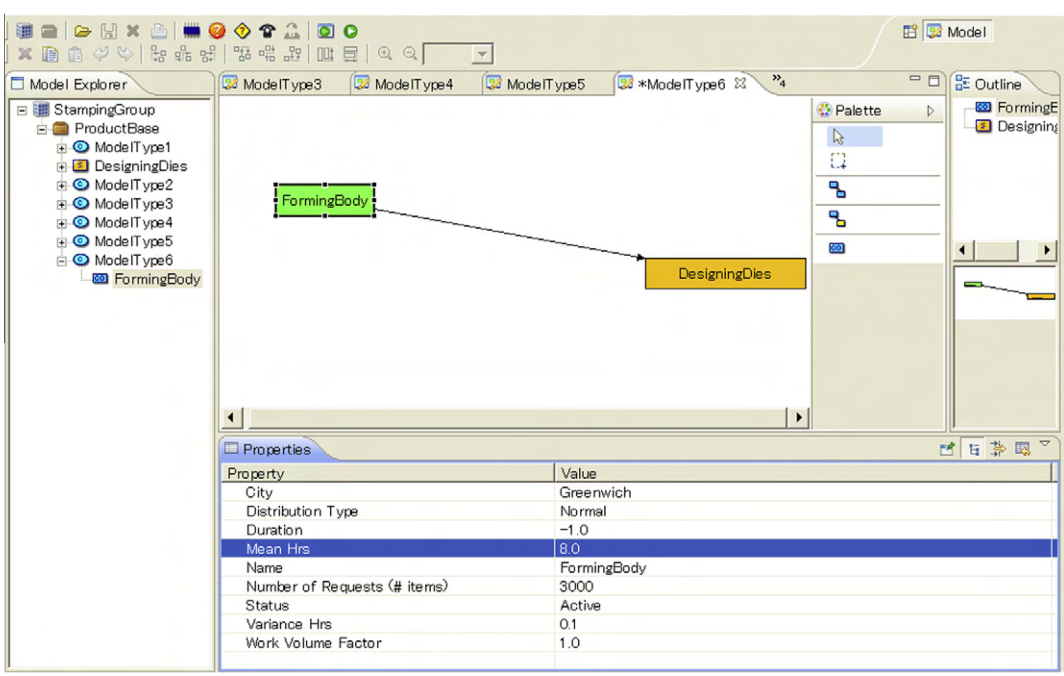

Fig. 17. The attributes setting of a COP on the PMT modeling editor.

tion processes requests received from its assigned operations and sends them to the next operations after processing. When a position is assigned to a set of operations with respect to a specific model type, it forms a product based process (Fig. 18). When a position is assigned with respect to a specific function of operations, it forms a function based process (Fig. 19).

As the third step, the report-decision relationships between the positions are defined. The network of the relationships forms a

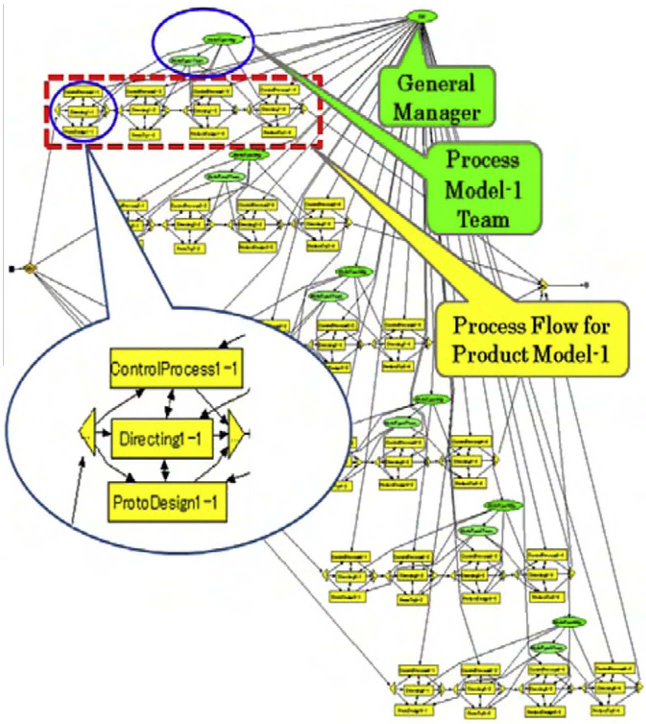

Fig. 18. Product based process model.

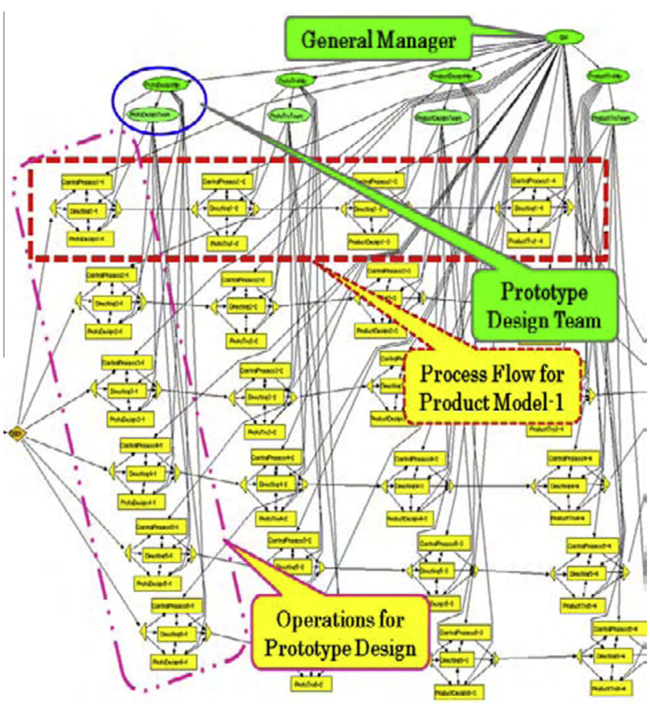

Fig. 19. Function based process model.

service organization. For instance, when a designing operation is executed, it may result in an unexpected consequence (called exception) based on a probability. In PMT simulation, when an exception is generated, the exception report and its decision are sent through the network.

Finally, all objects in the models are defined by setting their properties. For instance, ''work volume'' is a property to define a SOP representing how many people and hours are required for completing the operation. Table 4, Table 5, and Table 6 show the attributes setting of SOPs respectively.

Table 4 shows the attributes setting of the design operations, prototype design, prototype try, product design, and product try. As described in the Section 4.2, the prototype design is the most complex and the product try is the simplest operation. The complexity decreases from the prototype design to the product try gradually. Based on the information gathered in the section, the complexity of the four operations, were defined as ''High'', ''High'', ''Medium'', and ''Low'' respectively. ''Uncertainty'' defines the information dependency on the other operations. The designing operations and the directing operations have the information dependency each other. Especially in the first two operations, the prototype design and the prototype try, there must be more information exchanges than the other operations. Based on this observation, the uncertainties of the first two operations were defined as ''High''. In this simulation model, the higher the uncertainty is, the more the communication events are generated. ''Priority'' defines the degree of the attentions paid to the operations. The higher the priority of a SOP is, the earlier the SOP might be executed. In this simulation model, all operations have same degree of priority. ''Work Volume'' defines the estimated time and the number of staffs to perform the operation. The values were defined through the interview to the manager of the target process. ''Communication life time'' defines the deadline of a communication response. In the target organization, all communication requests were expected to be responded within 72 h. Based on the observation, all communication events not processed within 72 h were evaporated in the simulation.

Table 5 shows the attributes setting of the directing operations, directing prototype design, directing prototype try, directing product design, and directing product try. The directing operations were modeled as dummies in order to virtually realize the communication interaction between the directors and the designers. A director is needed to execute a direct operation only when the director receives a communication request from its directing design team. The communication request has a certain amount of work volume (in this simulation case, it was 0.5 man – hours) and is processed as a directing work by the director. In this point of view, the values of the work volumes of the all directing operations were defined as ''0''. The complexities of the all directing operations were defined as ''Low'', meaning simple operations. The operations require the directing skill, a type of management skills, however, they are general and not expertise. The uncertainty of the all directing operations were defined as ''Low'', meaning less dependent on the designing operations, because it was observed that the most communication requests were sent from the design team to the director through the interview (Section 4.2). The priorities and the communication life time were defined as the same for the designing operations.

Table 6 shows the attributes setting of the controlling operations, controlling prototype design, controlling prototype try, controlling product design, and controlling product try. The controlling operations were modeled as dummies in order to virtually realize the communication interaction between the general manager and the directors. All the priorities, therefore, were defined as the same for the directing operations.

In addition, as an example of the attributes setting of a SOP, the screenshots of modeling a SOP is shown in Fig. 20.

''Skills'' and their ''levels'' are the properties defining a position representing how fast and appropriately the position can complete the allocated SOPs. The attributes setting of each object is reflected in the simulation behavior. As an example, how to assign the human resources to a position is shown in Fig. 21. The human resource allocation examined in this case study is shown in Section 6.

Table 4
The attributes setting of SOPs (the designing operation).

Attributes	Operation type: the designing operations			
Name	Prototype design	Prototype try	Product design	Product try
Required skill	Prototype design	Product try	Product design	Product try
Complexity	High	High	Medium	Low
Uncertainty	High	High	Medium	Low
Work volume: Man – hours	13.33	13.33	13.33	13.33
Priority	Medium	Medium	Medium	Medium
Communication life time: hours	72	72	72	72

Table 5
The attributes setting of SOPs (the directing operation).

Attributes	Operation type: the directing operations			
Name	Directing prototype design	Directing prototype try	Directing product design	Directing product try
Required skill	Directing	Directing	Directing	Directing
Complexity	Low	Low	Low	Low
Uncertainty	Low	Low	Low	Low
Work volume: Man – hours	0	0	0	0
Priority	Medium	Medium	Medium	Medium
Communication life time: hours	72	72	72	72

Table 6
The attributes setting of SOPs (the control process operation).

Attributes	Operation type: the control process operations			
Name	Controlling prototype design	Controlling prototype try	Controlling product design	Controlling product try
Required skill	Controlling	Controlling	Controlling	Controlling
Complexity	Low	Low	Low	Low
Uncertainty	Low	Low	Low	Low
Work volume: Man – hours	0	0	0	0
Priority	Medium	Medium	Medium	Medium
Communication life time: hours	72	72	72	72

6. Simulating the business process

Our simulation based approach evaluates a designed process in a three dimensional space. This space is formed with three axes, which are the Client axis, the Enterprise axis, and the Performance axis (Fig. 22). The client axis represents a setting of the market environment such as the demand changes, the changes of the corporate market strategies, and the changes of the relating laws. The enterprise axis represents a setting of the enterprise business process such as the changes of the human resource allocation, the changes of the organization structure, and the unit labor cost changes. The performance axis represents a process performance such as the process throughput, profit, efficiency, and service quality with respect to the defined market and enterprise setting. In our simulation based approach, the impacts of the potential risks caused from the market or enterprise to the performances are examined moving the setting along the two axes, the client and enterprise axis. Before executing the simulations, how to simulate the designed business processes are systematically planned based on the concept of this evaluation space.

6.1. Planning simulation

Prior to executing the simulations, the examined process models must be prepared considering the potential risks to be examined and the performance measures based on the evaluation space. In the simulation models, the performance measures are the measured variables and the potential risks are the setting variables. The objective of this case study is to examine and predict the impact of the overload on the throughput (Tolerance to the overload) and OJT (On Job Training) with regards to the two different process types. In order to fulfill the objectives, their sensitivities against the client factors and the enterprise factors must be examined. The set of examined performance measures and the factors as the potential risks are summarized in Table 7 and represented in Fig. 23. The design work load, the types of the process, and the human resource allocation were varied through the simulations and their impacts to the design throughput and OJT were examined.

6.2. Simulation scenarios

With respect to the enterprise setting, four types of scenarios were applied (Table 8). In Scenarios 1 and 2, the average skill levels of all design teams were equal. Scenarios 1 and 2 were for the product based process (Table 10) and the function based process (Table 9), respectively. Scenario3 was for the product based process (Table 10). Its average skill levels of all design teams were different from each other. Scenario4 was for the function based process (Table 9). In this scenario, the average skill levels of the two teams assigned to the first two complex operations, "prototype design" and "prototype try", were higher than the other two teams. In other words, it considered the complexity and skill level matching. The human resources shown in Table 2 were allocated into the 6 design teams, which were Model-1, -2, -3, -4, -5, and -6 design team (Table 10), for the product based process because the teams must be formed in respect to the each car model. On the other hand, they were allocated into 4 design teams (Table 9), which are Prototype design, Prototype try, Product design, and Product try team, for the function based process because the teams must be formed in respect to the each operation.

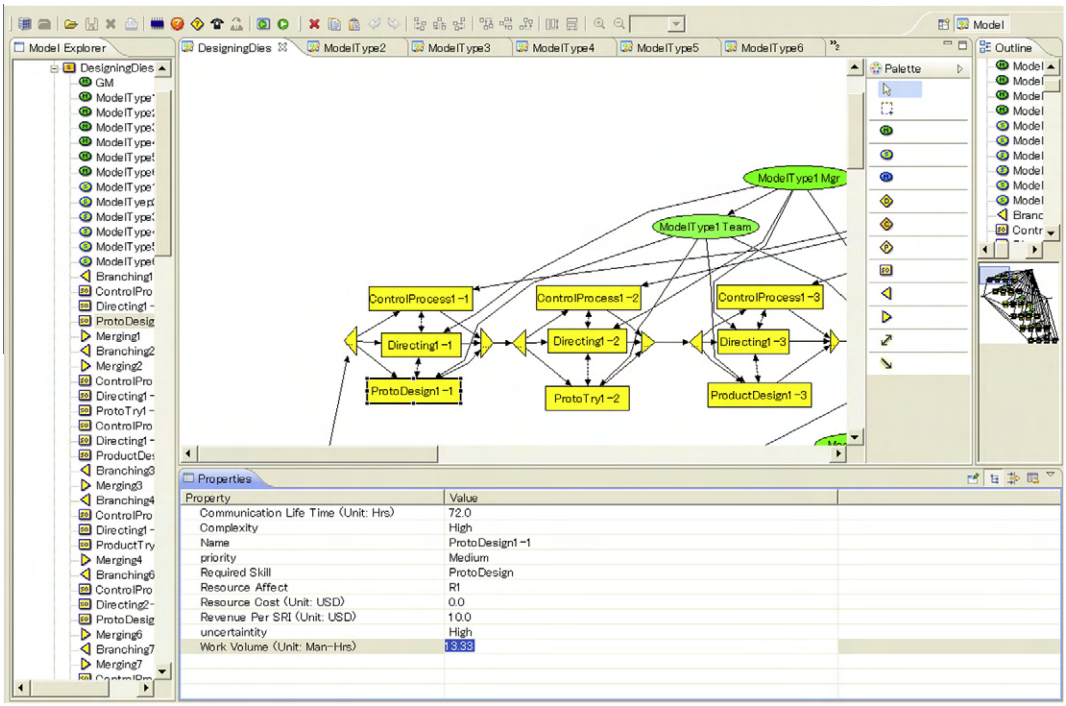

Fig. 20. The attributes setting of a SOP on the PMT modeling editor.

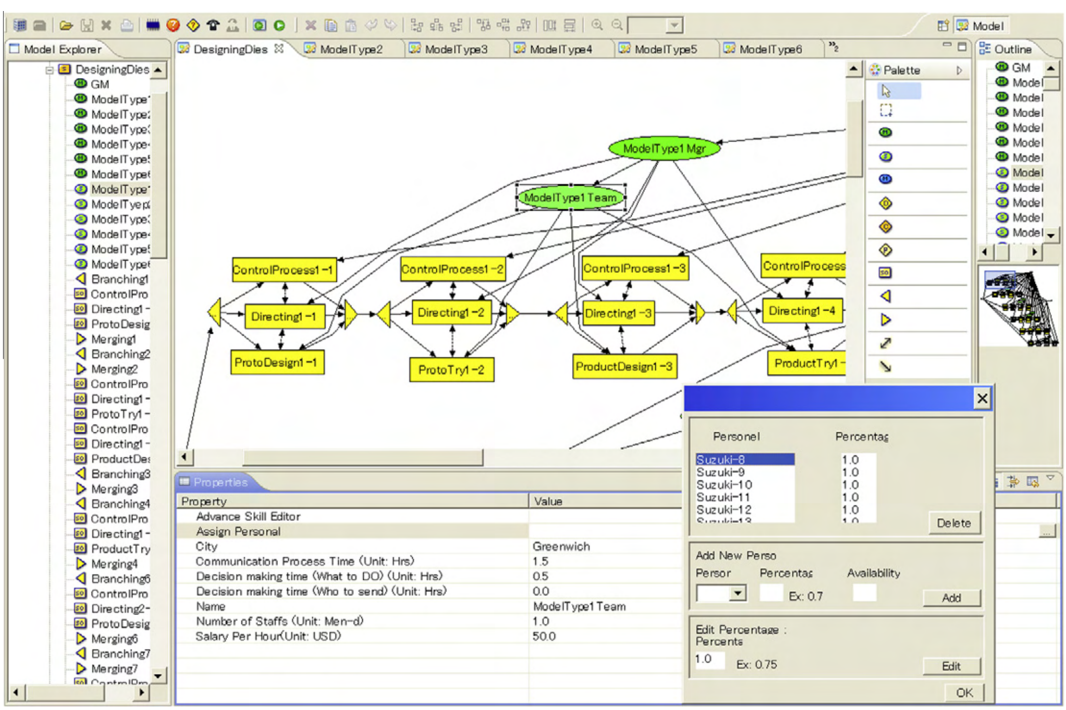

Fig. 21. Allocating human resources to a position on the PMT modeling editor.

The human allocations for the four scenarios are shown as the skill maps in Figs. 24–27. They show the types of skill the staffs possess and their levels in respect to the assigned teams. The marks "H", "M", and "L" represent the skill level of the corresponding operations and means "High", "Medium", and "Low" respectively. Fig. 24 shows the human resource allocation in scenario 1. In scenario 1, there are 6 teams, Model "1" to "6" design team, and the skill levels of all teams are equal to each other. In Fig. 24, All teams have the same number of staffs possessing high, medium, and low skill in respect to the all operations. Again, scenario 1 is for the product based process and each team was required to execute the all four operations, prototype design, prototype try, product design, and product try design.

In scenario 2, there are 4 teams, prototype design, prototype try, product design, and product try team, and the skill levels of all teams are equal to each other. As shown in Fig. 25, all teams have the same number of staffs possessing high, medium, and low skill in respect to the four operations. Scenario 2 is for the function

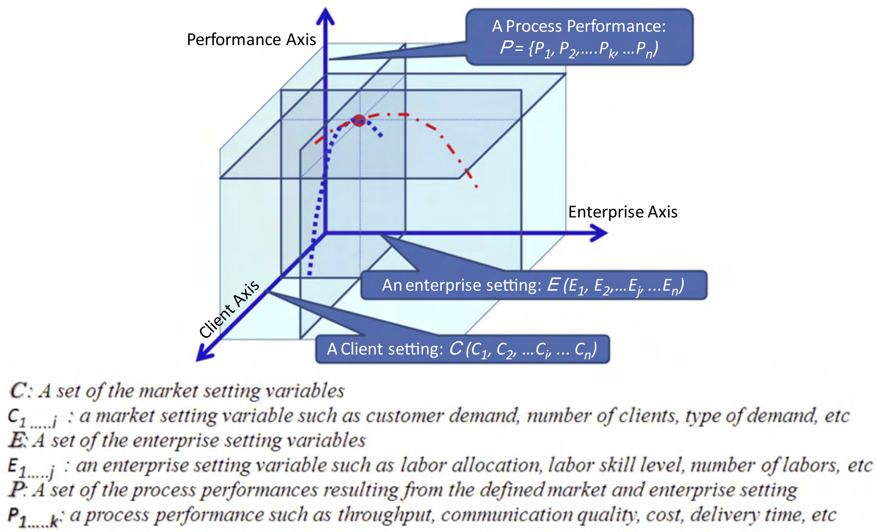

Fig. 22. Process evaluation space.

Table 7
The variables in this case study.

Variable types	Factors (axis)	Setting as potential risks
Setting variables	Client: C	• C_1 = {Design work loads}
Setting variables	Enterprise: E	• E_1 = {Types of process}
Measured variables	Performance: P	• E_2 = {Human resource allocation}
		• P_1 = {Design throughput}
		• P_2 = {OJT}

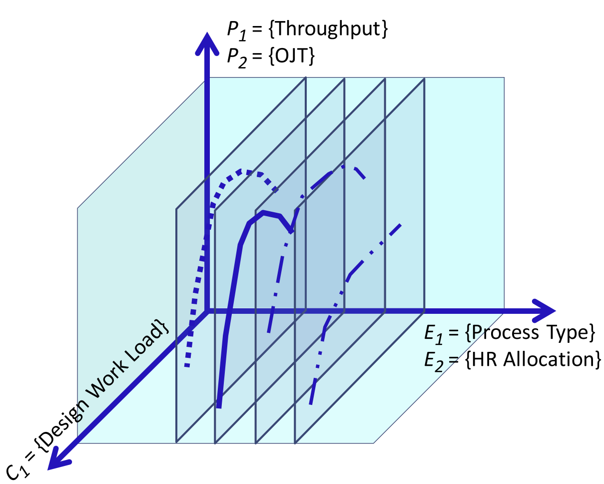

Fig. 23. The evaluation space in this case.

Table 8
Simulation scenarios by the enterprise settings.

Scenario No.	Applied for: $E_{1(i)}$	Human resource allocation: $E_{2(i)}$	
Scenario-1	Product based: PB	HRA1	Skill level of all teams are equal
Scenario-2	Function based: FB	HRA2	Skill level of all teams are equal
Scenario-3	Product based: PB	HRA3	Skill level of all teams are varied
Scenario-4	Function based: FB	HRA4	Two teams have higher skill than others

based process and each team was required to execute a specific operation for the all product models. For instance, Prototype design team in Fig. 25 was required to execute the only prototype design operation for all product models, Model 1–6.

In scenario 3, there are 6 teams, Model "1" to "6" design team, and the skill levels of all teams are varied to each other. As shown in Fig. 26, Model 1 design team has the largest number of the high skilled staffs in respect to the all operations and the number decreases from Model 1 to Model 6 design team. Model 6 design team has no high skilled staffs in respect to any operations. Scenario 3 is for the product based process and each team was required to execute the all four operations, prototype design, prototype try, product design, and product try design.

In scenario 4, there are 4 teams, prototype design, prototype try, product design, and product try team, and the skill levels of the prototype design and prototype try teams are higher than the other two teams. As shown in Fig. 27, the prototype team has the largest number of the high skilled staffs in respect to its allocated operation, the prototype design, and the number gradually decreases to the product try team. The product try team has the least numbers of the high skilled staffs in respect to its allocated operation, product try. Scenario 4 is for the function based process and each team was required to execute a specific operation for the all product models. For instance, Prototype design team in Fig. 27 was required to execute the only prototype design operation for all product models, Model 1–6.

For the all scenarios, the design work load was varied from 50% to 100% by 10% steps. Again, the load 100% means the current daily work load onto the designing-dies-service and it is 20% more than the daily load of the planned schedule due to the delay of the clay model design. Finally, 20 cases were prepared in this case study.

6.3. Performance measures

For evaluating the actual business process by the simulation model, the actual performance must be appropriately mapped to the simulation performance measures. In this case study, design throughput was mapped to the process throughput and the performance regarding the OJT was mapped to the communication quality respectively. In PMT, the process throughput and the communication quality are explicitly defined as follows.

6.4. Process throughput

The process throughput is defined by the number of completed requests from the clients (Model Types) in a specific period of time (3 months in this simulation).

Table 9
Team allocation for the function based process.

Design target	The operations which the teams were allocated to			
	1st Operation prototype design	2nd Operation prototype try	3rd Operation product design	4th Operation product try
Model 1	Prototype design team	Prototype try team	Product design team	Product try team
Model 2	Prototype design team	Prototype try team	Product design team	Product try team
Model 3	Prototype design team	Prototype try team	Product design team	Product try team
Model 4	Prototype design team	Prototype try team	Product design team	Product try team
Model 5	Prototype design team	Prototype try team	Product design team	Product try team
Model 6	Prototype design team	Prototype try team	Product design team	Product try team

Table 10
Team allocation for the product based process.

Design target	The operations which the teams were allocated to			
	1st Operation prototype design	2nd Operation prototype try	3rd Operation product design	4th Operation product try
Model 1	Model 1 design team	Model 1 design team	Model 1 design team	Model 1 design team
Model 2	Model 2 design team	Model 2 design team	Model 2 design team	Model 2 design team
Model 3	Model 3 design team	Model 3 design team	Model 3 design team	Model 3 design team
Model 4	Model 4 design team	Model 4 design team	Model 4 design team	Model 4 design team
Model 5	Model 5 design team	Model 5 design team	Model 5 design team	Model 5 design team
Model 6	Model 6 design team	Model 6 design team	Model 6 design team	Model 6 design team

Model 1 design team

ID	Operation Skill Level: Prototype design	Prototype try	Product design	Product try
1	H	H	H	H
12	M	H	H	H
13	M	H	H	H
24	M	M	M	H
25	M	M	M	H
36	L	L	L	M
37	L	L	L	M
48	L	L	L	L

Model 2 design team

ID	Operation Skill Level: Prototype design	Prototype try	Product design	Product try
2	H	H	H	H
11	M	H	H	H
14	M	H	H	H
23	M	M	M	H
26	L	M	M	M
35	L	L	M	M
38	L	L	L	M
47	L	L	L	L

Model 3 design team

ID	Operation Skill Level: Prototype design	Prototype try	Product design	Product try
3	H	H	H	H
10	H	H	H	H
15	M	H	H	H
22	M	M	M	H
27	L	M	M	M
34	L	L	M	M
39	L	L	L	M
46	L	L	L	L

Model 4 design team

ID	Operation Skill Level: Prototype design	Prototype try	Product design	Product try
4	H	H	H	H
9	H	H	H	H
16	M	M	H	H
21	M	M	M	H
28	L	M	M	M
33	L	L	M	M
40	L	L	L	M
45	L	L	L	L

Model 5 design team

ID	Operation Skill Level: Prototype design	Prototype try	Product design	Product try
5	H	H	H	H
8	H	H	H	H
17	M	M	H	H
20	M	M	H	H
29	L	M	M	M
32	L	L	M	M
41	L	L	L	L
44	L	L	L	L

Model 6 design team

ID	Operation Skill Level: Prototype design	Prototype try	Product design	Product try
6	H	H	H	H
7	H	H	H	H
18	M	M	H	H
19	M	M	H	H
30	L	M	M	M
31	L	L	M	M
42	L	L	L	L
43	L	L	L	L

Fig. 24. The allocated HR skill maps in scenario 1.

$$TP = \frac{Total\_TP}{Sim\_T} \quad (2)$$

where *TP*: Process Throughput (Number of requests / Month).
Total_TP: Throughput during a simulation period (#).
Sim_T: Simulation period (Month).

6.5. Communication quality

Communication quality is defined by the ratio of the number of responded communications to the number of the initiated communications within a defined period of time. In this simulation model, a communication-request evaporates after 72 h. It means that the communication fails if the position cannot respond it within 72 h. As the number of responded communications decreases, communication quality becomes worse (low).

$$Comm\_Quality = \frac{Processed\_Comm}{Initiated\_Comm} \quad (3)$$

where *Comm_Quality*: Communication Quality.
Processed_Comm: The number of responded communications by a position (#).
Initiated_Comm: The number of received communications by a position (#).

Prototype design team

ID	Operation Skill Level: Prototype design	Prototype try	Product design	Product try
1	H	H	H	H
8	H	H	H	H
9	H	H	H	H
16	M	M	H	H
17	M	M	H	H
24	M	M	M	H
25	M	M	M	H
32	L	L	M	M
33	L	L	M	M
40	L	L	L	M
41	L	L	L	L
48	L	L	L	L

Prototype try team

ID	Operation Skill Level: Prototype design	Prototype try	Product design	Product try
2	H	H	H	H
7	H	H	H	H
10	H	H	H	H
15	M	H	H	H
18	M	M	H	H
23	M	M	M	H
26	L	M	M	M
31	L	L	M	M
34	L	L	M	M
39	L	L	L	M
42	L	L	L	L
47	L	L	L	L

Product design team

ID	Operation Skill Level: Prototype design	Prototype try	Product design	Product try
3	H	H	H	H
6	H	H	H	H
11	M	H	H	H
14	M	H	H	H
19	M	M	H	H
22	M	M	M	H
27	L	M	M	M
30	L	M	M	M
35	L	L	M	M
38	L	L	L	M
43	L	L	L	L
46	L	L	L	L

Product try team

ID	Operation Skill Level: Prototype design	Prototype try	Product design	Product try
4	H	H	H	H
5	H	H	H	H
12	M	H	H	H
13	M	H	H	H
20	M	M	H	H
21	M	M	M	H
28	L	M	M	M
29	L	M	M	M
36	L	L	L	M
37	L	L	L	M
44	L	L	L	L
45	L	L	L	L

Fig. 25. The allocated HR skill maps in scenario 2.

Model 1 design team

ID	Operation Skill Level: Prototype design	Prototype try	Product design	Product try
1	H	H	H	H
2	H	H	H	H
3	H	H	H	H
4	H	H	H	H
5	H	H	H	H
6	H	H	H	H
37	L	L	L	M
38	L	L	L	M

Model 2 design team

ID	Operation Skill Level: Prototype design	Prototype try	Product design	Product try
7	H	H	H	H
8	H	H	H	H
9	H	H	H	H
10	H	H	H	H
11	M	H	H	H
12	M	H	H	H
39	L	L	L	M
40	L	L	L	M

Model 3 design team

ID	Operation Skill Level: Prototype design	Prototype try	Product design	Product try
13	M	H	H	H
14	M	H	H	H
15	M	H	H	H
16	M	M	H	H
17	M	M	H	H
18	M	M	H	H
41	L	L	L	L
42	L	L	L	L

Model 4 design team

ID	Operation Skill Level: Prototype design	Prototype try	Product design	Product try
19	M	M	H	H
20	M	M	H	H
21	M	M	M	H
22	M	M	M	H
23	M	M	M	H
24	M	M	M	H
43	L	L	L	L
44	L	L	L	L

Model 5 design team

ID	Operation Skill Level: Prototype design	Prototype try	Product design	Product try
25	M	M	M	H
26	L	M	M	M
27	L	M	M	M
28	L	M	M	M
29	L	M	M	M
30	L	M	M	M
45	L	L	L	L
46	L	L	L	L

Model 6 design team

ID	Operation Skill Level: Prototype design	Prototype try	Product design	Product try
31	L	L	M	M
32	L	L	M	M
33	L	L	M	M
34	L	L	M	M
35	L	L	M	M
36	L	L	L	M
47	L	L	L	L
48	L	L	L	L

Fig. 26. The allocated HR skill maps in scenario 3.

7. Analyzing the design process

At the end, the four sets of the simulation results with respect to the four enterprise cases, Scenarios 1–4, were obtained (Fig. 28). Through the following analysis, the impacts of design work overload on the process throughput and the communication quality were exposed with respect to the product based and function based process. In addition, the effective human resource allocation for improving the throughput and the communication was examined with respect to the two processes. Finally, as a report to the responsible manager's questions for the process innovation, the applicable knowledge in this case was provided based on the analysis.

7.1. Structural impact on both the process throughputs

Fig. 29 shows the changes of the throughput to the workload with respect to the product based process. The only difference between the two scenarios is the human resource allocation in the skill perspective. As shown in the figure, the peak throughput of Scenario 1 is higher than that of Scenario 3, indicating that the maximum throughput can be improved by human resource allocation. However, the improvement is only effective around the peak and the throughput after the peak decreases as the workload for the design process increases.

This observation from the simulation result shows the good match to the actual observation of the responsible manager. This peak out observed in the actual product based process was the first motive for him to consider the process innovation.

In this simulation model, the pickup strategy a team follows is FIFO (First In First Out) based on the interview to the responsible manager. It means that the earliest arriving work is chosen as the next work to be done. A team of the product based process must execute the four operations on a design work. After an operation is done on a work, the work in process must wait for the other works done before executing the next operation. The more

Prototype design team

ID	Operation Skill Level: Prototype design	Prototype try	Product design	Product try
1	H	H	H	H
2	H	H	H	H
3	H	H	H	H
4	H	H	H	H
11	M	H	H	H
12	M	H	H	H
13	M	H	H	H
14	M	H	H	H
21	M	M	M	H
22	M	M	M	H
23	M	M	M	H
24	M	M	M	H

Prototype try team

ID	Operation Skill Level: Prototype design	Prototype try	Product design	Product try
5	H	H	H	H
6	H	H	H	H
7	H	H	H	H
15	M	H	H	H
16	M	M	H	H
17	M	M	H	H
25	M	M	M	H
26	L	M	M	M
27	L	M	M	M
31	L	L	M	M
32	L	L	M	M
33	L	L	M	M

Product design team

ID	Operation Skill Level: Prototype design	Prototype try	Product design	Product try
8	H	H	H	H
9	H	H	H	H
18	M	M	H	H
19	M	M	H	H
28	L	M	M	M
29	L	M	M	M
34	L	L	M	M
35	L	L	M	M
36	L	L	L	M
37	L	L	L	M
46	L	L	L	L
47	L	L	L	L

Product try team

ID	Operation Skill Level: Prototype design	Prototype try	Product design	Product try
10	H	H	H	H
20	M	M	H	H
30	L	M	M	M
38	L	L	L	M
39	L	L	L	M
40	L	L	L	M
41	L	L	L	L
42	L	L	L	L
43	L	L	L	L
44	L	L	L	L
45	L	L	L	L
48	L	L	L	L

Fig. 27. The allocated HR skill maps in scenario 4.

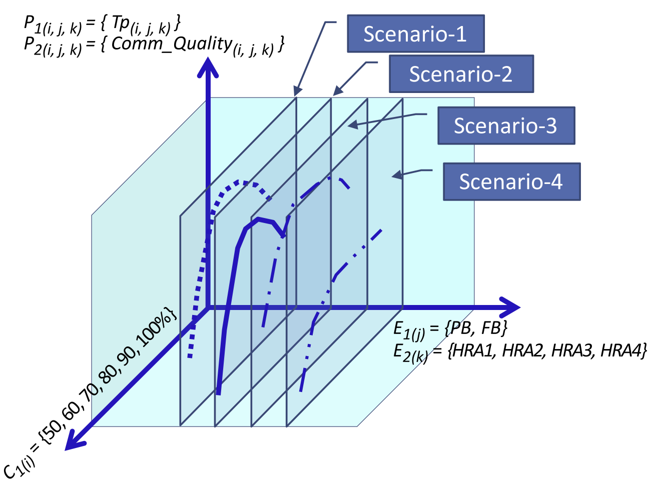

Fig. 28. Four sets of the simulation results.

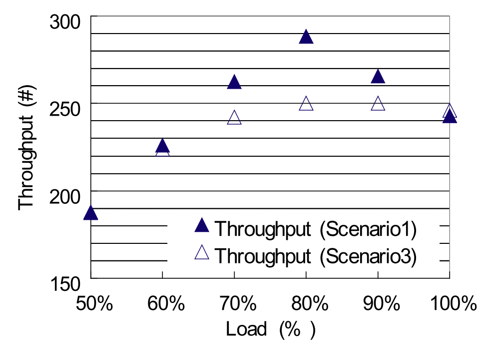

Fig. 29. Process throughput (product based process).

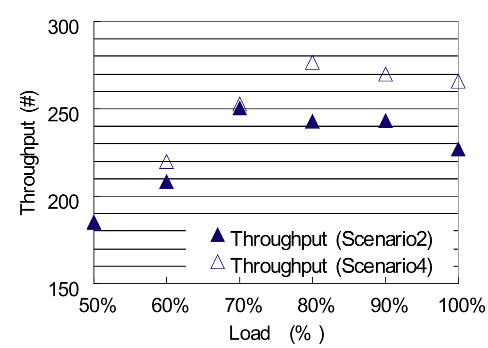

Fig. 30. Process throughput (function based process).

new works the design team receives, the longer the work in process must wait for the next operation. Finally, in a certain load, the number of the works in process gets increasing and the throughput gets decreasing.

Fig. 30 shows the changes of the throughput in response to the workload in case of applying a function based process. As shown in Fig. 30, the throughput of Scenario 4 is higher than that of Scenario 2. The only difference between the two scenarios is the human resource allocation in the skill perspective. From this result, it is recognized that the maximum throughput can be improved by the human resource allocation. In addition, the improvement is still effective after the peak and the throughput after the peak remains almost the same as its maximum.

A team of the function based process only executes an assigned operation on a design work. When a first team receives more new works than its capability, it only executes the assigned operation as much as it is capable and sends the works done to the next team. The next team receives as much works as the predecessor team is capable to execute. As a result, even if the work load exceeds the capability of the first team, the following teams can process the constant amount of works in the function based process.

7.2. Structural impact on both communication qualities

Fig. 31 shows the communication quality among the design teams with respect to the various daily workloads as a client setting. In the figure, the communication qualities for processing the prototype design operation and the product try operation are shown. As mentioned in 4.2, the Prototype design is the first and most complex operation. On the other hand, the Product try is the last and most simple operation. In order to clarify the impact of the process structure on the communication, the product based process was given an advantage regarding the human resource allocation. To the product based process, the better human resource allocation regarding the processing capability, Scenario-1, was applied. On the other hand, to the function based process, the worse allocation, Scenario-2, was applied in order to emphasize the effect of the function based process to the communication quality.

In the product based process, the communication qualities of Prototype-Design and Product-Try become worse at the same pace

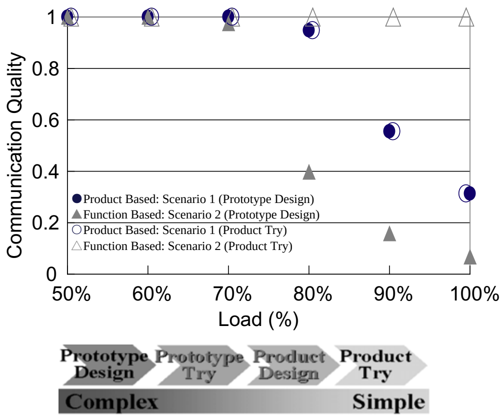

Fig. 31. Communication processing performance.

after a certain workload level. It is considered that the communication qualities of all operations would decrease in a similar way when the workload reaches to the maximum capability of all operations in a process.

This observation from the simulation result shows the good match to the actual observation. According to the responsible manager, after many fresh-unskilled designers were allocated, the design throughput got drastically worse due to the OJT. In other words, although there was no available time for OJT, the effort spent for it accelerated the reduction of the design throughput. This throughput reduction due to the OJT observed in the actual product based process was the second motive for him to consider the process innovation.

In the function based process, the communication quality of Prototype-Design becomes worse after a certain workload level. However, the communication quality of Product-Try stays almost constant with all load levels. It is considered that the last operation Product-Try is less sensitive to the overload situations because the first operation Prototype-Design would not send to the operation the amount of work more than it can complete.

7.3. Case summary

Through the analyses described above, we concluded the impact of the overload on the design throughput and OJT as follows.

Design Throughput:

- Function based process is more tolerant to the overload than the product based process.
- Although human resource allocation to the product based process can improve maximum throughput, it cannot improve its tolerance to overload.
- The human resource allocation to the function based process can improve the maximum throughput and the tolerance to the overload.
- In function based process, human resource allocation must consider the skill matches between the individuals and assigned operations.

The Quality of the OJT:

- When the product based process is overloaded or highly loaded, the unskilled designers are unable to receive enough information to complete their work because they need more information than the skilled designers.
- In the function based process, the unskilled designers should be allocated at the last or later operations in order to get enough information for them.

Table 11
Problems and predictions.

Problems	Predictions	
	Product based process	Function based process
Tolerance to the overload	• Weak	• Improved by human resource allocation
Where to allocate the unskilled designer	• Cannot be improved • Cannot be solved	• Allocating to the last operation

As a conclusion of this case study, we assisted the manager's intuitive idea to reform the press-forming-dies design process from the product based process to the function based process with the quantitative evidences. The predictions provided through our proposing approach are summarized in Table 11.

8. Conclusions

In this paper, we presented a computer simulation based approach to business process design. PMT, a model of enterprise business processes, is a general business modeling tool that captures basic concepts, relationships, and processes found in the literature of organization behavior. In addition, it expands the action workflow model by treating business clients as *consumers* (of the service processes) and enterprise processes as *performers*. To embed these general concepts into a computational model and make it powerful enough to represent and simulate real world business processes, modeling efforts have been made to capture not only production work, but also coordination and managerial work such as information exchange, exception report, and decision making. Together with an easy to operate graphical user interface, PMT is a general process modeling tool that can be applied to represent various types business and engineering processes at different levels, from job shop design and manufacturing to enterprise level strategic client selection and service process portfolio management.

As an application example of our proposed simulation based approach for process design, a press-forming-dies design process was examined using PMT. Through this examination, it has been demonstrated that PMT is a highly useful and effective technology for business process design. First, this examination verified the usability of the PMT for modeling and simulating the actual design processes. Especially in the analysis, the concept of the client object contributed to exposing the impacts of the overload on the throughput and the OJT quality. Second, it demonstrated the capability of PMT to sense the possible risks in future through simulation. In this examination, the effect of human resource allocation to the throughput was discussed as a factor that impacts on the design throughput. This knowledge enables the responsible managers to prepare for the risk before it brings real critical problems. In addition, it was also verified that the simulation results could deliver effective solutions for designing business processes. In this case, reforming the current product based process into a function based process was recommended as a solution considering the tolerance to the overload. This solution was generated through the simulation based analysis with quantitative predictions. This recommendation was accepted by the manager who was engaged in this case study and the quantitative evidences were the driving force that led the manager to making the process change decision.

In the case study, although the function based process was recommended as a solution, it does not mean that it should always be recommended. In this case, the tolerance to the overload was the most crucial requirement. In other words, as a possible market risk, the changes of the design work load had to be considered. If it was not, the recommendation would have been different. In this way, our PMT based approach serves as a test bed in which various business scenarios can be innovated and tested, leading to accumulations of process management knowledge that can be applied to guide practical decision making in various conditions covering the market, the enterprise conditions, and the business objective.

From a theoretical perspective, the model proposed in this research is unique in comparison with existing approaches. Traditional business process reengineering (e.g., [18] focuses mostly on clarification and rationalizing processes and resources rather than producing implementable and computational models. The previous computational modeling approaches are either project centered (e.g., [21]) or product development specific (e.g., [9]). Little has been done in developing models that can capture the perpetual business operation processes that vary depending on the market situations. Recent research has addressed service-oriented process modeling issues (e.g., [6]), but the work has been limited in ontology development and web-computer applications. The major contributions of this research include (1) a service based computational model of business organizations and processes that not only identifies key concepts and operations but also allows trade-off studies by comparing different organization and process designs along three dimensions of market situation, enterprise setting, and performance, and (2) a proven useful methodology for modeling specific business situations for the purposes of analysis and design. The case studies presented in this paper demonstrate the effectiveness of our proposed model and methodology. Our ongoing research is advancing in two directions. First we continue to perform more case studies in various industrial domains. By collecting more cases and building case models, we seek opportunities to revise and update our PMT model as well as to create a shareable database of executable PMT models. Second, as the database of PMT case models grows, we intend to develop "mining" technologies that can be used by the database users to extract process management knowledge from the sheer database of PMT models.

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