INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED11
15 - 18 AUGUST 2011, TECHNICAL UNIVERSITY OF DENMARK

MANAGEMENT OF PRODUCT DEVELOPMENT PROJECTS THROUGH INTEGRATED MODELING OF PRODUCT AND PROCESS INFORMATION

Kazuya Oizumi[1], Kei Kitajima[2], Naoto Yoshie[3], Tsuyoshi Koga[4] and Kazuhiro Aoyama[1]
(1) The University of Tokyo (2) Hitachi, Ltd. (3) DeNA Co., Ltd. (4) Yamaguchi University

ABSTRACT
As the complexity of mechatronic products in particular has increased, the difficulty of managing development projects is steadily increasing. For better management of product development projects, this paper proposes an integrated model of product and process information. Most information in the proposed model is described by a multiple domain matrix (MDM) that consists of a domain mapping matrix (DMM) and a design structure matrix (DSM). Furthermore, to overcome the difficulty of acquiring information, this paper proposes methodologies of model-based assistance for model refinement, including multiple cyclic processes to continuously refine models. Computational methods to utilize the acquired model are also discussed. The proposed methods employ techniques on DSMs and DMMs to deliberate candidate development processes, incorporating manageability of design process and resource allocation. Therefore, the methods provide planners with an arena to consider the tradeoff between the development span and the difficulty of managing development processes. Finally, an example of a solar boat development project demonstrates the plausibility of the proposed methods.

Keywords: Project Management, Product Development, Product Modeling, Multiple Domain Matrix, Design Structure Matrix

1 INTRODUCTION
Of the multitude of products, mechatronic products in particular have become significantly complex because of technological competition and shortened product development cycles. As a result, the achievement of high quality has gradually become more difficult. At the same time, as a product becomes more complex, the corresponding development project also becomes more complex. For this reason, the management of a product development project becomes quite difficult. In fact, product failures originating at the product development phase have significantly increased in recent years.
Products are released with their embedded problems unnoticed. One reason for this is the complexity of a product development project and the concomitant difficulty of managing it. Many individuals are involved in a project, on which each has his/her own perspective (Figure 1). This makes it more difficult to manage a project while maintaining a broad overview. In other words, it is not entirely clear how a part of a project affects the whole, and this leads to quality failures. Therefore, project managers are struggling to better manage product development projects.
This study aims to establish a management methodology for product development projects by means of an integrated model of product and process information. By integrating discretely recognized information on a project into a model, relations among the contents of this information are understood and visualized. This leads to improved management of a project.

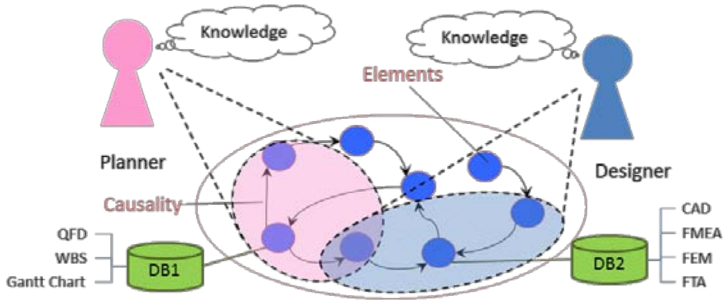

Figure 1. Different views on a project

In this study, a multiple domain matrix (MDM) [1], [2] is employed to yield a model for product and process information. An MDM, which describes the relations among the contents of project information as a matrix, is divided into domain mapping matrices (DMMs) [3] and design structure matrices (DSMs) [4]. Quality function deployment (QFD) [5]–[7] is also employed to yield DMMs.

Several studies have discussed the application of MDM, DMM, and DSM to the management of designs and/or processes. Eppinger suggested employing DSM to obtain product development processes with a lower likelihood of iterations [8]. Clarkson proposed a method to predict the potential propagation of effects triggered by changing a design parameter [9]. Lindemann explored MDMs to understand complex systems from a structural point of view [10].

This paper proposes a method to assist process coordination that considers both product information and resource constraints. In other words, the proposed method can deal with the possible effects of resource constraints on process coordination. For instance, design processes are coordinated or reordered by taking prototyping and test processes into account.

Based on modeling by means of MDM, this paper first introduces a methodology for information acquisition and refinement. An acquired model can be refined through confirmation of its internal consistency. Second, the utilization of an acquired model to identify better design processes that lead to higher quality and reduced probability of failure is discussed.

2 INTERACTIVE MODELING OF PRODUCT AND PROCESS INFORMATION

2.1 Modeling approach

To model information, it is important to link product and process information by considering their relations. Provided that problems of project management originate from indirect and unnoticed relations among the contents of product information, it is important to understand their relations precisely. In the proposed method, modeling is implemented in three steps to reflect this concern: product information modeling, process information modeling, and model integration.

2.2 Product information modeling

The following three domains of elements represent product information.

- Design parameters
- Structure elements
- Function metrics

Design parameters are specifications and characteristics of a product determined through design. Structure elements are the physical components of a product. Function metrics evaluate whether each function of a product meets a required level of performance. Each domain has many elements with complex inter- and intra-domain relations.

2.3 Process information modeling

A process consists of three types of tasks, which are the minimal units of business processes.

- Design task
- Prototyping task
- Test task

Design parameters are determined in each design task. Similarly, appropriate parameters are determined for each prototyping or test task. Prototyping tasks are where structure elements are actually manufactured. Test tasks evaluate whether function metrics achieve the required performance levels. Thus, all tasks are defined in relation to the corresponding product information. Further, the human resources and equipment needed to implement the tasks are defined as resources.

2.4 Model integration

A representation of product and process information integrated by means of an MDM is shown in Figure 2. In an MDM, the intra-domain matrix (i.e., the DSM) depicts the relations within elements in a specific domain. Although intra-domain relations in a product model simply depict non-directional relations, the relations in a task domain can be directional, i.e., they may define order.

As for inter-domain relations, design parameters are related to both function metrics and structure elements because they realize functions and strongly affect the determination of product structure,

respectively. Thus, it is possible to fill in the corresponding matrices. Figure 3 illustrates these relations using both matrix and network representations.
In essence, the relation between product and process information is one of allocation. That is, design parameters are defined in the design task, structures are realized in the prototyping task, and function metrics are evaluated in the test task. Here, it is important to match their levels of abstraction.
The relations between tasks and resources are also those of allocation. By describing the workload of tasks and the power of resources, it is possible to obtain a Gantt chart [11]. At the same time, this can constrain the order of tasks. Figure 4 shows an example of a Gantt chart.

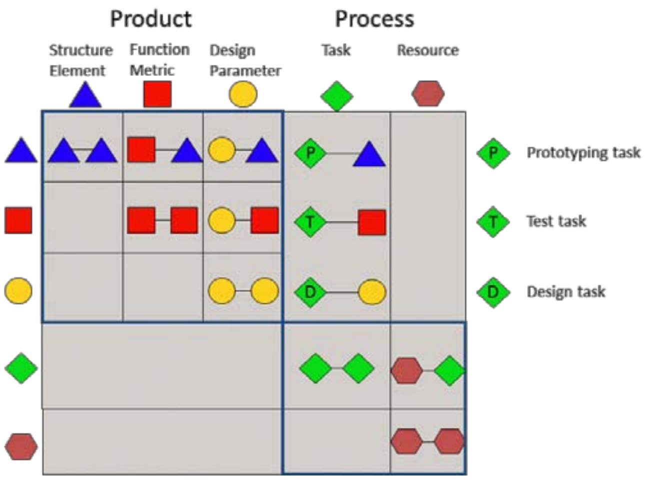

Figure 2. Overview of product and process information by means of an MDM

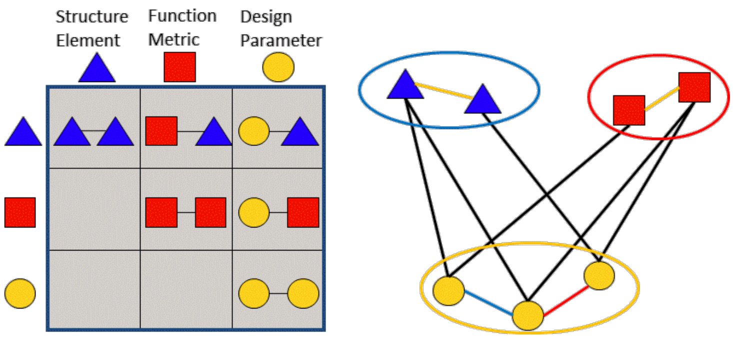

Figure 3. Relations among structure elements, function metrics, and design parameters in both matrix and network representations

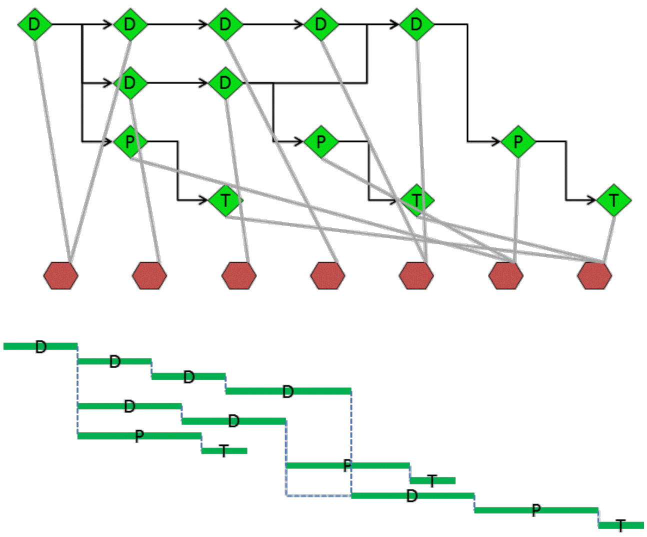

Figure 4. Allocation of resources and deducted Gantt chart

3 INFORMATION ACQUISITION AND REFINEMENT

3.1 Difficulty acquiring information

As information on a project is recognized separately, information between different engineers in particular can be lacking. Furthermore, some relations are difficult to recognize. Therefore, it is almost impossible to acquire complete information in a model. The methodology presented here is intended to refine models based on partial information.

Some relations tend not to be recognized explicitly. For instance, although relations among function metrics and design parameters are explicitly recognized, relations among design parameters are rather implicitly recognized. In other words, relations within the same domain tend to be implicitly recognized and thus lacking information. Verifying the consistency between a direct intra-domain relation and an indirect intra-domain relation mediated through other domains can help refine such incomplete information.

As for design parameters frequently referred to and changed through the design process, it is important to understand the possible effects when they are changed and what other parameters should be adjusted to compensate for these effects. For this reason, a description of relations is quite important and required to approximate reality. For refinement of an acquired model, this method suggests complementation of information with partial information inputs, as shown in Figure 5.

3.2 Refining acquired models

It can be said that design parameters that share the same function metrics or structure elements are related. This general rule can be used to complement missing information in a model. The right side of Figure 6 illustrates this complementation process.

Using this process, it is possible to refine a model by comparing it with an acquired model. The procedures are as follows.

1. Describe relations among design parameters that are recognized by the engineers involved. Then visualize them in matrix form.
2. Complement relations among design parameters through function metrics and structure elements.
3. Compare the two resulting matrices, identify contradictions, and make corrections.

Figure 6 illustrates an example. The colored cells suggest complementary relations through other domains, whereas the black checks are relations recognized by engineers. The vividness of cells reflects the strength of the complemented relations. Cells with yellow borders show contradictions. That is, although strong relations are suggested through other domains, the relations are not acquired from designers. Likewise, cells with blue borders show contradictions in the other direction.

By focusing on these contradictions, it is possible to consider errors, misunderstandings, and unrecognized relations. This subsequently leads to the refinement of a model, thereby improving its accuracy.

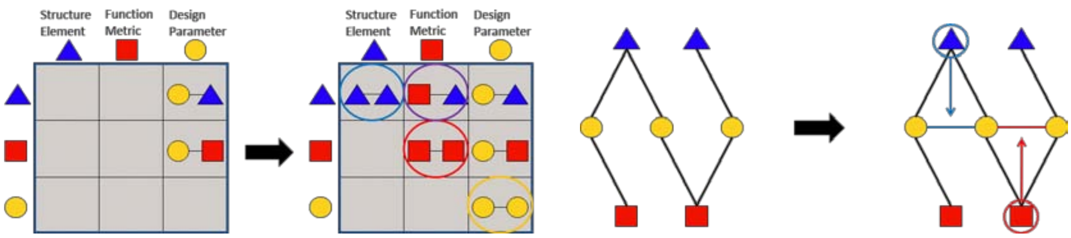

Figure 5. Complementation of information with partial information inputs

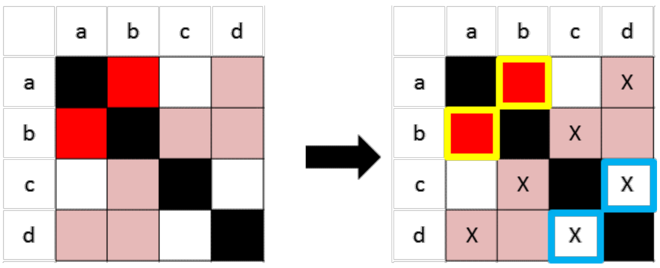

Figure 6. Suggestion of complementary relations

3.3 Detailing dependencies

The section above addressed only the "presence or absence" of relations. However, it is preferable to use more detailed information. This section discusses how to enrich the information in a model.

To begin with, information can be categorized according to its association with domains: information associated with function metrics, design parameters, and the relations among them. The information to be associated with a model is explained below. Figure 7 illustrates an overview of the information associated with a model.

Information associated with function metrics

- Importance
  Function metrics differ from one another in terms of importance. Design philosophy, principles, and decision-making give importance to function metrics.
- Association with function
  A function metric reflects a part of the functionality of a product. During a test, several metrics are tested together within a functional unit. Thus, function metrics are associated with functions.

Information associated with design parameters

- Importance
  Design parameters differ from one another in terms of their importance, which is determined through their relations to other elements.
- Technical difficulty
  When a design parameter may cause trade-offs among function metrics, the determination of such parameters is rather difficult. For instance, increasing the value of a parameter may diminish one function metric and improve others. Otherwise, design parameters that are preferable when close to a target are also rather difficult to determine.
- Association with structure
  Design parameters are associated with a physical structural element.

Information associated with relations among function metrics and design parameters

- Sensitivity
  Changing some of the design parameters strongly affects function metrics. Sensitivity, which indicates the strength of such effects, can be represented numerically.
- Direction of control
  Whereas sensitivity expresses the extent of the effect, the direction of control is expressed by the sign (plus or minus). For instance, when increasing the value of a design parameter worsens function metrics, the direction of control is negative for this relation.
- Preference for control
  In design tasks, some design parameters are given as uncontrollable variables for achieving a required function metric because they are determined to achieve another function metric. Therefore, there is a preference for controlling each parameter in connection with respective function metrics.

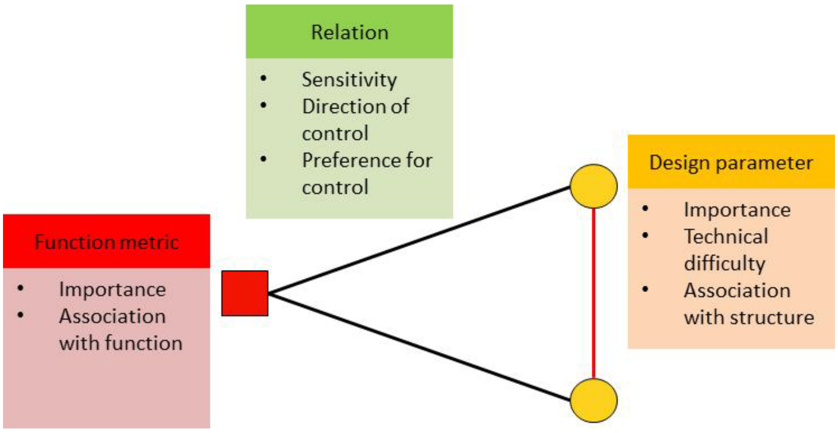

Figure 7. Information associated with a model

3.4 Typology of dependencies

The relations among design parameters are dependencies because it can be said that determination of a parameter with relations to other parameters are dependent on them in some way. These dependencies can be categorized as follows: those that are direct, those explained through function metrics, and those explained through structure.

Dependencies specified by function metrics

As shown above, some design parameters are related to common function metrics. Their dependencies can be analyzed by means of the information associated with them.

- Prioritize parameters with preference for control
  There are design parameters to be controlled to achieve a certain function metric and those not expected to be controlled for this purpose. Therefore, it is possible to prioritize parameters from this viewpoint. The left side of Figure 8 illustrates this type of prioritization. Comparing two design parameters related to the same function metric, in which preference for control exists for one but not for the other, the former design parameter is given priority over the latter one.
  If the preferences are the same (preference for control is either present or absent for both), neither is given priority. However, they remain dependent on each other to some extent. Thus, the priority between them is bidirectional (as shown on the left side of Figure 8).
- Prioritize technically difficult parameters
  Some design parameters are difficult to control because they cause trade-offs among function metrics. Postponing the determination of these parameters makes it increasingly difficult to find an optimal design. Thus, they should be determined prior to other design parameters. The right side of Figure 8 illustrates this type of prioritization.
- Prioritize sensitive parameters
  Each design parameter can affect function metrics in a different way. If a parameter strongly affects function metrics, it can be considered to have priority over others.
- Weighting dependencies among parameters
  Design management is concerned with how to deal with dependencies among design parameters. Thus, considering the importance of such dependencies is quite important. The importance of a dependency is assumed to be determined by its association with function metrics. Therefore, if the function metrics are important, dependencies associated with these metrics are also important.

As function metrics are tested together, it is possible that some design parameters are interdependent even though they do not share a common function metric.

Dependencies specified by structure

It is also possible to apply the same logic to dependencies among design parameters through structure. As shown in Figure 9, structure elements usually have a hierarchy. Thus, all design parameters are connected through the highest structure. To avoid such a meaningless description, the to-be-described dependencies are limited to those between parameters connected via the minimal size of structure for prototyping and testing.

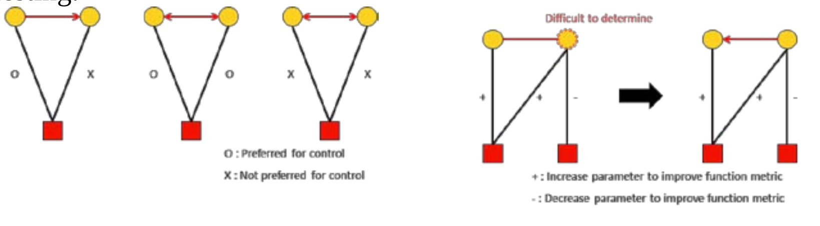

Figure 8. Prioritization among design parameters

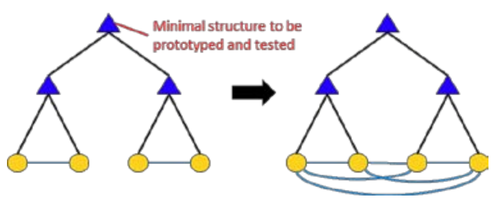

Figure 9. Dependencies among design parameters through minimal structure

Direct dependencies

The interdependence of some design parameters is specified neither by function nor structure but by other reasons: physical, chemical, and/or electrical laws, geometry, and so on. These should also be described.

4 MODEL-BASED ASSISTANCE FOR PROJECT MANAGEMENT

4.1 Assisting project management with dependencies among design parameters

In the former section, product information is mapped onto a model that describes design parameters and their dependencies. This section discusses how to use this model for management of product development.

Provided that all dependencies among design parameters are described, it is possible to observe change propagation through design parameters [9]. Visualizing the potential effects of changing a design parameter is quite useful, especially for design tasks where flexible changes are required along the development process. Furthermore, this leads to the planning of design tasks with a lower likelihood of rework [8].

4.2 Obtaining design process candidates

By understanding the design process as a process to determine design parameters, it is possible to discuss how design process to be structured, by means of the dependencies among design parameters. First of all, prioritizations among the design parameters are described in a DSM (Figure 10 left). The design parameters are then realigned so that those prior to others come earlier (Figure 10 middle). Assuming that design parameters with higher priority should be determined earlier, the order of design parameters implies possible sequences for the design process. Together with DSM partitioning, this information can suggest potential design tasks and processes. The blue squares on the right side of Figure 10 indicate suggested design tasks.

4.3 Evaluation of design process candidates and feedback for information acquisition

Process candidates are obtained assuming that the acquired dependencies among design parameters are precise. Howsoever, as complete acquisition of information is quite difficult, the resulting process candidates can be far different from designers' expectations. If so, the acquired information can be corrected by comparing the suggested process with an actually recognized process. This feedback loop can make a model more precisely reflect a real product. Figure 11 illustrates this feedback loop.

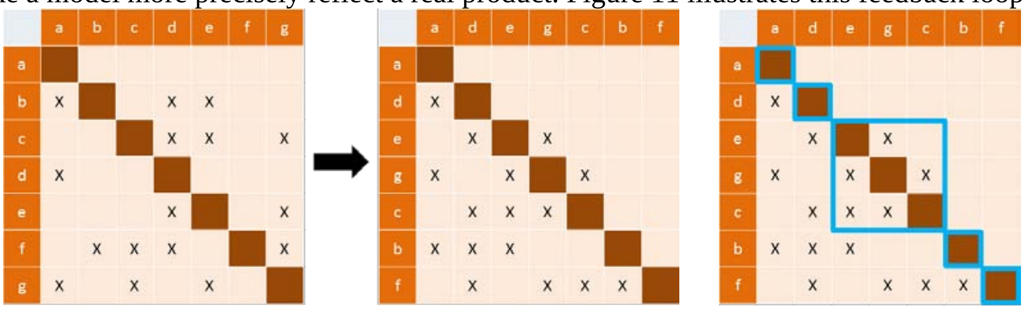

Figure 10. Prioritization of design parameters and suggested process coordination

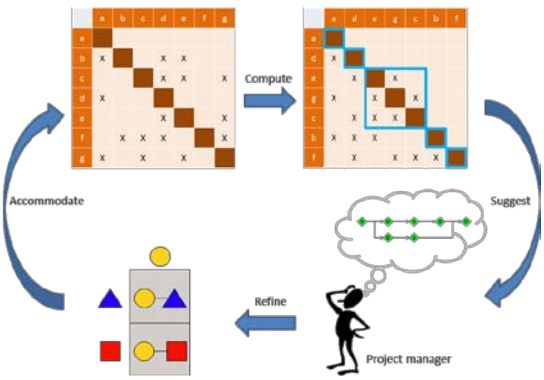

Figure 11. Feedback loop to refine acquired information

4.4 Integrated process candidates including prototyping and test phases

The former sections discussed how to derive a design process from dependencies among design parameters. However, a design process cannot be defined merely from these dependencies. To shorten the development cycle, companies prefer to start prototyping and testing as they become possible. This also affects design process, as design tasks are rearranged by considering resource constraints for prototyping and testing.

Together with the DSMs, DMMs that describe the association of design parameters to structure elements as well as the relation of design parameters to function metrics, can suggest candidates for the overall development process (including design prototyping and test tasks). Figure 12 illustrates process consideration by means of DSMs and DMMs.

Figure 12 is composed of four matrices.

- A DSM among design parameters (Orange)
- A DMM among design parameters and structure elements (Red)
- A DMM among design parameters and function metrics (Blue)
- A DMM among design parameters, structure elements, and function metrics as a function of resources (Green)

Upon analyzing dependencies among design parameters, three types of tasks are suggested.

- Design tasks (Blue squares)
- Prototyping tasks (Green rectangles)
- Test tasks (Orange rectangles)

Design tasks are suggested by means of a DSM partitioning technique. By analyzing when the design parameters allocated to the structure elements are all determined, it is possible to observe when the corresponding prototyping task of that element can begin. The time at which each structure element is ready for prototyping, and the resource allocation to prototyping it, can decide which structure elements can be prototyped together in the same task and which can be implemented in parallel. Then, by analyzing when the structure elements that have design parameters allocated to function metrics are all prototyped, it is possible to observe when the corresponding test task of that function metric can begin. Timing and resource allocation also suggest which function metrics can be prototyped together in the same task and which can be implemented in parallel.

However, tasks cannot be determined with such a straightforward logic that examines dependencies among design parameters and then considers the resources. Resource constraints and shortened development span may affect how the tasks are implemented. Thus, there should be feedback for the suggested task allocation from resources allocated to the tasks. Figure 13 compares two candidate task allocations. The upper candidate is suggested solely with straightforward logic. The lower is a candidate that shortens the entire development span by considering resource constraints on test tasks.

In the latter case, ineffective use of resources in the test is corrected to shorten the span. To do so, design and prototyping tasks are reordered. Accordingly, feedback appears in the design process (Red check in the DSM portion of the lower part of Figure 13). As this check indicates prioritization of design parameters and the dependency between them, it indicates inverted priority and possible rework. Thus, the interface between these two design tasks requires intensive management. As illustrated in Figure 13, it is possible to examine the tradeoffs between the development span and the difficulty of managing development processes.

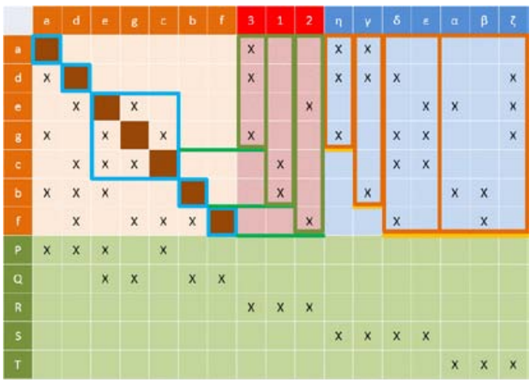

Figure 12. Process consideration by means of DSM and DMMs

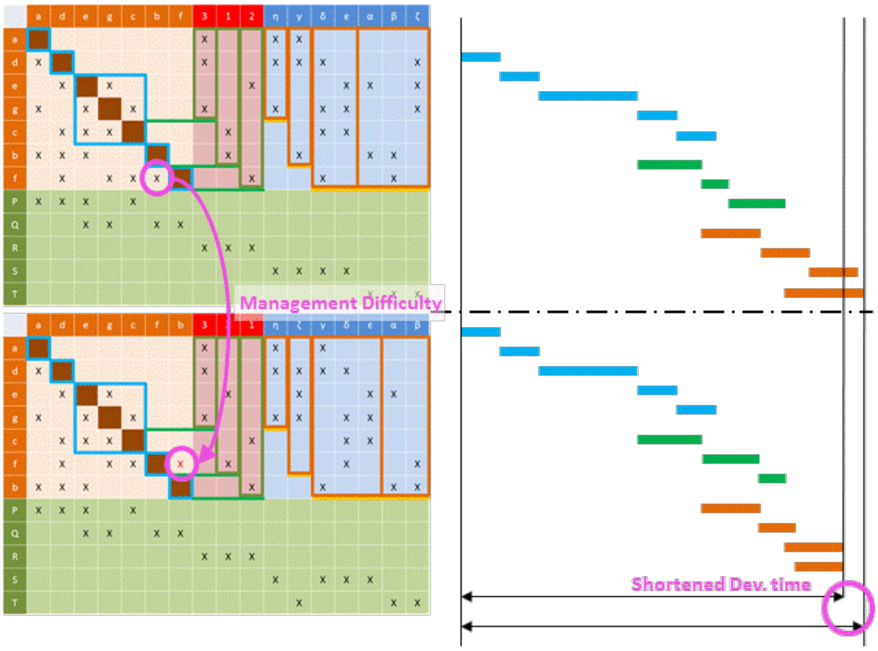

Figure 13. Comparison of process candidates with tradeoff between span and manageability

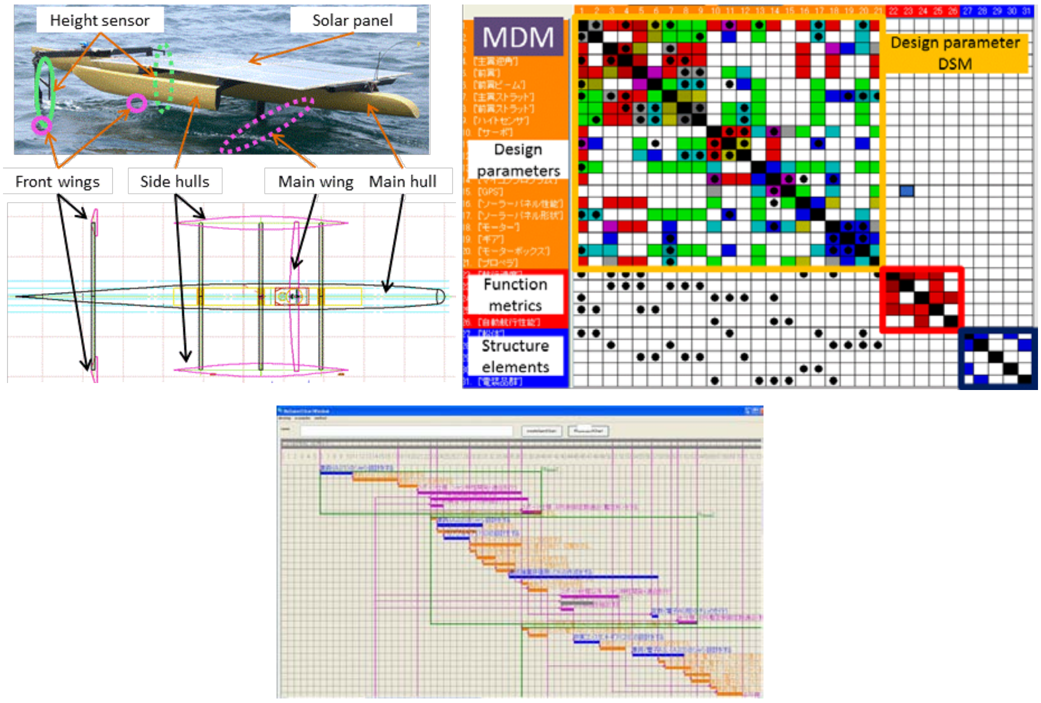

Figure 14. Case study: development project of solar boat

5 EXAMPLE

As an example, the proposed method was applied to a solar boat development project. The upper left panel of Figure 14 shows an overview of the solar boat. In this project, the product structure is fixed as shown. Thus, the project concerns the detail design stage of the design process.

First of all, information on the solar boat is acquired, and the MDM shown in upper right of Figure 14 is obtained. The upper left part of the matrix surrounded by yellow lines is the DSM of the design parameters. This part comprises both the relations described by designers and those suggested from the relations of the design parameters to other domains. The former kind of relation is expressed as a dot, whereas the latter gives color to the cells. Thus, it was possible to acquire information more precisely by comparing these two kinds of information.

Subsequently, by providing process information to the obtained tasks such as required manpower, a Gantt chart was obtained. The lower part of Figure 14 shows the resulting Gantt chart.

6 DISCUSSION

The example above assured that describing product information could lead to process coordination which designers could recognize. Furthermore, the proposed method may be said to assist in the acquisition of precise information and suggest possible improvement of the development process for better management of a project.

With the incorporation of product and process perspectives on a project, the suggested design process could be adjusted by considering both dependencies among design parameters and resource constraints. However, this relies to some extent on the planners' manual control of a model. The process can be more useful if it is assisted by a computational method. In particular, when it comes to large-scale problems, it is quite difficult to manually control models.

As for model refinement, this paper proposed a methodology with a feedback process where the planners obtain a suggested process and compare it with their actual recognition. However this depends on the planners' abductive thinking. Here also, there is room for improving the method with computation.

7 CONCLUDING REMARKS

The proposed method is intended to assist project management of product development by means of modeling product and process information. Specifically, dependencies among design parameters are described with their relation to function metrics and structure elements. Basing on the resulting dependencies, candidate design processes are obtained. Based on the suggested process, it is possible to deliberate how a process is coordinated, incorporating manageability of design process and resource constraints.

Finally, as precise acquisition of information is quite difficult, this paper proposes several ways to provide feedback for refinement of acquired information.

REFERENCES

[1] Maurer M. and Lindemann U. Facing Multi-Domain Complexity in Product Development. *CiDaD Working Paper Series*, 2007, 3(1), 1-12.

[2] Puls C., Bongulielmi L., Henseler P. and Meier M. Management of Different Types of Configuration Knowledge with the K- & V-Matrix and Wiki. In *the 7th International Design Conference – DESIGN 2002*, Dubrovnik, May 2002, pp.403-410.

[3] Danilovic M. and Börjesson H. MANAGING THE MULTIPROJECT ENVIRONMENT. In *The Third Dependence Structure Matrix (DSM) International Workshop*, Boston, October 2001.

[4] Steward D. V. The design structure system - A method for managing the design of complex systems. *IEEE Transactions on Engineering Management*, 1981, EM-28, 71-74.

[5] Akao Y. *Introduction to Quality function Deployment* (Japanese), 1990 (Union of Japanese Scientists and Engineers).

[6] Daitou T., Ono M. and Akao Y. *Quality function Deployment (1)* (Japanese), 1990 (Union of Japanese Scientists and Engineers).

[7] Nagai K., and Daitou T. *the Third Generation QFD* (Japanese), 2008 (Union of Japanese Scientists and Engineers).

[8] Eppinger S. D., Whitney D. E., Smith R. P. and Gebala D. A. A Model-Based Method for Organizing Tasks in Product Development. *Research in Engineering Design*, 1994, 6, 1-13.

[9] Eckert C. M., Keller R., Earl C. and Clarkson P. J. Supporting change processes in design: Complexity, prediction and reliability. *Reliability Engineering and System Safety*, 2006, 91, 1521-1534.

[10] Lindemann U., Maurer M. and Braun T. *Structural Complexity Management An Approach for the Field of Product Design*, 2009 (Springer).

[11] Carrascosa M., Eppinger S. D. and Whitney D. E. USING THE DESIGN STRUCTURE MATRIX TO ESTIMATE PRODUCT DEVELOPMENT TIME. In *ASME Design Engineering Technical Conference DETC'98*, Atlanta, September 1998.

Contact: Kazuya Oizumi
the University of Tokyo
Department of Systems Innovation
7-3-1, Hongo, Bunkyo

113-8656, Tokyo
Japan
Tel: +81 3 5841 6506
Fax: +81 3 3815 8364
Email: oizumi@m.sys.t.u-tokyo.ac.jp

Kazuya is a Ph.D. student in the Department of Systems Innovation at the University of Tokyo. He researches in engineering design and service design. His interests are in integrated modeling of design objectives and design activities, in particular how to obtain insightful information for innovation and management from these models.

Kei graduated the master course of the Department of Systems Innovation at the University of Tokyo on Mar. 2011. He researched in modeling of relations among design parameters, specifically elicitation of relations and refinement of models. He is working for Hitachi, an electronics development company.

Naoto graduated the master course of the Department of Systems Innovation at the University of Tokyo on Mar. 2010. He researched in modeling of relations among design parameters and processes. He is working for DeNA, a software development company.

Tsuyoshi Koga is Associate Professor of Systems Engineering in the Department of Mechanical Engineering at the Yamaguchi University. He teaches in analysis-lead design based on product model, and researches in model-based systems engineering. His current research interests are design and development of next-generation automobile and product service systems.

Kazuhiro Aoyama is Professor of Manufacturing Systems Engineering in the Department of Systems Innovation at the University of Tokyo. His interest is information modeling and system integration to develop the design environment for large scale products and systems, including computational design for manufacturing, simultaneous design of products, manufacturing systems, and SCM.