The Role of Software Models in Developing New Software Systems; A Case Study in Project Management

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Abstract
The collaboration process in a joint project with a Japanese company is introduced. Topics included are the role of software models at each phase of the joint project and the skill set model of the collaboration.

We have developed a software project scheduling tool suited to the Japanese work environment.

Through the joint project, models play a key role as an effective communication media between Academia and Industry. They are useful for:
- Problem-discovery and problem-setting;
- Abstraction of the real world to extract necessary information, organizing this data into a useful information structure;
- Construction of a mathematical model to assure the generalizability of the theory and the tool;
- Visualization of the organizational resource usage state and definitions of several metrics.

Keywords: Joint Project with Company; Project Scheduling Tool; Load-Capacity Model; Resource Binding; Integer Linear Programming (ILP).

1 Introduction
Many activities for incremental technological innovations are now performed in Japanese companies. For the success of a new technological innovation, collaboration between industry and academia is very important. In this paper, I will address the role of models as communication media between academia and industrial people in the joint project mentioned below.

1.1 Technical Results
Embedded software for digital electrical appliances development projects in recent years are planned based on appropriate release time.

However, most projects require long-term development. Therefore, two or more projects are implemented concurrently, as shown in Fig. 1.

Fig.1 Multiple Projects Problem

To evaluate the feasibility of a new software development project in a situation in which two or more projects are being implemented concurrently, it is necessary to consider not only software development workload but also residual capacity of an organization.

We have developed the Load-Capacity Model for verifying feasibility at an early stage of the software development project. We have developed a method for simultaneous project scheduling, and a resource-binding based on the Load-Capacity Model. This method is formulated as Integer Linear Programming, using Load-graph and Capacity-graph, which represent workload and organizational capacity, respectively, as inputs. Outputs of this method are Gantt Charts and Load-Capacity Diagrams. The load-capacity diagram shows the state of an organization after workload has been assigned. Experimental results on realistic examples show that the method provided useful solutions in a practical time period. (Saito, Kusanagi, Ochimizu 2011), (Kusanagi, Saito, Ochimizu 2011), (Saito, Kusanagi, Ochimizu 2012).

1.2 Skill Set Model of Collaboration
One effective method to promote research on software engineering is joint work with industry, which enables us to recognize and solve problems in the real world. Through several case studies we performed, including this case, four types of key persons are needed for the success of collaborations.

(1) Key person 1 (from industry)
A person who is highly motivated for problem-discovery and problem-solving, and knows the real world very well.

(2) Key person 2 (from academia)
A person who has expertise in software engineering, and who knows the various kinds of research outcomes in software engineering. Key person 2 should try to discover the real problem together with key person 1 from superficial problem statements. Key person 2 is also responsible for proposing several candidates for a solution, based on his/her knowledge and experience. Key person 1 should be able to evaluate the effectiveness of the proposed solutions.

(3) Key person 3 (expert on mathematics)
A person who can propose and formulate mathematical models for the solution. Mathematical model is important to assure generalizability of the problem and the solution.

(4) Key person 4
A person who can develop a prototype tool based on the conceptual models and the mathematical models adopted. A tool is very important for field testing and then for familiarizing the new result in industry.

(5) Key person 1 again
Key person 1 should have authority to perform several field tests using a tool, with the permission and help of people in the field.

2 Problem-Discovery and Problem-Setting
Both key person 1 and key person 2 should discover a real problem to be solved, from among the superficial problem statements in the field.

2.1 Original Proposal from Industry
Fig. 2 shows the original proposal from key person 1 which represents the structure of the organization with problem statements.

<table>
<thead>
<tr>
<th>Role</th>
<th>Problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senior Manager</td>
<td>- should manage all of the products</td>
</tr>
<tr>
<td></td>
<td>- should propose situations both of projects and functional teams to release all of the derivatives by due date</td>
</tr>
<tr>
<td></td>
<td>- hard to understand excess or shortage of resources of his organization</td>
</tr>
<tr>
<td></td>
<td>- hard to adjust resource allocation among multiple projects</td>
</tr>
<tr>
<td>Project Leader</td>
<td>- should achieve QCD goals of his last project</td>
</tr>
<tr>
<td></td>
<td>- worry about whether each functional team can supply sufficient human resources to his project to meet his QCD goals</td>
</tr>
<tr>
<td>Functional Team Leader</td>
<td>- is responsible to supply proper human resources to multiple projects simultaneously</td>
</tr>
<tr>
<td></td>
<td>- should allow proper time for team members to improve their skills</td>
</tr>
<tr>
<td></td>
<td>- should accumulate know-how</td>
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<tr>
<td></td>
<td>- hard to decide whether he can accept workload requested by a new project</td>
</tr>
<tr>
<td></td>
<td>- education and training of his team member</td>
</tr>
</tbody>
</table>

Table 1 Role and Problem Statement of each Stakeholder (Kusanagi 2012)

There are several superficial problems; process-related ones, product-related ones, and human-resource-related ones. In our collaboration, we agreed the human-resource-related problem is the most influential one.

2.2 Our Solution
Through discussion, we reached the following conclusion, as shown in Fig.3.

A project scheduling method should take into account both work load of a project and the residual capacity of an organization.
Now we need to develop a theory and models which can deal with resource management of functional teams for a given workload. We proposed the Load-Capacity Model, which contains necessary information to evaluate feasibility of a new project.

2.3 Abstraction of the real world to extract necessary information and to organize this data into a useful information structure

Next we tried to extract necessary information for both work load and capacity. Fig.4 shows the extracted information.

Fig. 4 Load-Capacity Model (Kusanagi 2012)

The Load-Capacity Model shown in Fig.4 consists of five components: Architecture Type, WBS Type, WBS Instance, Project Team and Organization (Regular Organization and Outsource Organization). Architecture Type, WBS Type and WBS Instance are basic components of the load structure. Regular Organization and Outsource Organization are basic components of the capacity structure. Teams of a new project need to satisfy the requirements of both the load structure and the capacity structure (Saito, Kusanagi, and Ochimizu 2011, 2012).

1) Architecture Type: “Architecture type” means the structural aspects of a system architecture, typically it consists of GUI, application, middleware, driver, and operating system. The attributes of an architecture type are dependency relations and communications. In general, functional teams are organized according to the architecture of the system. Relationships among components of the architecture require communications between the developers. These communications are one of the load factors.

2) WBS Type: WBS (Work Breakdown Structure) type is a set of basic work units, named Work Packages (WPs) usually organized as a tree structure. There are two WBS types, WBS type for new developments and WBS type for derivative developments. WBS types are usually defined by the Software Engineering Process Group (SEPG) of each organization. The attributes of a WBS type are the load unit of each WP (WP load unit) and the process. WP load unit of each WP becomes the standard of the estimation. The process is a set of one or more WPs, and WBS type includes processes as subsets.

3) WBS Instance: The WBS instance is a set of WPs instantiated and tailored from the WBS type, and it corresponds to all WPs that are actually executed by the project. The attributes of a WBS instance are the total load, the standard estimated man-hours (SEH), the required skills, and the precedence constraints. In the Load-Capacity Model, the total load is the sum of the SEH of each WP and the communication overhead. However, the communication overhead does not appear easily in the WBS instance. SEH is derived from WP load unit. There are precedence constraints between WPs, which are derived from the dependency relations and the processes.

The skill given to each WP as an attribute is called the required skill, and a skill of a resource is called “own” skill. We use $\Theta$ as the symbol of skill. Examples of skills are business knowledge in requirement definition, design methodology in system design, and programming language in software implementation. “skill” in this model is different from ability. In our model, we temporarily deal with skill as a classification of skill. We can assign WP to the resource if the required skill corresponds to “own” skill.

4) Project Team: A project team is a set of people involved in product development. The attributes of a project team are the consumption of resources, the distribution of the load, and the communication overhead. Resource consumption is the assignment of the load (WP) to the resources based on the relation between the delivery date and the skill.

5) Organization: The organization is a set of developers. The organization consists of a regular organization and outsource organizations. Each organization has two or more subsets, and we call each subset a functional team. An organization offers members of functional teams to each project as resources to accomplish the project. The attributes of a regular organization are resources, capacity and skill. The attributes of an outsource organization are cost, quality and skill. In the Load-Capacity Model, the resources are classified according to the number of skills. In our model, a resource which has two or more skills is defined as a highly-skilled resource.

3 Formulation of a mathematical model to assure the generalizability of the theory and the tool

Mathematical model of the solution is necessary to assure the generalizability of the problem and the solution.
We formulated our resource-binding method as Integer Linear Programming. Fig. 5 shows an outline of our model.

3.1 Load Graph

There are two inputs of our algorithm. One is the Load Graph, which is a graph representation of the upper part of Fig. 4. A WBS instance showing all precedence constraints is called a load-graph. An example is shown in Fig. 6 (Saito, Kusanagi, and Ochimizu 2011).

A Load Graph is a directed acyclic graph. Each vertex represents a WP, and the directed edge represents the sequencing relation between WPs. It is assumed that SEH (number of time slots) and a required skill are given to each WP as attributes.

3.2 Capacity Graph

Another input is a Capacity Graph, which is a graph representation of the lower part of Fig. 4. The capacity-graph is derived from the capacity structure of the Load-Capacity Model. Figure 7 shows an example of a capacity-graph (Saito, Kusanagi, and Ochimizu 2011).

The capacity-graph shows the hierarchical structure of the organization. In a capacity graph, a vertex represents a resource (human) and a role, and edges represent relations in the organization. A vertex (resource) in the capacity-graph has one or more “own” skills. The residual capacity of resource \( r \) at time \( l \) is shown by a capacity function \( f(r, l) \in \{0, 1\} \) where value 1 means WP is assigned. This team’s “own” skill is shown in the table in Fig. 7.

3.3 Load-Capacity Diagram

The load-capacity diagram shows the state of an organization after workload has been assigned. The idea is to embed the load-graph into the capacity-graph satisfying the constraints (Saito, Kusanagi, and Ochimizu 2011).

Each row of the Load-Capacity Graph corresponds to a member of a project, representing who has time resources, represented by a sequence of time slots. In this example, we assume a project consists of only middleware team members.

3.4 Gantt chart

Gantt chart is added as one of the outputs, because key person 1 advised us that it is necessary to prepare user-familiar output. Fig. 9 shows an example of a Gantt chart produced by our system.

3.5 Resource-Binding algorithm

We adopted Integer Linear Programming as a resource binding algorithm. The reasons why we adopted the ILP are mentioned below.

(1) Various conditions of the project can be formulated as the constraints of ILP

(2) Two or more schedules can easily be generated by changing the objective function and the constraints
(3) The minimum resources or the minimum development period are obtained by an optimal solution under the given constraints.

(4) The solution is obtained faster than in the past, by improvement of the performance of the ILP-solver and calculator.

Table 2 shows examples of constraint representation, and Table 3 shows an example of an objective function which represents the resource-allocation policy.

### Table 2 Decision Variables and Constraints

(Saito 2011)

- Binary decision variable: \( x_{ij} \in \{0,1\} \)
- Only when \( WP_i \) is bound to resource \( r \) and starts in slot \( l \)

Constraints:

1. Each WP must be implemented at least one time:
   \[ \sum_{i=1}^{n} z_{il} = 1 \]

2. The sequencing relation must be satisfied:
   \[ \sum_{j=1}^{n} z_{ij} \geq \sum_{j=1}^{n} z_{ij} - h \]

3. WPs bound to the same resource must not be concurrent:
   \[ \sum_{j=1}^{n} z_{ij} \leq 1 \]

4. Remaining capacity of each resource must be considered:
   \[ \sum_{j=1}^{n} z_{ij} \leq \prod_{j=1}^{n} r_i \]

### Table 3 Objective Function

(Saito 2011)

- We can consider various objective functions, which express the policies adopted in the project.
- Example: Minimize the development period and the number of WPs to be assigned to Team Leader and Member2

\[
\min \left( \sum_{i=1}^{n} z_{ilm} + \sum_{i=1}^{n} z_{imd} \right)
\]

#### 4 Visualization of resource allocation state by “pieces of ice in a cup” metaphor

We adopted “pieces of ice in a cup” metaphor to visualize the resource-binding result, and to develop metrics.

### Fig. 10 “ice pieces in a cup” metaphor

If we compare the capacity of an organization to a cup, and the load of a project to a piece of ice, scheduling can be compared to putting several pieces of ice into the cup. The shape of a piece of ice depends on the project management policy (Fig. 10).

Fig. 11, Fig. 12, and Fig. 13 show examples of the scheduling result of a third project, based on different work-load-allocation policies. All of the results used real data collected in field testing.

### Fig. 11 “Smoothing of work load” policy (Kusanagi 2012)

### Fig. 12 “Use only skilled people” policy (Kusanagi 2012)

### Fig. 13 “Uneven distribution of work load” policy (Kusanagi 2012)

#### 5 Developing the Metrics

Fig. 14 helps to visualize the resource allocation. We can define several metrics based on the presentation of...
6 Prototype Development

We developed a prototype tool, named Load-Capacity Balancer, based on the conceptual models and mathematical models, to publicize the new results.

7 Conclusion

We created many informal diagrams through the joint project. All of them played an important role at each phase of the collaboration.

1. The abstract depiction is a trigger of discussion, and was useful for sharing knowledge about situations in the field.

2. The abstract depiction is also useful for extracting the necessary information from the field.

3. Mathematical model is necessary to develop the tool.

4. Visualization of computing results is also necessary for practical usage of the method and the tool in the field.

Without the informal models created through our collaboration, we could not communicate with each other to achieve valuable consensus and agreement.

8 Acknowledgement

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9 References


