STUDY ON FRAMEWORK OF CONSTRUCTION PROFILE FOR COLLABORATIVE AND INTELLIGENT CONSTRUCTION

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Abstract: Collaborative and intelligent construction means production system that rationalizes construction by applying information technology to utilize a great variety of information. This paper presents pre-survey, framework of representation being possible to utilize data, general framework of processing data and managing information to assess construction profile, and development of prototype of construction information management system, which are included in study on framework of construction profile to support the collaborative and intelligent construction system.

Keywords : Collaborative and intelligent construction, framework of construction profile, construction profile assessment, XML

１． Motive

Collaborative and intelligent construction (CIC) means production system that rationalizes construction by applying information technology to utilize a great variety of information. This study focuses on earth-moving work of road construction where construction machine such as hydraulic excavator, dump truck, bulldozer, vibration roller, etc. are operated. The CIC view is shown in **Fig. 1**. Required here is an extranet to gather and store construction data and to generate administrative information. The extranet enables users, who take parts in construction project, to retrieve and edit construction data and administrative information anywhere at any time. However, there are problems as follows:

- Measurement device attached with construction machine, which measures its geographical position and its time worked, make it difficult to utilize the measurement data generated by different data formats; and
- Construction information management system manages data and documents being generated under construction as many diverse files. These files are stored and controlled based on their metadata. By daily work reports, anyone might know each state of work in progress, such as time worked by construction machine, number of dump trucks allocated, etc.. And yet it is difficult to grasp overall state of construction activities by these different and diverse files.

This study is intended to develop frameworks with respect to:

- Expression and evaluation of construction profile to vision overall state of construction works; and
- Information processing and retrieval to utilize data.

The construction profile is defined as a set of data to vision characteristics of phenomena being generated along with construction in progress and indices to show their patterns

As shown in **Fig. 2**, this study consists of the three phases as presented below.

Phase 1: Build of framework to express construction profile for utilization of data among and between different systems and diverse organizations;

Phase 2: Construction of framework regarding information management and processing to evaluate construction profile; and

Phase 3: Development of framework of systematic information management and retrieval to utilize lessons learned, which are gathered and documented by many people, various systems and at different places.

Scope of this study is shown as gray parts in **Fig. 2**.

First, this paper presents pre-survey study on framework regarding expression of construction profile. Secondly, this paper describes structure of construction

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profile to utilize data. Finally, represented is framework of information management and retrieval to evaluate construction profile, to diagnose causes of phenomena in undesirable conditions and to predict its effects.

2. Related Research and Development

This chapter describes research and development related to this study.

Joint research on data exchange among and between systems to support construction on machinery basis has been and being conducted by Incorporated Administrative Agency Public Works Research Institute, Ohbayashi-Gumi Co., Hitachi Construction Machinery, Co., and Kick Co.. In fiscal year of 2004, field experiment of data exchange technology, which has been developed by the joint research, was conducted.

Nishigaki et al developed template to describe symptom of unsafe behavior on construction site and to predict probability to experience hiyari-hat[1]. Furthermore, they have developed and are doing research on C2MP (Collaborative Construction Management Professional) to support daily meeting and to store and utilize construction documents and information on construction plan.

Hitachi Construction Machinery, Co. is conducting research and development of machinery management system the e-Service in which GPS and PDA are utilized. This system gathers data regarding working position, time worked, and left-fuel of construction machine on real timely basis, and provides users results of time analysis, inspections, etc. over the Internet [3), 4)].

This study is related to the research and development as mentioned above in respects as follows:

- Support machinery construction works of earth moving on road construction;
- Template, which has been developed to evaluate construction profile, utilizes the diagnosis model to predict probability to experience hiyari-hat; and
- The C2MP and the e-Service are utilized as core-system of collaborative and intelligent construction system.

3. Pre-survey Study

(1) Overview of pre-survey study

To grasp structure of work activities on construction site, the following surveys were conducted at embankment construction site. At this construction site, operated is vibration roller with measurement device to record work time, vibration times and maintenance activities.

- Organize activities of day-to-day management on construction site; and
- Grasp use cases based on analysis of construction data.

This pre-survey study was conducted from 1 March 2004 to 20 March 2004. The vibration roller used at this construction site is shown in **Fig. 3**.

(2) Comprehension of day-to-day management on construction site

Conducted was interview survey to personnel of constructor and workers of subcontractor on the construction site where the above pre-survey study was done. **Table 1** shows keywords used in the interview survey. Business activities in day-to-day management being extracted by the interview survey were classified along with cyclic management stream as shown in **Fig. 4**. Moreover, information flow from whom to whom and requirements of supports by computer system were grasped. These requirements were grouped together into three business activities as follows:

- Existing business activity that needs supports by computer system;
- New business activity that could be done based on supports by computer system; and
- Existing business activity that could be preceded without any support by computer system.

(3) Comprehension of use cases based on construction data analysis

Information gathered and lessons learned by the interview survey are analyzed as stated below.

First, time chart of day-to-day cyclic management stream was drawn to grasp business process on construction site. The time chart is shown in **Fig. 5**.

Secondly, sequence diagram was drawn to grasp interactions among and between personnel who take part in day-to-day management. The sequence diagram is shown in **Fig. 6**.

The above works show time-driven works and event-driven works in day-to-day management. Furthermore, materials made by the above works show what kind of information need to be digitized and interchanged among and between concerned people on field works and at site office, in order to accomplish work-saving of day-to-day business activities.

On the other hand, observing field works enables us to understand existing conditions as presented below.

(1) In many cases, viva voce interchange or data exchange based on documents are being conducted among and between day-to-day business activities. Tacit Knowledge and known information are interchanged by signal or wireless method among and between operators who take part in works by construction machine through construction process in **Fig. 7**.

(2) In addition, information on construction activities is concentrated in daily meeting in the afternoon and is distributed to concerned people at toolbox meeting in the morning of the following day, for example, a morning assembly, and Kiken-Yochi activity.

(3)The interview survey, the analysis results, and the observation results as mentioned above give us use cases of daily business activities that need supports by computer system. These uses cases are shown in **Table 2**. The use case diagram is shown in **Fig. 8**.

4. Framework for Utilization of Data

Business collaboration throughout a series of works along with day-to-day cyclic management on construction site and machinery construction is viewed in **Fig.9**.

The CIC might require realizing process integration, that is, collaboration of data and information throughout a series of works instead of domain data processed by each computer system.

It is important to coordinate collaboration throughout a series of works and to distinguish human-readable and machine-readable expression of data and information. Examples include:

(1) Data and information described in work diary should be human-readable;

(2) Data and information of work orders should be both human-readable and machine-readable;

(3) Automated measurement data should be machine-readable and could be automatically processed; and

(4) Data and information described in daily work reports should be human-readable.

Data elements being extracted and relationship between them is analyzed as mentioned below.

First, data elements and relationship between them used in the use cases as described before are represented

Secondly, in order to understand information required by construction management, planning data and construction data are classified into data elements shown in Table 3. The data structure is drawn by class diagram.

DTD (Document Type Definition) and XML schema are methods to describe data structure[5]. It is said that XML schema is more operable than DTD[6), 7]. In this study, first, data elements and data types are drawn by class diagram. Secondly, primary keys and external keys are defined. Finally, data structure is described by XML schema.

Data utilization view by construction information management system is shown in **Fig.11**. Data consumers, who are users of the construction information management system, are:

(1) Login users for the construction information management system:

The login users can directly access and use functions of the construction information management system. For example, personnel of constructor and works of subcontractor who are working on construction site are the login users; and

(2) Users for other systems:

Administrators belonging to owner and personnel belonging to management office of constructor are users for other systems.

The construction information management system provides the login users data in the Excel files. In many cases, the Excel is used at many site offices on construction sites. Therefore, people in construction work get used to handle and analyze data by using the Excel.

In case of using other system, the data elements and data formats are often unknown in advance by the construction information management system. The construction information management system provides data of XML instances in this case.

Data elements are largely grouped into two categories. One is as-designed/planned data element that composes construction target data, design data, work plan data, and work order data. The other is as-built data element that composes machine working data.

The as-designed/planned data is stored in relational database through HTML form and is retrieved and managed as XML instances. The as-built data is presented as csv format. Measurement device attached with construction machine transmits construction data in csv format to the construction information management system. Construction data received is stored in relational database and then is retrieved and edited as XML instances by the construction information management system.

5. Framework of Information Management and Processing to Evaluate Construction Profile

This chapter describes framework to evaluate construction profile. In the framework, phenomena not going well might be predicted, and the causes might be diagnosed based on construction target data, design data, work plan data, work order data, and construction working data.

Overview of the framework to evaluate construction profile is shown in **Fig.12**. This framework consists of construction profile, template for its evaluation, undesirable conditions as prediction results and causes as diagnosis results. The construction profile is composed of schema, which shows structure of data elements and relationship between them, and instances of construction data being generated under construction. Construction data are gathered and then statistic data are calculated and edited.

So far, this paper describes vocabularies, relationship between them and frameworks that focus on data and information flow and use cases. As shown in **Fig.12**, It is required to define vocabularies built in each schema and ontology that clearly shows relationship between them. In addition, required are rules and logics to predict potential undesirable conditions and to diagnose the causes. These rules and logics described in the template are applied to infer undesirable conditions and the causes[8)].

Work management, progress management, quality management, and safety management are listed from viewpoints of construction manager to evaluate construction profile. Focused on work management and progress management, this study enumerates viewpoints follows:

- Viewpoint 1: Watch line balance. For example, search unbalance of productive capacity among construction resources;
- Viewpoint 2: Search outliers. For example, find construction resources that have extra-high production capacity and one in the opposite side;
- Viewpoint 3: Watch state of control. For example, look at tendency toward expansion or reduction of variance from average values;
- Viewpoint 4: Watch productivity. For example, look at planned versus actual productivity a work package, and make a comparison between the two; and
- Viewpoint 5: Look at construction speed. For example, first, set base line of construction progress; secondly, calculate progress rate, and finally make a comparison between the two.

From the viewpoints above, construction profile is evaluated at cross section and toward longitudinal in construction progress (**Fig.13**).

Construction profile template is built by tuple that consists of construction profile data, statistic values, assumption, and plausibility.

Construction profile data are data entries, observed data, and calculated or edited data. Control values are average values and standard deviations that are calculated by the construction profile data.

This study focuses on a series of construction process of earth moving in road construction shown in **Fig.7**. Construction profile data elements are grouped together into control data elements and indication data elements as shown in **Table 4**. The control data elements are calculated based on construction profile data. Data entries of the indication data elements are used for classification.

Control data elements of capacities with respect to excavation, loading, transportation, compaction, and slope trimming have target values as follows:

(1) Target values: Target average value a day, maximum target value a day, and minimum target value a day; and

(2) Observed values: Actual average value a day, maximum observed value a day, and minimum observed value a day.

These values are classified by the indication data elements and then calculated.

Control data element of work volume a work package has target values and observed values as follows:

(1) Target values: Target work volume a work package, target work volume accomplished by construction machine, and target work volume a head; and

(2) Observed values: Actual work volume a work package, actual work volume attained by construction machine, and actual work volume a head.

Construction speed as control data element has base line of construction progress rate. The base line is presented as

$$y=\alpha x+(\beta-\alpha)(x-a)+(\gamma-\beta)(x-b), \qquad (1)$$

where “y” means progress rate to total construction volume; “x” means lapsed time rate to construction duration; and “a” and “b” are set for 25% and 75% of the progress rate scheduled as milestones, respectively, where “a” equals to 33 and “b” equals to 66. Then there is relationship between the above coefficients as follows:

$$\alpha=25/a,$$

$\beta = 50/(b-a)$, and

$\gamma = 25/(100-b)$,

where $0 \leqq x \leqq 100$ and

if $x \leqq a$ then $\beta = \gamma = 0$

if $a < x \leqq b$ then $\beta = \gamma$

Fig.14 shows this base line. Small value of the "a" makes construction speed fast at the early phase of construction. On the other hand, Small value of the "b" makes construction speed fast at the middle phase of construction.

The assumption comprises tuple of rules, logics, bad conditions and the causes. **Table 5** shows examples of rules. In addition, there are also the other rules. Examples include:

(1) Comparison between construction resources based on deviation from average value of work capacity;

(2) Tendency to expand or reduce variance;

(3) Comparison between operation rates of each construction machine; and

(4) Comparison between work volume scheduled and the one performed related to work package.

Table 6 shows examples of the logics. As described earlier, this study focuses on construction process in **Fig.7**. By unbalance between works performed by construction resources in the construction process, inferred are undesirable conditions anticipated in some time and the causes. **Table 7** shows examples of inference related to undesirable conditions. The causes are inferred by comparisons between statistics that are calculated from construction data by indication elements such as control brocks. Table 8 shows items related to phenomena of bad conditions and the causes.

The viewpoints of construction manager, structure of the construction profile, relationship among statistic data, undesirable conditions and the causes as mentioned earlier are described by XML, XSLT and ASP, and are built in a template to evaluate construction profile. Applying the template to construction target data, design data, work plan data, work order data, operation data of construction machine makes it possible to predict possible undesirable conditions and search the causes.

Degree of plausibility is represented by items as follows:

(1) Retention level: attention and warning

(2) Operation level: bad, ordinary, good, and fine; and

(3) Achievement level: not achieved, partially achieved, largely achieved, and achieved.

The plausibility above is shown as a result of evaluation of construction profile.

Construction profile elements as mentioned above, however, are subset of construction phenomena. There are also many elements that this study does not consider. Concerning construction phenomena being abducted, construction manager, utilizing her/his knowledge, lessons learned, findings and results by field inspections, makes decisions about corrective and preventive actions for allocation of construction resources, order of works, work procedures, etc.

6. Development of Prototype of Construction Information Management System

Prototype of construction information management system is developed based on the research results as mentioned before. Fig.15 shows primary display of the construction information management system. In addition to functions of groupware and file management, the construction information management system has functions as to construction target, daily meeting support, data gathering on construction site, and construction profile. Management worksheets are automatically generated and stored as the Excel files in the system. Users can see targeted file in the pane of HTML data by clicking on one of metadata displayed in the pane of file list. The construction profile function enables users to see evaluation results from the five viewpoints as mentioned before.

Personnel of constructor or subcontractor enter data of construction target and work plan into the system. Data of work performed is gathered when working on construction site by using mobile technology. Since operators and workers contact with computer system, their information literacy needs to be required here.

Table 1 Keywords used in Interview Survey

No	Keyword
1	Business process from planning to completion
2	Documents given by owner
3	Kinds of drawings and the workflow
4	Method to make construction plan and work plan
5	Work a day and business cycle
6	Content of day-to-day meeting
7	Method of work order
8	Role of finishing stake
9	Method to manage transportation
10	Content of site management by constructor
11	Index and standard of quality and shape
12	Documents made by constructor and the aim
13	Method to record works
14	Method to make construction data feedback
15	Inspection by owner
16	Documents submitted to owner
17	Contents submitted to owner when completion
18	Operability and improvement of vibration roller

Table 2 List of Use cases

Code	Use Case
Uc1	Personnel belonging to constructor make construction target data based on design and construction plan.
Uc2	Personnel belonging to constructor and subcontractor fill tomorrow work plan in work plan diary used in day-to-day meeting.
Uc3	Distribute the work plan diary to concerned people.
Uc4	Personnel belonging to constructor writes document of work order based on the work plan diary and the construction target data.
Uc5	Toolbox meeting is held based on the work order documents.
Uc6	Personnel belonging to constructor or operators input designated data into measurement device attached with construction machine.
Uc7	Operator drives her/his construction machine based on the work order.
Uc8	Measurement device automatically gathers data of works by the construction machine.
Uc9	The measurement device automatically uploads the gathered data to construction information management system.
Uc10	Operators write daily work reports and upload them to the construction information management system.
Uc11	Workers do their jobs based on the work order.
Uc12	Drivers transport materials based on the work order.
Uc13	The drivers write daily work reports and upload them to the construction information management system.
Uc14	Foremen manage works.
Uc16	Foremen write daily work reports and upload them to the construction information management system.
Uc17	Information to support construction management is generated by the construction information management system.
Uc18	Personnel belonging to constructor manage construction activities.

Table 3 Data Elements

No	Data Element
1	Construction target
2	Design
3	Control block
4	Meeting for work plan
5	Work order
6	Operation of construction machine
7	Daily work report

Table 4 Elements of Construction Profile evaluation

Control elements	Loading capacity
	Transportation capacity
	Compaction capacity
	Slope trimming capacity
	Work volume a work package
	Construction speed
Indication elements	Work type
	Work item
	Machine number
	Number of survey stake
	Number of control block
	Time stamp and position of work
	Number of construction layer
	Name of material for embankment

Table 5 Examples of Rules

No	Description	Condition	Result
1	Work volume analysis a day		
1_1	Comparison between quantity planned and the one performed	Quantity performed>quantity planned	+
		Quantity performed<quantity planned	-
1_3	Comparison between Maximum target quantity and the one performed	Quantity performed>Maximum target quantity	++
		Quantity performed>Maximum target quantity	--

Table 6 Examples of Logics

No	Item	Condition	Result
1	Caution level	Result "+" or "-" occurs three times continuously.	Attention
		Result "+" or "-" occurs four times continuously.	Warning
		Result "++" or "--" occurs.	Alert
2	Operation level	Operation rate performed <54%	Bad
		74%>Operation rate performed >=54%	Ordinal
		85%>Operation rate performed >=74%	Good
		Operation rate performed >=85%	Better
3	Achievement level	Work volume performed a work package > the one planned	Achieved
		Achievement rate > 95%	Roughly achieved
		Achievement rate >95%, and work volume performed by construction machine > the one planned, and work volume performed worker > the one planned	Partially achieved
		Achievement rate < 95%	Not achieved

Table 7 Examples of Undesirable Phenomena

	Construction Process				
	Excav.	Loading	Trans.	Compact.	Slope
Excav.	+	++			
Loading		-	--		
Trans.			+	++	
Compact.				-	--
Slope					+

Undesirable Phenomena

Table 8 Undesirable Phenomena and Causes

Undesirable Phenomena	Low productivity
	Unstable schedule
	Delay
	Incident
Causes	Deficiency of work capacity
	Bad line balance
	Bad resource allocation
	Bad work order
	Natural conditions

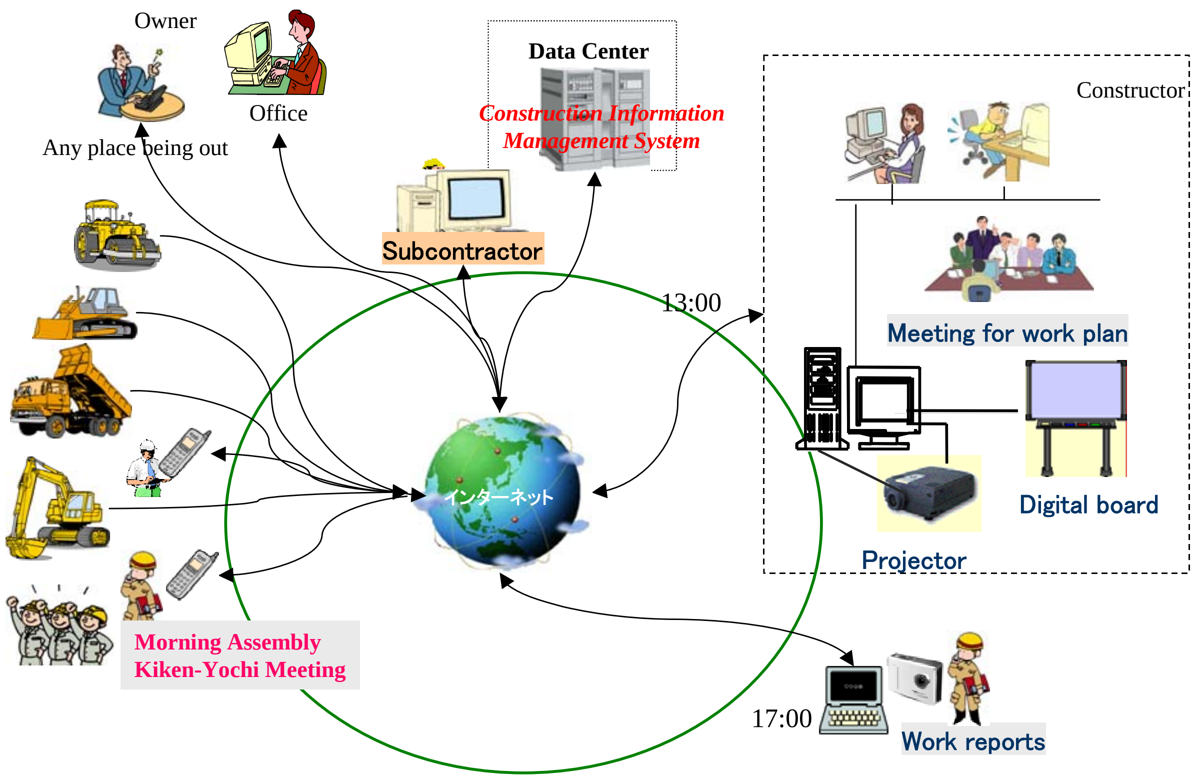

Fig. 1 Collaborative and Intelligent Construction

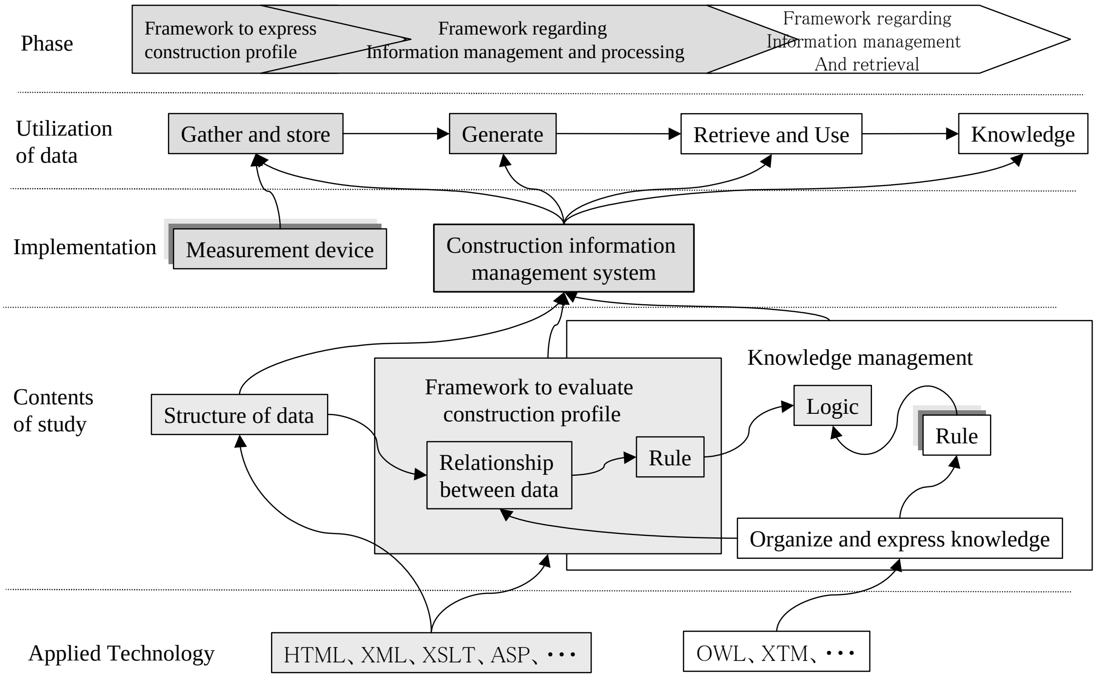

Fig. 2 Scope of this study

Fig. 3 Vibration Roller used in Pre-survey Study

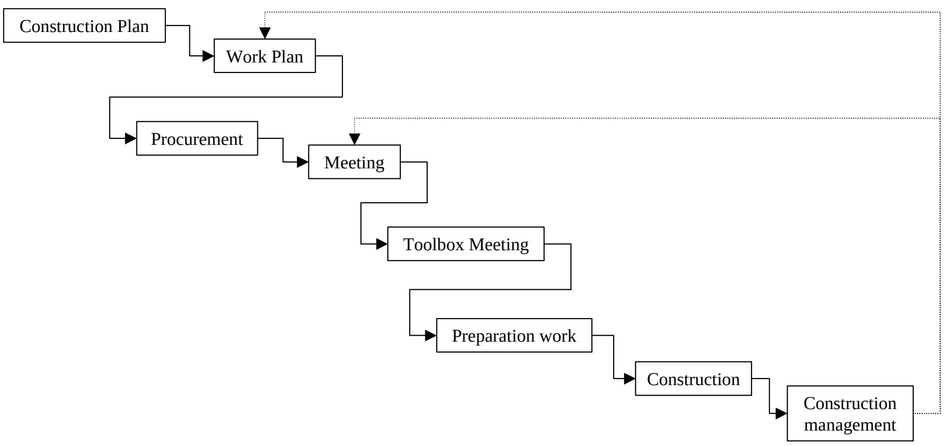

Fig. 4 Management Cycle

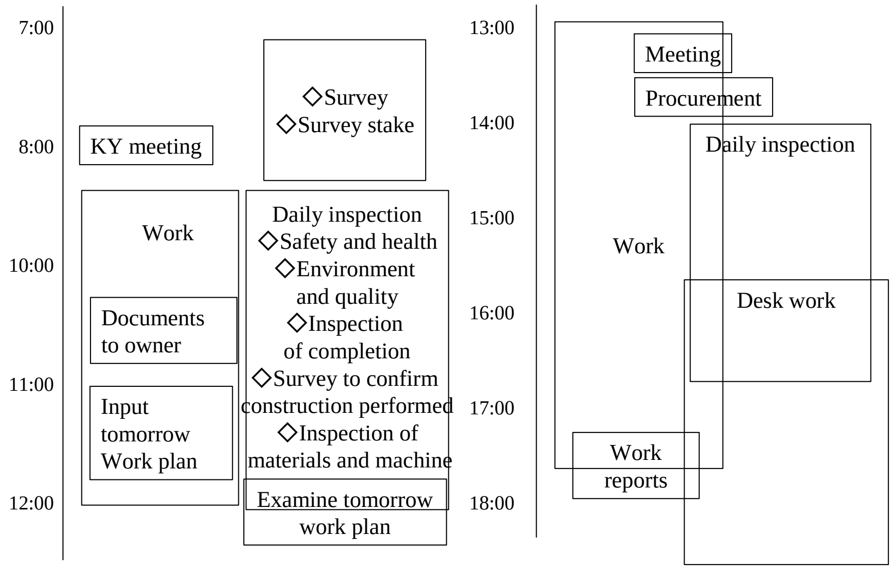

Fig. 5 Time Chart of Work a Day

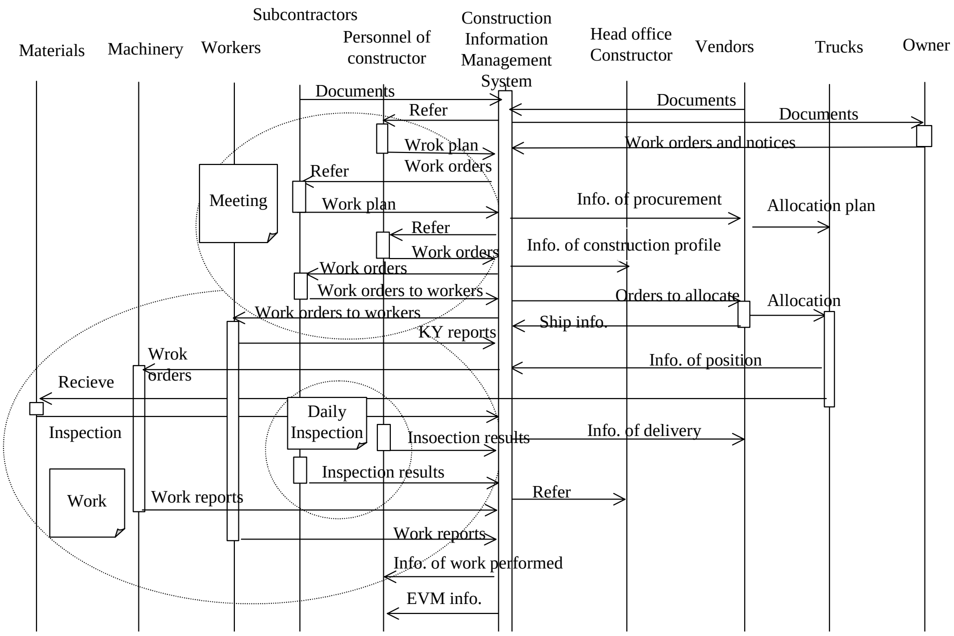

Fig. 6 Interactions among and between Actors in Daily Management

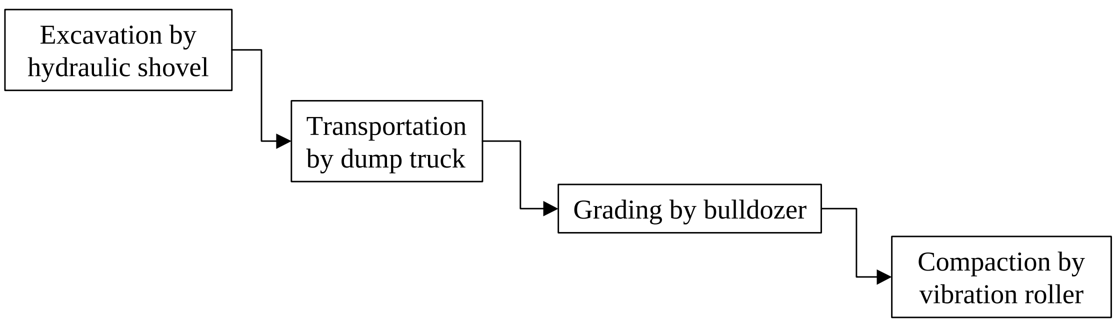

Fig. 7 Work Stream by Construction Machines

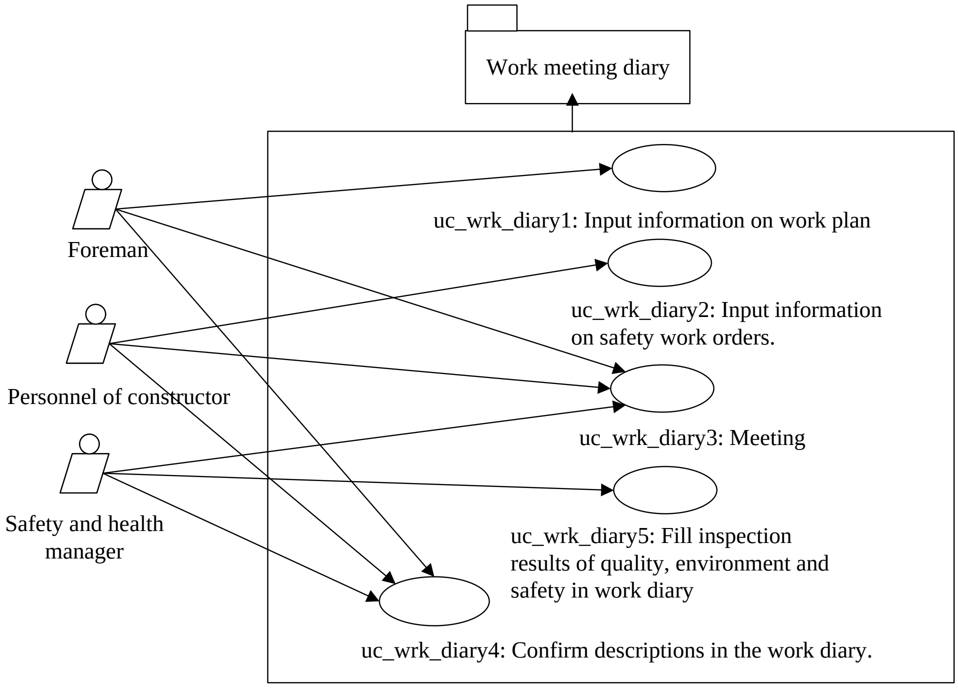

Fig. 8 Use Case Diagram of Work Meeting

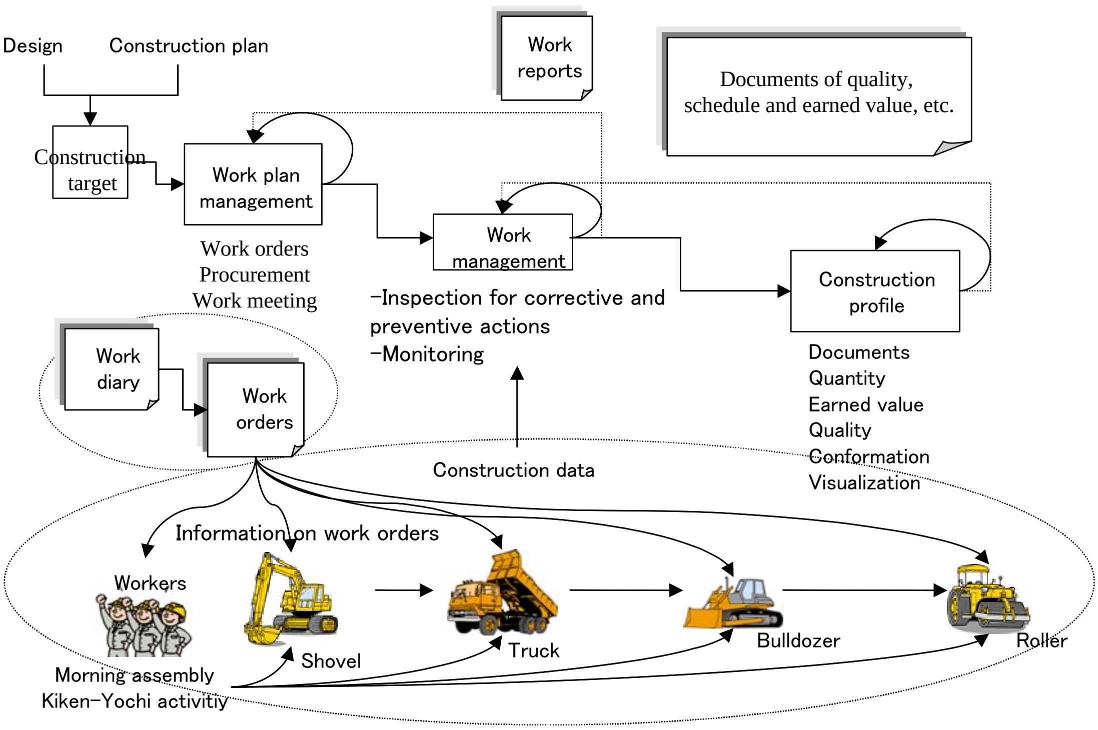

Fig. 9 Image of Construction Activities by Construction Machinery

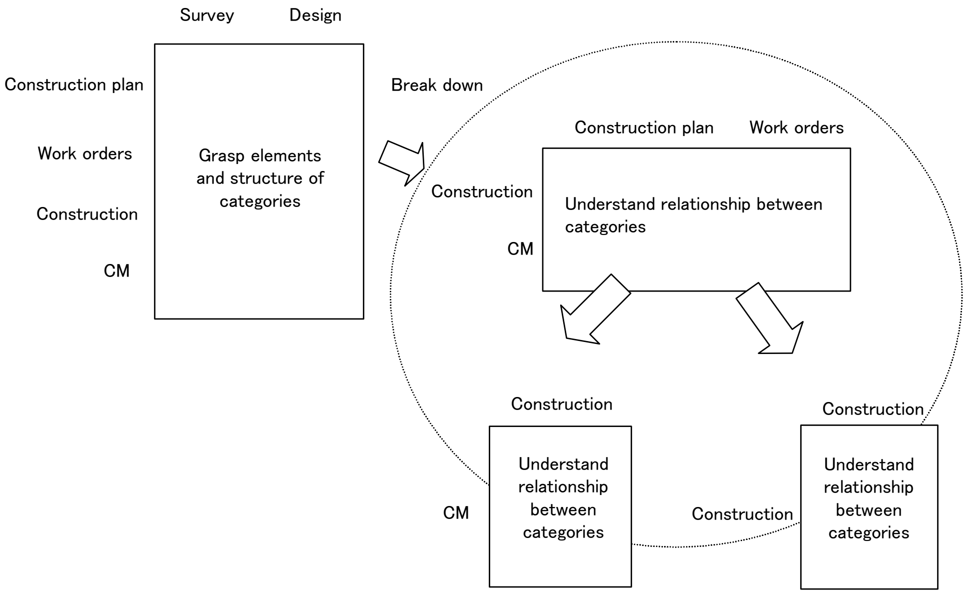

Fig. 10 Matrix Diagram of Data Elements

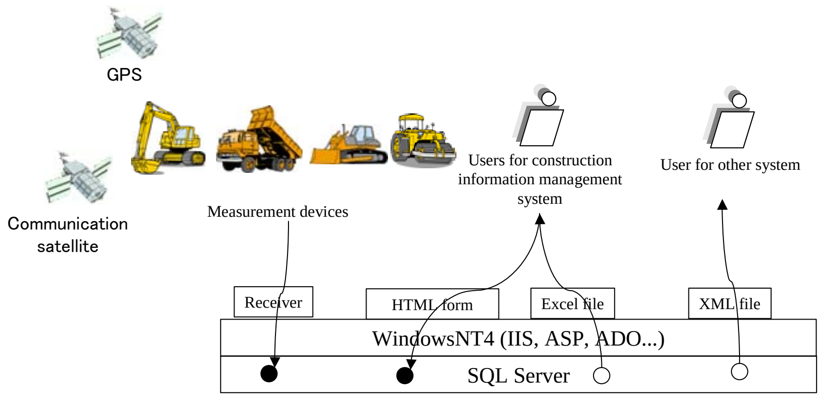

Fig. 11 Image of Data Utilization

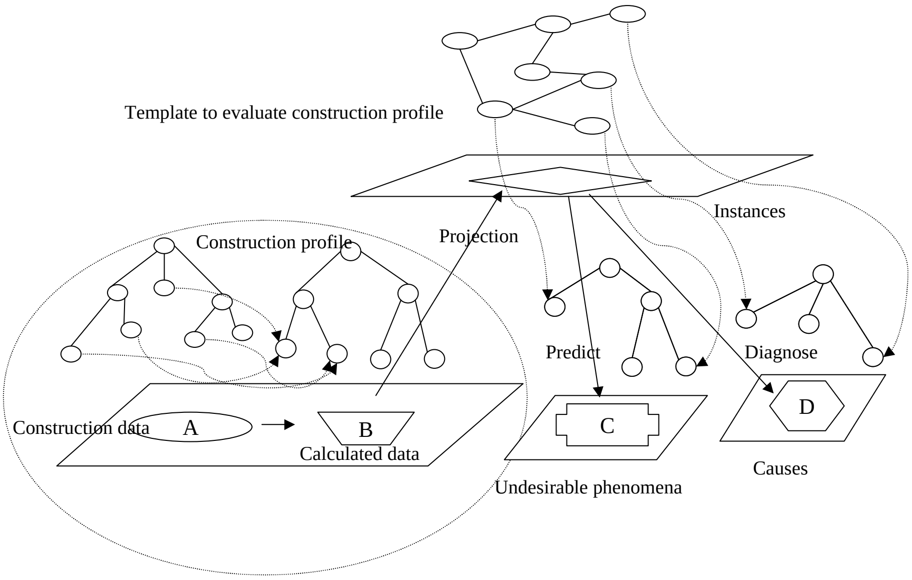

Fig. 12 Image of Framework to Evaluate Construction Profile

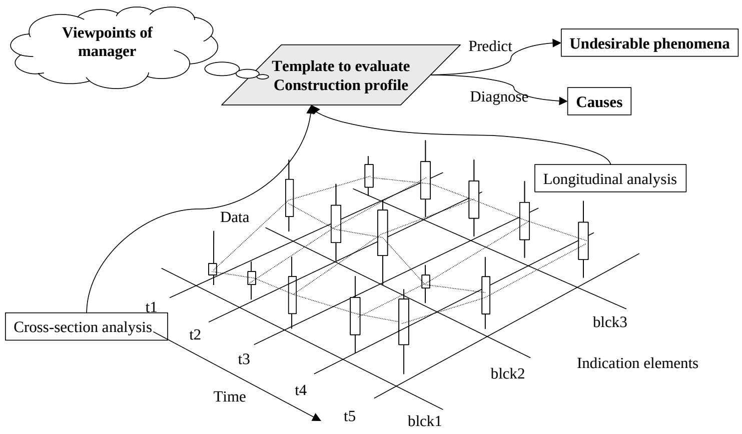

Fig. 13 Evaluation of Construction Profile

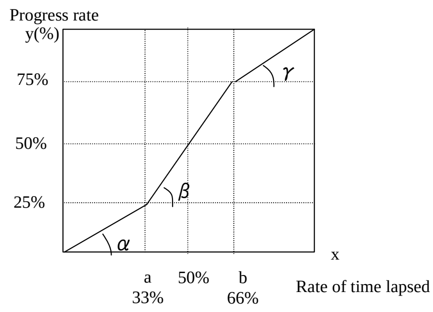

Fig. 14 Baseline of Schedule

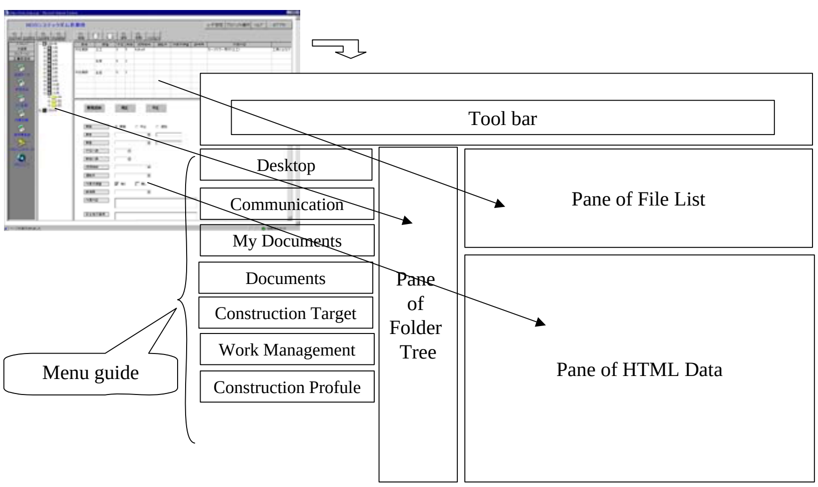

Fig. 15 Primary Display of Construction Information Management System

7. Summary and Further Research

In summary, this paper reports pre-survey study, frameworks with respect to utilization of data, information management and processing for evaluation of construction profile, and development of prototype of construction information management system related to framework of construction profile to support the CIC.

Further research is shown below:

- Field experiment and improvement of the prototype of construction information management system is scheduled; and
- Studied is information and retrieval to utilize data and lessons learned, which are stored and managed at different locations and by diverse computer systems.

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