

Cooperative Software Development and Usability Evaluation: A Web-based Work Management System for Construction Sites

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Abstract—In construction work, information systems that use mobile communications are required in order to eliminate the troublesome task of writing and retyping data and to acquire realtime data. The information must be shared effectively. Therefore, we developed a construction site work management system that reduces the burden of input from mobile phones in cooperation with construction companies from the viewpoint of user-centered design. The system's main features are easy data input from mobile phones and functions for authentication, data input, data retrieval, data update/deletion, and graphic representation of work progress reports. Input data is stored in a database over the Internet, enabling the shared data to be used to carry out work smoothly. At an early stage of development after we demonstrated an early version of the system, we circulated a questionnaire to construction companies so that we could incorporate their opinions. Responses from construction workers showed that easy data input is important. Therefore, we devised three methods for reducing the burden of input from mobile phones and two support tools. Furthermore, we evaluated an encoding method and a method using position information.

Index Terms—cooperative software development, real-time work management system, user-centered design, construction site, mobile phone, encoding

I. INTRODUCTION

For lean construction to proceed smoothly, information must be effectively shared among the foremen, staff at the site, and staff at the head offices of the contractor and subcontractors. Several construction companies have recently adopted the Toyota Production System at their construction sites, doing weekly or daily factor analyses

of failures in the construction plan. However, progress on jobs is still reported orally or in printed form, so information is not passed on "just in time", and a lot of time is spent processing information by hand. Many construction companies want information that can be used effectively and immediately.

In general, construction work differs from work in factories. For it to be implemented efficiently, explicit information must be shared and an effective realtime information system is required at the construction site [1], [2]. Normally, the data collected at the site is input to a personal computer (PC). In construction work, information systems that use mobile communications are required [3], [4] to eliminate the troublesome task of writing and retyping all of the data and to acquire realtime data [1], [2]. The system presented in [5] uses personal digital assistants (PDAs), hand-held terminals, and bar codes to share information at the worksite quickly. The Lean Enterprise Web-based Information System for Construction [6] also uses PDAs. That system shows the Percent Plan Complete (PPC) on the PC. PPC is the number of planned activities completed divided by the total number of planned activities. The table showing why planned work was not completed is called the Table of Reasons for Failure. Since the PPC approach was first introduced in "The Last Planner" [7], its usefulness has been demonstrated, and it has been reported on many times [8]–[10].

Various technologies are being developed in computer fields. Among them, Internet application services based on mobile phones and databases are increasingly common in business and daily life. A new mobile phone technology that identifies a user's position using the GPS (global positioning system) function is also receiving a lot of attention [11]. Moreover, user satisfaction and cost-cutting are becoming increasingly important. Norman et al. have a

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theory that user-centered design (UCD) is necessary [12]. In recent years, agile software development based on UCD has received a lot of attention. In fact, the Swedish National Union Catalogue was rebuilt by agile methods [13]. There is a real need for development based on UCD amid the growing diversity and complexity of technology.

In our research, we developed a work management system for construction sites cooperatively with construction companies taking UCD into consideration. The system uses mobile phones as transmission devices to share construction work data at a site in real time. Sharing construction data could improve the transparency of the construction work flow in order to pursue perfection. The system features authentication, data input, data retrieval, data update/deletion, and graphic representation of work progress reports. Input data is stored in a database over the Internet, enabling the shared data to be used to carry out work smoothly. We circulated a questionnaire to construction companies in order to incorporate their the opinions and we also evaluated the system in actual use. In their responses to our questionnaire, construction workers indicated that easy data input is important. Therefore, we devised some input methods and evaluated them. We also created a function that uses position information to reduce the number of steps that a user must take and we extended the system. In this paper, we explain how the construction site work management system reduces the burden of input from mobile phones.

The rest of this paper is organized as follows. Section 2 explains how our construction site work management system works. Section 3 presents an overview of the system, focusing on the system features and user interfaces. Section 4 describes the questionnaire that was circulated to 45 construction companies and the responses we received. Section 5 describes our three methods for reducing the burden of input from mobile phones and two support tools for these methods. Section 6 presents evaluation results for the methods. Section 7 concludes the paper.

II. SYSTEM REQUIREMENTS

First, we discussed system development with people in charge of construction companies. Figure 1 shows how the system works. At the construction site, the foreman (of sub-contractors A and B) input progress or factor information using their mobile phones. The server then processes this data into work management charts that are designed to be readable on mobile phones at the job site. This system enables each foreman to give appropriate instructions at any time, making work more efficient.

III. SYSTEM OVERVIEW

We developed a construction site work management system that meets the requirements. Here, we explain the system configuration, features and user interfaces.

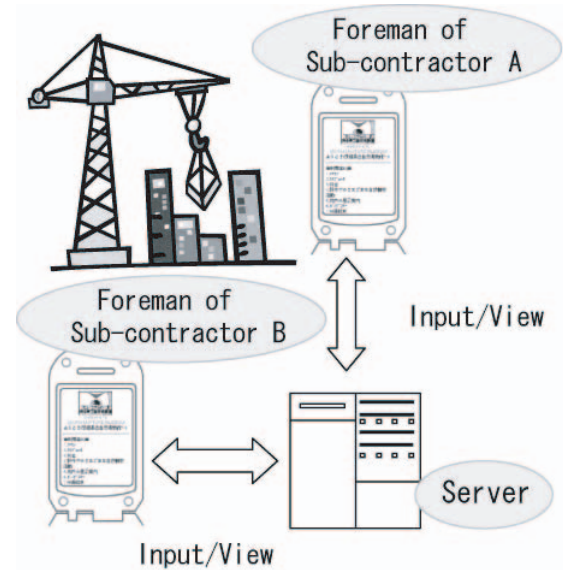


Figure 1. How the system works.

A. System Configuration

The system configuration is shown in Figure 2. The system is implemented on Linux and uses Tomcat as the application server and MySQL as the database management system. The server is entirely made using open source software. Users can use either NTT DoCoMo phones with i-mode or PCs as clients.

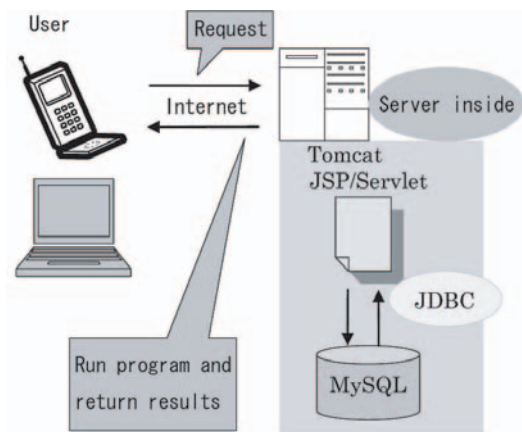


Figure 2. System configuration.

B. System features

The system handles inputs from both mobile phones and PCs and has the following main features: (1) authentication, (2) data input, (3) data retrieval and update/deletion, (4) graphic representation of work progress reports, and (5) data output to Microsoft Excel (only on PC clients). The system automatically processes input data from mobile phones at construction sites and stores it in the MySQL database management system. Stored data can be shared for just-in-time use. These features should improve the efficiency of communication and productivity in comparison with oral reports.

C. User Interfaces

Screen shots of a mobile phone through which a user inputs data are shown in Figure 3 and 4. The graph was generated by the system using the progress data already in the system. Although these screenshots are of an i-mode HTML simulator-II for sharpness, the actual mobile phone user interface is identical. The i-mode HTML simulator-II is the simulation software running on a PC for i-mode [14]. Figure 3 is a data input screen where the user inputs the progress report, the number of workers, the work address, the foreman's name, and so on. Figure 4 is a sample progress data graph that charts the time series of the data input on the screen in Figure 3.

Figure 3. Data input screen.

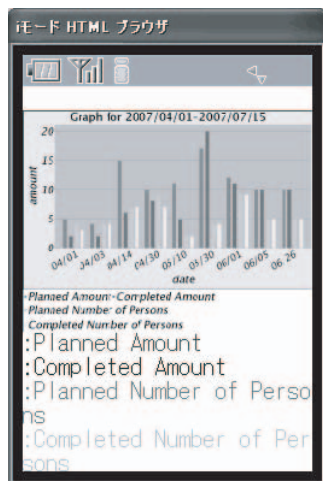


Figure 4. Graph representation screen.

IV. QUESTIONNAIRE AND RESPONSES

We circulated a questionnaire to 45 construction companies to incorporate the opinions of construction companies after we demonstrated our system to them. The results are summarized in Table I. Thirty-five of them responded. Moreover, 25 companies answered that they had an interest in our system and wanted to know more about it. Another common response was that there seemed

to be a lot of data to input information with a mobile phone. In response to the question "Can a foreman input information through a mobile phone in our system?" there were 14 responses of "possible", 17 of "impossible", and 4 of "other". We followed up by asking those who responded that it was "impossible" why they answered that way. Their reasons are tabulated in Table II.

TABLE I.
QUESTIONNAIRE

	Questionnaire content	Result
1	Do you monitor task progress?	Yes: 29 No: 5
2	Do you grasp problem in a task?	Yes: 31 No: 3
3	Do you get daily quantity per unit?	Yes: 28 No: 6
4	Do you figure out the number of personnel for the next day?	Yes: 24 No: 9
5	By what time do you figure out the number of personnel for the next day?	A.M.: 19 P.M.: 7 No response: 8
6	Can a foreman input information through a mobile phone in our system?	Yes: 14 No: 17 No opinion: 4
7	If you gave a negative answer to Question 6, give the reason here.	
8	Do you need Microsoft Excel data such as task progress, daily quantity per unit and number of personnel?	Yes: 30 No: 5
9	If you gave a negative answer to Question 8, give the reason here.	
10	Are you interested in our construction site work management system?	Yes: 25 No: 10

V. FUNCTION ENHANCEMENT

We extended our system in response to the questionnaire results. From the questionnaire results, we guessed that inputting data through mobile phones might be too burdensome for the users. Therefore, we devised three methods for reducing the burden of input from mobile phones: input with encoding, information retrieval using position information, and authentication using subscriber ID. Furthermore, we developed two support tools for these methods.

A. Input method with encoding

We thought that it would be effective to replace complex sequences of characters for input by short easy string of figures (codes). We studied four encoding methods: Types 1, 2, 3, and 4.

TABLE II.
REASONS FOR RESPONDING "IMPOSSIBLE"

Skepticism that older foremen can become skilled in use of mobile phones.	12
Belief that it is better for foremen to report by telephone.	3
Foremen's feelings that inputting information is a waste of time.	1
Fact that information can already be exchanged by email on P.C.	1

Type 1 encodes input items into incremental numbers on a one-to-one basis (see Table III). This reduces the quantity of numbers to be entered.

TABLE III.
TABLE FOR TYPE-1 ENCODING.

ID	Name of Construction Site
1	Toyo University Construction Site
2	Software Science Lab Construction Site

Type 2 encodes input items into strings of numbers converted from text input using the Roman characters on the buttons (see Figure 5 and Table IV). Even if a user forgets what ID 1 represents in encoding Type 1, he or she can enter "Toyo University Construction Site" by inputting TOYO (8696 in numerals). It is easier to remember a meaningful word such as "TOYO" than a sequence of numbers, as in Type 1.

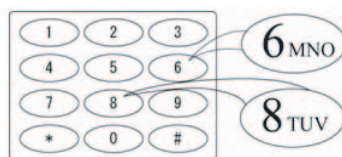


Figure 5. Layout of number/letter buttons on a mobile phone.

TABLE IV.
TABLE FOR TYPE-2 ENCODING.

ID	Name of Construction Site
8696	Toyo University Construction Site
76389273	Software Science Lab Construction Site

Type 3 encodes input items into sequences of the same number repeated a variable number of times (see Table V). This reduces finger movement time (time from button

release until button touch). Therefore, the overall time is reduced even if more keystrokes are required.

TABLE V.
TABLE FOR TYPE-3 ENCODING.

ID	Name of Construction Site
00	Toyo University Construction Site
000	Software Science Lab Construction Site

Type 4 encodes input items into number sequences that can be easily input with left or right hand (see Table VI). We thought that the numbers 3, 6, and 9 can be easily input with the left hand. Therefore, Type 4 encodes using only the numbers 3, 6, and 9.

TABLE VI.
TABLE FOR TYPE-4 ENCODING.

ID	Name of Construction Site
39	Toyo University Construction Site
69	Software Science Lab Construction Site

We incorporated these input methods into the system. In the extended system, the items "Site name", "Work Unit", "Work place", and "Cause of Trouble" can be input using codes. Screenshots of the first version and the extended version are shown in Figure 6 and 7, respectively.

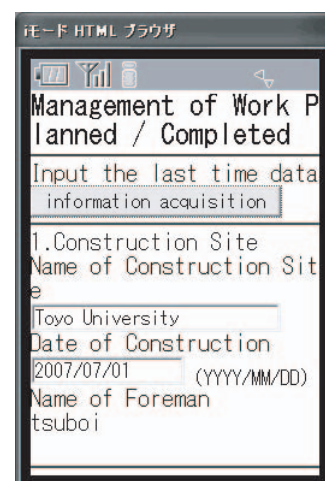
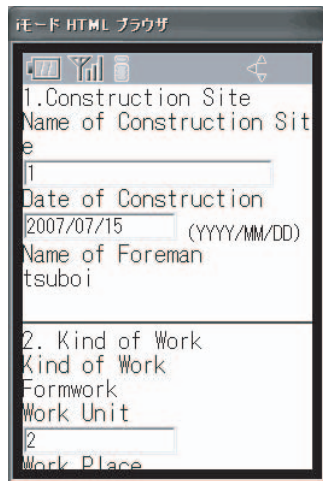


Figure 6. Screenshot of first version.

B. Information retrieval using position information

In response to concern that using mobile phones is burdensome for users, we incorporated position information using the GPS functions of mobile phones. We assumed



ウェブ HTML ブラウザ

1. Construction Site
Name of Construction Site
1
Date of Construction
2007/07/15 (YYYY/MM/DD)
Name of Foreman
tsuboi

2. Kind of Work
Kind of Work
Formwork
Work Unit
2
Work Place

Figure 7. Screenshot of extended version

that mobile phones from NTT DoCoMo would be used in our system (as described in Section 3). However, to make future research easier, we tried to build a new system with **au** mobile phones because they have better GPS functions than NTT DoCoMo phones.

When **au** mobile phones are being used, it is possible to know the current position information of the terminal. When the user transmits the position information to the server, the server retrieves and returns the data that matches the information. The system uses position information to help users find a nearby target object (such as a building) in the fewest possible steps. A screenshot of this function being executed is shown in Figure 8. Retrievals in the vicinity of Tsurugashima Station using the data registered in the database returned the result for Toyo University Kawagoe campus and Tsurugashima Station shown in Figure 8.



ウェブ HTML ブラウザ

Result

No.	Name of Building
2	Toyo University Kawagoe
3	Tsurugashima Station

back

OK

Figure 8. Retrieval results.

When Tsurugashima Station was chosen, a detailed screen containing a building map information was displayed, as shown in Figure 9.



ウェブ HTML ブラウザ

Result

No.	3
Name of Building	Tsurugashima Station
Date	1932/04/10
Name of Master	Yoshizumi Nedu
Address	埼玉県川口市大字上谷18番地
Latitude	35.936772
Longitude	139.623799

戻る

Figure 9. Detailed results.

C. Authentication using subscriber ID

We also used the subscriber ID of the mobile phone to reduce the burden of user authentication. Authentication is based on the FORM authentication used in the JDBC Realm of Tomcat. Using the subscriber IDs, the system can permit access from registered terminals and refuse access from non-registered ones. This ensures a high degree of security. After the subscriber ID has been identified, personal identification by password authentication is performed. After the login terminal has been authenticated by the subscriber ID, it is not necessary for the user to re-input the ID but only to input the password to log in. This reduces input time. The authentication screen is shown in Figure 10. When a user accesses by mobile phone and his or her user name is authenticated, the name is displayed in Username ("kk" in Figure 10) and the password is requested.



ウェブ HTML ブラウザ

Username: kk

Password:

Log In Reset

Figure 10. Authentication.

D. Encoding support and management tool

Some construction companies requested a tool that can manage the encoding for system managers in their compa-

nies In response, we decided to develop an encoding support management tool and then designed and implemented an encoding support management editor with two points in mind. First, the editor is a tool that handles various encoding tables. Second, the user interface is friendly and effective for editing encoding tables.

In developing the editor, we chose to use H10-Code Table Editor [15] as the underlying system. This editor is the product of our previous work. In that project, we developed a graph representation for complicated tables, and defined its XML representation, which we called H10-Code. In the H10-Code Table Editor, the editing operation is closely defined. The reasons for using H10-Code Table Editor are as follows.

- The internal data structure is clear and the process is explicit. Consequently, the behavior of the editor is guaranteed and the editor is transparent.
- A specialized tool for the encoding table editor can be developed.
- The utilization of XML in the field of construction can be supported because H10-Code is an XML representation.

The encoding support management editor manages input items, corresponding code numbers, and encoding tables. Items can be added, deleted and edited. Encoding tables can be organized by category. Encoding table data is stored in our system database and the encoding is reflected in the system instantly. A screenshot of the editor is shown in Figure 11. As shown in this figure, users can define code values in the editor.

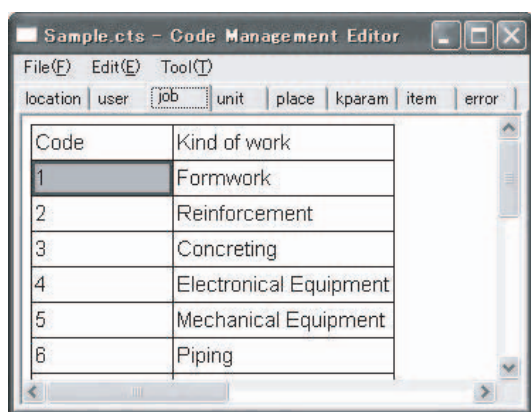


Figure 11. Screenshot of encoding support management editor.

Moreover users can save encoding tables as H10-Code. Therefore, encoding tables can be viewed with a common Web browser such as Internet Explorer by applying the XSLT stylesheet to their H10-Code. An example of viewing H10-Code with Internet Explorer is shown in Figure 12.

E. Support tool for position information registration

To enable retrieval using position information, each data item in the database should be associated with its position information. However, it is difficult for users to handle latitude and longitude data directly. Accordingly,

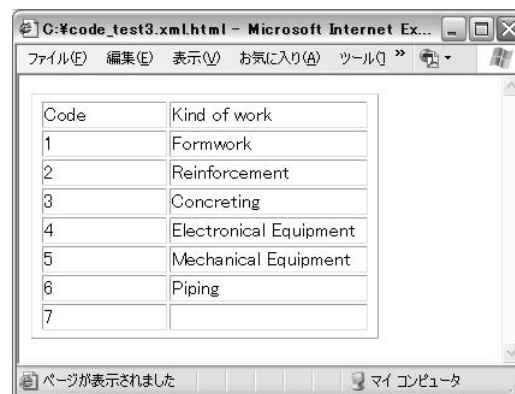


Figure 12. H10-Code of encoding table can be browsed using Internet Explorer.

we developed a tool that lets a user register latitude and longitude by finding the target on the map and clicking it on the PC's screen. A screenshot of the support system on a PC is shown in Figure 13.

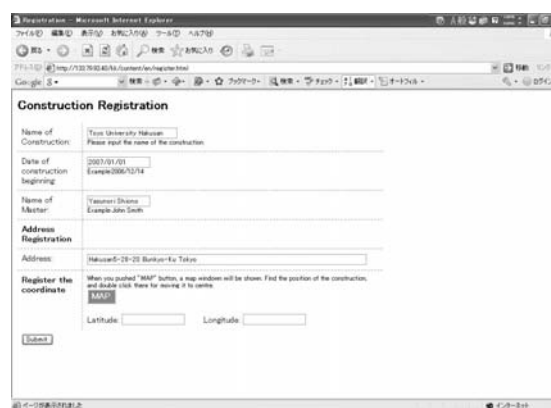


Figure 13. Screenshot of position information registration.

When a user inputs an address on the registration page and clicks the "MAP" button (see Figure 13), the address is converted into latitude and longitude information and a detailed map centered on that point is displayed using the Google Maps API. Then, when the user checks the map, magnifies it, and drags the target to the center of the map, the latitude and longitude are displayed (see Figure 14). Latitude and longitude data can easily be input (see Figure 15), even if the user does not know them, merely by clicking a final button. This is how we simplified operations. When the rest of the form on the registration page has been filled out, the user clicks "Submit". Then a confirmation screen is displayed (see Figure 16) and the construction site information is registered in the database (see Figure 17). This method makes it easy to register latitude and longitude data.

VI. EVALUATION

To check the effectiveness of our two methods—input method with encoding and information retrieval using position information—we evaluated them at a university. The test users were all graduate students at Toyo University.

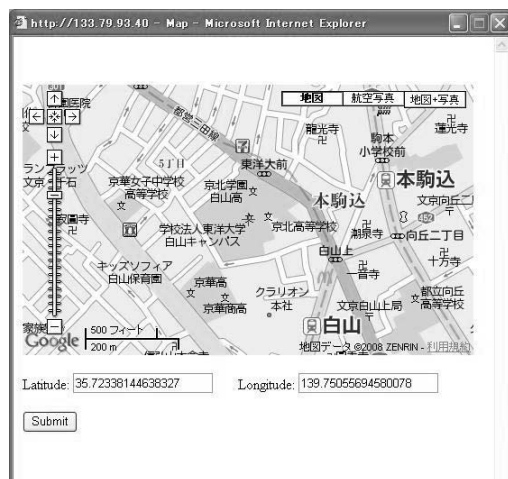


Figure 14. Latitude and longitude on the map.

Address: Hakusan5-28-20 Bunkyo-Ku Tokyo

Register the coordinate

When you pushed "MAP" button, a map window will be shown. Find the position of the construction, and double click there for moving it to centre.

MAP

Latitude: 35.72338144638327 Longitude: 139.75055694580078

Submit

Figure 15. Latitude and longitude data can easily be registered.

A. Evaluation of input encoding

First of all, we evaluated inputs without encoding, with type-1 encoding and with type-2 encoding. There were two tasks in the evaluation. One was to input all items and the other was to input only the items that correspond to encoding. For each trial we measured the time taken to complete the task. The seven participants were all graduate students at Toyo University.

The results are given in Table VII. They show that inputting items using either type-1 or -2 encoding was faster and more effective than inputting them without encoding.

The following comments were among those commonly made by the participants.

- I personally much prefer inputting by encoding.
- Input by encoding is easier than input without en-

Identification - Microsoft Internet Explorer

http://133.79.93.40/ks/content/en/ikunin.jsp

Registration

Name of Building	Toyo University Hakusan
Date of construction beginning	2007/01/01
Name of Master	Yasunori Shiono
Address of construction	Hakusan5-28-20 Bunkyo-Ku Tokyo
Coordinate	Latitude:35.72338144638327 Longitude:139.75055694580078

Are you sure this is OK?

Register Correct

Figure 16. Confirmation screen.

Identify registration of constructions - Microsoft Internet Explorer

http://133.79.93.40/ks/content/en/building_list.asp

Identify registration of constructions

No	Name of Construction	Date of construction beginning	Name of Master	Address	Latitude	Longitude
1	Toyo University Hakusan	2007/01/01	Yasunori Shiono	Hakusan5-28-20 Bunkyo-Ku Tokyo	35.723381	139.750556
2	Toyo University Kanagoe	2007/02/01	Zhongli Kuang	2100 Kujira Kanagoe-Shi Saitama-Ken	35.934791	139.422253
3	Tsunagashima Station	2007/03/01	Yuichi Sato	19 Kamihiraya Tsunagashima-Shi Saitama-Ken	35.936772	139.423799
5	Babukuro Station	2007/04/01	Yasunori Shiono	Nishibabukuro1-1-21 Toyoshima-Ku Tokyo	35.73007	139.711117
6	Narimasu Station	2007/05/01	Zhongli Kuang	Narimasu2-13-1 Itabashi-Ku Tokyo	35.777853	139.632496
7	Wakoshi Station	2007/06/01	Yasunori Shiono	Honcyo4-6 Wako-Shi Saitama-Ken	35.788384	139.612863
8	Asaka Station	2007/07/01	Zhongli Kuang	Honcyo2 Asaka-Shi Saitama-Ken	35.796547	139.600396
9	Shiki Station	2007/08/01	Yasunori Shiono	Tohoku2 Niza-Shi Saitama-Ken	35.822302	139.575078
10	Kanagoe Station	2007/09/01	Zhongli Kuang	Wakidacyo2-9 Kanagoe-Shi Saitama-Ken	35.907693	139.462538

Figure 17. Registered construction sites.

TABLE VII.
COMPARISON OF TIME TAKEN FOR INPUT WITHOUT ENCODING,
WITH TYPE-1 ENCODING, AND WITH TYPE-2 ENCODING.

Number of Participants	Input time (seconds)					
	Input all items			Input only items that correspond to encoding		
	Without Encoding	Encoding Type_1	Encoding Type_2	Without Encoding	Encoding Type_1	Encoding Type_2
1	185	125	158	86	37	52
2	145	80	85	74	40	42
3	162	89	88	88	45	46
4	280	164	140	116	60	49
5	121	119	111	58	34	54
6	239	175	182	89	59	100
7	235	99	95	72	37	43
Ave.	195	122	123	83	45	55

coding.

- A short code is very easy to input, but a long code is hard to input.
- I wanted to confirm the content of the code I had input.
- After inputting an item with a code, it is inefficient to check the code in the code table.

To perform further evaluation of input encoding, we performed a preliminary evaluation to measure individual input times and then evaluated the input encoded by the following eight methods.

- (1) Input without encoding.
- (2) Type 1 encoded by incremental numbers.
- (3) Type 2 encoded by Kunrei-shiki romanization.
- (4) Type 2 encoded by Hepburn romanization.
- (5) Type 2 encoded by hiragana.
- (6) Type 3 encoded by same-number sequences.
- (7) Type 4 encoded by left-handed number sequence.
- (8) Type 4 encoded by right-handed number sequence.

In the preliminary evaluation, we measured the individual input times for given texts consisting of about 100 characters. The seven participants were all graduate students at Toyo University. In this evaluation, input was typically done left-handed on mobile phones without using predictive transform function. The measured input times are given in Table VIII. The ten participants were

all graduate students at Toyo University. As expected, the input times for nonhabitual users were much longer than those for habitual users.

TABLE VIII.
INDIVIDUAL INPUT TIMES

Participant ID	Age	Habitual or Nonhabitual	Input Time (seconds)
A	24	Habitual	179
B	34	Nonhabitual	339
C	24	Nonhabitual	410
D	23	Habitual	132
E	21	Habitual	153
F	23	Habitual	243
G	25	Habitual	149
H	23	Habitual	186
I	26	Habitual	289
J	29	Habitual	210

After the preliminary evaluation, we measured the time for input encoded by the eight methods. In this evaluation, only input items were encoded and we distinguished between habitual and nonhabitual assuming that nonhabitual users were older foremen. As before, input was typically done left-handed on mobile phones without using predictive transform function. The measured input times for these methods are given in Table IX. The nine participants were graduate students in the preliminary evaluation. The variation in average input time for the eight methods is shown in Figure 18 and the standard deviation of input time for the eight methods is shown in Figure 19.

Overall, input with encoding was faster than without encoding. In methods (3), (4), and (5), there were great differences in input time between habitual and nonhabitual users because there were many characters to input. Taken all together, from their standard deviation, the results show great variability. In methods (2), (7), and (8), there was little difference in input time between habitual and nonhabitual users because the number of characters to input was small. Taken all together, from their standard deviation, these results show little variability. In method (6), although the number of inputs increased, there was little difference in input time between habitual and nonhabitual because the number of characters to input was small and there was also little variability.

These results show effectiveness of input method with encoding. Input would be even more efficient if all these input methods were supported and users could choose the methods they prefer.

B. Evaluation of using position information

To evaluate the method, we asked 16 people to use it and then answer the questionnaire. Fifteen of them

TABLE IX.
COMPARISON OF TIME TAKEN FOR INPUT BY THE EIGHT METHODS.

ID	Habitual or Nonhabitual	Age	Input Method (seconds)							
			(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A	Habitual	24	61	48	64	60	48	40	36	42
B	Nonhabitual	34	121	62	104	87	71	53	64	71
C	Nonhabitual	24	162	55	126	101	100	46	43	46
D	Habitual	23	63	33	54	44	28	25	30	20
E	Habitual	21	100	47	56	49	36	45	38	30
F	Habitual	23	76	37	61	52	46	47	45	53
H	Habitual	23	68	67	71	80	41	48	44	30
I	Habitual	26	83	61	87	52	37	40	42	34
J	Habitual	29	80	41	49	43	42	36	37	45
Average			90	50	75	63	50	42	42	41

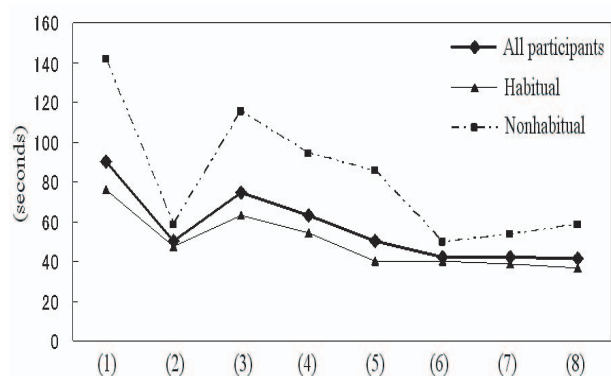


Figure 18. Variation in average input time for the eight methods.

answered that the position information was helpful. The reasons they thought it was helpful are listed in Table X.

It can be seen from the questionnaire results that retrieval by position information can reduce the necessary input and the number of steps with a mobile phone and return results quickly. All participants were able to register data easily because no one was more familiar with using latitude and longitude directly. All participants were able to register position information by using the position information registration tool.

VII. DISCUSSION AND CONCLUSION

We developed a construction site work management system that reduces the burden of input from mobile phones in cooperation with construction companies taking into consideration UCD.

Encode Method	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Standard Deviation	32.9	9.9	20.7	17.5	15.8	6.2	6.1	11.3

Figure 19. Standard deviation of input time for the eight methods.

TABLE X.
REASONS THAT RETRIEVAL BY POSITION INFORMATION WAS
HELPFUL.

Reason	Number of responses
No input is needed.	9
Retrieval results were displayed quickly.	7
There were not a lot of steps.	14
Even if input condition is not known, it is possible to retrieve it.	4
Other	2

At an early stage of development, after demonstrating an early version of our system, we circulated a questionnaire to construction companies in order to incorporate their opinions. The replies showed that easy data input is important. Therefore, we devised three methods for reducing the burden of input from mobile phones: input with encoding, information retrieval using position information, and authentication using subscriber ID. Since some construction companies requested support tools for the methods, we also devised two support tools: an encoding support management editor and a position information registration tool. Furthermore, we evaluated the encoding methods and the position information method. The methods received high evaluation from users. However, few foremen are using the system on an ongoing basis, possibly because of a lack of collaboration between developers and frontline workers. Therefore, it will be more necessary to build close relationships with frontline workers and implement methods based on UCD.

The just-in-time sharing of construction work information using mobile phones as transmission devices makes it possible for the foremen, the project manager, the engineers, the head offices of the contractor and sub-contractors, and so on to join together and implement improvement activities, enabling lean construction to become a reality. The system that reduces the burden of input from mobile phones not only enables problems at the site to be identified in order to execute lean construction but also supports improvements in the efficiency of the construction process. Since construction site workers demand easy data input from mobile phones as a practical matter, our approaches present a reasonable solution to the problems.

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