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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 real-time 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 real-time 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 real-time 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
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 thei 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 foremen (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.

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.

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.

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

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"

<table>
<thead>
<tr>
<th>Reason</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skepticism that older foremen can become</td>
<td>12</td>
</tr>
<tr>
<td>skilled in use of mobile phones</td>
<td></td>
</tr>
<tr>
<td>Belief that it is better for foremen to</td>
<td>3</td>
</tr>
<tr>
<td>report by telephone</td>
<td></td>
</tr>
<tr>
<td>Foremen’s feelings that inputting</td>
<td>1</td>
</tr>
<tr>
<td>information is a waste of time</td>
<td></td>
</tr>
<tr>
<td>Fact that information can already be</td>
<td>1</td>
</tr>
<tr>
<td>exchanged by email on P.C.</td>
<td></td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>ID</th>
<th>Name of Construction Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Toyo University Construction Site</td>
</tr>
<tr>
<td>2</td>
<td>Software Science Lab Construction Site</td>
</tr>
</tbody>
</table>

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.](image)

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

TABLE IV.
TABLE FOR TYPE-2 ENCODING.

<table>
<thead>
<tr>
<th>ID</th>
<th>Name of Construction Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>8696</td>
<td>Toyo University Construction Site</td>
</tr>
<tr>
<td>76389273</td>
<td>Software Science Lab Construction Site</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>ID</th>
<th>Name of Construction Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>Toyo University Construction Site</td>
</tr>
<tr>
<td>000</td>
<td>Software Science Lab Construction Site</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>ID</th>
<th>Name of Construction Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>39</td>
<td>Toyo University Construction Site</td>
</tr>
<tr>
<td>69</td>
<td>Software Science Lab Construction Site</td>
</tr>
</tbody>
</table>

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.](image)

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...
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.

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.

D. Encoding support and management tool

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

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, 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.

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.
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.
- 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**

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

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 distin-
guished 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 nonhabit-
ual 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 non-
habitual 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
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.

#### Table IX.

**COMPARISON OF TIME TAKEN FOR INPUT BY THE EIGHT METHODS.**

<table>
<thead>
<tr>
<th>Input Method</th>
<th>Habitual or Nonhabitual</th>
<th>Age</th>
<th>Input Time (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>Habitual</td>
<td>24</td>
<td>61</td>
</tr>
<tr>
<td>(2)</td>
<td>Habitual</td>
<td>34</td>
<td>121</td>
</tr>
<tr>
<td>(3)</td>
<td>Habitual</td>
<td>24</td>
<td>162</td>
</tr>
<tr>
<td>(4)</td>
<td>Habitual</td>
<td>23</td>
<td>63</td>
</tr>
<tr>
<td>(5)</td>
<td>Habitual</td>
<td>21</td>
<td>100</td>
</tr>
<tr>
<td>(6)</td>
<td>Habitual</td>
<td>23</td>
<td>76</td>
</tr>
<tr>
<td>(7)</td>
<td>Habitual</td>
<td>26</td>
<td>80</td>
</tr>
<tr>
<td>(8)</td>
<td>Nonhabitual</td>
<td>29</td>
<td>33</td>
</tr>
</tbody>
</table>

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

#### Figure 19. Standard deviation of input time for the eight methods.
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 subcontractors, 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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### References


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