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Development of Virtual and Real-field Construction Management Systems in Innovative, Intelligent Field Factory

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Abstract:

In this study, developed is virtual and real-field construction management system (VR-Coms) where integrated are virtual construction simulation, planning, scheduling and performance management system to evaluate productivity and safety in virtual simulated and real-field construction. VR-Coms offer supporting modules for learning and discovering solutions with objective to manage construction at right speed with improved humanware and constructability. The configuration of VR-Coms is described. This paper also shows the application of agent theory to construction management

Keywords:
construction management, planning, scheduling, construction simulation, collaboration

1.Introduction

In this study, we developed a virtual and real-field construction management system (VR-Coms), which is integrated with virtual construction simulation, planning, scheduling and performance management systems to evaluate productivity and safety in virtual simulated and real-field constructions. The VR-Coms offer supporting modules for learning and discovering solutions based on previous experience and performance evaluation with the objective to manage construction at the right speed with improved humanware and constructability. The function of leadership, followership and the reciprocal interaction between the leaders and the followers are collectively termed as humanware ([1], [2], [3]). Constructability is defined as the optimum use of construction knowledge and experience in planning, engineering, procurement, and field operations to achieve overall project objective [4].

IMS IF7 titled "Innovative, Intelligent Field Factory" is one of IMS research project in Japan. Intelligent Manufacturing System (IMS) program was proposed by Japan in 1989. The objectives of IMS program are to provide an exciting opportunity for international cooperation in advanced manufacturing, and a vision and structure for worldwide sharing of manufacturing technology development with cost, risks and benefits in a balanced and equitable manner.

The research program IMS IF7 consists of three work packages as follows.

Work package 1: Assembly methods for large-scale structures

Within this package, particular emphasis will be placed on realization of modularized construction system by utilizing flexible advanced manufacturing technologies.

Work package 2: Mechanization systems for assemble of large-scale structures

In this package, automated systems are studied

such as technology of heavy material transportation, 3D position detection system, development of a theory of construction material handling method.

Work package 3: Virtual and real-field construction management systems (VR-Coms)

VR-Coms in the innovative, intelligent field factory is studied and developed in this work package. This package has four tasks as follows,

Task 1: Study on real time based concurrent construction management systems to add value by enhancing safety and productivity in overall works from construction planning to field factory operations,

Task 2: Development of construction simulation systems using VR technique integrated with planning, scheduling and performance management systems,

Task 3: Study on field factory transparency, where detailed information, proactive advises and guidelines in all locations are accessible electronically by workers for thinking and decision making, and

Task 4: Study on application of agent theory to safety management, resources management, facility management and large-scale distributed information management.

This paper reports on the development of VR-Coms as part of the research of IF7.

2. Concept of the virtual and real-field construction management systems

Figure 2-1 shows the schematic view of the VR-Coms. The VR-Coms has tow construction field, one is virtual construction field, and the other is real construction field. The upper row of this figure shows the concept of virtual construction field. In this world, information technology (IT) is made good use of and information on the building design and the scheme of execution is generated before real construction is started. On the other hand, the lower shows the real construction field. Here, parties concerned necessary for constructing the reality are shown, such as construction management office, cite factory, a special construction trader, materials trader, an equipment trader, a machine parts traders, and architect offices

VR-Coms can be used for the site manager to study construction planning and management. Moreover, it is possible to use VR-Coms to support construction planning and to manage construction projects.

3. Development of test bed of VR-Coms

To develop the VR-Coms, a computerized

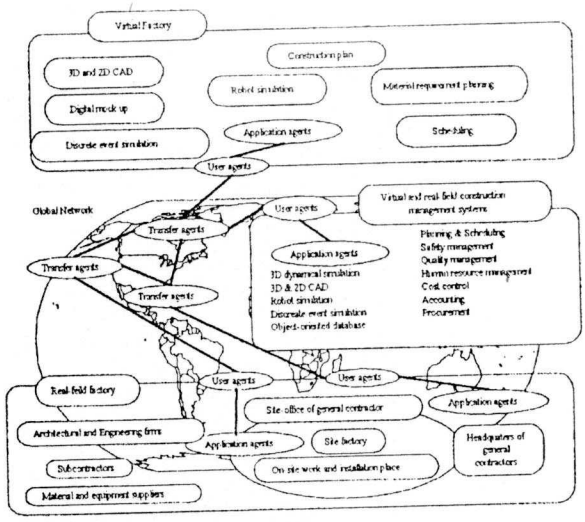

Figure 2-1 Schematic view of the VR-Coms.

environment as shown in Figure 3-1 was build up within the School of Business Administration, Aoyama Gakuin University.

The VR-Coms are composed of the following functions,

(1) Design function,
(2) Planning and Scheduling function,
(3) Line simulation function,
(4) Work simulation function,
(5) Real-time based construction management and performance management function,
(6) Common data base,
(7) Cyber agents.

Experienced and skilled workers review and modify all construction plans and schedules before the implementation of the plans. Typically, an iterative procedure is taken to develop solution to accommodate resource constraints, including the

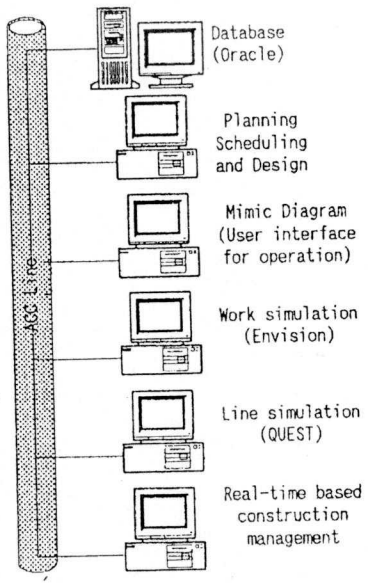

Fig. 3-1 The Computerized environment to develop the VR-Coms

workers and equipment involved in the project. In this iterative process, alternatives are generated and tested for feasibility. Further improvements or detection of potential problems are studied to generate new alternatives. This iterative generate-and-test strategy can be applied to evaluate alternative plans and schedules until a satisfactory plan with an appropriate schedule is obtained.

3.1 Design function

The role of the design function is to make two dimension drawings, and to make building model necessary for the construction planning and for the execution of virtual construction simulation. The building model contains not only three dimension shapes but also the materials that compose the building and the data of the amount and cost, etc.

A basic composition element of the building is the following six-element [5]. The design function should decide details of the following elements concerning an individual building.

(1) Base element:

Semantics of physical environment like plan site, road, and adjoining land, etc.

(2) Basic composition element

Main semantic group, which composes spaces such as wall, pillars, and roofs that form main structure of building.

(3) Opening composition element

This elements are fittings in door and window, etc., and simple openings.

(4) Part composition element 1

Machines such as elevators and escalators and the stairs.

(5) Part composition element 2

Parts such as sanitary wares and chairs.

(6) Space composition element

This is composed of the combination with the basic composition element. This element is classified into an external space, the buffer space, and the interior space.

3.2 Line simulation function

The line simulation function is used to simulate material flow in the entire construction site. The purpose of the line simulation is to confirm whether the construction schedule outputted from scheduling function is actually executable. Moreover, this forecasts whether an undesirable phase appears by calculating the load under construction of the building.

The following items can be examined by using the line simulation,

(1) Through put,

(2) Capacity of temporary depository and its operation,

(3) Concerning the order of turning on materials and turning on time,

(4) Whole layout of construction site including site factory,

(5) Estimation of influence by disturbance and examination of countermeasures,

The construction schedule from the scheduling function and the temporary housing plan obtained from the design function are necessary to execute the line simulation. The line simulation function outputs the following results,

(1) Whole of construction site layout,

(2) Presumption value of through put,

(3) Storage capacity and its operation method,

(4) The order of turning on materials and turning on time,

(5) Countermeasures against turbulence.

3.3 Planning and scheduling function

The objective of planning and scheduling function is to make the construction schedule based on the network diagram, the time required each work and the restriction condition of building construction project. This function makes the process plan over the entire construction project. Moreover, the daily work schedule of every day and the work plan of the construction machines should be able to be made by this function.

The earliest node time and latest node time of each node can be calculated by inputting the time required of each work, the beginning date of the project, and the completion date of the project in the network diagram. In addition, four kinds of time to each work can be calculated by the following equations,

Earliest Starting Time = earliest node time, (1)

Earliest Finishing Time

= Earliest Node Time + duration of work, (2)

Latest Starting Time

= Latest Node Time – duration of work, (3)

Latest Finishing Time = latest node time. (4)

The critical path of the work schedule is clarified with use of these four kinds of time and the network diagram. If the number of worker and a resource necessary for each work are input, necessary number of worker for the construction project and the amount of the resource can be estimated.

The output obtained from the planning and scheduling function are following,

(1) Work schedule which resource allocation was completed,

(2) Earliest starting time, earliest finishing time, latest starting time, latest finishing time, and float of each work,

(3) Critical path of the project, and

(4) Total cost of the project.

3.4 Work simulation function

The work simulation function in the VR-Coms will be able to create virtual construction in 3D computer-simulated environment before the planned construction is put into practice. The virtual construction simulation system is integrated with a planning, scheduling and performance management function, so that we will be able to find potential hazards latent in the plan being considered and to evaluate productivity.

The 3D model to be simulated is necessary to execute the work simulation. The model comes from the output of design function. Moreover, the work description, the work plan, and the operation plan of workers and machines are needed to decide to run the work simulation. The engineer should be making these before executing the simulation.

The following outputs are obtained by the simulation,

(1) Time necessary for work,
(2) Place with which some one spatially interferes,
(3) Verified control algorithm of construction equipment,
(4) Verified transportation path,
(5) Verified work traffic line,

Figure 3-3 shows the flow of the planning and scheduling process, which uses each function of the work simulation, the line simulation, and planning, and scheduling.

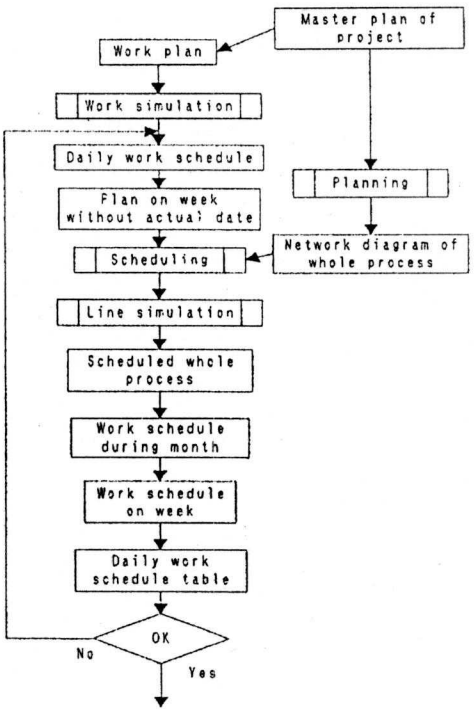

Fig 3-3 Construction planning flow using VR-Coms

3.5 Real-time based construction management and performance management function

The Real-time based construction management and performance management system monitors the behavior of the virtual construction simulation and captures the data needed to analyze productivity and safety.

The purpose of real-time based construction management system is that manufacturing overhead reduces and bears the third profit. The real-time based construction management system should correctly tell the situation of the construction site to the site manager. The system converts input data into following information and offers it to the site manager,

(1) Information for production control,
(2) Information for cost control,
(3) Information for quality control,
(4) Information for operation of equipment machine,
(5) Information for maintenance of equipment machine.

3.6 Common data base

It is a role of the database to store the data that the output of each function or each function uses. The library, which can be used together by all projects, as-designed data and as-built data of particular building, are main contents.

3.7 Cyber agents

The term "agent" means someone acting on behalf of someone else. A computerized agent is an entity who has own mental state being composed of beliefs, capabilities, and commitment [7]. Beliefs refer to the state of the world in the past, present, or future, and to the mental state of other computerized agents. Capabilities are taken to be a primitive notion defined in terms of future-branching structures. Commitment rules are activated based on certain patterns in the incoming message and current mental condition, that is, the mental state of this computerized agent. When the time comes to execute the action, the mental state at the time will be examined to see whether the mental condition is satisfied. Generally, computerized agents may be characterized in terms of autonomous, intelligent, communication, and anthropomorphic.

In this research project, considered are the following cyber-agents,

(1) Application agent,
  (a) Control-recovery agents,
  (b) Fault-warning agents,
  (c) Procedure-knowledge agents, and
  (d) Data mining agents, and
(2) Network agents.

4. Current Research Activities

Below listed are current research activities that we are doing:

(1) Control-recovery agent and fault-warning agent for automated construction operations;

(2) Virtual dynamic construction simulation:

(a) Case study on Takada model of new construction method for multi-stories apartment building;

(b) Construction line simulation; and

(c) Computational models to evaluate safety and productivity;

(3) Improvement of the computerized test bed environment toward the VR-Coms; and

(4) Object-oriented database model with respect to building construction.

4.1 Case Study of Control-recovery Agent

At the last fiscal year, conducted was the case study of agentification of control-recovery aids in the control, monitoring and warning computerized system for a semi-automated sliding system of assembled roof within a underground power plan. Figure 4-1 presents the schematic view of the prototype of the control-recovery agents being developed in the case of operating a hydraulic jack.

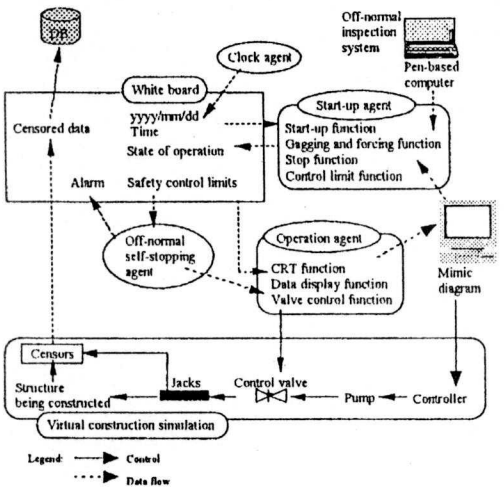

Fig. 4-1: The Schematic View of the Prototype of the Control-recovery Agents

The control, monitoring and warning computerized system here is functioning to:

(1) Monitor the behavior of the assembled roof being slid,

(2) Check whether its behavior is approaching its safety operating limits under operations, and

(3) Automatically stop its behavior in emergency.

The control-recovery agents translate the raw sensory data associated with the key variables into control or error signals, signs for displaying key warning and taking proactive actions, and symbols [7] for reasoning the underlying causes in order to invoke error recovery functions at skill-, rule- and knowledge-based levels [8].

4.2 Case Study on Takada Model

Shimizu Corporation proposes Takada model of a new construction method called chabudai construction method for multi-stories apartment building. In Japanese, "chabudai" means a table with short four legs. In this case study, created is a virtual dynamic construction of the Takada model in the computerized test bed environment as shown in Figure 4-2.

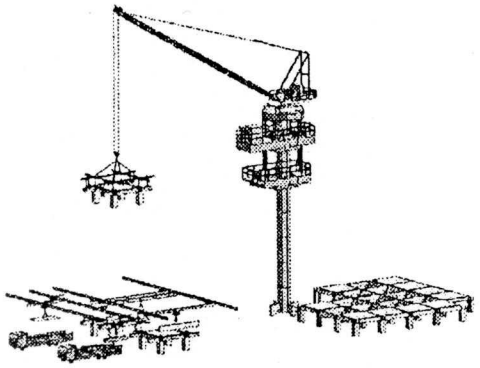

Fig. 4-2: The Virtual Dynamic Construction of the Takada model

This virtual dynamic construction centers on:

(1) Multilevel assembly sequence
- Tooling operation
- Assembly operation
- Delay operation

(2) Interference checks and Collision avoidance
- Part trajectory paths
- Swept volume envelope
- Dynamic cross sectioning

Simulating the Takada model in the computerized test bed environment enables us to do research on;

(1) Planning: Determine work that can be released during certain time interval;

(2) Scheduling: Determine work when that work is released into the field factory on a-minute-by-minute basis;

(3) Status and clock time: Know work position and machine status as well as ensuring that the plan representation covers the current clock time up to some predefined future plan horizon; and

(4) What-if:
- Accept or reject the resulting plan; and
- Explore the consequence of changes to the current state of the field factory.

Besides, the following items are studied:

(1) Object-oriented database model of chabudai construction method;

(2) Automated construction operations to assemble a chabudai; and

(3) Control-recovery agent and fault-warning agent for the automated construction operations.

4.3 Improvement of the Computerized Test bed Environment

Figure 4-3 shows mechanism to be built in the computerized test bed environment.

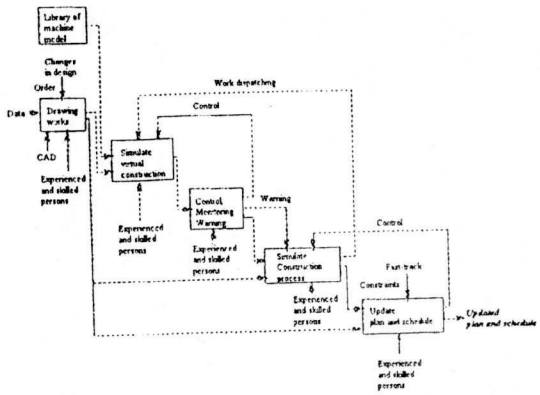

Fig. 4-3: Improvement of the Computerized Test bed Environment

Each task involved in construction works is grouped into the work packages, so that their forms can be identified in the three-dimensional simulation and their progress can be monitored. The planning and scheduling systems are employed to produce the information regarding the work packages on the project and to determine when each work package is dispatched to the construction site. With the planning module and virtual simulation tools, "what-if" analyses can be carried out to explore what happens in the construction site, as well as when and where the events occur. The virtual simulation, when combining with the scheduling system, can be used to study the status of the project and to relate the work performed at a specific time and specific location.

The control, monitoring and warning system monitors the behavior of the virtual construction simulation and captures the data needed to analyze productivity and safety.

The chabudai construction method being simulated in and this improvement of the computerized test bed environment will configure the VR-Coms as shown in Figure 4-4.

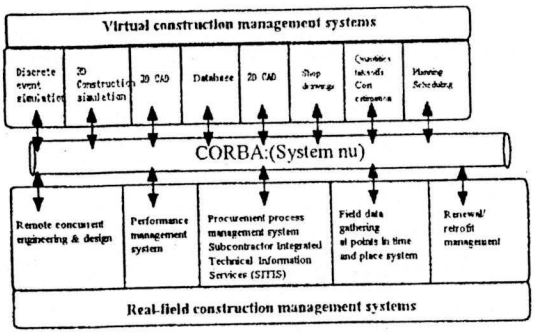

Fig. 4-4: Configuration of VR-Coms

5. Anticipated Results

The anticipated results that this study incubates are summarized as follows:

(1) Purchaser's merits.
- The content of the order is enhanced.
- The design change is flexible.
- Term of works shortening
- Reduction of construction expense

(2) Cooperation trader's merits
- An increase in unexpected construction expense is prevented.
- The construction delay is prevented.
- The arrangement to expect the big factor of safety becomes useless.

(3) Designer and contractor's merits.
- The design change is flexible.
- Term of works shortening.
- Reduction of construction expense.

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