ROBOT ORIENTED MODULAR CONSTRUCTION SYSTEM

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ABSTRACT

The tasks that the construction industry should be accomplished at construction sites today and in the future are the saving labor and the reduction of the construction period. To accomplish these challenging objectives, automatic and robotic construction systems of construction work have been actively by construction industry in Japan.

However, a basic concept of a proposed automatic and robotic construction system is equivalent to those of a conventional construction system. What has so far been proposed is mere automation and robotization of mechanism used and manual work. Innovations of this, however, will hardly help us accomplish such challenging objectives that are the saving labor and the reduction of the construction period.

In the focusing of these circumstances in the construction industry, authors have studied a construction system by a new logic that is based on the concept of a assemble-line system instead of the conventional final-line system in construction work.

With a view to substantiating our new logic, a mock up model test was carried out with full-size space module unit which was fabricated in the factory line on site. As a result, it was cleared that one floor of the model building could be completed in one day with one-fourth or less the labor that would otherwise have been required to the conventional system.

1. INTRODUCTION

The under-18 population that foretells the future working force in Japan has been decreasing in a slow curve after reaching a peak in 1992. The working force in Japan will from now on decrease in power and increase in age. And the tendency of young generations to desert manufacturing is compounding this labor problem. For these reason, the labor shortage on the future in Japan is an important probrem that the production sites will be faced with across industry.

For these probrem, the manufacturing industry with factory-line system has been introducing automatic system in many line of factory. In the automated processes of manufacturing have successfully rationalized production by reducing much of their manpower and production costs.

In Japan, automobile industry are the sector of industry where automation is so advanced. In automobile industry, the automation of its welding lines are nearing completion. In the car body assembling lines, however, much work still depends on manual labor. At present, car body assembly is carried out in the so-called final-line system in which car body assembly is carried out by mounting one part after another in a long production line in a factory. In the final-line system, car body is assembled from external work to internal work so that some processes are not amenable to automatic assembly. It is said that for this reason there is a limit to automate for car body assembly.

It is said that any attempt to automate car body assembly in the final-line system would be in any more than 15% to 20% of the entire assembling processes. Many Japan's automakers who are quite effort to achieve a breakthrough in automation are studying the introduction of the assemble-line system based on the module unit technology.

From the standpoint of automation, construction industry have more constraints than do manufacturing industry whose production is factory based. First of all, the construction sites varies with each product of construction, that is, building, and size and function also vary with each product. What is more, the working environment is susceptible of the influence of weather. These variable factors not only require that adhoc judgment be made in each processes of construction based on the experience and knowledge of workers, but also make it difficult to standardize the dimensions of building structure. Constructors under these restrictions bring large quantities of raw materials to each actual site where a large variety jobs are undertaken by various specialists to build a building. This system is the final-line system in construction work, as shown in Fig.1. In the construction industry, modular coordination has been introduced for factory made materials, such as steel members, and components that need to be replaced later, such as furniture and equipment. In the area of production work, however, where worker's judgment is needed most keenly in the processes of production, the effort to save manpower through production rationalization and automation in combination has just begun in Japan.

This paper discusses a "modular construction system" resorting as its basic technology to the three-dimensional space module which was conceived as a practical approach to production rationalization which is essential in after this for serious labor shortages.

2. THE AIM OF THE MODULAR CONSTRUCTION SYSTEM

In contrast to production in other industries, production work in the construction industry is characterized by (1) the bulkiness and heaviness of building members and (2) limited production using a variety of materials from precast members to connecting bolts. These characteristics of construction work have significant implications when it is to be automated. The automatic and robotic construction systems that the many general contractors in Japan has recently been making to automate their works concerns the mechanization of multiple-type production and high-level energy work such as the transport of large building components are said a construction system of final-line system. However, these automatic construction systems means the replacement of labor with machines in production work that realizes the functional design imparting necessary functions to the building to be built. It does not have for its purpose to facilitate the erection work of a building at the construction site.

To facilitate automation in construction it is necessary to improve the processes of assembly full of disturbing factors. This tasks requires simultaneous engineering that meets the requirements of both production design which gives due consideration to production methods and processes and of functional design which imparts necessary functions to the building to be built.

The problem with conventional construction systems are the fact that modules are considered at the building member level. In other words, no attempt has been made at a break with traditional continuous production method in the final-line system. Accordingly, the necessity is not felt of standardizing modules beyond the building member and part level. None of the conventional construction systems have been improved with a view to "facilitating assembly".

As shown in Fig.2, in the modular construction system of assemble-line system, by contrast, three-dimensional space module units are employed to "facilitate assembly" at the construction sites, thus rationalizing the processes of construction.

3. THE LOGIC OF MODULAR CONSTRUCTION SYSTEM

In recent years construction productivity has reached a plateau. This is in large part due to the final-line system in which materials and parts brought to the construction sites are processed and assembled by specialists, floor by floor, from bottom to top. To increase construction productivity on site, the processing and assembly of materials and parts should be held down to a minimum, and complicated, time-consuming works should be improved to make them amenable to ground subassembly. In other words, it is necessary to increase the level of industrialization to shift to the assemble-line system in construction on site.

As shown in Fig.3, the modular construction system regards a building as an assembly of three-dimensional space module units. And modular construction system is required to carry out production in the assemble-line system.

The basic units of a building to be built by the modular construction system are spaces with one-span, one-floor. The dimensions of basic units are determined by the site conditions, conditions of unit connection, unit weight, and other factors. The connections around basic units are systematized. With the modular construction system construction work consists of merely connecting space module units. All other processes of complicated work are eliminated.

The space module units are assembled in the factory automation line on ground in site, as shown in Fig.4. The assembly of space module units stratify material processing, part mounting, and unit assembly so that mutual dependence of production processes can be eliminated. This system spreads factory production to the scale of transportable components and make space module units amenable to production in the factory automation line that is designed to turn out assembled units at tact schedule.

The modular construction system greatly simplifies the processes of construction both because space module units can be assembled in parallel lines and because a building can be erected by merely connecting three-dimensional space module units. As a result, the introduction of automation technology is easier.

4. PREREQUISITES OF THE MODULAR CONSTRUCTION SYSTEM

The relationship between modules and architecture has long existed. Modules are deeply concerned with architecture not only as a factor conducive to the convenience of use of building but also as means of production.

As the production of building materials was industrialized, modules which are closely associated with building material production equipment and facilities are hard to change came into use as building units. In the modern society where amenities are acquiring increasing importance the standardization of functions, especially utilities, by the use of modules is the prerequisite of the modern building.

The modular construction system requires that standards be established concerning structural space and that structural space subassembly be materialized through improvement of construction production processes so as to rationalize the construction work.

Success in modular construction sysytem depends on whether or not space module units can improved to the extent that they can be assembled at the construction sites in the shortest possible time. To this end, (1) space module units must be of such structual design that they are quite easy to assemble and dynamically reasonable. (2) To facilitate the joining of space module units it is necessary to establish a method of disassembling a building into space module units. It is also necessary to establish a dimensional module that is consonant with the functional dimensions that are determined by the design of uses and living quality of building. To make such a dimensional module a real space module units should be designed by a dimensional system, assuming that buildings built by the modular construction system have a uniform span and height, although they may be varieties, no matter whichever way they may be viewed, plane or elevation planning.

Furthermore, (3) space module units should also be standardized to attain high stability when they are erected into a building. In modular construction three-dimensional units may be used. Conditions (1) and (2) indicate the need of concurrent product and process development methodology which takes into consideration not only functional design but also production design to make space module units easy to assembly.

To meet conditions (3) cranes with high power motor must be available which are capable of lifting large and heavy space module units. In Japan, cranes today are showing a tendency to grow up in power.

5. EXPERIMENTAL MOCK-UP TEST BY THE MODULAR CONSTRUCTION SYSTEM

This section discusses the results of experimental mock-up test of a model building with full-size space module units. The model building was designed by a mixed structural system built with steel-pipe columns filled with concrete, steel girders, and reinforced concrete floor. This combination of building members saves most effective in manpower and reduces the unit joining time to a significant extent.

The standard floor of the model building was disassembled into 14 three-dimensional space module units. The space module unit was assembled on the ground subassemble line in the following order.

(1)Setting up of columns
(2)Setting up of girders
(3)Jointing of girders to columns
(4)Attachment of floor slabs on girders

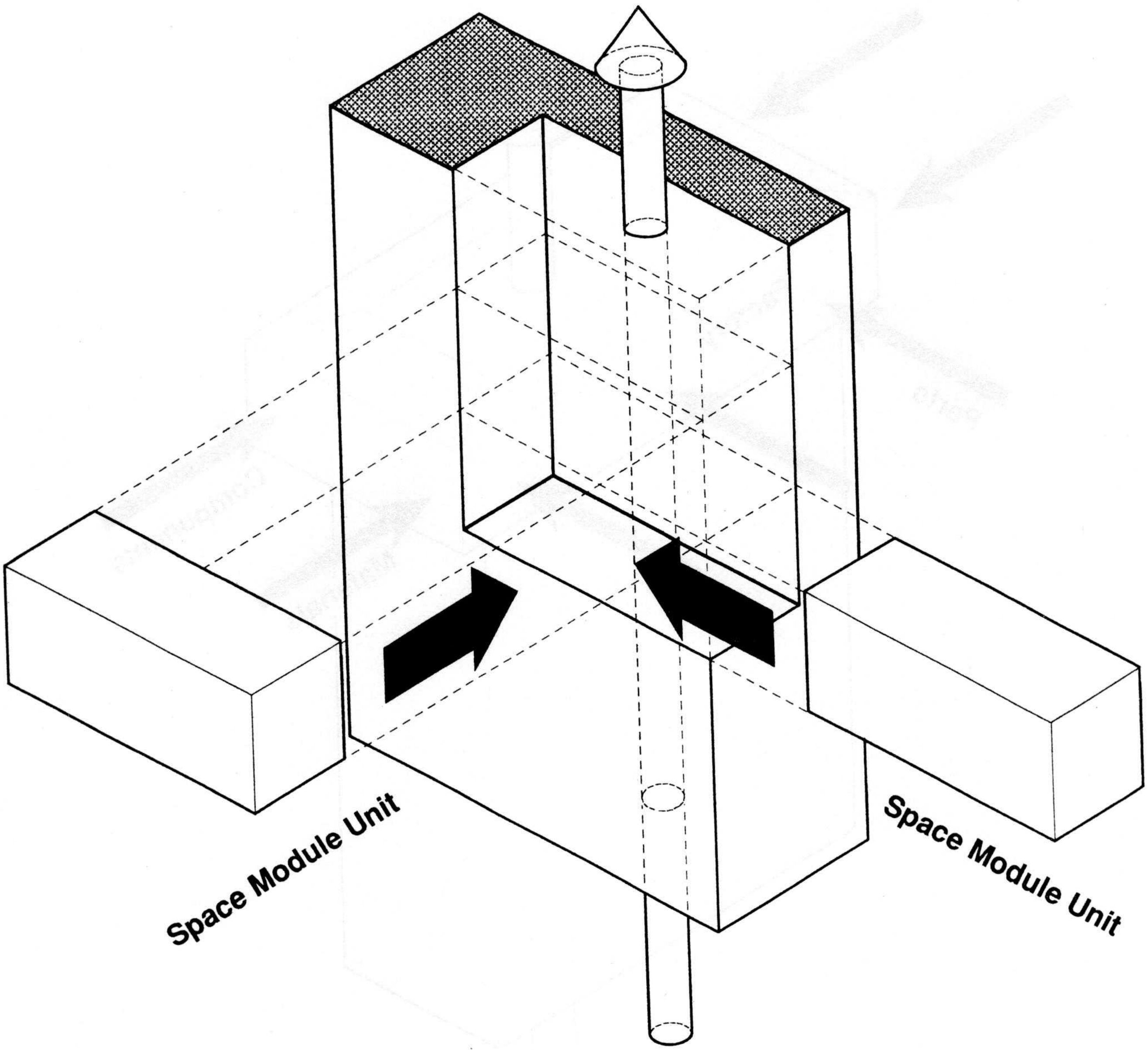
6. CONCLUSION

The measured manpower, that is, the time required from the time a full-size space module unit is assembled to the time a building is erected by joining space module units is 29 man-hours/unit.

Since one floor of the model building is built with 14 space module units, it takes 406 man-hours to complete one floor by modular construction system.

This means that total amounts of construction workers by the modular construction system are less than 1/4 compared with the those of the conventional construction systems require. The analysis of experimental results indicates that each floor of the model building can be completed in one day.

By the "modular construction system" of assemble-line system, it can be accomplished that is the saving labor and realize the super reduction of the construction period.



(Modular Construction System)

Fig.2 Assemble-Line System

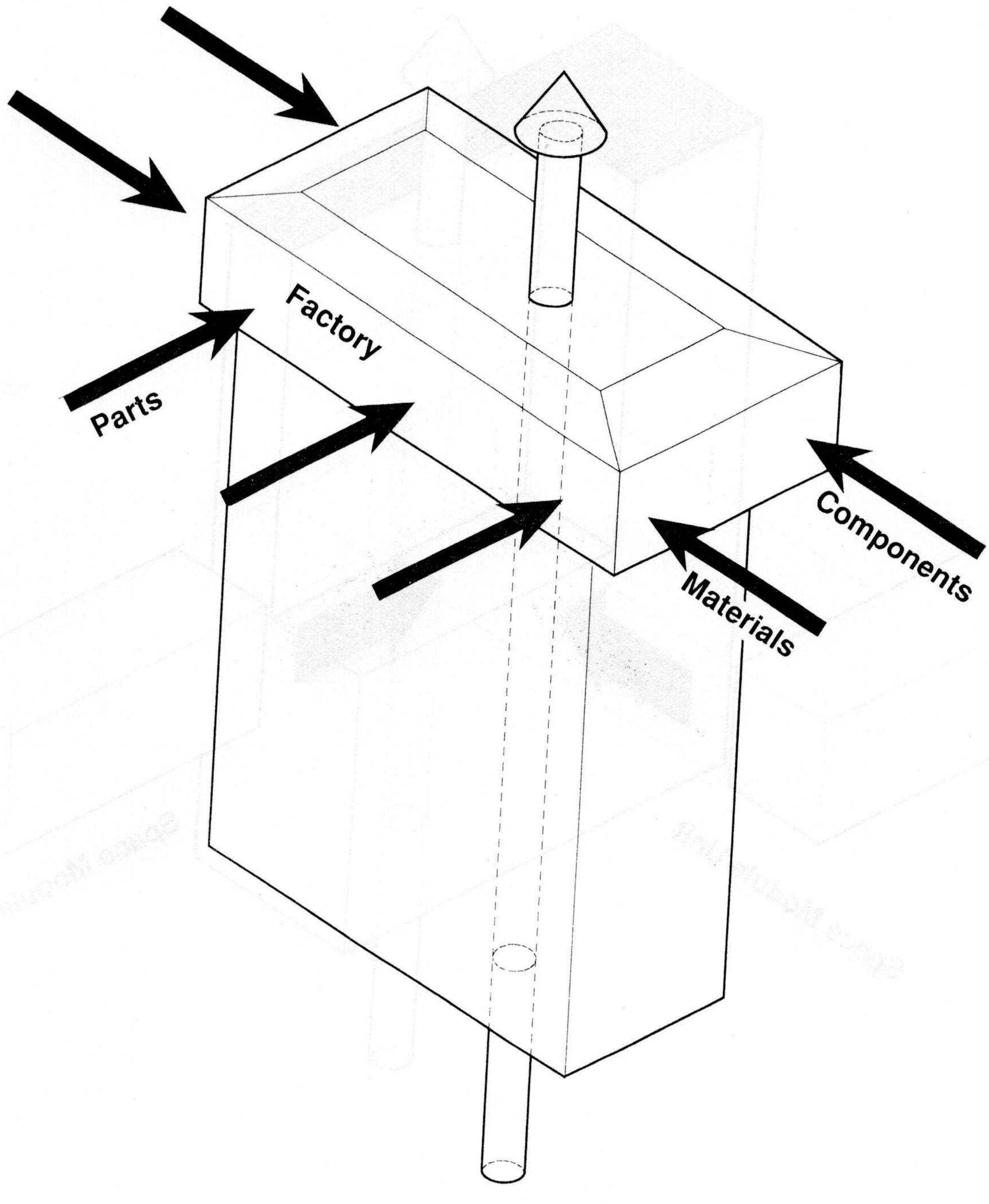


Fig.1 Final - Line System

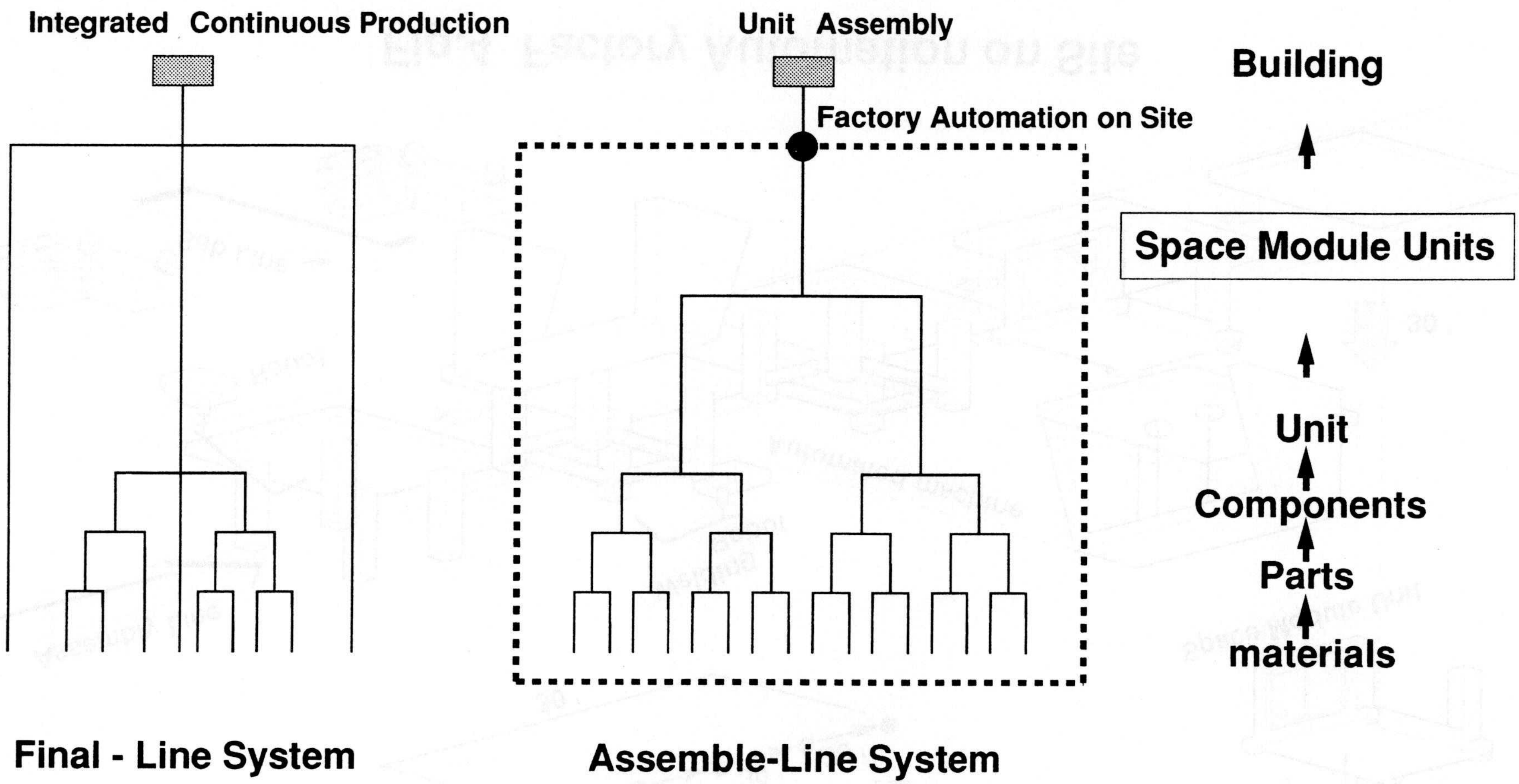


Fig.3 The Hierarchies of Construction Processes

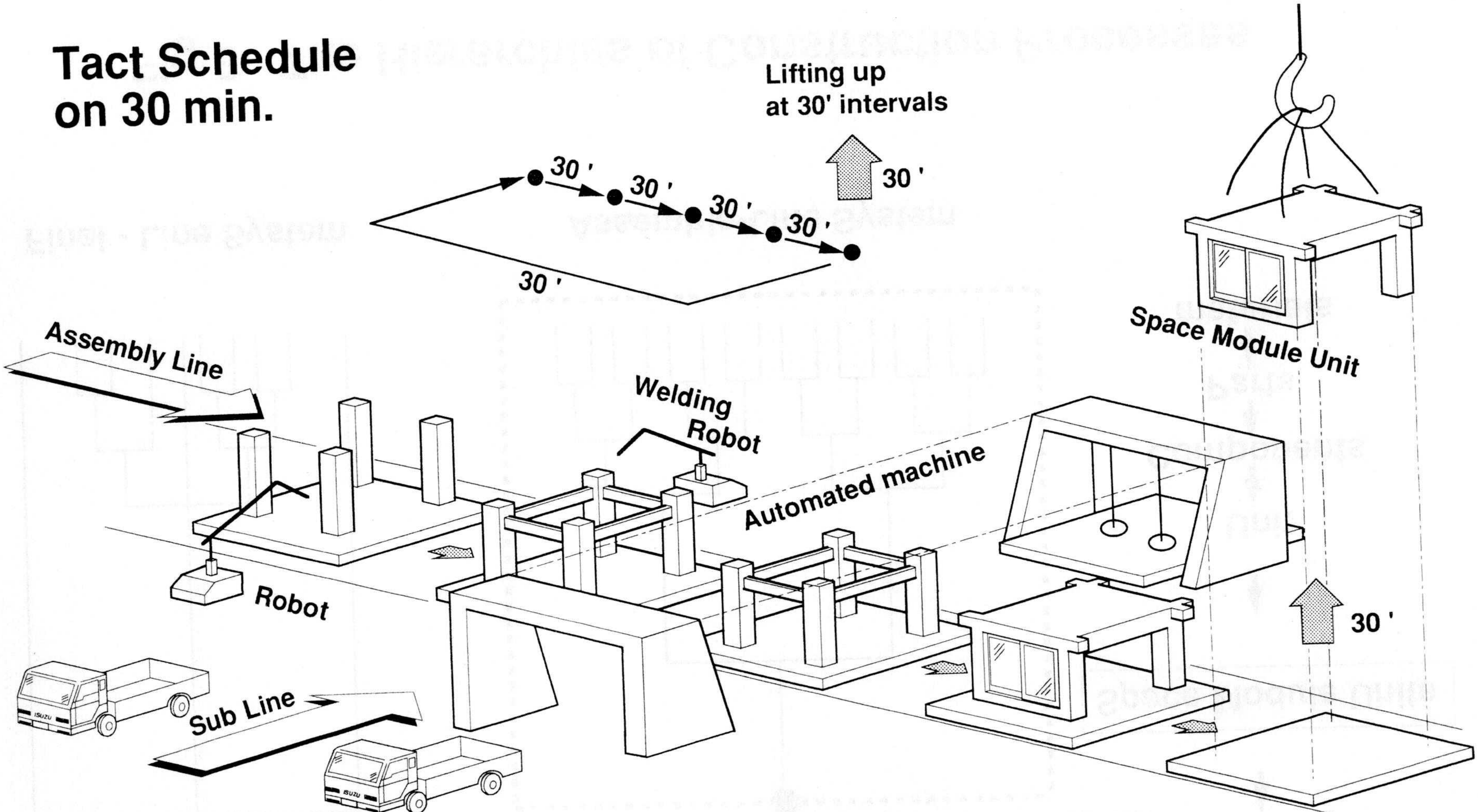


Fig.4 Factory Automation on Site