A Knowledge-Based System for Construction Planning and Scheduling

A Prototype System Based on the Down-from-the-Top Methodology

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Abstract

This paper describes an expert system aiming at creating the environment for engineers to generate construction plans efficiently based on the Down-from-the-Top planning methodology. An experiment for a building project was studied to investigate the competence of the methodology. A prototype system has been implemented in KEE on a Macintosh II with a TI MicroExplorer board. This expert system is named ConsPlans (Construction Planning and Scheduling System).

Keywords

Knowledge-Based system; Construction Planning; Construction Scheduling; Work Package

1. Introduction

This paper is to present an expert system which is based on the Down-from-the-Top planning methodology[1) 2)]. The system has two main inference tasks: planning and scheduling. The planning task is to generate the construction process in accordance with the content of CAD data, and the scheduling task is to pursue the schedule and the resource allocations.

As a prototype system, ConsPlans (Construction Planning and Scheduling System) has been developed so as to have the capabilities of handling the breakdown structures which are required in construction planning.

2. Down-from-the-Top vs. Up-from-the-Bottom

It is essential in making a plan to minimize time, expenditure and manpower required for the planning process as well as to optimize the plan itself. Efficiency of planning is particularly important when the process has to be planned anew for each individual project, as in construction projects. Planning process can be broadly classified into the down-from-the-top methodology and the up-from-the-bottom methodology.

By the Down-from-the-Top methodology, the planning policy and the deadline of the construction project are first set. Then, the proper construction methods are selected within the general framework so defined, and the planning proceeds to increasingly fine details while maintaining compatibility with the whole process. On the other hand, by the Up-from-the-Bottom methodology, details of each segment of the prospective construction plan are first considered; various construction methods are compared to choose the best, and the feasibility of the draft plan is evaluated. The segments of the plan are then integrated up into a whole while defining their mutual relationships.

While the Down-from-the-Top methodology cannot be used without sufficient information on which the planning process is based, it has the advantage of requiring less manpower and time than the Up-from-the-Bottom methodology. The Down-from-the-Top methodology, therefore, plays an important part in formulating a plan for a construction project.

3. A Prototype System Based on the Down-from-the-Top Method

3.1. System Configuration

ConsPlans (Construction Planning and Scheduling System) is a prototype system for the construction planning phase. The development of the prototype system has been implemented in KEE environment, which is running on a Macintosh II with a TI MicroExplorer board.

The prototype system is designed to generate construction plans based on the content in CAD data which specify the information on drawings and specifications of a building project ,and to schedule the construction process based on the construction plan generated by the system.

With ConsPlans, the engineer first installs the information on drawings and specifications of a given building project from CAD data. Then he selects and defines the work packages for the components specified by the input data. In planning, the engineer breaks down activities and resources such as materials, equipment and workers, in order to detail his plans step by step. Moreover, he might schedule the process under the resource constraint at each detail level. During those planning procedures, ConsPlans assists him for selecting work packages, evaluating the duration of activities and resource requirement, assuming precedence relationships among activities, and calculating the schedule of the construction process.

3.2 Definition of a Construction Project in ConsPlans

A building is represented with a set of components in ConsPlans. Each component has the following data.

1) Component identifier
2) A space attribute
3) Slot attributes
4) Breakdown structures

Each component has a unique component identifier such as "REINFORCED_COLUMN" and "REINFORCED_BEAM". It is one of the distinct features of ConsPlans' project definition that a building project is broken down into various detail levels of components; therefore each component represents not only a part of a building but also a set of components. To distinguish components at different locations, a space attribute is postfixed to the identifier of the component like "REINFORCED_COLUMN.2ND_FLOOR", where a period is located between the component identifier and the space attribute as a connector. This combination of an component identifier and a space attribute is applied to activities and substances at site in the same way.

The space attribute has its own spatial structure in order to recognize the spatial relationships among the spaces. These relationships are used for the inference of the spatial reasoning among components and activities.

Each component has various slots representing the detail information of the project such as the quantity ,the dimensions of components and other characteristics. Furthermore, each component has certain breakdown structures, which organize the components on different detail levels.

3.3. Knowledge Base in ConsPlans

3.3.1 Work Package for a Component

A work package consists of an activity and substances required for the activity performance. The term "substance" means physical objects needed for the construction process at the site such as materials, workers and equipment. The relationships between the activity and those substances are classified into the following three categories:

1) input : the substance will be consumed by the activity.
2) use : the substance will be occupied or sustained during the activity performance.
3) output : the substance will be created as an output of the activity.

Besides those relationships, each work package has various information which are required in planning the activity, such as duration, the amount of materials, the numbers of workers in respect to the amount of components to be produced. Most of these data are acquired by using an acquisition algorithm to be mentioned later.

3.3.2 Precedences between activities

The precedence relationships among specific activities are stored in the knowledge base. In addition to those specific relationships, the knowledge base installs the universal knowledge on inferring precedences between activities using the spatial information, such as a rule: *an activity on a floor precedes the activity on the upper floor.*

3.3.3 Value Acquisition Algorithm

The slots of the activities, substances and relationships in a work package might be assigned a certain value or an identifier according to the components to be produced when they are inferred.

ConsPlans implements this role by using an acquisition algorithm. The acquisition algorithm defines the calculation formula and the method to instantiate variables to be used in the formula. The following acquisition algorithm shows an example specifying the duration of a superstructure work. This formula shows that the value of duration will be acquired by using an slot attribute (number_of_floors) in a component and a given plot function. In this example, the number of floors is five, which implies a duration of 125.

```
(@plot (thisvalue 20 60 100 250 600)
       ((thisunit >output * :number_of_floor) 1 2 4 10 30))
                                    ------------------ (1)
```

3.4. Procedures for Generating a Construction process

To generate the construction process, first of all the planner might define the over-all top plan: which represents construction process with only a few activities. After the planner has established the over-all plan, the more detail part of the plan should be explored in respect to the work package, and the precedence relationship.

To generate a construction process, a planner might perform the following planning actions.

1) get a work package for components
2) get precedences among activities
3) break down his plan

The inferences for generating construction process are performed based on the knowledge base. Using the knowledge base, the system acquires the necessary information, such as work packages and precedences by matching the keywords of the request with tags in a set of knowledge on construction planning.

3.5. Procedures for Scheduling a Construction Plan

The scheduling is performed from the upper level of the structure. In the scheduling, the start date and the finish date which have been calculated in the upper level become constraints to the schedule of the lower level.

However, when the construction planner is not sure whether the schedules of activities which have been calculated are appropriate, he might intend to explore the lower level of the structure and induce the revised schedules from the lower level schedules in order to get more precise plan. This procedure corresponds to the Up-from-the-Bottom method. In this case, the schedules of the lower level activities are the elements which compose the upper schedule.

The schedule is calculated by the back and forth directions in the breakdown structure. The planner is asked for his confirmation on the results of scheduling at each level of the structure. If it has confidence in the schedule, the value of this level will constrain the rest of the lower levels of the structure. In case that it is not confident of the results of the schedule at a certain level, the scheduling for the lower level is explored and this result is converted into the upper level schedules.

4. An Experimental Study for ConsPlans

4.1. An Experiment for a building project

The experiment is for the construction project of an office building. Figure 1 shows the breakdown structure of components representing an example office building: two basements, five stories and 5,000 m^2 of total floor area.

To produce the construction process and the schedule, the system installs the information of components and the information of the space structure before conducting the inferences required.

4.2. Procedure of Planning

To generate the construction process, the information of components has to be converted into the information of activities. This manipulation will be done by pointing at the term "define.workpackage" on the menu. (Figure 2), which results in retrieving the information from the knowledge base and storing it in the planning board like a blackboard.

As a result of the retrieval, the planner could acquire the detail of the work package such as requirements of workers, materials and equipment in addition to duration and cost.

After the inferences for work packages and break down structures, the planner gets the construction process from the composed work breakdown structure in Figure 3. Each activity has the full information on duration, resource requirements and cost as shown in Figure 4. Figure 4 also shows the details of the work package of super_structure_work.site.

The precedences among those activities are inferred from the knowledge base as several sets of sub-network diagram in Figure 5.

Figure 6 shows the breakdown structure of the workers in this project. This breakdown structure is used to take account of the number of workers for resource allocation in scheduling at each level of the details.

4.3. Procedure of Scheduling

The schedule is carried out from the top activity in the breakdown structure, for the above example building_construction.site. This activity has a duration of 370 days which has been specified by the owner. Therefore, the latter schedules are governed by this period.

Figure 7 shows the intermediate schedule, which overruns the mandatory days (370 days) by 25 days. After modifications on the activities in order to meet the schedule, a planner is able to establish a revised plan which satisfies the upper level of schedule as shown in Figure 8. By the same procedure a planner develops further detail schedules as shown in Figure 9 and 10.

As a result of the resource allocations, Figure 10 shows the worker requirement for each trade at the site.

5. Conclusion

The experiment in this paper shows the competence of the Down-from-the-Top methodology in construction planning and scheduling. Through the experiment, the author has been convinced that the methodology mentioned here would play an essential role for an expert system in construction planning stage.

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2) Naruo Kano: "Planning and Scheduling in Building Construction - Methodologies for Construction Planning and Presentation," Memoirs of the School of Science & Engineering, No.52, 1988, Waseda University, pp89-102

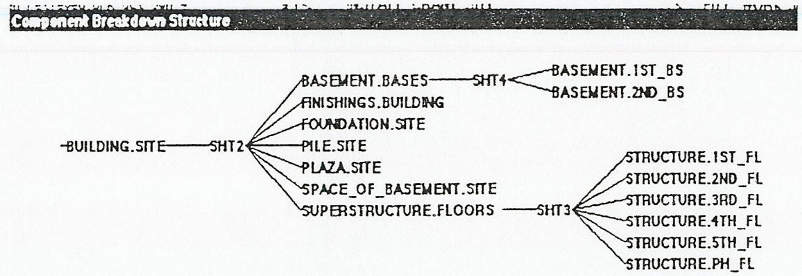


Figure 1 Breakdown Structure of Components

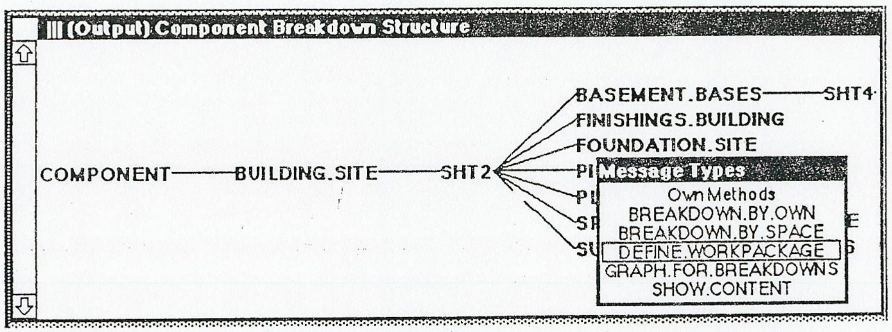


Figure 2 Menu for Construction Planning

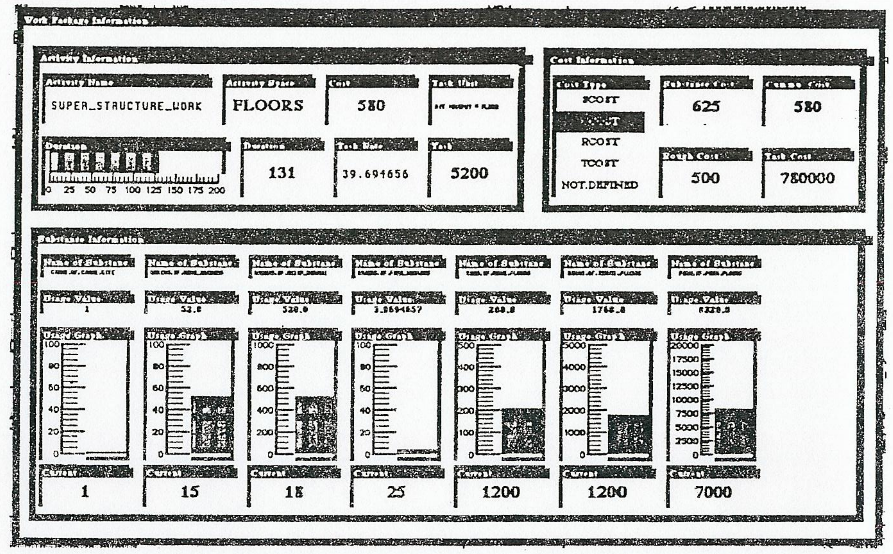


Figure 4 Panel for Workpackage of Superstructure_Work.Site

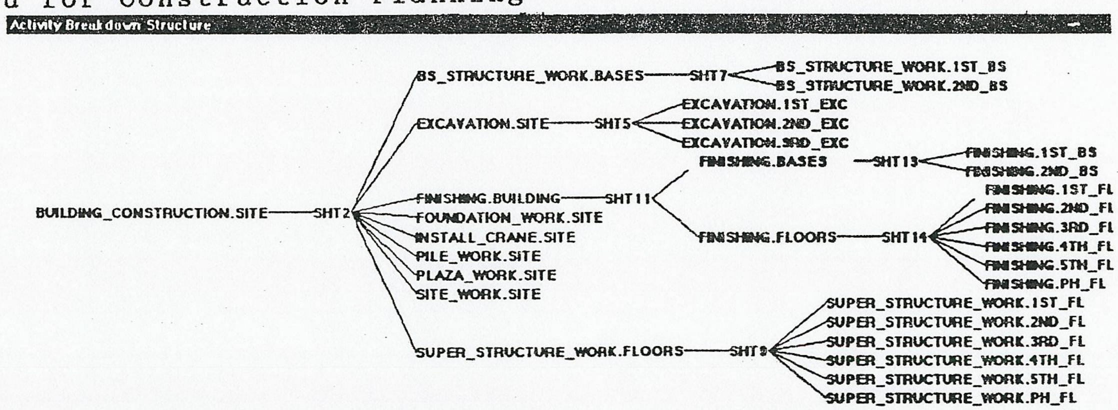
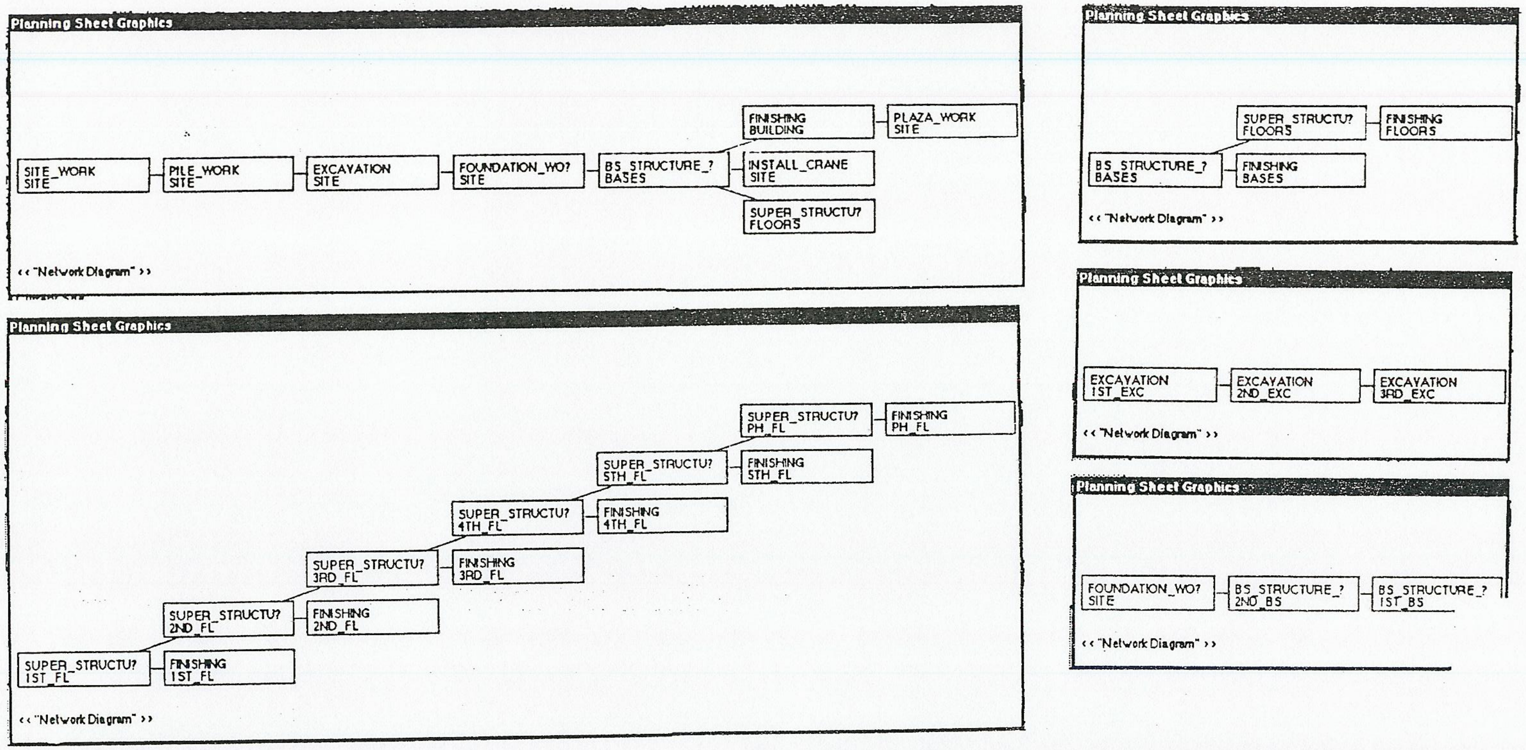


Figure 3 Breakdown Structure of Activities



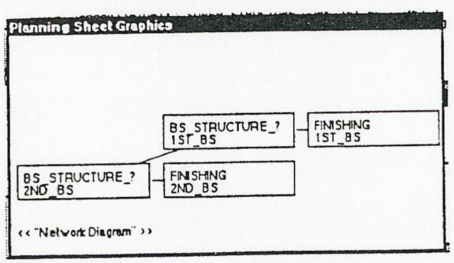


Figure 5 Network Diagrams

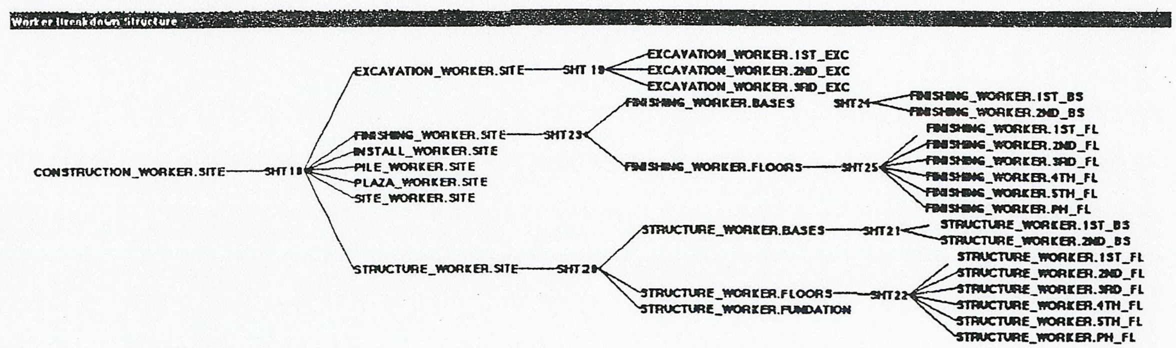


Figure 6 Breakdown Structure of Construction Workers

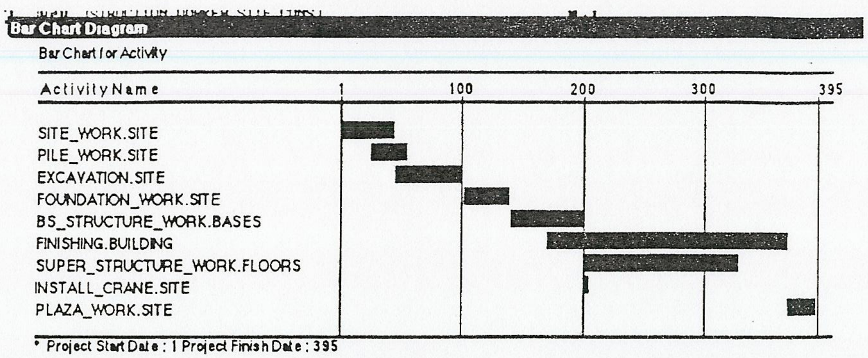


Figure 7 Bar Chart Diagram - 395 Days (Level II)

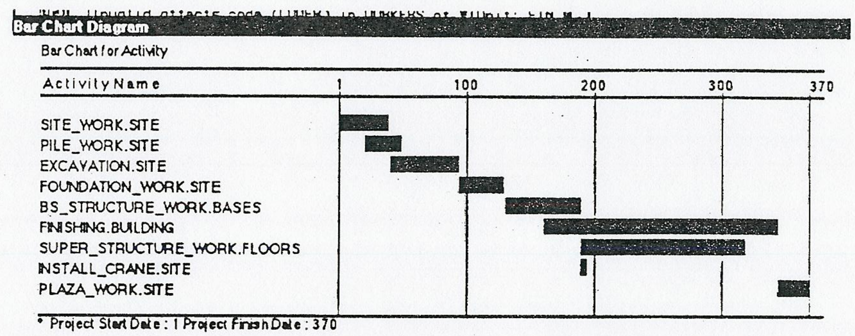


Figure 8 Bar Chart Diagram - 370 Days (Level II)

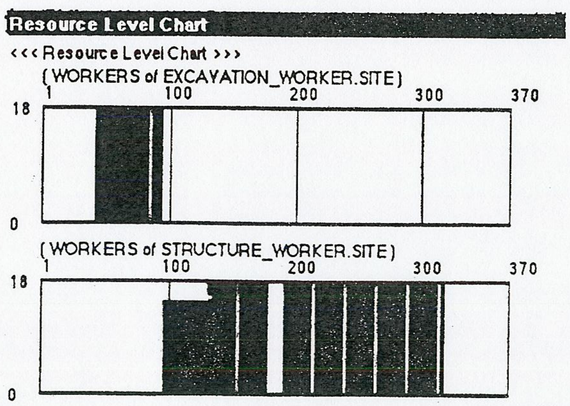


Figure 11 Worker Requirement for Each Trade

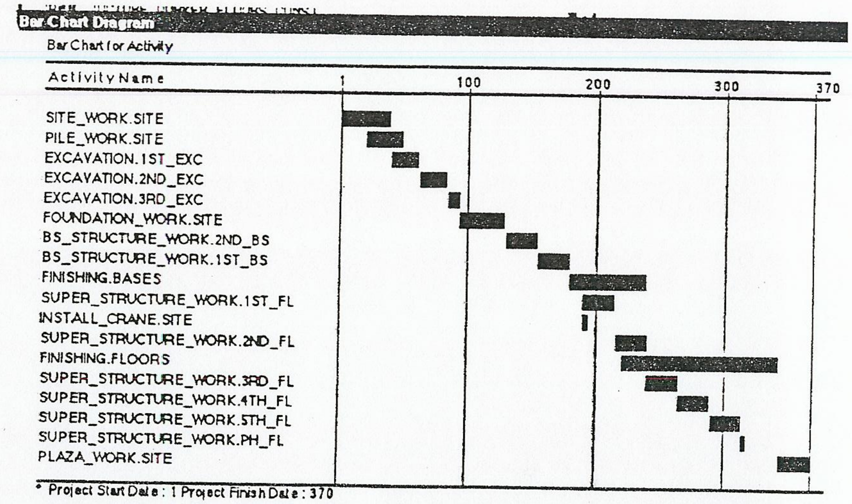


Figure 9 Bar Chart Diagram (Level III)

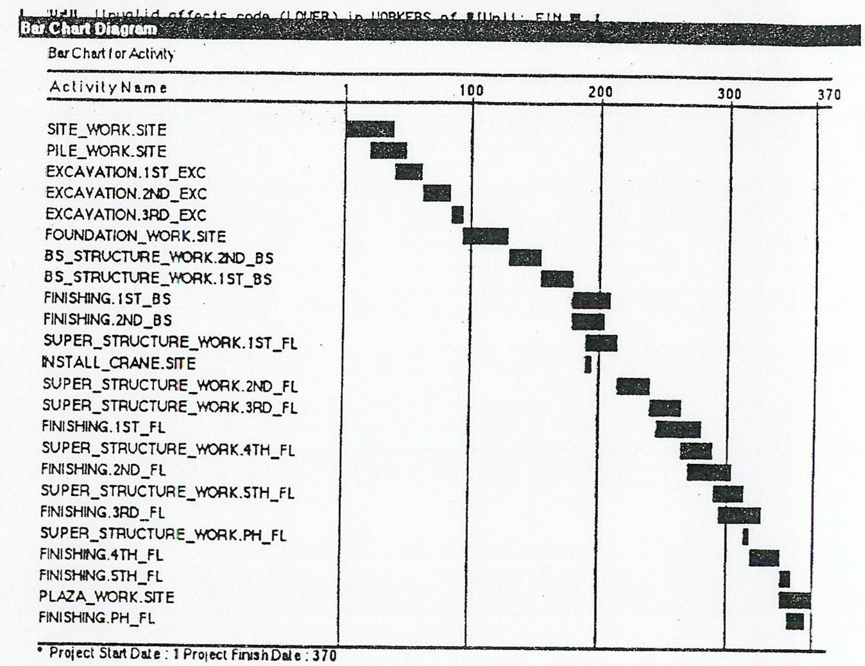


Figure 10 Bar Chart Diagram (Level IV)