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عمـــادة الدراســـات العـــليا
كلـــية الهندســـة
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"Simulation Modules Development to Estimate Activities Duration of Infrastructure Projects during Planning Phase"

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"A Thesis Submitted in Partial Fulfillment of the Requirements for Degree of Master of Science in Construction Management"

The Islamic University of Gaza – Palestine

June, 2005

ABSTRACT

For any construction project, life cycle is divided into five main phases. Planning and designed is one of the most important phases, because project features are assigned at this phase. One of these features is the duration required to execute the project.

In Gaza, most construction projects were accomplished with durations exceeding the planned durations assigned by the owners. The recurring of the problem ensures that this aspect does not occur accidentally. One of reasons for this problem is the way used to estimate the durations for the projects, where deterministic approach is used. The decision makers depend on their experiences to estimate project durations or by making comparisons between similar projects.

This thesis represents how simulation technique can be used in estimating project durations. An approach was developed depending on probabilistic concept to built simulation modules to be used in assigning projects durations. Simulation technique was used to design general simulation model that can be used for different infrastructure projects.

This simulation model was designed to simulate construction activities required for sewer and pavement construction projects. The model involves construction processes with their probabilistic distribution functions. It also contains logical relationships that represent the actual behavior of the project. The model was designed to support the user with a number of alternatives that cover the actual site conditions.

Verification and validation processes were applied to the model at different levels. Each template or module was separately verified then validated integrally within the model. Parts of the model were applied to previously executed projects and outputs results were compared with actual durations and the results were found good.

For more facilitation, Visual Basic interfaces were developed to facilitate data entry for the model. These interfaces provide the user with many alternatives options according to site conditions and type of work.

ACKNOWLEDGEMENTS

Completing this thesis would have been impossible without the help of a great many people. Chief among them is my advisor and mentor Dr. Rifat Rustom. His concern for my success and efforts on my behalf are almost without end.

My parents, brother and sisters have always been a real support to achieve my educational goals. I want to express my deep gratitude to them. Finally, my wife, Rana, who was always on my side and motivated me for this work.

تلخيص

تقسم فترة إنشاء المشاريع الهندسية الي خمس مراحل رئيسية وتعتبر مرحلة التخطيط والتصميم هي واحدة من أهم هذه المراحل وذلك لأن كل ملامح المشروع وخصائصه تحدد في هذه الفترة، وأحد أهم هذه الخصائص هي تحديد الفترة الزمنية الازمة لتنفيذ وتشغيل المشروع.

في قطاع غزة،معظم المشاريع الهندسية قد تم تنفيذها بفترات زمنية تجاوزت الفترات المحددة من قبل مالكي المشاريع. تكرار هذه المشكلة أكد بأن حدوث هذة التأخير في المشاريع ليس عشوائيا،وكان واضحا ان الطرق المتبعة في تحديد الفترات الزمنية غير دقيقةلإعتمادها علي خبرة المهندسين وعلي عمل المقارنات مع مشاريع هندسية مشابه. في هذا البحث تم تطوير طريقه جديدة لتقدير الوقت اللازم لتنفيذ المشاريع الهندسية بالإعتماد على المبدأ الإحتمالي لبناء نموذج محاكاة يستخدم لتقدير الزمن. تقنية المحاكاة استخدمت لعمل نموذج عام يمكن إستخدامه لمشاريع البنية التحتية.

تم تصميم هذا النموذج ليشمل الأنشطة الخاصة بإنشاء شبكات الصرف الصحي وأعمال الطرق بحيث يحتوي هذا النموذج علي العمليات اللازمة لتنفيذ هذه الأنشطة وتم تصميم العلاقات المنطقية بينها لمحاكاة الأداء الحقيقي للمشروع بكل المتغيرات المتوقعة.

تم التحقق من أداء النموذج بعمل فحوصات تجريبية لكل جزئيات النموذج بالإضافة لفحصه بصورة متكامله. تم استخدام أجزاء من النموذج وتطبيقه علي مشاريع سابقة وعمل مقارنات للنتائج وكانت النتائج متقاربه . لعمل مزيد من التسهيلات في استخدام النموذج، تم تصميم واجهات ادخال بيانات للنموذج والتي تمكن المستخدم من إدخال عدد كبير من الخيارات بطريقه سهله وبدون معرفة مسبقة لبرنامج المحاكاة المستخدم .

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1 INTRODUCTION

1.1 Background

For any construction project there are many objectives that must be achieved after the completion of the project. These objectives exist in many shapes, but by closely looking at these objectives, it is clear that these objectives aim to complete the project within time, cost and quality constraints set by the client (Burke 1992).

The objective within the project management may be defined in terms of the three previous parameters: time, cost, and quality and each one of these parameter must be considered separately as well as integrally with the others.

Duration (time) as one of the previous parameters; was considered in this research. Simulation technique was used to develop multi-use model for infrastructure projects. This multi-use model can be used by planners or decision makers (at the planning phase) as a tool in assessing durations required to accomplish construction of infrastructure projects.

In order to increase the value of this multi-use model; simple user interfaces were designed to facilitate the interaction of users with the simulation software.

1.2 Research Importance

It is well known that infrastructure projects take the largest quota of construction projects budget in the municipalities or governmental institutes in Gaza Strip, because these projects require large quantities of raw materials and huge effort of heavy machinery.

So, the sector of infrastructure projects was the target of this research in order to concentrate the effort of research on an effective side of the construction industry. For any construction project; life cycle of the project is divided mainly into five phases (Barrie 1992):

1. Concept and feasibility study phase.
2. Engineering and design (Planning) phase.
3. Procurement phase
4. Construction phase.
5. Start up and implementation phase.

During the second phase, planners estimate one of the most important things in the planning phase; the expected duration required to accomplish the project.

This expectation generally is made by the planners (engineers) depending on their own experiences or by making comparison with similar executed projects ignoring the rule that says "each project is unique". This uniqueness comes from many reasons like differences between any two sites in their subsurface conditions, or by the residential obstacles or even in the specifications and detailing of the project.

As a result of these differences, the proposed duration presented in the tender becomes either insufficient to complete the project within the expected date or higher than expected. In Gaza Strip, during the period from 1995 to 2000, most infrastructure projects were not finished at the defined dates even during the period when normal political conditions prevailed (PECDAR 1999). As a result of under estimated projects durations, the contractors always took the risk and mulcted by liquidated damages due to the delay of handing over their projects.

1.3 Research Aim and Objectives

The recurring of the problem (delay in handing over projects) ensures that this aspect does not occur accidentally, and one of the main causation is in the estimated duration that proposed by the owner's engineers during the design and planning phase. So, this research attempted to treat the debility of the methods normally used in estimating durations of construction infrastructure projects during the planning phase. Simulation as an advance technique was used to develop multi-use model that support the engineers in estimating projects durations with adequate level of confidence. Simulation technique is a powerful and quick tool that helps the engineers (planners) in taking the right decision about this point.

The specific objectives of the research are summarized in the following two points:

- Developing a general simulation approach to create multi-use simulation models for different construction projects. These simulation models are used to determinate appropriate durations required during the planning phase.
- Developing a verified and validated computer simulation model that suits the infrastructure construction projects in Gaza Strip. The use of this simulation model will be simplified by creating a user friendly interface where no need for previous simulation knowledge to operate this model.

1.4 Thesis Organization

This thesis was divided into 10 chapters; each chapter covered certain area and went through as follows:

Chapter 1 which introduces the reader to the general features of the subject and represents the objectives and importance of the research. *Chapter 2* presented the literature review. This chapter covered the previously efforts made to the principles of using simulation techniques in studying construction projects. Especial concentration was made to what is called "General Purpose Simulation fundamentals" and to the concepts of reusable simulation templates and modules. *Chapter 3* represented the methodology followed in the thesis. *Chapter 4* explained the developed general simulation approach and showed the ability of using this approach in creating reusable simulation models to be applied for different type of projects and not limited to infrastructure projects. *Chapter 5* represented the procedure required to create simulation model by applying the approach. *Chapter 6* and *chapter 7* demonstrate the development of sewer and pavement works modules by using Arena software. *Chapter 8* explained how to develop the overall simulation model. *Chapter 9* presented verification and validation processes executed to the modules. Finally *Chapter 10* presented conclusions from the research and recommendations. See Figure 1.1.

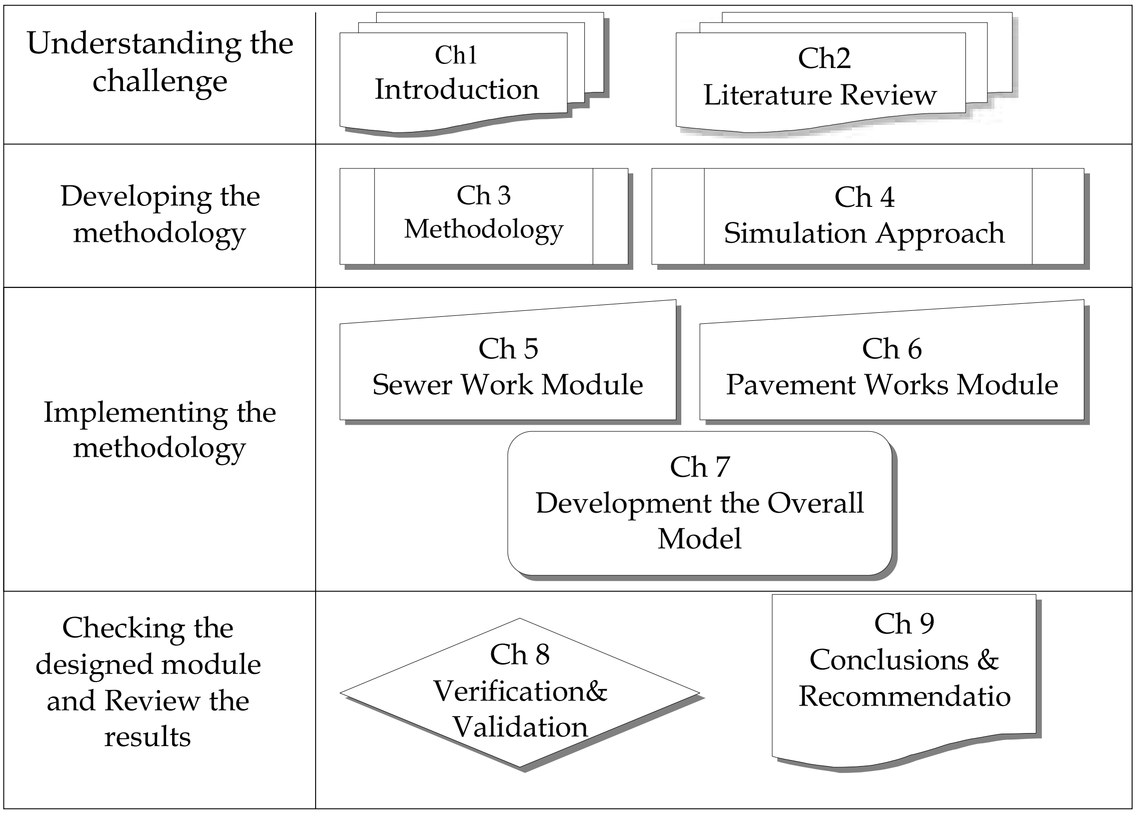


Figure 1.1 Document map of the thesis

Chapter 3

15 – 18 missed

Chapter3

From 15 to 17 missed

4 General Simulation Approach for Construction Projects

One of the main factors that affects the success of simulation models is the approach. The approach represents how actual environment would be converted to virtual one. An approach may be designed to be applied in simulating special cases, or it may be designed as a general one. The second option is preferable as it covers all possibilities that may occur in real environment.

So, in order to build a realistic comprehensive simulation model, an approach is developed which represents the concept of simulating construction projects. Each process, step and stage in the approach is well defined to facilitate comprehending of the approach.

4.1 Requirements for a Successful Approach

Requirements for a successful approach come from two different sources. The first set of requirements is mainly based on literature and is aimed to improve the effectiveness of simulation studies. The second set of requirements stem from the experience with the architecture of available simulation approaches (Valentin and Verbraeck 2002).

4.1.1 Requirements Based on Literature

The first set of requirements for the development of simulation approach is based on analysis that looks at the possible contribution of an approach to the improvement of the effectiveness of a simulation study (Valentin and Verbraeck 2002).

The requirements for this part can be summarized as follows:

1. *Usable within several simulation studies*

The development of simulation models and simulation approaches is a time-consuming task. No matter how many experiences a simulation analyst has, it would be very uncommon to get the full pay-back of the extra investment for creating simulation model in one simulation study. Therefore, the simulation approach should be applicable in creating simulation models that could be used in more than one simulation study.

2. *Applicable when applied in current simulation tools*

The available commercial simulation tools have taken years to develop and to reach a high-level of user friendliness. Even though better founded concepts like the DEVSframework (Zeigler *et al.,* 2000) and pure object oriented simulation (Balci *et al.,* 1997) are available simulation tools but the average simulation user is not able to use these frameworks. Therefore, the approach should be applicable to be used by users in one of the currently available commercial simulation tools like Arena Package.

3. *Support easy model development*

The development of a simulation model is more than just the coding of the model. If possible, the developed approach should also ease the phases of conceptualization of the system, before the model construction can start, and give support with the gathering of data during the model construction phase (Banks 1998).

4. *Resulting models should be understandable by users*

Simulation models are not just meant to generate numbers; they should also provide insight in the system. The insight should be at two different levels. One level is that the *structure* of the model is understandable for the problem owner, i.e. that he/she recognizes the processing of the simulation model. The other level is the ability of the user to assess the model. In addition, the quantitative *output* always remains important, the user always use the output in the decision making, but not before credibility has been assured through understanding of the working of the model.

5. *Resulting models should be ready for verification and validation*

After the step of developing simulation approaches and simulation models completed, simulation models are followed by verification and validation before the simulation run can be performed (Banks, 1998). Also, the developed approach should enable the researcher for easy and fast verification and validation of the model, because many simulation models contain large number of features, entities, operations, etc, which consume large scale of time when running the model for testing.

6. *Easy adaptation*

Systems that are modeled in a simulation study usually evolve over time. This means that when the simulation models are used for answering questions over a prolonged period, the model builder should be able to adapt the models to the system changes with minimal effort. On the other hand, the created simulation models should be capable of handling these changes, and if possible easing the change process (i.e. easy internal changes in the model).

4.1.2 Requirements Based on Experiences with Current Simulation Tools

By close look at the available simulation tools, some positive and negative characteristics are observed. The experience with these characteristics in different projects represents more requirements for accurate simulation approach depending on the used simulation tools (Valentin and Verbraeck 2002).

The requirements for this part can be summarized as follows:

1. *Domain specific with a manageable size*

In several of the existing simulation models, a limited set of powerful simulation models with adequate features and specific domains are available. All trials for such simulation models have extensive user interfaces. This indicates that the simulation models contain functionality that is not required every time, which means overhead in the models, overhead for the user, and problems with maintenance. So the approach here should be able to create models that show some domain specificity and that are not as general and small as a queue or a resource.

2. *Not closed, but also not completely open*

Simulation models in a simulation tool like Simule8 (simulation software) are compiled and you cannot have a look inside. In other simulation tools, the simulation models are completely open and the user can change each attribute value and call every internal function. Both options have their disadvantages, so the approach of the simulation model should give the normal user limited area of changing parameters inside the model and to stay away of the inner building of the model to protect the model from damage.

4.2 Development of the Approach

4.2.1 Requirements of the Approach

The developed approach in this thesis is applicable for general construction projects, and facilitates the simulating of these projects. By reviewing the general requirements (previously presented), three specific requirements were carefully considered in the approach:

1. The modeling process should be done in a manner that is natural and relevant to the specific target domain of the simulation tool. Users should not be exposed to the modeling complexity, which require expertise with fundamental simulation concepts.

2. Construction methods vary in complexity and, as a result, the simulation tools must be able to accommodate different types of simulations especially the simulation of a process that is related to a repetitive process as in infrastructure activities.
3. Users should be able to enter different values for the processes and attributes in an effective and simple manner, so that the model could simulate all possible situations.

The simulation approach developed in this thesis mainly involves two stages of information. Part one, contains data related to the logical behavior of the model during the simulation process. Part two, concerns about detailed information related to the construction processes of the project. So, the approach here assumes that the user of the simulation model (which developed from the approach) should be able to prepare two different parts of information as follows:

1. Part one (information about hierarchy of the model).

   Here it is required to prepare information about project activities relationships (logical relationships). The user could use any of traditional methods like CPM (critical path method) or bar chart method. These methods are essential to represent the relations between different activities of the project.

   Also, it is required to prepare all possible scenarios that may be followed during the executing process, so it is important to specify all relationships between different processes of the project before start designing the simulation model.

2. Part two (detailed information about processes).

   In order to simulate different construction activities, the construction processes fundamentals should be studied first. Then it is important to identify the requirements for the custom simulation tool to be developed. The user at this level is required to provide the model with data about quantities, obstacles, dimensions, etc.

After preparing all of this required information, the next step will be the identification of project levels. These levels were designed to divide the project into sequential levels to facilitate the simulation process.

4.2.2 Project Levels and Scenarios

For any construction project, there are many scenarios that work can go through in order to execute the project. These scenarios may differ in many ways because each project has different characteristics, and always decision makers have more than one scenario to follow depending on their experience and on expected difficulties. So to build project scenarios (for simulation process), project levels concept was proposed.

4.2.2.1 Project Levels

In order to simplify the creation of the scenarios of a project, the project is divided into 4 different levels as shown in Figure 4.1. These four levels are summarized as follows:

1. *Level 1 (Project):*

   This level concerns about information related to the project in general, which means the nature and scope of the project (infrastructure project, construction of buildings, construction of dams, etc).

2. *Level 2 (Sub-project):*

   In this level, the project is divided into many sub-projects. Each sub-project represents certain part of the project. For example in an infrastructure project, the sub-projects are the different roads in the project (these roads which to be constructed). Each road contains some activities which required for construction road facilities (sewer networks, water networks…).

3. *Level 3 (Activity):*

   Each sub-project involves many activities. These activities represent different types of works to be executed within the sub-project. For example, for a road (sub-project) there are many activities like: sewer works, water works, pavement works, etc.

4. *Level 4 (Process):*

   The lowest level of a project is the process level. Each activity has many processes embedded inside it. These processes are essential to accomplish the work in details. As an example, in sewer works activity, there are many processes inside the activity like excavation, bedding, pipe installation, etc.

By reviewing the previous levels, it is obvious that this concept is applicable for any types of construction projects.

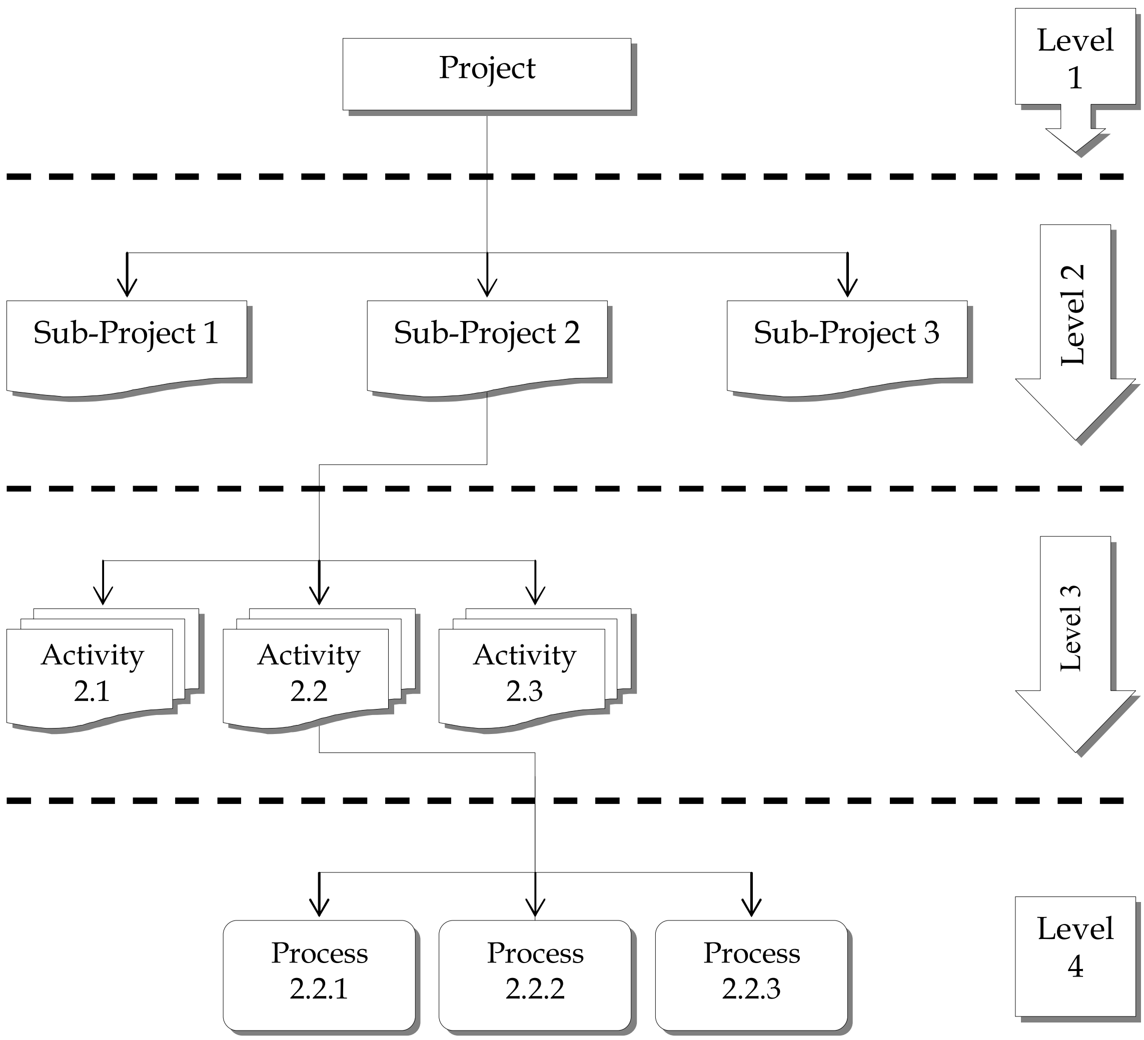


Figure 4.1 Projects levels

For more illustration, the following examples demonstrate the application of the concept for two different types of projects.

- *Example 1 (Infrastructure Project)*

For an infrastructure project the work shall include many roads (R1, R2, R3, etc) within specific area and these roads are considered the sub-projects (level 2). Each sub-project (road) involves many activities. These activities (level 3) shall be many construction works like sewer works, water works, drainage works, pavement works and other specific works.

Finally, each activity has many processes inside and logically connected to each other. Example of these processes (sewer work activity) is: excavation, bedding, pipe installation, hydraulic test, etc. Figure 4.2 represents these sequential levels.

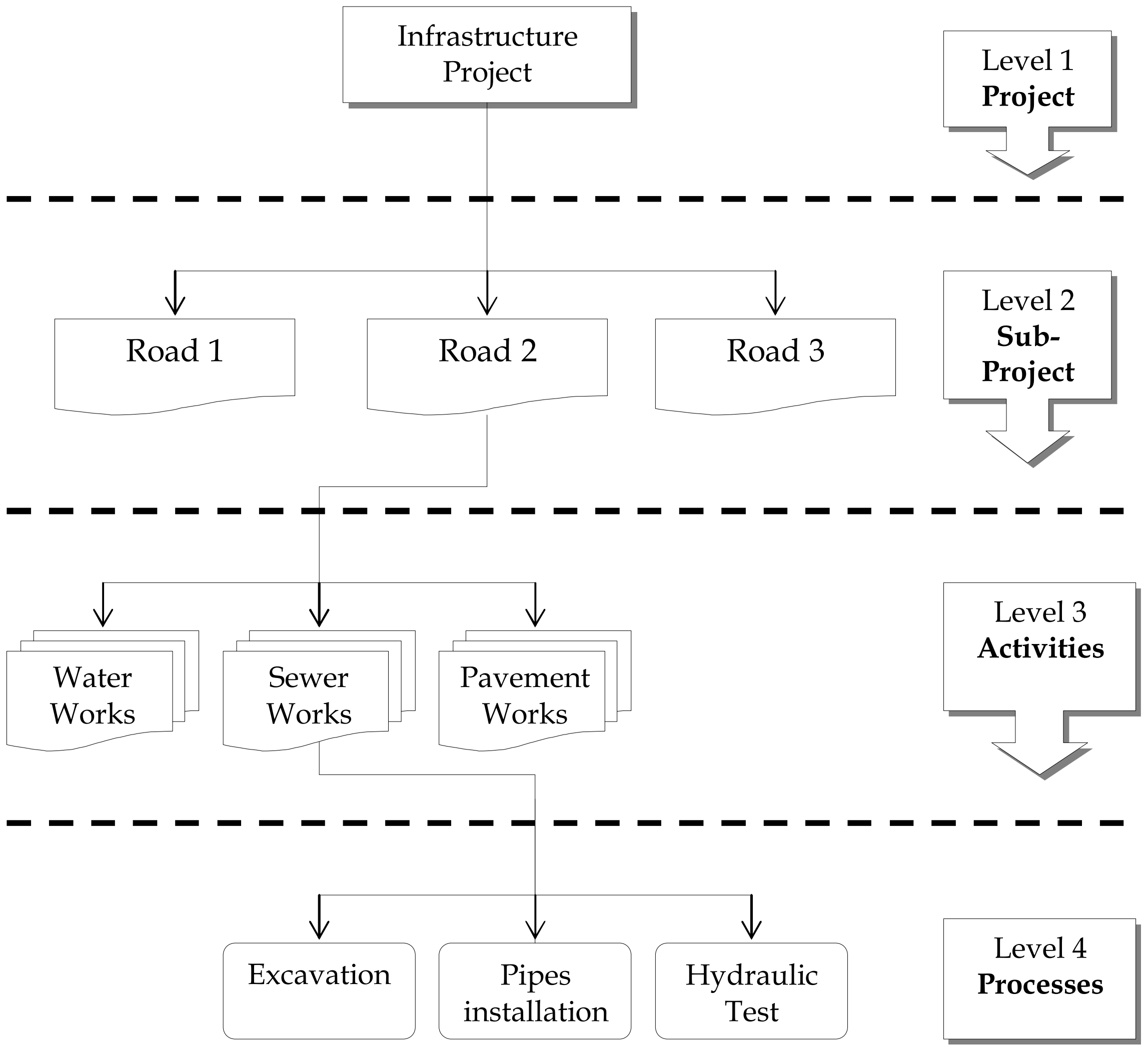


Figure 4.2 Infrastructure project levels

All these processes have many variables that change due to site conditions, characteristics of the project and many other factors. Example of these variables: diameter of pipes, type of soil, method of excavation and depth of trench and many other variables which affect the productivity of the process.

- *Example 2 (Superstructure Project)*

For a superstructure project, the work shall include many floors (F1, F2…) within a specific building and these floors are considered the sub-projects (level2) for the project. Each sub-project (floor) involves many activities. These activities (level3) are any construction works like concrete works, finishing works and electrical works.

Finally, each activity has many processes that are logically connected to each other. Example of these processes (concrete work activity) is: formwork, steel fixing and casting of concrete. Figure 4.3 represents these sequential levels.

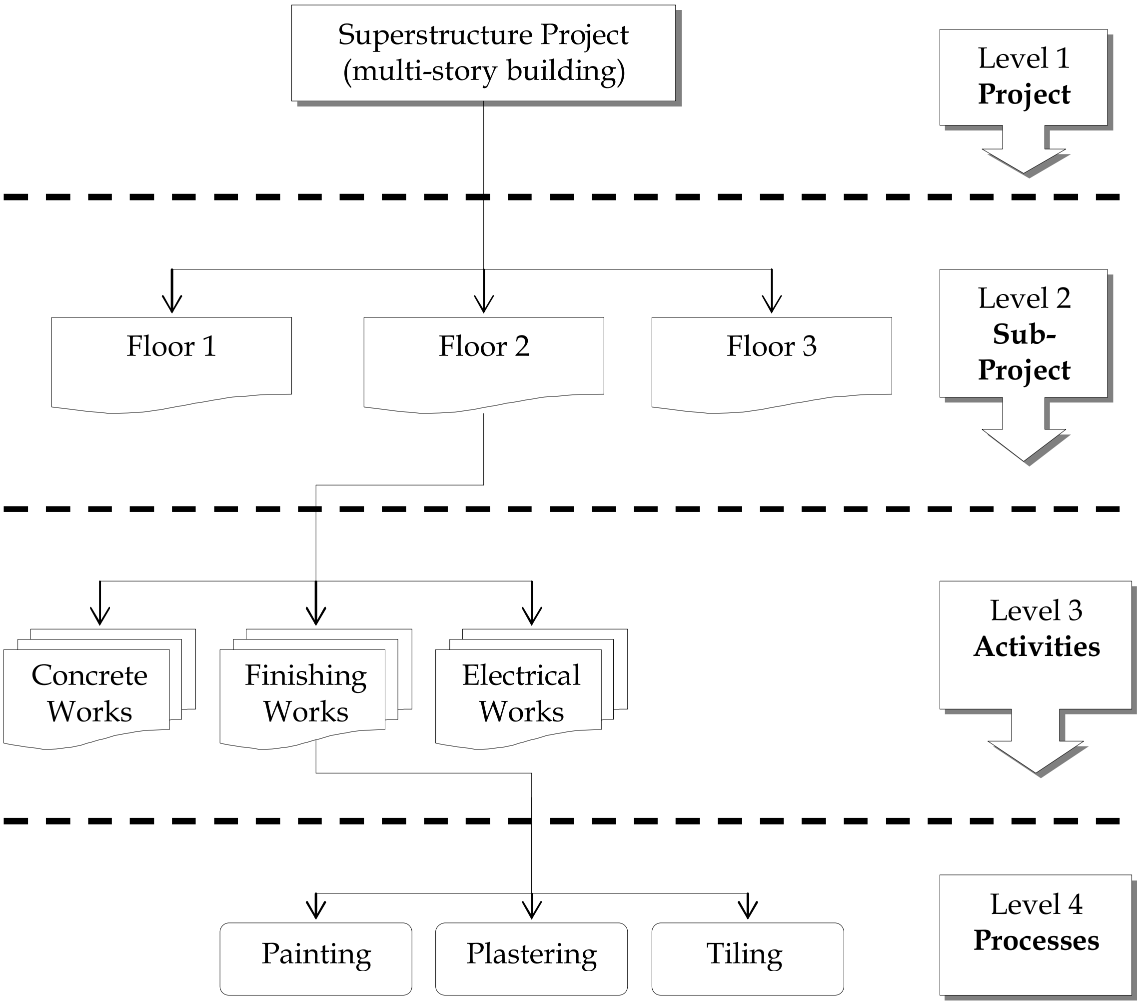


Figure 4.3 Superstructure project levels

4.2.2.2 Project Scenarios

After dividing the construction project into the four levels, it then can be easily to use time schedule techniques (bar chart or CPM method) to build different project scenarios.

Burke (1992) mentioned that all proposed scenarios which are prepared by the planner to execute the work, should pay attention to many factors that affect the productivity of the process like: available resources, site conditions, expected obstacles in the site, underground facilities, etc.

Also, the scenarios shall define the logical relationships between the different Sub-projects, activities, and processes. See Chapter 7 for more details about the project scenarios.

4.2.3 Converting Project Levels Into Simulation levels

After preparing the project levels it will then be easy to convert these levels into simulation levels. These simulation levels will facilitate the building of the simulation model. These levels are assumed to simulation actual project levels. Each level simulates certain part of the real project. See Figure 4.4.

Figure 4.5 represents how the simulation levels are embedded in each other to formulate the final simulation model.

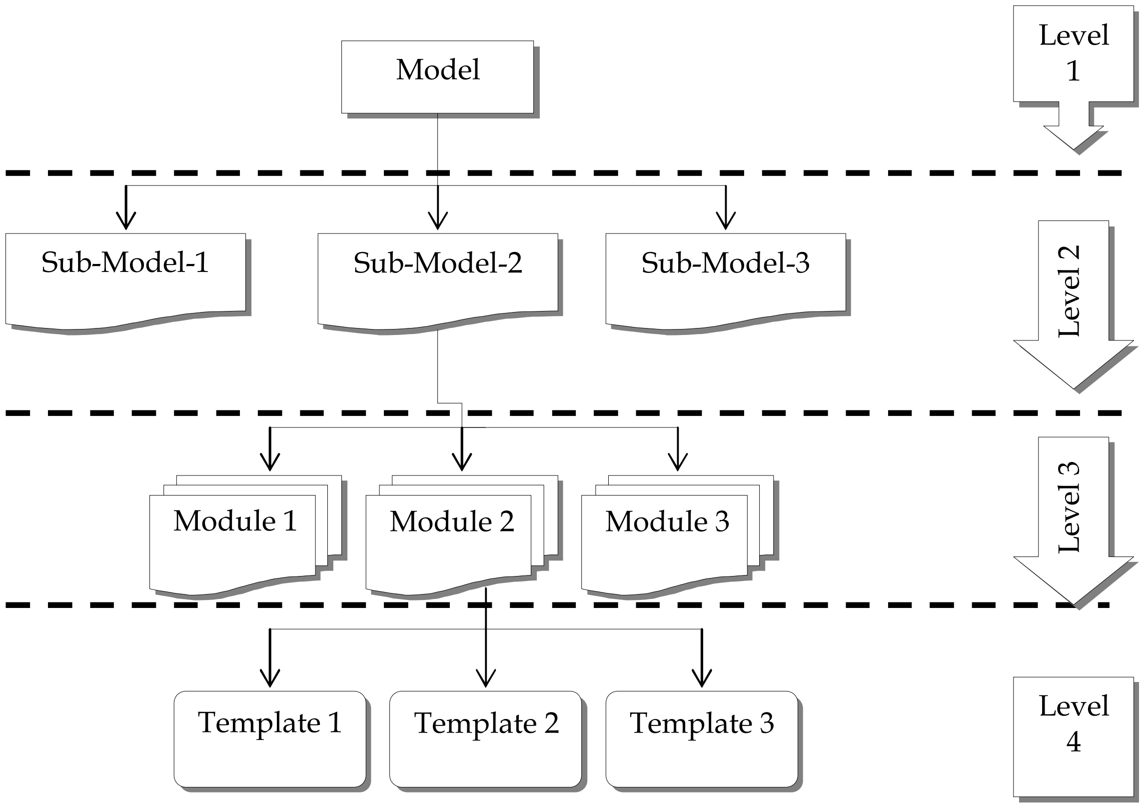


Figure 4.4 Flowchart of general simulation apprach (Simulation Levels)

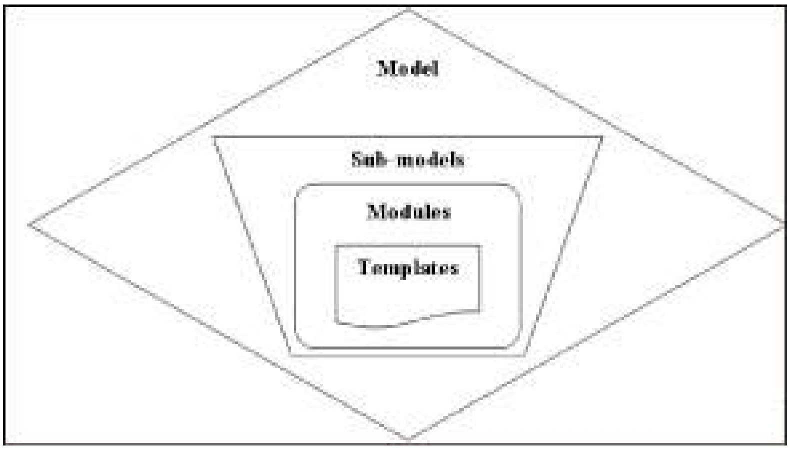


Figure 4.5 Sequence of model formation

4.2.3.1 Simulation Model Levels

In a real construction project, a simulation model will involve the following four levels:

1. Level 1(Model)

This simulation model is responsible for representing the entire project. To create the simulation model, all sub-models (which to be generated in the next stage) will be connected to each other to create the entire model. So, the final model will constitute a group of sub-models which hold the characteristics of the construction activities and user can be able to run the model to get the results for each scenario.

2. Level 2(Sub-model)

The sub-model level is composed of a group of modules which are logically connected to each other. The logical connections will depend on the different scenarios that were assigned at the beginning of the work by the planners. For example, in infrastructure projects there are many modules in certain area (i.e. sewer works, pavement works, etc) when connecting these modules by logical relationships they form a sub-model for the project in this certain area. See Figure 4.6.

3. Level 3(Module)

A module is the basic buildings block which to be developed in project simulation. These modules can be considered as flow of logic that simulates different construction activities. So, simply each construction activity could be considered as a module which contains many templates. Because this approach is developed to be used in building multi-use simulation models, the module will facilitate the user role in simulation modeling process. By using the approach of model leveling, the user will just pick the required module from a library of modules (previously designed), and connect it with other modules to create the sub-model. See Figure 4.6.

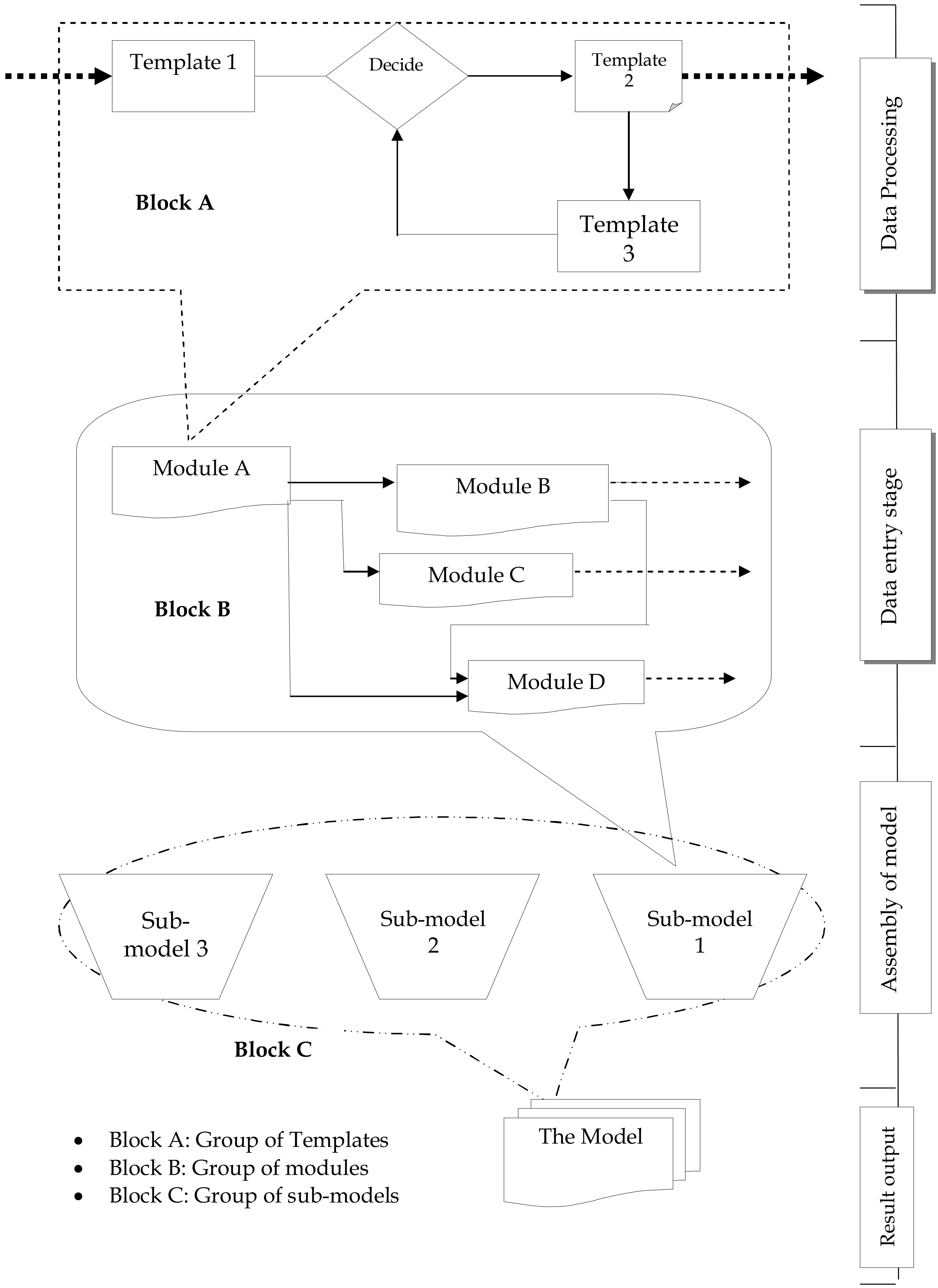


Figure 4.6 General simulation approaches flowchart

For example, sewer works activity with all of its processes is considered as a module, also concrete work for a roof is considered as a module.

4. Level 4 (Templates)

The templates are used to simulate construction processes. For example, to simulate sewer work processes, it is required to develop some of the following templates:

- Excavation process.
- Bedding and leveling.
- Installing of the pipes.
- Backfilling the trench.

All probability distribution functions for these processes shall be incorporated into the templates. These functions which are developed based on actual historical data records are collected from the site and regard to the construction process. For more information about probability distribution functions see Sections 6.5 and 7.5.

Each template is connected to other templates depending on the logical relationships in the model.

The developed simulation approach assumes that the templates will not appear to the user, but they will be hidden inside the module.

It is important to understand that templates in this simulation approach do not represent the activity but they represent the process (or processes) that form the activity.

Figure 4.6 represents the hierarchy of the simulation approach from the lower level to the highest.

To illustrate the application of the approach, the following example will explain how to use the approach in creating an infrastructure simulation model.

- *Illustrative example :*

  Assume that it is required to apply this simulation approach in developing multi-use simulation model for an infrastructure project. The project involves a number of roads. Each road contains a number of construction activities (water works, sewer woks, drainage and pavement works).

  The data required for this simulation model is divided into two parts:

  1. *Part one: Data required by the developer*

  This data is related to the production rates for different construction processes. These rates are entered to the simulation model as probability distribution functions. The distribution functions were generated from many statistical records that represent the effect of each factor (the site conditions factors and many other factors previously explained) on the overall productivity during the actual construction processes. This data has to be previously saved in different simulation templates prepared by the developer. Also, it is required to prepare all logical relationships to connect different templates in order to create the modules.

2. *Part two: Data required by the user*

This portion is concerned with variable data related to the process itself (i.e. depth of excavation, type of soil, type of paving material, etc). This data is to be entered by the user who has no previous knowledge in simulation. After preparing all required data, the developed approach can be used to create the multi-use simulation model for infrastructure projects. See Figure 4.7.

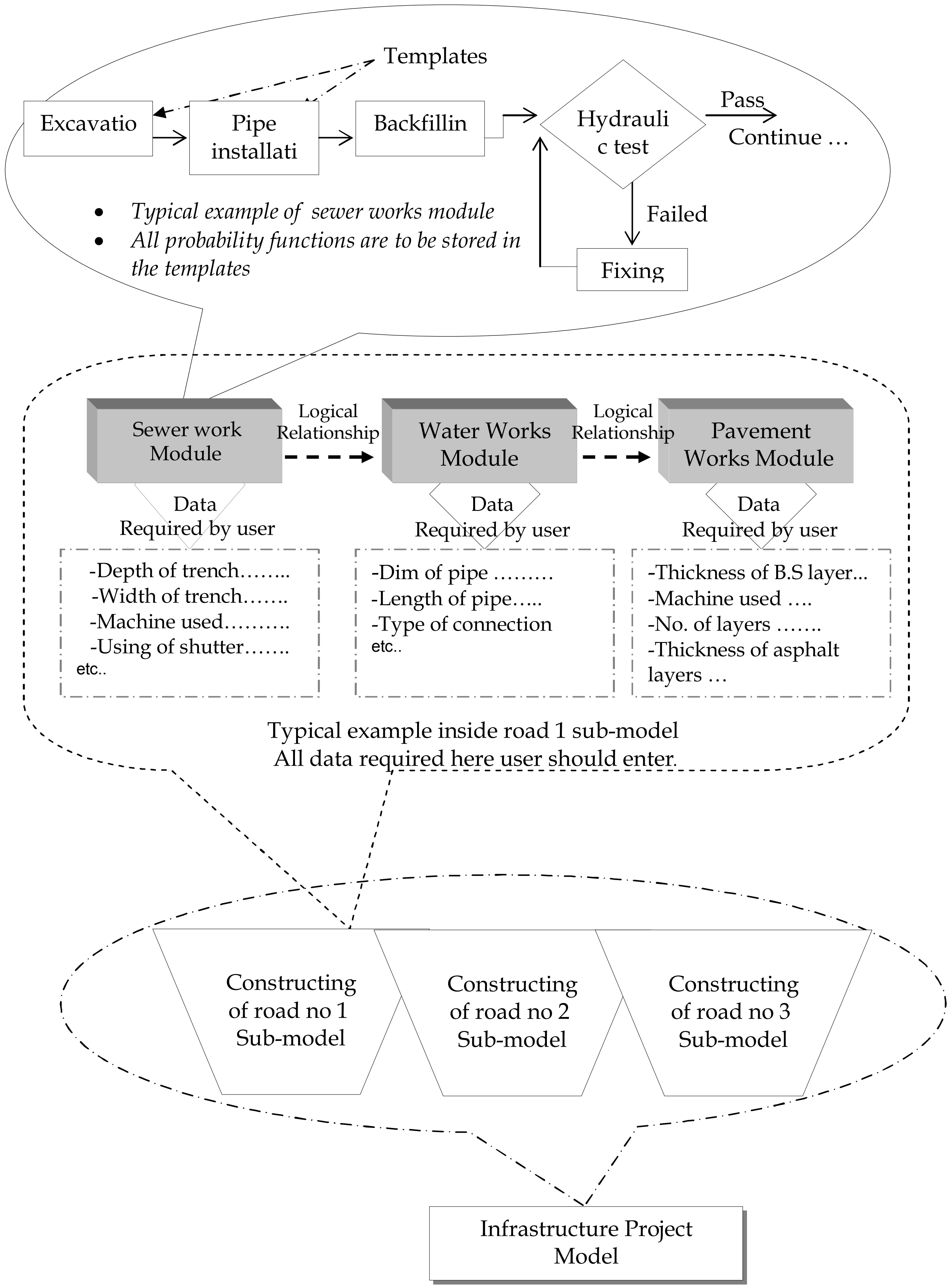


Figure 4.7 An illustration of a typical infrastructure project

4.3 Arena Simulation Software

4.3.1 Introduction to Arena

There are several simulation techniques which were designed for business and research sectors in order to simulate real systems, and Arena is one of them.

Arena is used to simulate and represent real systems which enable planners and decision makers to observe the behavior of a system when changes are occurred to it. Also Arena enables the planners to bring the power of modeling and simulation to their planning.

In this thesis, Arena software was used as a technique to create general simulation model that simulate infrastructure projects in order to estimate durations required by these project during the planning phase.

The next section represents brief description of Arena panels and elements. These simulation elements were used in creating simulation modules.

4.3.2 Basic Process Panel of Arena

The basic process panel is used for model building and consists of (8) flowchart elements and (6) data elements. There are two types of elements in panel:

1. Flowchart element, which placed in the model window and connected to form a flowchart, describing the logic of any desired process.

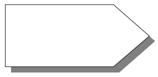
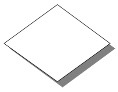
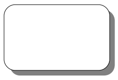
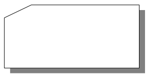
2. Data element, which not placed in the model window. Instead, they are edited via a spreadsheet interface and include entity, queue, resource, schedule, set and variable model. See Table 5.2.

4.3.2.1 Flowchart Elements

There are eight flowchart elements are used for model building of Arena package as follows:

- Create: This element is intended as the starting point for entities in a simulation model. Entities are created using a schedule or based on a time between arrivals. Entities then leave the module to begin processing through the system.
- Process: This element is intended as the main processing method in the simulation. Options for seizing and releasing resource constrains are available. The process time is allocated to the entity and may be considered to be value added, non- value added, transfer, wait, or other.

Table 4.2 Basic elements of Arena simulation

No.	Name	Symbol	Description
1.	Create Element		Starting point for entities in a Simulation model
2.	Process Element		The main processing method in the simulation
3.	Decide Element		Decision-Making processes in the system
4.	Assign Element		Assigning new values to a variables
5.	Batch Element		The grouping mechanism within the simulation model.
6.	Separate Element		Split a previously batches entity.
7.	Record Element		Collect statistics in the simulation model.
8.	Dispose Element		Ending point for entities in a simulation model.

- Decide: This element allows for decision making processes in the system. It includes options to make decisions based on one or more conditions.
- Assign: This element is used for assigning new values to variables, entity attributes, entity type, entity pictures, or other system variables. Multiple assignments can be made with a single assign module.
- Batch: This element is intended as the grouping mechanism of the simulation model. Batches can be permanently or temporarily grouped .Batches may be made with any specified number of entering entities or may be matched together based on an attribute.
- Separate: This element can be used to either copy an incoming entity into multiple entities or to split a previously batches entity. Rules for allocation cost and time to the duplicate are also specified.

- Record: This element is used to collect statistics in the simulation model. Various types of observational statistics are available, including time between exits through the element, entity statistics, and interval statistics.
- Dispose: This element is intended as the ending point for entities in a simulation model. Entity statistics may be recorded before the entity is disposed.

4.3.2.2 Data Elements

- Entity: This data element defines the various entity types and their initial picture values in a simulation.
- Queue: This data element may be utilized to change the ranking rule for a specified queue.
- Schedule: this data element may be used in conjunction with the resource element to define an operating schedule for a resource or with the create element to define an arrival schedule.
- Set: This data element defines various types of sets, including resource, counter, tally, entity type, and entity picture.
- Variable: This data element is used to define a variable's dimension and initial values. Variables can be referenced in other element, can be reassigned a new value with the assign element, and can be used in any expression.

5 SEWER WORKS MODULE

5.1 Introduction

Sewer works in real projects contain many variables depending on the nature of the site (site conditions) and type of executed work. In order to develop an effective simulation module, four basic group of information should be defined (Vanegas et al 1993):

1. General information about the module
2. Information about the hierarchy of the work.
3. Information about the durations of work tasks, and the parameters of distribution functions.
4. Information about available resources.

5.2 Hierarchy of Sewer Works Module

For any successful and effective simulation module, logical flowcharts must be designed to represent the hierarchy of the module. This flowchart must be clearly defined and to have the correct logic, because as this flowchart comes close to reflect the real situation with all of variables and logics as this module will be close to give relatively correct output results.

Therefore, a real situation of sewer works activity was carefully studied to identify the logical relationships required for logical formation of the module from inside. Also, all construction processes required in real sewer construction activities were reviewed to design representative simulation templates.

Figure 6.1 shows a flowchart that represents all logical relationships and construction processes required for sewer construction projects.

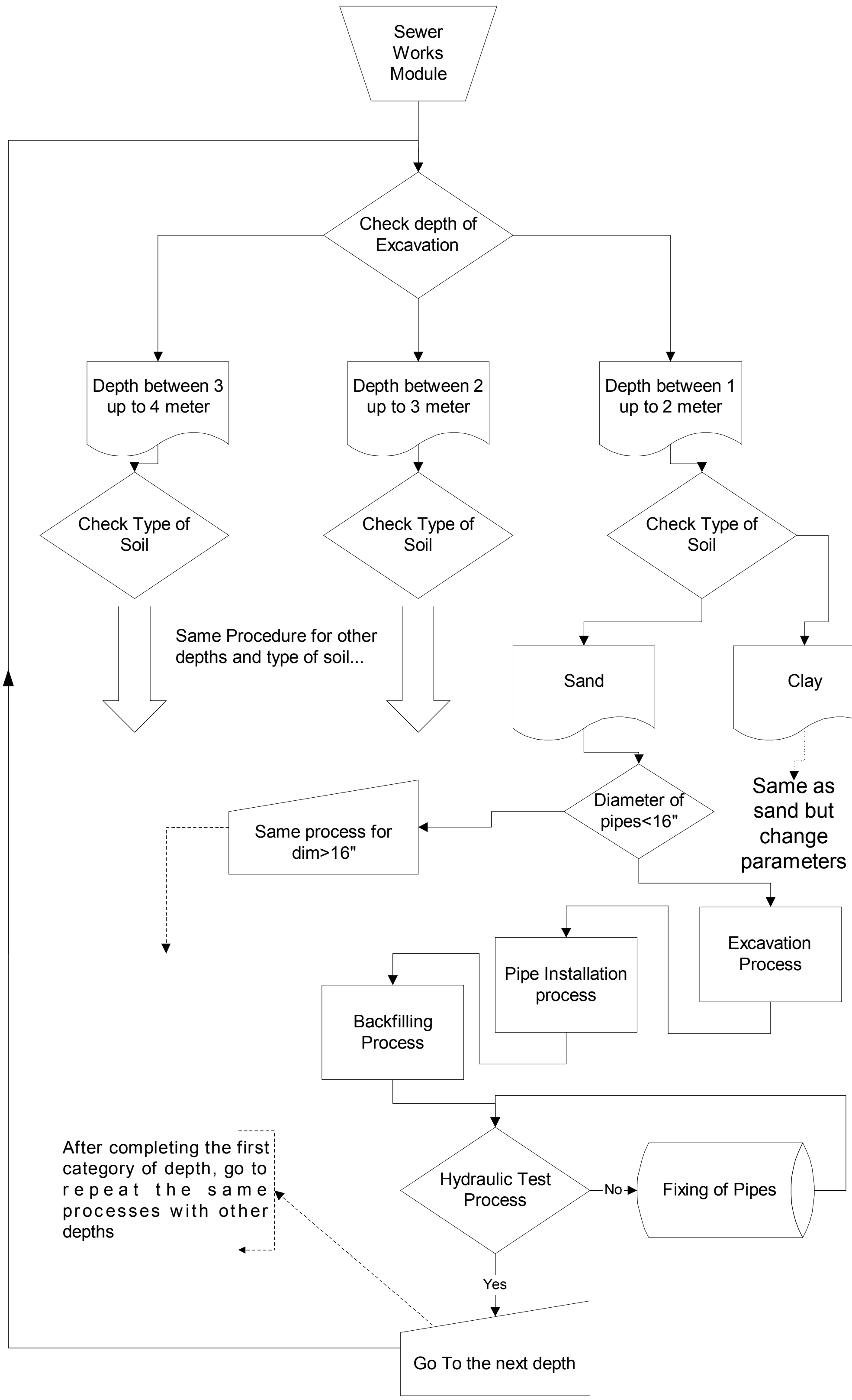


Figure 5.1 Sewer Works Module Flowchart

5.2.1 Hierarchy Description

In a sewer construction activity, the work may include the following processes:

- Excavation of the trench
- Pipes and manholes installation.
- Backfilling of the trench.
- Watering and compaction after backfilling.
- Hydraulic test for pipes.

The parameters for these processes were limited to the following different conditions (i.e. site conditions and environment of work):

1. *Depth of excavation*

This variable is related to the depth of the trench required to reach designed invert levels. In this sewer module, depths of excavation were limited to three categories. See Figure 5.2:

- Depth from 1.5 up to 2 meter
- Depth from 2 up to 3 meter
- Depth from 3 up to 4 meter

The depth categories of the module were limited to these values, because most of locally designed sewer networks fall within these depths. Also, for depths more than 4 meters the process of excavation is affected by many other factors like width of road, type of shuttering system, type of machinery and many other factors which complicate the modeling process.

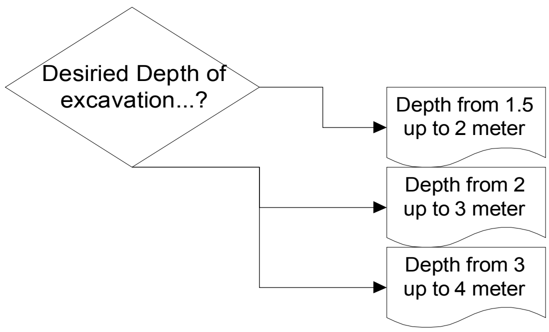


Figure 5.2 Flowchart of excavation depths opptions

2. *Type of soil*

This option allows for two variables related to the type of excavated soil. See Figure 5.3.

These two types of soil were selected because they are the most likely to be found during excavation in Gaza Strip. The type of soil was considered in the module design as it affects the productivity; excavation in sandy soils is almost three times lower than clay.

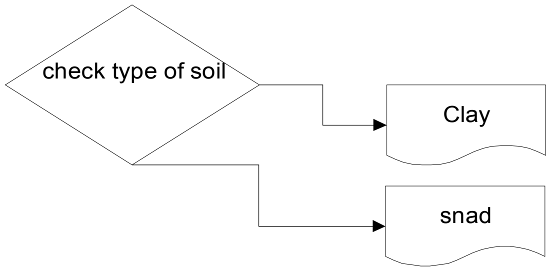


Figure 5.3 Flowchart for type of soil opptions

3. *Diameter of pipes*

After an extensive study (local projects) for the effect of pipe diameter on productivity, it was clear that large diameter of pipes would take more time for installation. This is because this large diameter, pipes are required to be lifted by a machine rather than by hand due to its heavy weight. In such cases the excavating machine is used as lifting machine which means idle time spent in waiting for installing the pipes by workers.

So, from experience, two options were assigned, as shown in Figure 5.4:

- Option I: pipe diameter less that 16" which do not required a lifting machine in installation process, due to their relatively light weights.
- Option II: pipe diameter equal to or more that 16" which require a lifting machine in installation process, because of their heavy weight.

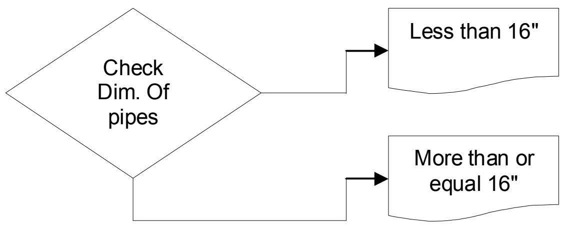


Figure 5.4 Flowchart for pipes diameter opptions

5.3 Sewer Works Processes

5.3.1 Site Observations

In order to create a realistic simulation model, all required construction processes (demanded in sewer construction projects) must be clearly specified. An investigation was made to identify all required sewer construction processes from different construction sites. The observation continued for a period of more than four months, and it was located at twelve different construction sites. All consumed times (durations) required by different construction processes were recorded at different conditions in order to be used in developing probability distribution functions necessary for the simulation module. Section 5.5 describes all probability distribution functions required to simulate processes production rates.

Appendix A represents all data records for all sewer construction processes.

5.3.2 Construction Processes of Sewer Works Activities

The sewer works processes are affected by many factors (variables) like the type of pipes, depth of excavation, type of soil, etc.

Many construction processes are to be used in this simulation sewer module, these processes can be summarized as follows:

1. *Trench excavation*

   For this simulation module (sewer module) it is assumed that the depth of excavation is made at three different depths (1.0 to 2.0, 2.0 to 3.0, and 3.0 to 4.0 meters) and for two different types of soil (sand and clay).These different conditions would yield different production rates for each one. (All production rates and probability distribution functions are presented in section 5.5 and at appendix A).

2. *Pipes bedding*

   Before installing a sewer pipe at the trench, it is required that the pipe bedding be prepared to the design invert level and if the bedding soil is not sand a layer of 20 cm under the pipe must be removed and replaced with another layer of clean sand.

3. *Pipe installation*

This process concerns about erection of sewer pipes in order to establish overall sewer pipeline. It is a precision process because invert levels of pipes should be very accurate (with respect to the designed values) in order to allow waste water going through sewer network.

This process includes the construction of the proper length of pipes as well as the required manholes at different distances according to the specifications (ranges from 30 to 40 meters). In this research, it is assumed that the distance between manholes is 30 meters (generally used).

4. *Pipes backfilling,, watering and compaction*

After installing of sewer pipes, excavated trenches shall be backfilled by machine (loader). This process is essential to be done in layers and each layer should be watered and well compacted in order to ensure that this layer has reached the maximum degree of compaction.

5. *Hydraulic test*

To ensure that there is no leakage in the network, hydraulic test must be performed. This test could be done for the entire network as well as for some parts according to specifications.

6. *Fixing of pipes*

In case it is discovered that there is a leakage, this defect should be fixed after allocating its position in the network. It is found (by observations) that 99% of sampled sewer pipes examined passed the test and only 1% failed.

Finally, after considering all of the previous processes and logical relationships Arena computer software was used to build sewer work module.

5.4 Arena Sewer Works Module

5.4.1 Introduction

Sewer works module is a simulation model designed to simulate the sewer construction process. This module involves all processes required for sewer construction projects.

This section describes the procedure followed to develop the sewer module by using Arena Software as well as assumptions and limitations.

5.4.2 Assumptions and Limitations

The assumptions and limitations adapted in this module are as follows:

- ***Assumptions***

1. Distance between manholes is 30 meters. This assumption is taken as most designers consider this distance during the design phase.
2. The durations required for installing the manholes are included in the pipe installation process.
3. The how of work in the module goes in series (i.e. all work is done by one crew). In case there are more than one crew (work done in parallel) the duration is divided by the number of the crews.
4. The user should prepare all pipes lengths, designed depths, and their diameters.
5. For depths more than 3 meters excavation for the trench will be done using shuttering.
6. Diameters of pipes are limited to two groups, less than 16 inch and more than 16 inch. These two groups were assumed because UPVC pipes with diameters up to 16 inch could be handled by workers only and no need for a lifting machine; while for pipes diameters more that 16 inch a lifting machine is required.
7. Working day equals to 8 working hours. All output durations are considered as working days not calendar days.
8. Hydraulic tests for the sewer pipes pass 99% of the executed tests.
9. Weather conditions were not considered in the module, because heavy rain days in Palestine are limited to few days in a year.

- ***Limitations***

1. Minimum depth of trench excavation is limited to 1.5 meters while the maximum depth is limited to 4 meters. This range was taken because most of local sewer construction projects belong to this category. Also for depths more than 4 meters, the excavation process is affected by many other factors like width of road and type of shuttering method.
2. Type of soil (where trench to be excavated) is limited to only two types: sand and clay.

5.4.3 Module Description

After considering the previous limitations and assumption, the module was created using Arena software. Sewer module consists of these parts where each one is designed for a certain function, see Figure 5.5.

These parts can be summarized as:

1. Part I (Data entry): deals with input data.
2. Part II (Controlling): responsible for controlling the logic of the module is which related to depths categories.
3. Part III (Processing): deals with the data processing inside the module.

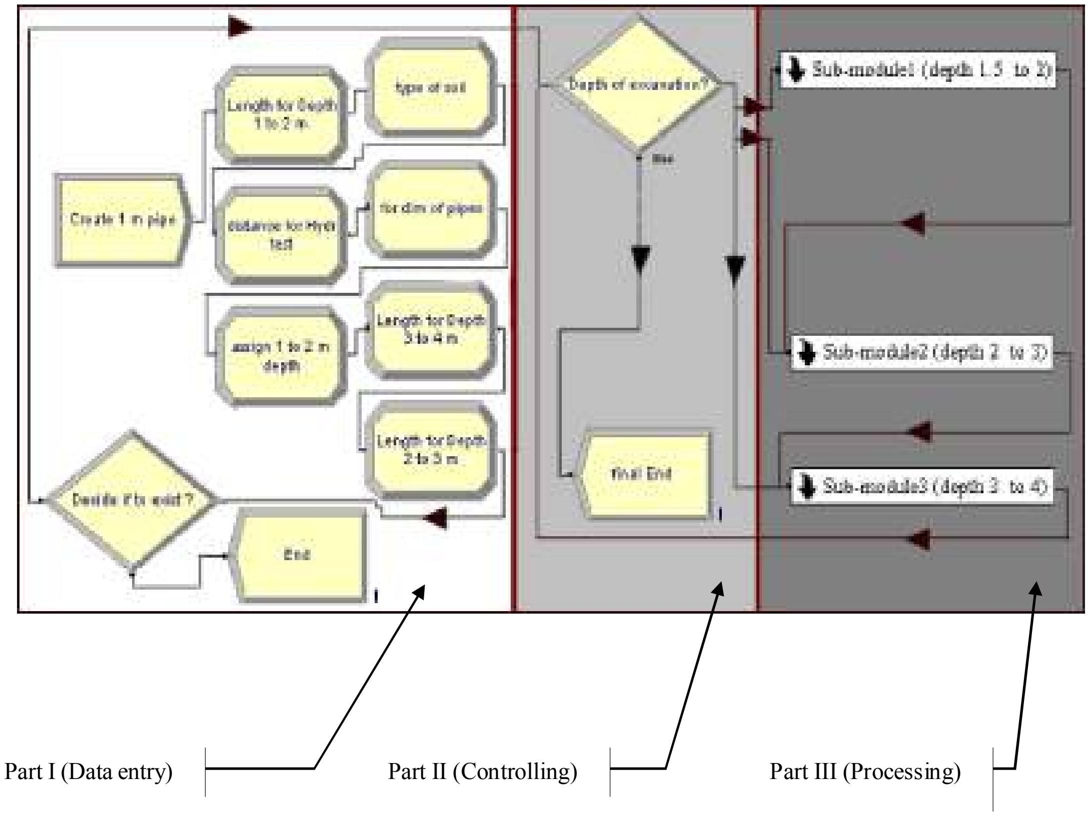


Figure 5.5 Overall Sewer work module and module parts

5.4.3.1 Part I (Data Entry)

This part is responsible for creating only one entity which represents one meter length of pipe, this entity will operate the whole module by activating different simulation templates. Also, this part will be used for inputting all data required for the module.

All variables which are required for the module will be inserted by using module assign elements. See Figure 5.6 and Table 5.1.

The creation of one entity is done by the Create element of Arena, this element will create only one element which represents one meter length of pipe.

Seven Assign elements that designed for inserting different variables related to site conditions and nature of work. Insertion of data in these assign elements could be done in two ways: by direct insertion of data to the assign elements or by using visual basic (VBA) interface where no prior knowledge about Arena is required (VBA interface is presented in section 5.5). Table 5.1 contains all these simulation elements and their functions.

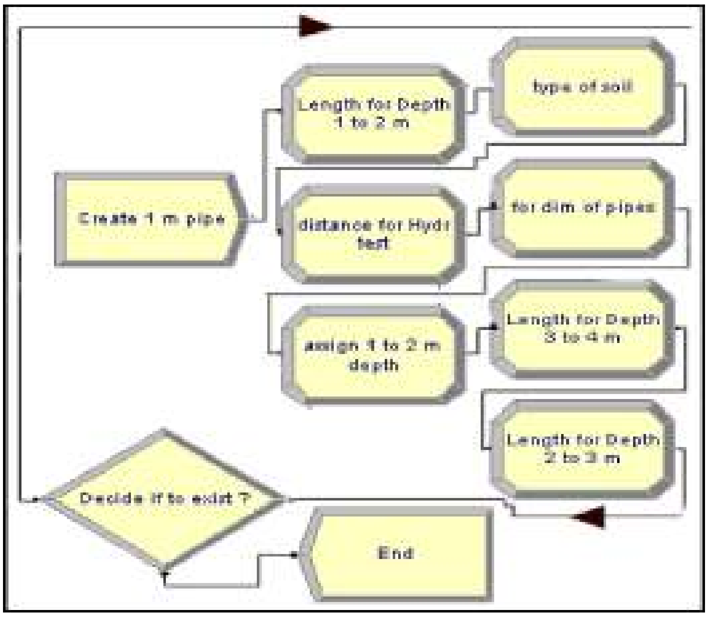


Figure 5.6 Part I (Data entry)

Table 5.1 Assign elements used in the module and their functions

Assign element Name (As in Arena)	Attribute Name	Function
length for D(depth) between 1 and 2 m	Total length A	Inserting the total length of pipes with depths between 1.5 to 2 meter.
length for D(depth) between 2 and 3 m	Total length B	Inserting the total length of pipes with depths between 2 to 3 meter.
length for D(depth) between 3 and 4 m	Total length C	Inserting the total length of pipes with depths between 3 to 4 meter.
Type of soil	Type of soil	Assigning type of soil (sand or clay)
For dim of pipes	Dim of pipes	Assigning diameter of pipe (less than 16" or more)
Distance for Hydraulic test	Distance for test	Assigning distance that it must be completed to execute the test
Assign 1 to 2 m depth	Depth	Programming requirement in VBA.

5.4.3.2 Part II (Controlling)

This part controls the flow of the module logic, where it consists from one *decide* element only. Controlling occurred by batching each length of pipes with its excavation depth then directing each batch to the specific sub-modules. See Figure 5.7

Each batch (which contains certain length of pips and its depth) will be directed to a defined sub-module which involves all processes required for that depth of excavation.

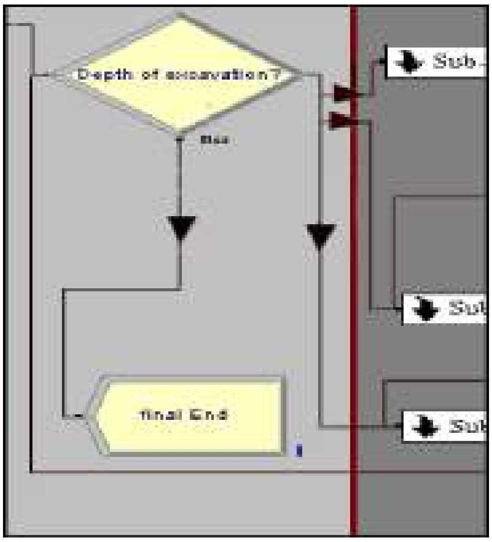


Figure 5.7 Part II (Controlling)

5.4.3.3 Part III (Processing)

Part three is the processing part, where all simulation processes are operated in this part. It consists of three sub-modules and each one is designed for simulating pipe installation work at different depth. See Figure 5.8.

The three sub-modules are:

1. *Sub-module 1(depth of excavation form 1.5 m up to 2.0 m)*
2. *Sub-module 2(depth of excavation form 2.0 m up to 3.0 m)*
3. *Sub-module 3(depth of excavation form 3.0 m up to 4.0 m)*

These sub-modules contain all templates and logical relationships which are required for simulating sewer construction processes at different depths.

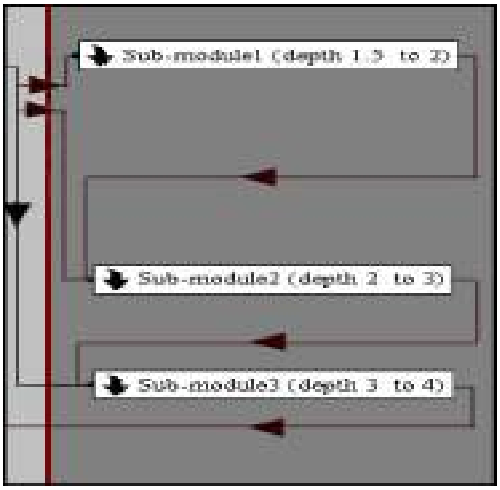


Figure 5.8 Part III (Processing)

1. Sub-module 1 (depth of excavation from 1.5m up to 2.0)

This sub-module contains all templates and logic relationships required to simulate real construction processes for depth category between 1.5 and 2.0 m.

Sub-module 1 is responsible for manipulating two different variables: type of soil and diameter of pipes. When the module is activated, the generated entity that represents 1 meter of sewer pipe enters only this sub-module; if there is length of sewer pipes with depth of excavation between 1.5 to 2 meter. After the entity goes through sub-module 1, see Figure 5.9, a *decide* element would check for the type of soil (which was previously inserted by the user), and to send this entity either to sand or clay category.

After processing inside any of the categories sand or clay (will be explained later), it gets out and passes through the hydraulic test then repeats the operations until completing total length of pipes at this depth. Figure 5.9 demonstrates the logic that entity will go through during processing in sub-module 1.

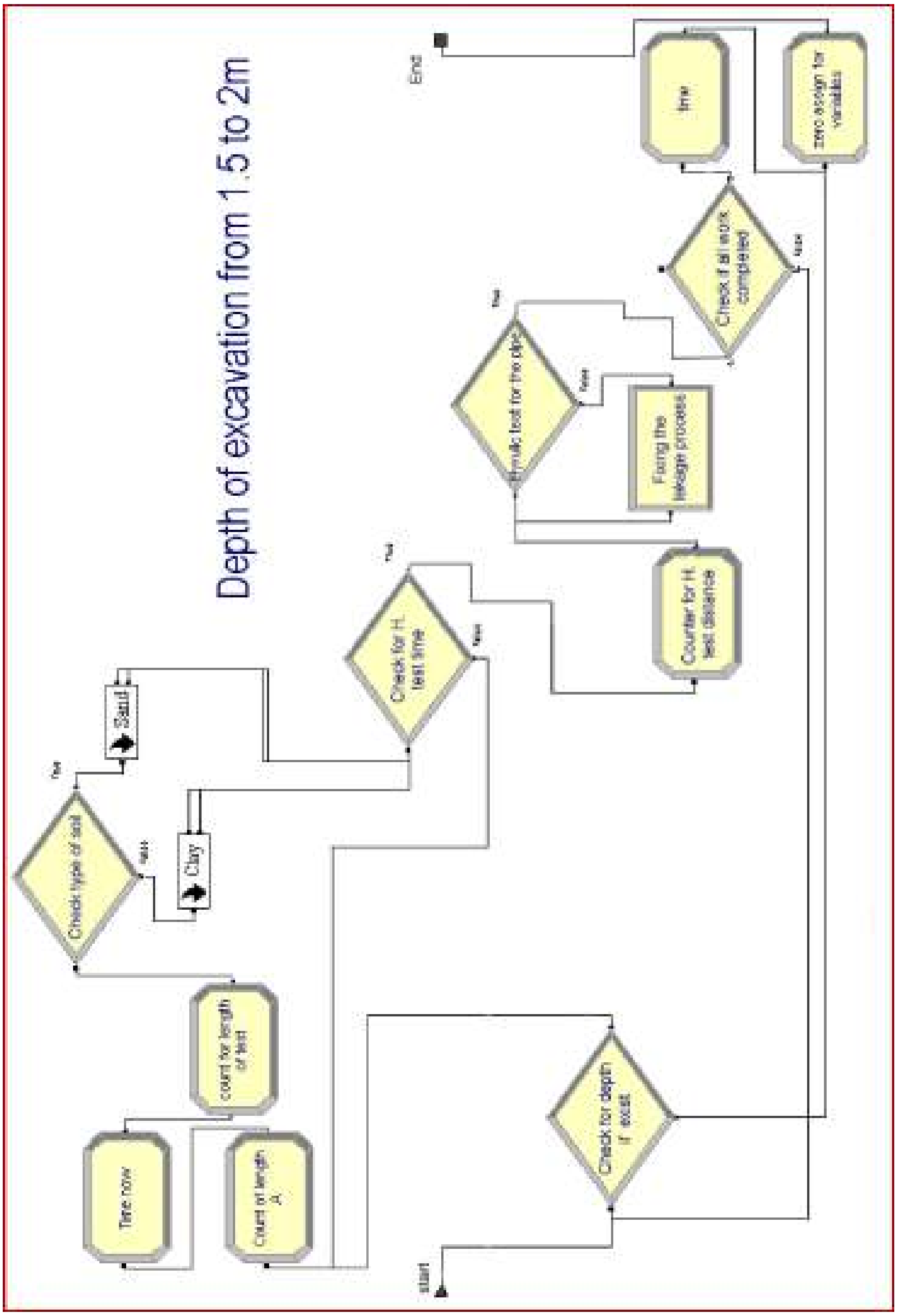


Figure 5.9 Sub-module 1, templates and relationships

All elements and templates required for the simulation processes and their functions are summarized in the following tables. See Table 5.2.

Table 5.2 Elements and templates of sewer works module

Element Name (as in Arena)	Type of Element	Function
Check for depth if exist	Decide element	Check if there is a pipe with depth between 1.5 to 2 meters.
Check type of soil	Decide element	Direct the flow of logic according to type of soil.
Check for hydraulic test	Decide element	Check if pipes length reach distance required for hydraulic test.
Hydraulic test for the pipe	Decide element	Check for hydraulic test for executed pipes
Check if all work completed	Decide element	Check if all desired work has been done.
Time now	Assign element	Record time at start of the sub-module.
Count of length A	Assign element	Count for total length of pipes at depth between 1.5 to 2.0meter
Count for hydraulic test distance	Assign element	Count for length of pipes required to be tested
zero assign for variables	Assign element	Giving value of zero for all variables after finishing work in the sub-module.
Fixing the leakage	Template (process)	Adding time for fixing of leakage

Inside the two sand and clay categories; there are two other templates to process for the diameter of pipes options. See Figure 5.10.

If the excavated material is sandy soil, then the flow of logic would go in this category and there will be two choices: less than 16 inch and more than 16 inch (this option to be inserted by the user). See Figure 5.10.

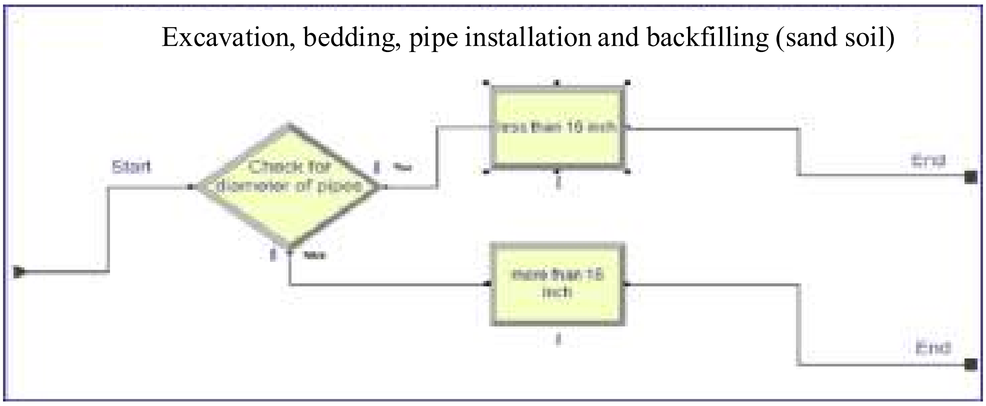


Figure 5.10 Excavation, bidding, pipe installation and backfilling template for sand soil category

For each diameter category there is a template (less than 16" or more than 16") that designed to simulate all process required to complete 30 meter length of sewer pipes. The template represents the following processes:

- Excavation
- Bedding
- Pipe installation
- Backfilling

These processes were selected because they are essential for constructing sewer pipes. For the templates of less than 16" and more than 16", data were collected form the site by direct observations to create probability distribution functions. These functions were created by the input analyzer software (explained in section 5.5, probability distribution functions section).

For the remaining two sub-modules (2 and 3), they contain same elements, templates and logical relationships. But inside these templates all probability distribution functions are changed to fit other depths of excavation. All probability functions represented in section 5.5, and all record data at Appendix A.

5.4.4 Sewer Module Output

As mentioned above, the results of this simulation module will appear in shape of durations (time values). Each output results will represent the durations (time) required to execute each length of sewer pipes at each of the specified depth of trench excavation.

Figure 5.11 represents the "summary of results" screen. The user will obtain the simulated durations for different construction processes of the sewer works at different depths of excavation. Also, the total estimated durations for the entire project will be obtained.

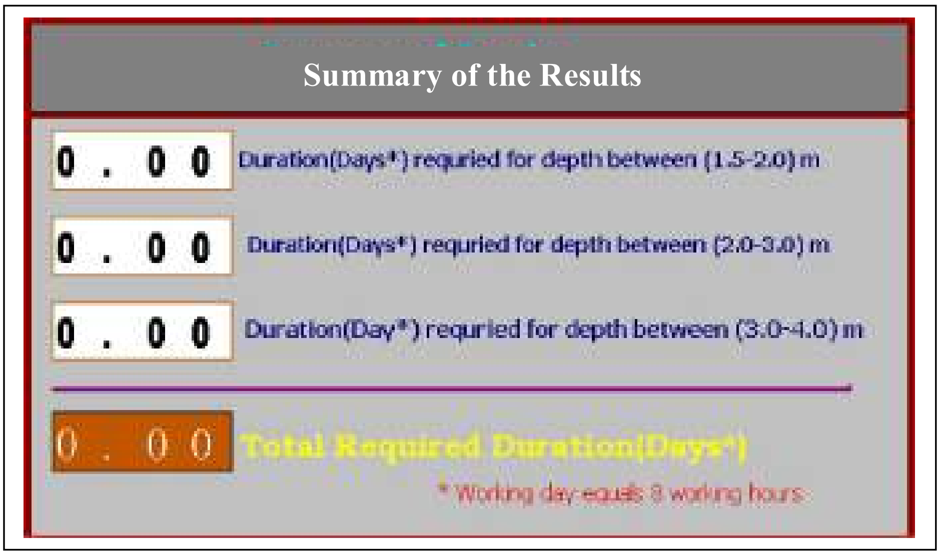


Figure 5.11 Output screen

Output results(durations)would appear in shape of working day by considering that each 8 working hours is equal to a working day, this format can easily be changed according to the needs of the user

The values obtained by this screen are the average values of the simulation process. The user may get other values by using the Arena output files (max or min values).

5.5 Probability Distribution Functions for Sewer Works

5.5.1 Introduction

Researchers have recognized that the quality of a simulation model's results is strictly related to the quality of the input information. So certain input information is necessary to mathematically represent the parameters of a system being modeled. Vanegas et al. (1993) defined four basic groups of information necessary for the input file:

- General information about the model
- Information about the network
- Information about the durations of work tasks, with regard to the type of distribution and the distribution's parameters.
- Information about the resources required in the model.

The type of distribution to be used (point three above) leads to the requirements for statistical data about the construction processes. Types of probability distribution functions and their application to sewer module are explained next.

5.5.2 Definition of Probability Distribution Functions (PDF)

Pritsker (1995) defined probability distributions as "any rule which assign a probability to each possible value of a random variable". Theoretical distributions are usually used to represent observed data and to level data irregularities that may be derived from field observations.

However, because field observations are usually restricted to a small number of data points, it is possible that extreme values, which could influence the overall performance responses of a model, may not be observed.

After the collection of the data on a random variable interest, such data can be used to specify a distribution based on one of the following approaches: *trace driven simulation, an empirical distribution, or a theoretical distribution function (Kannan 1999).* These distributions will be used as a tool to generate the random numbers required for the simulation input.

A Trace–driven simulation allows the use of real data in the simulation models; its major drawbacks are that the simulation reproduce solely happened and that obtaining and using large amounts of data may be time consuming (Law 1991).

When the collection of the data is used to define an *empirical distribution function*, the data are grouped to form a frequency histogram, and the resulting information is transferred to the simulation model.

On the other hand, when the data set is used to fit a theoretical distribution using heuristic procedure or goodness of fit technique, it smoothes irregularities of an empirical distribution, allows the possibility of sampling extreme values and represents the most compact and time saving procedure for performing simulations (Maio 2000). The most common method for collecting construction operation cycle data is by performing time studies. Time studies can be made after defining the cycle and then monitor each activity in the cycle and record the time consumed by each cycle.

5.5.3 Selection of the Appropriate Distribution

One method of choosing the appropriate distribution for the input data of the model is to plot the frequency histogram of the sample data to visualize the distribution. The development of the histogram based on the input data is complicated by the absence of a defined guide for choosing the number of class intervals. Several methods have been suggested for answering this question. By experience in construction industry it is recommended to use number of intervals between 5 and 20, this became by calculating the number of interval by taking the square root of the number of observation (Maio 2000).

5.5.4 Beta Distribution Function

For simulation of construction projects, it was found that the most suitable distribution function that represents the real model of the construction process with all variables is the Beta distribution function (Maio 2000). Beta distribution function is considered as a continuous distribution defined over a range and both of its end points are fixed at exact location and belong to the flexible family of the distribution functions. Because of its extreme flexibility, the distribution appears ideal suited for the description of subjective time estimates of activity duration. The shape of the Beta distribution function depends on the choice of its two parameters "a" and "b", the parameters are any real number greater than negative one.

In this research, all input data related to the different construction processes (sewer or pavement) was fitted to beta distribution function.

5.5.5 Beta (PDF) for Processes Durations of Sewer Module

All data required to simulate different construction processes required for the sewer module with different depths of excavation were collected by direct observation. Observations were taken to find the length of pipes which can be executed in 8 working hours at different conditions and depths. These observed records were then used to calculate durations required to complete 30 meters of pipes. Tables 5.3 shows a sample of the data recorded. All fitted Beta distribution function for different processes is summarized in the following table. See Table 5.4.

Appendix A summarized the data records for all processes.

Table 5.3

Observations records of excavation and pipe installation in clay at depths between1.5 to 2.0 m.

Production rates for pipe excavation, bedding, pipe installation and backfilling			
Depth of excavation(1.5-2.0m)			Type of soil: clay
Diameter of pipe less than 16"			
Observation number	Production Rate (meter /8 hr)	A*	B**
1	88.00	2.93	2.73
2	84.00	2.80	2.86
3	96.00	3.20	2.50
4	66.00	2.20	3.64
5	81.00	2.70	2.96
6	75.00	2.50	3.20
7	86.50	2.88	2.77
8	77.00	2.57	3.12
9	78.00	2.60	3.08
10	85.00	2.83	2.82
11	92.00	3.07	2.61
12	64.00	2.13	3.75
13	82.00	2.73	2.93
14	89.00	2.97	2.70
15	95.00	3.17	2.53
16	96.00	3.20	2.50
17	91.00	3.03	2.64
18	86.00	2.87	2.79
19	85.00	2.83	2.82
20	78.00	2.60	3.08
21	84.00	2.80	2.86
22	76.00	2.53	3.16
23	75.00	2.50	3.20
24	99.00	3.30	2.42
25	96.00	3.20	2.50

A*: number of 30 m intervals assuming the distance between manholes is 30 m.
Example: For 90 meter of executed work, number of intervals =3.0
B**: The durations required for each 30 meters.
Example: For the previous example, duration for the 30m intervals = 2.67 hour, (8.0/3.0)=2.67hr/30 interval.

Table 5.4 Beta distribution functions for different processes in the sewer simulation module.

No	Process	Pipe Diameter	Distribution Function
Depth of trench excavation (1.5 to 2.0 meters)			
1.	Excavation, bedding, pipe installation ,and backfilling (sand) for 30 m length	less than 16 inch	2.12 + 3.51 * BETA(1.55, 4.37)
2.	Excavation, bedding, pipe installation, and backfilling (sand) for 30 m length	More than 16 inch	2.34 + 2.21 * BETA(1.78, 3.19)
3.	Excavation, bedding, pipe installation, and backfilling(clay) for 30 m length	less than 16 inch	2.28 + 1.61 * BETA(1.88, 2.95)
4.	Excavation, bedding, pipe installation, and backfilling(clay) for 30 m length	More than 16 inch	2.23 + 1.77 * BETA(1.68, 2.47)
Depth of trench excavation (2.0 to 3.0 meters)			
5.	Excavation, bedding, pipe installation, and backfilling(sand) for 30 m length	less than 16 inch	3.1 + 2.71 * BETA(2.19, 3.75)
6.	Excavation, bedding, pipe installation, and backfilling(sand) for 30 m length	More than 16 inch	3.09 + 4.57 * BETA(1.57, 2.76)
7.	Excavation, bedding, pipe installation, and backfilling(clay) for 30 m length	less than 16 inch	3.23 + 2.3 * BETA(1.65, 2.55)
8.	Excavation, bedding, pipe installation, and backfilling(clay) for 30 m length	More than 16 inch	3.51 + 2.13 * BETA (1.59, 2.38).
Depth of trench excavation (3.0 to 4.0 meters)			
9.	Excavation, bedding, pipe installation, and backfilling(sand) for 30 m length	less than 16 inch	4.32 + 5.68 * BETA(2.26, 2.75)
10	Excavation, bedding, pipe installation, and backfilling(sand) for 30 m length	More than 16 inch	5.03 + 3.55 * BETA(1.57, 1.14)
11	Excavation, bedding, pipe installation, and backfilling(clay) for 30 m length	less than 16 inch	4 + 9 * BETA(0.886, 2.58)
12	Excavation, bedding, pipe installation, and backfilling(clay) for 30 m length	More than 16 inch	4.35 + 5.33 * BETA(1.72, 2.9)

5.6 Development of Visual Basic Interface for Sewer Module

5.6.1 Introduction

Visual Basic for Applications (VBA) considered as a high level programming language that enable user to develop simple to relatively complex programs. Also, it could be considered as a Microsoft's common application programming (macro) language for Access, Excel, Project, and the Visual Basic programming language environment (Halpin 2003).

One of the most effective functions of Visual Basic for Applications (VBA) is to automate various tasks within the application and even between different computer applications. This can occur only by running the code from or within a host application rather than as a standalone application. It can however be used to control one application from another, for example automatically creating a Word report from Excel data (Kelton 2002).

5.6.2 Visual Basic for Application (VBA) with Arena

Arena offers the ability to automate certain functions using (VBA). VBA allows custom routines to be inserted into a model. These routines may be used to allow for the user interaction with the model, allow for the manipulation of variables or delay times, change the number of replications, and many other useful functions.

Visual Basic Application was used in this thesis to create a simple user interface for data entry; this interface was designed to facilitate the interaction of the user with Arena software. The user interface was designed where no previously knowledge with Arena is needed to operate the model, but only few simple steps required by the user to be able to run the model and find the results.

6.6.3 Sewer Works Module Interface

The main aim of the VBA interface in the sewer work module is to facilitate the data entry for the modules. Information required by the user was divided into four groups as shown in Figure 6.12:

1. Length of pipes at different depths
2. Type of soil
3. Diameter of pipes
4. Hydraulic test distance

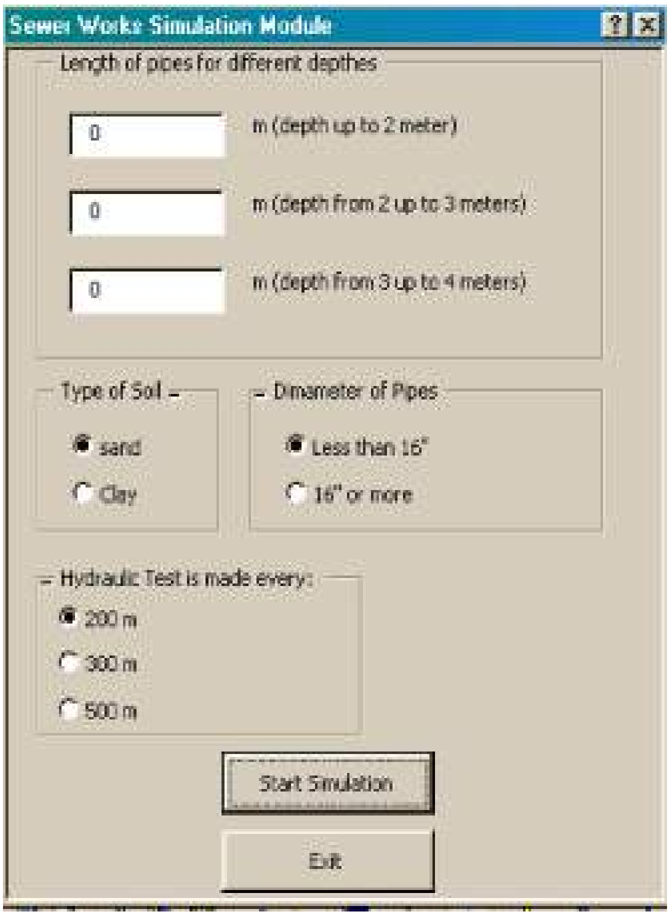


Figure 5.12 Sewer work module interface

1. *Length of pipes for different depths*

The user should define the total length of sewer pipes for each designed depth of excavation. This form has three text boxes for three different depths.

2. *Type of soil:*

Here the user should specify the expected type of soil. The available choices in this interface are two types sand or clay.

3. *Diameter of pipes:*

This group gives the user two types of pipes diameter; less than 16 inch and more than 16 inch.

4. *Hydraulic test distance*

In case of hydraulic test; the user should select the length of executed pipes that test has to be done at that length. The available lengths are: 200, 300 and 500 meter length.

After filling these data, the user run the module by clicking on the button "start simulations" then to find out the simulated durations required for execution the work for each depth.

All source codes used in programming the visual basic interface is represented in Appendix B.

6 PAVEMENT WORKS MODULE

6.1 Introduction

As in the sewer works module, the pavement works module contains many variables depending on the nature of the site (site conditions) and type of executed works.

The same four basic groups of information (used in the sewer module) are required to develop the pavement module. These basic groups can be summarized in the following points:

1. Information about the module (i.e., sub-grade work, base course works, type of pavement, etc.)
2. Information about the hierarchy of the works (how the work will be executed).
3. Information about the durations of tasks and the distribution functions parameters.
4. Information about required resources.

6.2 Hierarchy of Pavement Works Module

For a successful and effective pavement simulation module, the logical flowcharts must be designed first to represent the hierarchy.

The pavement works are divided into three parts:

1. Sub grade works.
2. Base course works.
3. Paving works.

The logical relationships and processes are represented in Figure 6.1.

Fig (6-1): Pavement Works Module Flowchart

6.2.1 Hierarchy Description

The flowchart of pavement module includes mainly the following three parts:

1. *Sub grade works*
2. *Base course work*
3. *Paving work*

Figure 6.1 shows that each part is represented by a number of processes (templates) and their logical relationships.

6.2.1.1 Part 1: Sub-grade Works

This part relates to earth works required for roads construction. These works are essential to prepare the sub-grade surfaces before spreading the base course layers. The sub-grade works contains three main activities:

- Excavation.
- Filling.
- Soil improvement.

Excavation is required when the road level is higher than the designed levels. Filling is required when road levels are lower than the designed levels. Soil improvement activity is required when the road sub-grade layer is unable to resist the expected stresses. Sub-grade works may contain one or more of these activities; so the flowchart includes the logical relations that permit these possibilities. See Figure 6.2.

It is good to know that each one of these activities includes many processes inside. For example, excavation activity contains many processes like excavation, leveling, watering and compaction.

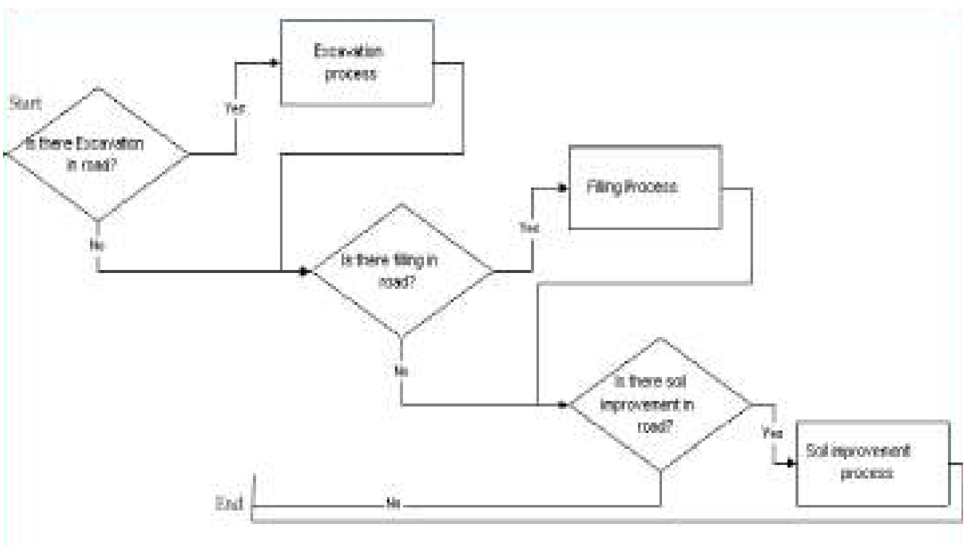


Figure 6.2 Part 1 (Sub-grade works) flowcharts

6.2.1.2 Part 2: Base Course Works

This division concerns about base course works. Almost all roads construction projects include base course works because it is the base foundation for any types of pavement. Most engineering specifications required the work of base course to be executed in two separated layers. In some cases, specifications required the work to be done in only one layer (like in alleys). The proposed flowchart of base course works considered the two options (one layer, or two layers). See Figure 6.3

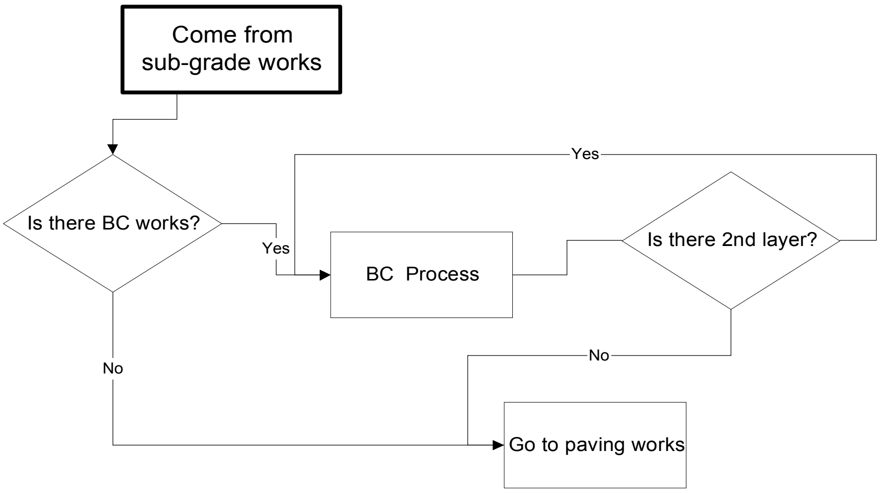


Figure 6.3 Part 2 (Base course Works) flowchart

6.2.1.3 Part 3: Paving Works

This part represents the logical flowchart of roads paving using tiles or asphalt. The flowchart starts with tiling works, and proceeds to represent all required processes. In case of asphalt paving works, the flowchart logic gives two options: one layer or two layers (i.e. this options depends on specification of the project). See Figure 6.4.

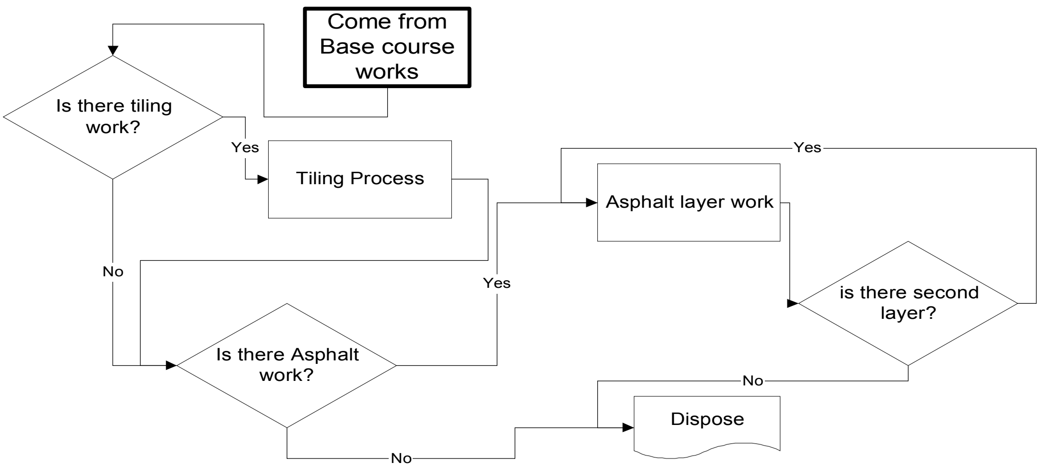


Figure 6.4 Part 3 (Pavement works) flowchart

6.3 Processes of Pavement Works

6.3.1 Site Observations

In order to create a realistic simulation model, all required construction processes (demanded in pavement construction projects) must be clearly specified. An investigation was made to identify all required paving construction processes from different construction sites. The observation continued for a period of more than four months, and it was located at twelve different construction sites. All consumed times (durations) required by different construction processes were recorded at different conditions in order to be used in developing probability distribution functions necessary for the simulation module. Section 6.5 describes all probability distribution functions required to simulate processes production rates. Appendix A represents all data records for all pavement construction processes.

6.3.2 Construction Processes of Pavement Activities

For pavement works, there are large numbers of construction processes required (these processes will be considered as templates in the simulation module). These processes are affected by many factors (variables) like: average depth of road excavation, number of base course layers, type of paving, etc. Most of these variables were taken into consideration during building the simulation templates.

The necessary construction processes can be summarized as follows:

1. *Road Excavation* :

   This process is required if the existing levels of the road is higher than the designed levels. The production rates for this process were measured in m^2 per eight working hours for specified average of depth. For this module, it is assumed that road excavation is executed in layers of 20 cm each, i.e. the production rate for road excavation process is presented in area with thickness of 20 cm which excavated in 8 working hours.

2. *Leveling to reach designed levels :*

   After excavations, it is required to adjust the sub-grade levels to the designed levels. The production rate for this process was measured in m^2 per 8 working hours.

3. *Watering and compaction:*

This process includes the watering process and compaction until reaching maximum compaction degree. The production rate for this process was measured in m^2 per 8 working hours.

4. *Field density test :*

This process is required to ensure that the sub-grade layer has reached the maximum degree of compaction. It is found (after observations) that 98% of the samples points pass the test and only 2% of the tested points fail.

5. *Road filling :*

This process is required if the ground levels are less than the designed ones, so layers of approved backfilling material are taken to reach the designed levels. For this module, it is assumed that road filling is executed in layers of 20 cm each, i.e. the production rate for road filling process is presented in area with thickness of 20 cm which executed in 8 working hours.

6. *Soil improvement :*

This process includes the removing of this feeble layer and replaces it with materials of higher strength. Also the replacement process should be followed by same above mentioned processes. For this module, it is assumed that soil improvement is executed in layers of 20 cm each, i.e. the production rate for soil improvement process is presented in area with thickness of 20 cm which executed in 8 working hours.

7. *Spreading, leveling and compaction of Base course :*

These processes are included in any base course works. It is required to spread the base course material over the entire compacted sub-grade layer.

The work may be done in one layer or two layers according to the specifications of the project. After finishing the course material, leveling process should be done to reach designed road levels. The final process required is watering followed by compaction to reach the maximum compaction degree. The production rates for all of these processes are measured in executed area within 8 working hours.

8. *Tiling process:*

In case that tiling works exists in a project, it starts after finishing both earth and base course works. This process includes spreading of clean layer of sand followed by tiling processing with interlock tiles. The production rates of tiling process are measured in area of tiles executed in 8 working hours.

9. *Spreading of MCO material:*

This process is required if asphalt works exists in the project. It includes the process of spreading MCO material by the pneumatic pump. The production rates of spreading process are measured in area executed in 8 working hours.

10. *Spreading of asphalt:*

When the road surface is completely covered with MCO material, asphalt material is spread on the surface by using finisher machine. The production rates of spreading of asphalt process are measured in area executed in 8 working hours.

11. *Compaction for asphalt layer:*

This process is the final step in asphalt works, the fresh layer of asphalt has to be compacted many times by using different types of compactors until reaching the desired hardness. The production rates of compaction process are measured in area executed in 8 working hours.

6.4 Arena Pavement Works Module

6.4.1 Introduction

Pavement works module is a simulation model designed to simulate road construction process. This module involves three main construction works: sub-grade, base course and paving works.

This section describes the procedure followed to develop the pavement module using Arena software. Some assumptions and limitation were considered in building the module.

6.4.2 Pavement Module Assumptions and Limitations

The assumptions and limitations adapted in this module are as follows:

- ***Assumptions for pavement works module*:**

1. Average depth of road excavation must be calculated by the user (average is calculated by dividing the summation of depths at each station by the number of stations). The same procedure of calculation must be done for filling and soil improvement works.
2. The total area of each excavation and filling works must be separately defined, i.e. it is required to specify the area of excavation and the area of filling each alone.
3. Working day equals 8 working hours. All output durations are considered as working days, not calendar days.
4. Field density tests for subgrade works and base course works pass 98% of the time.
5. Weather conditions weren't considered in the module, because heavy rainy days in Palestine are limited to few days in a year.

- ***Limitations for pavement works module*:**

1. Types of paving materials are limited to tiles and asphalt only.
2. Soil improvement option is limited to adding Kurkar material as an improvement material (replacement with Kurkar solution).

6.4.3 Module Description

After considering the previous limitations and assumptions, the simulation module was created using Arena software. It contains the following two parts, see Figure 6.5:

1. *Part I (Data entry):*

Containing the data entry to the module.

2. *Part II (Processing):*

This part is responsible for processing all data in the module and controlling the logic of processes. It involves three main sub-modules; each one is responsible for simulating specified construction works (i.e. sub-grade works, base course works and pavement works). Figure 6.5 represents the overall module.

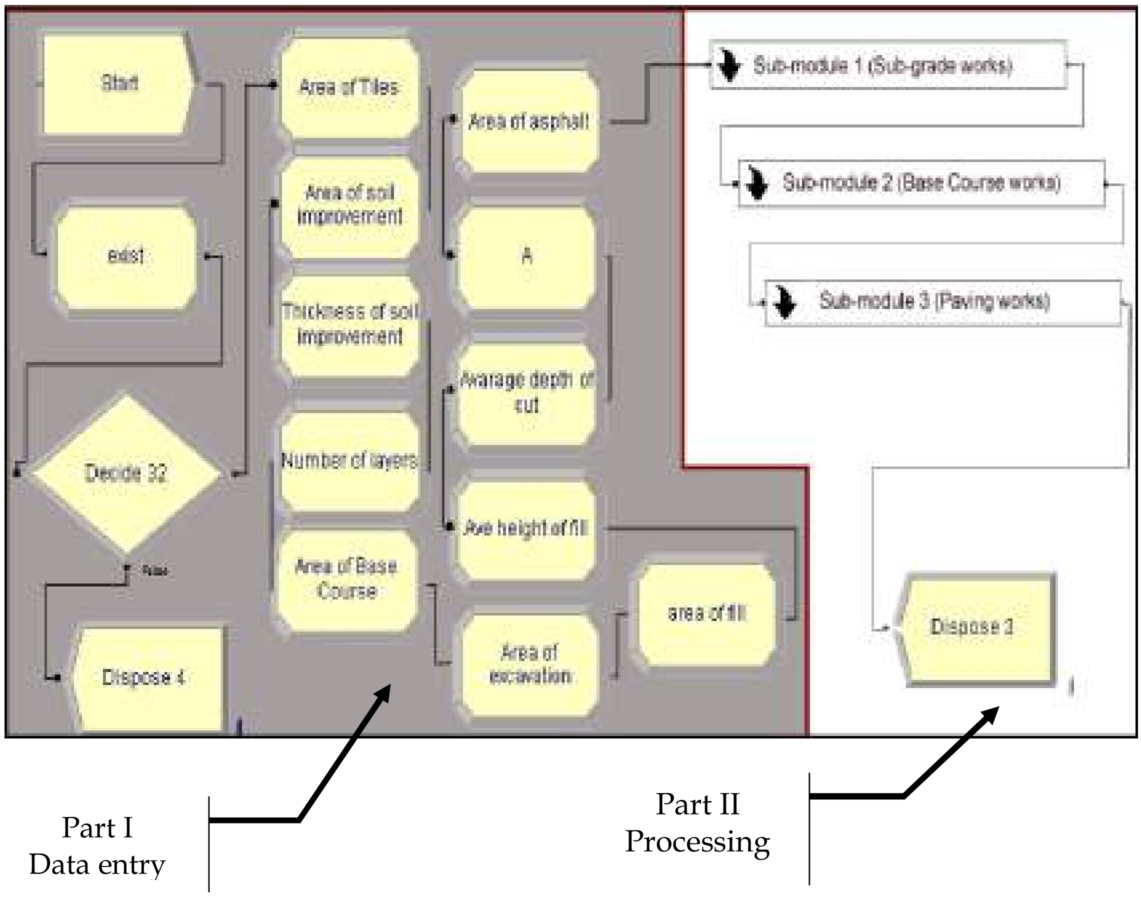


Figure 6.5 Overall Pavement works module

6.4.3.1 Part I (Data Entry Part)

This part was designed to initiate the modeling process through creating one *entity* when starting the module and for inputting data to the module.

The created entity represents one squared meter of road area. This entity will operate the whole module by activating different templates.

All variables (input data) required for the module will be inserted using the module assign elements, see Figure 6.6. Ten assign elements were used to insert different variables related to site conditions and type of works. Visual Basic interface was designed to facilitate the entry of all required data in a simple way (presented in section 6.6). These assign elements can be summarized in the following tables, see Table 6.1.

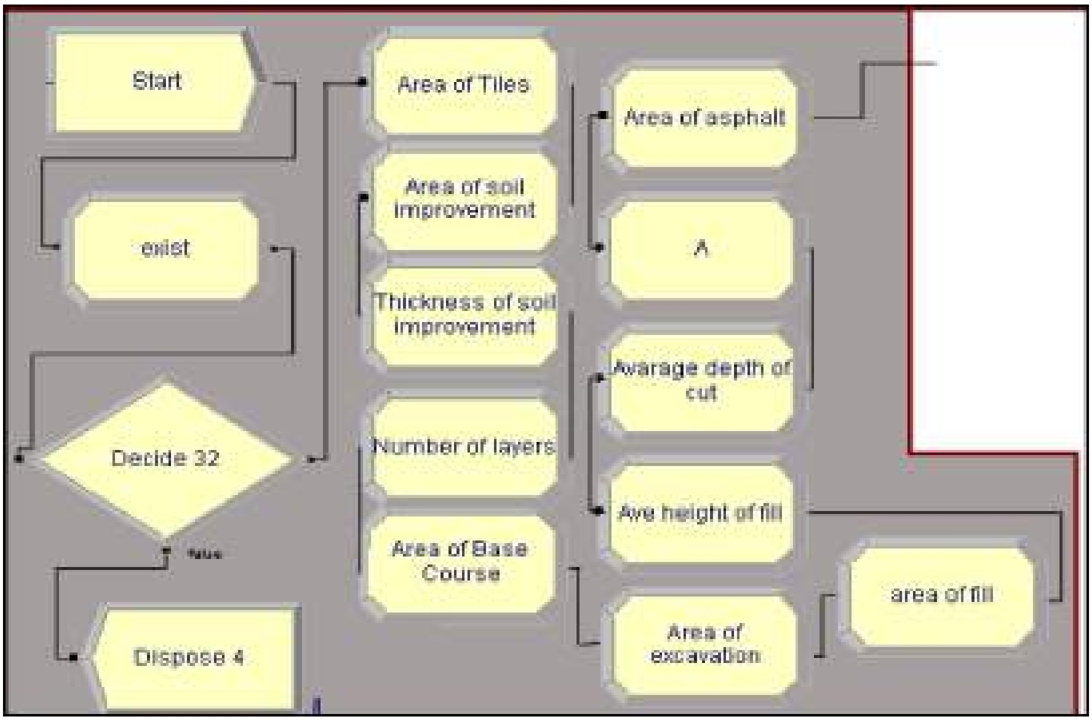


Figure 6.6 Part I (Data Entry Part)

Table 6.1 Assign elements used in the pavement module

Assign element Name(as in Arena)	Attribute Name	Function
Area of Tiles	A T	Insert total area of tiles to be used.
Area of soil improvement	area of soil impr	Insert total area of road to be improved.
Thickness of soil improvement	Thickness of impr.	Insert thickness of soil improvement layers
Number of layer	no of layer	Insert number of asphalt layer
Area of BC	total area of road	Insert total area of base course to be used
Area of asphalt	A A	Insert total area of asphalt to be used
Average depth of cut	depth of cut	Insert average depth of road to be excavated
Average height of fill	height of fill	Insert average height of fill to be added to the road
Area of road cut	total area of cut	Insert total area of road to be excavated
Area of road fill	total area of fill	Insert total area of road to be backfilled.

6.4.3.2 Part II (Processing)

This part is responsible for processing the module. All simulated processes (templates) are activated in this part. It composes of three sub-modules as shown in Figure 6.7. These sub-modules were designed for simulating sequential construction processes and these sub-modules are:

A. *Sub-module 1 (Sub-grade works).*
B. *Sub-module 2 (Base Course works).*
C. *Sub-module 3 (Paving works).*

Each one of the sub-modules involves several templates and logical relationships that simulate the performance of road construction activities.

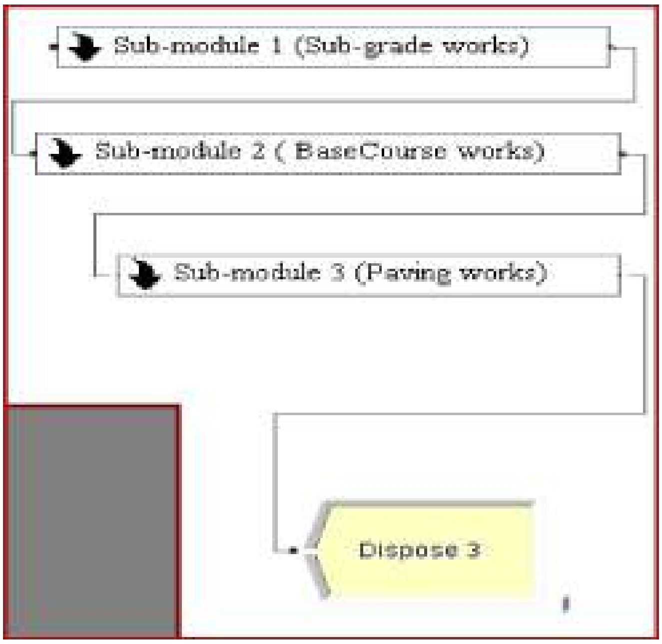


Figure 6.7 Part two (Processing)

6.4.3.2.1 *Sub-module 1(Sub-grade works)*

This sub-module contains three blocks (I, II, and III). Each block is responsible for simulating different sub-grade works (excavation works, backfilling works and soil improvement works). See Figure 6.8. When simulation starts, the entity will go through sub-module 1 first where different decide elements would check for the need of excavation or filling or soil improvement works.

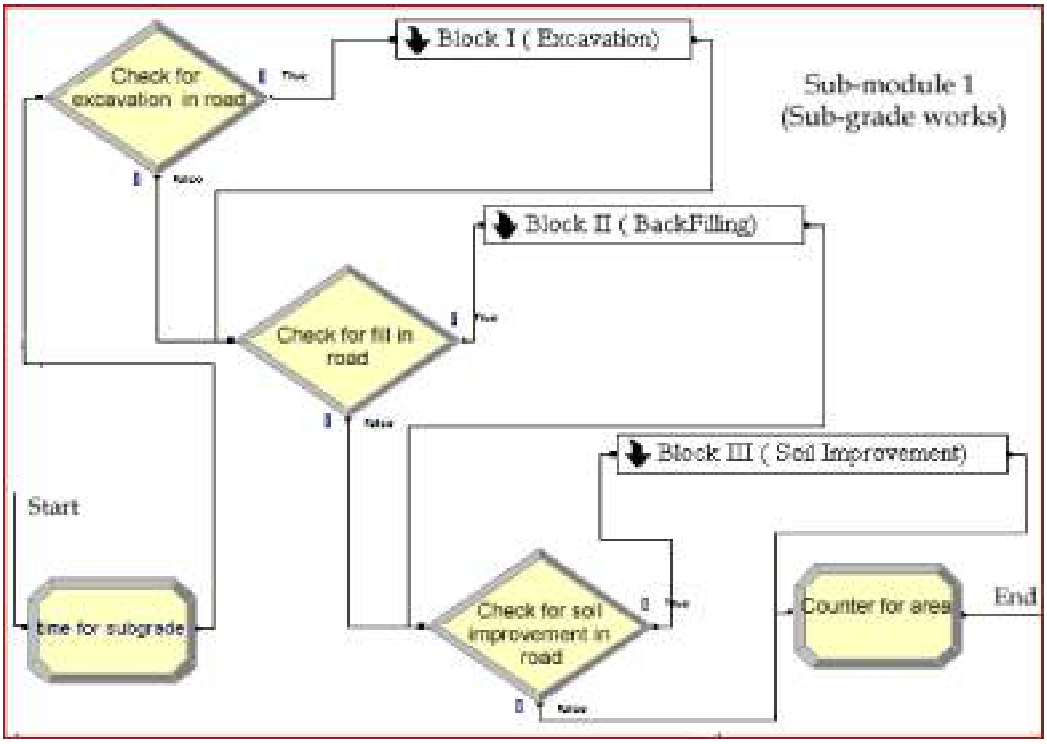


Figure 6.8 Blocks (I, II, and III) inside sub-module1 (Sub-grade works)

- **Block I (Excavation)**

This block is activated if the data entry includes excavation works. Block I contains all processes and logical relationships to simulate excavation works. Figure7.9 demonstrates the structure of this block. It contains four essential processes: excavation, leveling, watering, compaction and field density test.

The work in this block is based on dividing the total area of excavation into segments of 500 m^2. This segment will go through the block and will pass through all templates according to the designed logic.

At the beginning of the simulation process the entity initiates the excavation process. This entity which represents 500 m^2 of road area goes through a loop of templates (process) for excavation and each cycle executes 500 m^2. A counter inside the cycle adds 500m^2 of excavated area each time until reaching the desired total area which is to be excavated. The loop is designed to excavate only 20 cm at each cycle. If the average depth is more than 20 cm, the entity repeats the same previous loop until reaching the desired depth.

Leveling, watering and compaction are processed as above. The entity after finishing the excavation, process goes through the leveling process. In this loop, every cycle the entity goes through leveling process, which executes 500 m^2 leveling of road. This area (500 m^2) is added to the entity.

The entity stills passing in this loop until reaching the desired area. At the end of each leveling cycle, a decide element of Arena would check if the carried area by the entity has reached the desired area for leveling (inserted by the user). In case of completing the total desired area, the entity comes out the loop and goes for the next step.

In this step, watering and compaction templates (processes) were merged because they are simultaneous processes. Also, the entity goes through a loop and a count to add a value of 500 m^2 to the entity. The work proceeds until reaching the total desired area of road. Field density test is added to this loop and this test is assumed to be done each 500 m^2. Inside each of these loops, there are many templates which represent the actual processes and these templates include probability distribution functions required for time estimation. See Figure 6.9.

Table 6.2 demonstrates all Arena elements used in Block I (Excavation).

The probability distribution functions for the module are explained in section 6.5.

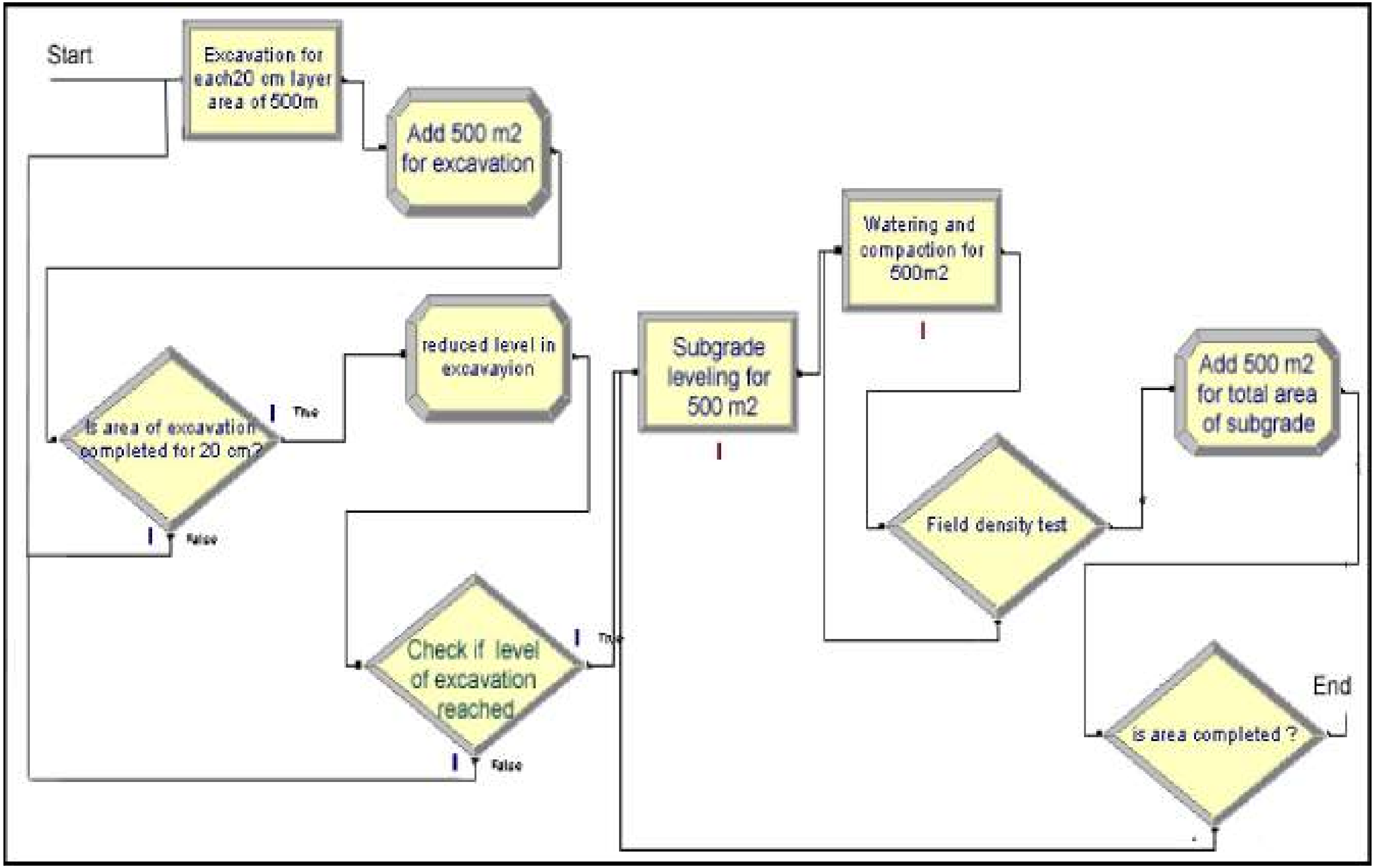


Figure 6.9 Block I (Excavation), templates and logic

Table 6.2 Elements and templates of Block I (Excavation)

Element Name (as in Arena)	Type of Element	Function
Is area of excavation completed for 20 cm	Decide element	Check if total area of excavation has been finished with depth of 20 cm.
Check if level of excavation reached	Decide element	Check if total area of excavation has been finished with required depth.
Field density test?	Decide element	Check to ensure that soil has reached to maximum density after compaction process.
Is area completed?	Decide element	Check if total area of road has been compacted.
Add 500 m^2 for excavation	Assign element	Add 500 m^2 to the entity at each time the entity passes this process (i.e. excavate a layer with thickness of 20 cm).
reduced level in excavation	Assign element	Add 500 m^2 to the entity at each time entity passes this assign element until excavating all desired depth.
Add 500 m^2 for total area of subgrade.	Assign element	Add 500 m^2 to the entity at each time entity passes this assign element (i.e. leveling and compaction processes).
Excavation for each 20 cm layer area of 500 m^2	Template (process)	Template required to simulate the process of excavating 500 m^2 with thickness of 20 cm.
sub grade leveling for 500 m^2	Template (process)	Template required to simulate the process of leveling 500 m^2.
Watering and compaction for 500 m^2	Template (process)	Template required to simulate the process of watering and compaction 500 m^2.

For the Blocks II and III (Backfilling and Soil improvement Blocks), the same procedure was applied; but with different templates and probability distribution functions. Figure 6.10 and 6.11 represent the templates and loops used.

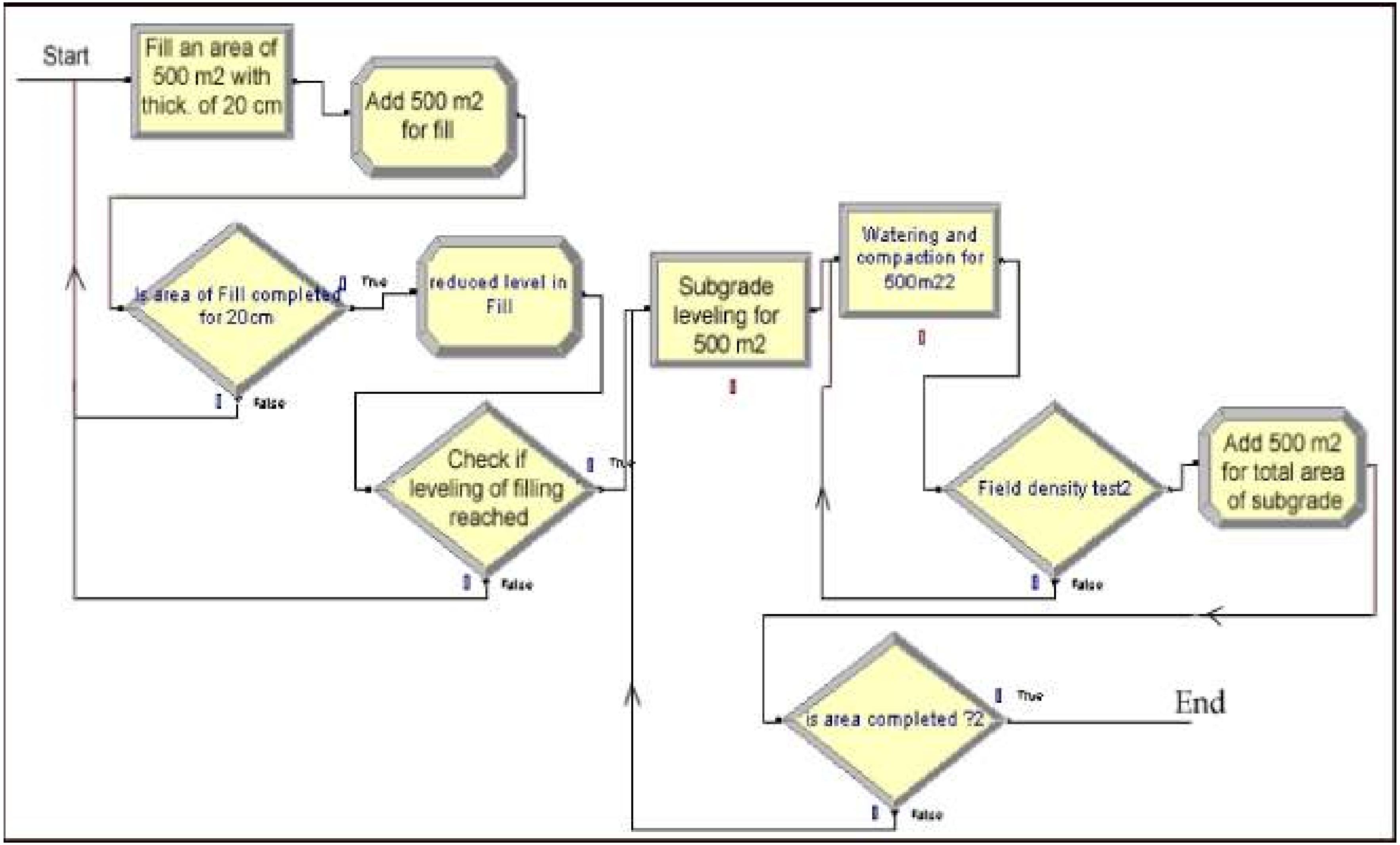


Figure 6.10 Block II (Backfilling), templates and logic

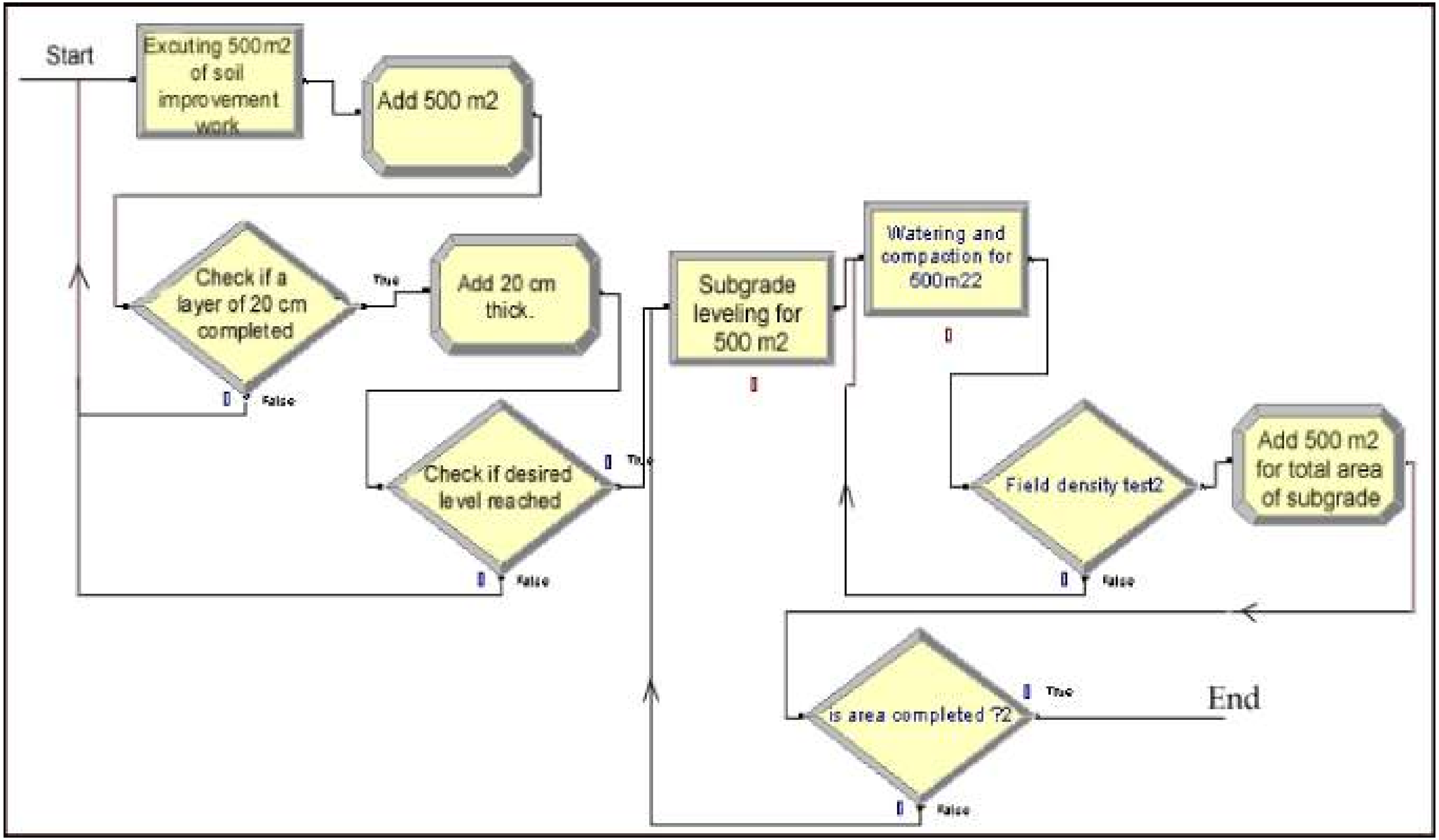


Figure 6.11 Block III (Soil improvement), templates and logic

6.4.3.2.2 *Sub-module 2 (Base Course works)*

This sub-module was designed to simulate the base course works in a project. The main feature of this sub-model is the same as discussed in sub-module 1 (Sub grade). See Figure 6.12.

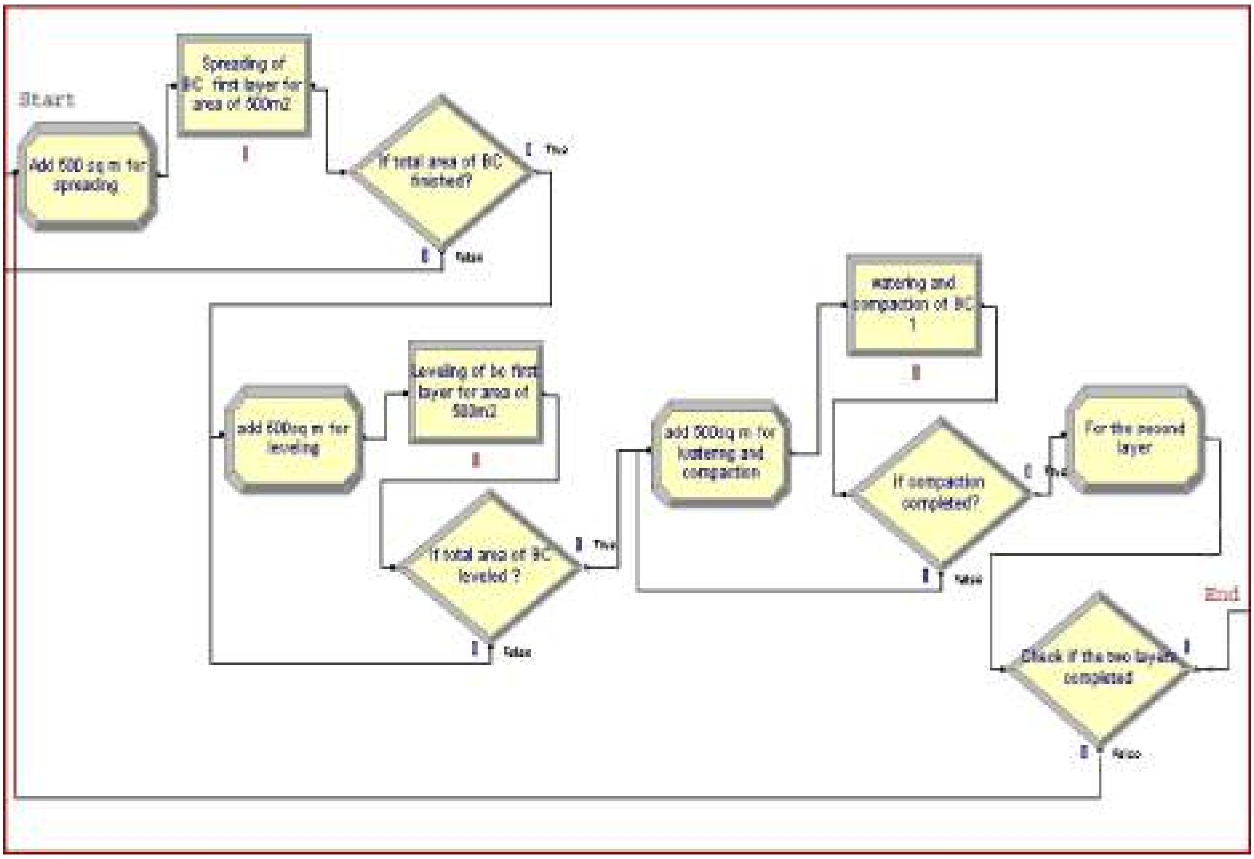


Figure 6.12 Sub-module 2 (Base Course works)

In this sub-module, three loops were designed to simulate three sequential construction processes. Figure 6.12 demonstrates these loops:

- Loop 1: Spreading of base course for unit area of 500 m^2.
- Loop 2: Leveling of base course layer for unit area of 500 m^2.
- Loop 3: Watering and compaction of base course for unit area of 500 m^2.

After finishing the sub-grade works, the entity goes through this sub-module. The entity enters the first loop which represents the spreading process for an area of 500 m^2. The entity keeps running in the loop until completing the designated total area. The second loop (leveling process) will be initiated by the entity when the spreading process is completed.

The entity goes through this loop to do for 500 m^2 at each cycle, and end this loop when completing the whole road area. When leveling is completed, the third loop will be activated. This loop represents the watering and compaction process for a unit area of 500 m^2 of base course. Also, the entity will stay in the loop until the total area is completed. When the road area is compacted, the entity will leave the sub-module. Table 6.3 represents all Arena elements used in sub-module 2.

Table 6.3 Elements and templates of sub-module 2 (Base course)

Element Name (as in Arena)	Type of Element	Function
If total area of BC finished?	Decide element	Check if total area of Base course has been spread.
If total area of BC leveled?	Decide element	Check if total area of Base course has been leveled
If compaction completed?	Decide element	Check if total area of Base course has been compacted
Check if the two layers completed	Decide element	Check if total area of Base for both two layers have finished.
Add 500 m^2 for spreading	Assign element	Add 500 m^2 to the entity at each time entity passes through this element (i.e. spreading layer of Base course with thickness from 10 to 15 cm).
add 500 m^2 for leveling	Assign element	Add 500 m^2 to the entity at each time entity passes through (i.e. leveling base course layer)
add 500 m^2 for watering and compaction	Assign element	Add 500 m^2 to the entity at each time entity passes through (i.e. compacting base course layer)
For the second layer	Assign element	Required to start the second layer.
Spreading of BC first layer for area of 500 m^2	Template (process)	Template required to simulate the process of spreading base course to area of 500 m^2.
Leveling of BC first layer for area of 500 m^2.	Template (process)	Template required to simulate the process of leveling 500 m^2 of base course layer.
Watering and compaction of BC 1	Template (process)	Template required to simulate the process of compacting 500 m^2 of base course layer.

6.4.3.2.3 *Sub-module 3 (Paving works)*

This sub-module is the final one, which relates to paving works. It simulates two type of paving works; paving with tiles or with asphalt material. The concept of this sub-model is the same as in sub grade and base course sub-modules. See Figure 6.13.

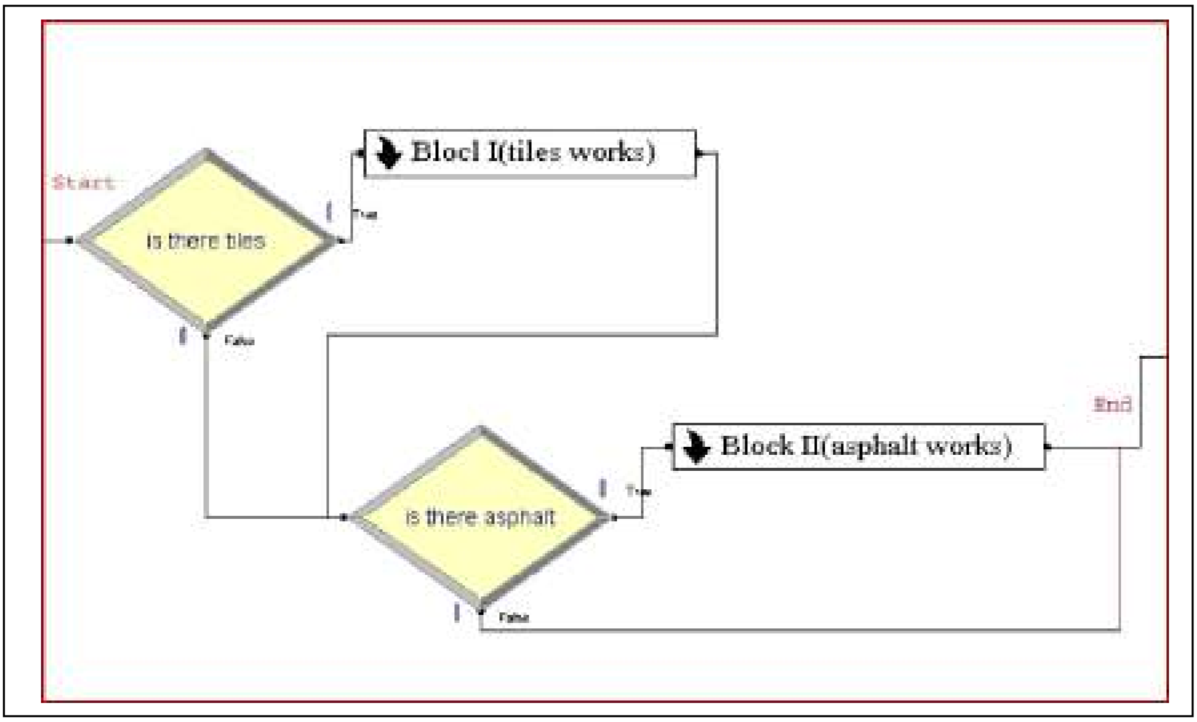


Figure 6.13 Sub-module 3 (Paving works), includes two blocks (tiles and asphalt)

This sub-module contains two blocks (I and II); each block is responsible for simulating different types of paving material (tiles or asphalt), see Figure 6.13. When the entity completes the base course works, it comes out from sub-module 2 and goes through sub-module 3 (paving works). In this sub-module, two decide elements check for the requirement of tiles or asphalt works in the project and directs the entity of the corresponding block.

- ***Block I (Tiles works):***

This block is activated if the input data includes an area for tiling works. Block I contains all the processes and logic relationships to simulate the tiling process. Figure 6.14 shows the essential process required to do the tiling work.

This block depends on dividing the total area of the tiles into segments of 100 m^2. At the beginning, the entity activates the tiling template. This entity which represents 100 m^2 of road goes through a loop of tiling process; each cycle executes 100 m^2.

The loop will continue until completing the assigned area defined by the user. The entity then leaves Block I to Block II.

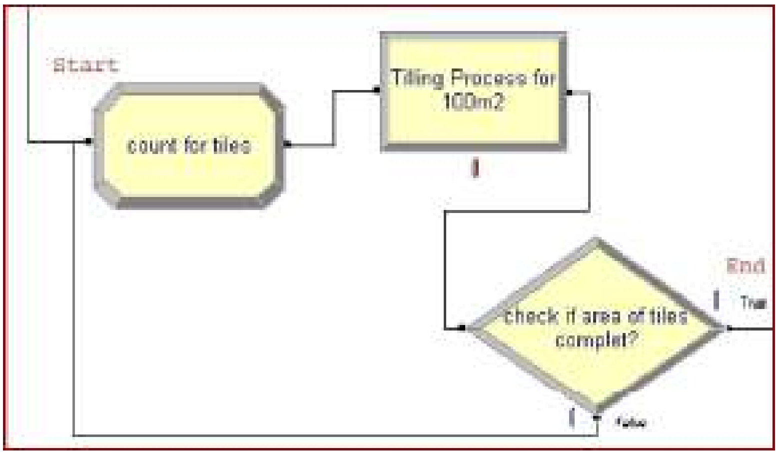


Figure 6.14 Block I – tiling works, templates and logic

- ***Block II (Asphalt works):***

After finishing the tiling works, this block will be activated if the project contains asphalt work.

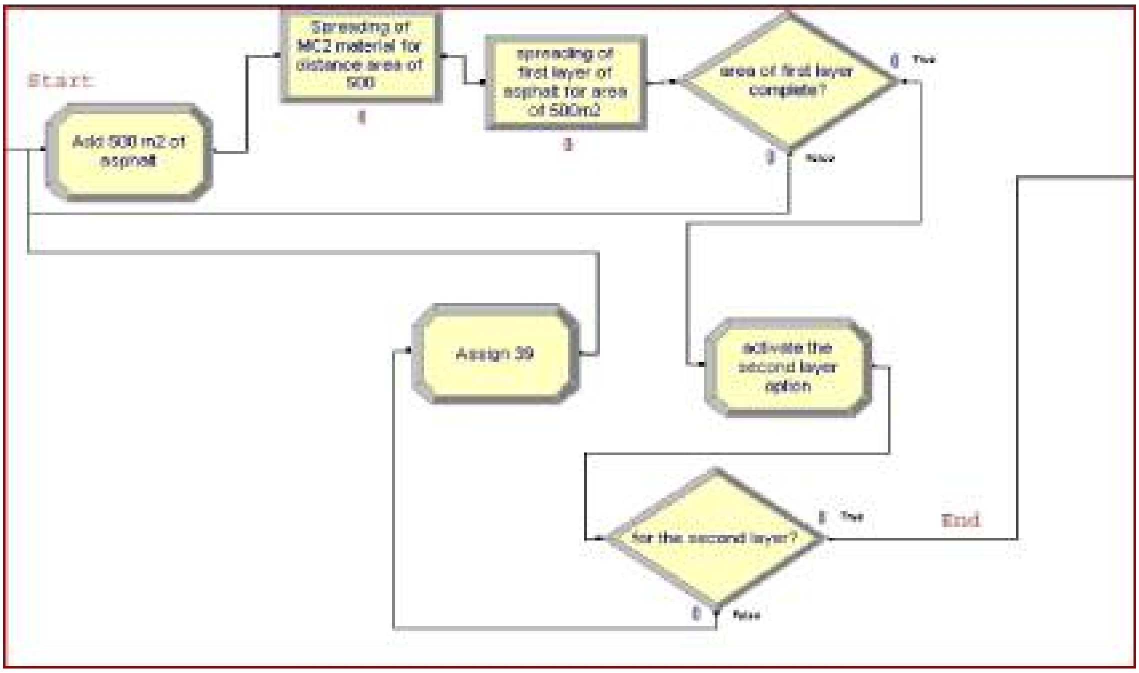


Figure 6.15 Block II – asphalt works, templates and logic

This block uses the same concept as in sub-module 2 (base course works). It depends on dividing the total area of asphalt into segments of 500 m^2 each. As shown in Figure 6.15, this segment which represents the work will go through the block and passes through the templates to simulate the work activities.

The entity (500m ^{2}) goes through a loop of cycles to execute 500 m^2 each time. The cycling will continue until reaching the assigned area defined by the user. The entity then checks if there is a second layer of asphalt (i.e. work to be done in one or two layers). If so, the entity will go through the loop again.

6.4.4 Pavement Module Output

The results of this module are represented by the durations required to execute the sub grade, base course and paving works. The shape of the simulation outputs was simplified to fit the needs of normal user. Figure 6.16 represents the "summary of results" screen. The user will obtain the simulated durations for different construction processes of the pavement works at different types of activities. Also, the total simulated durations for the entire project will be obtained.

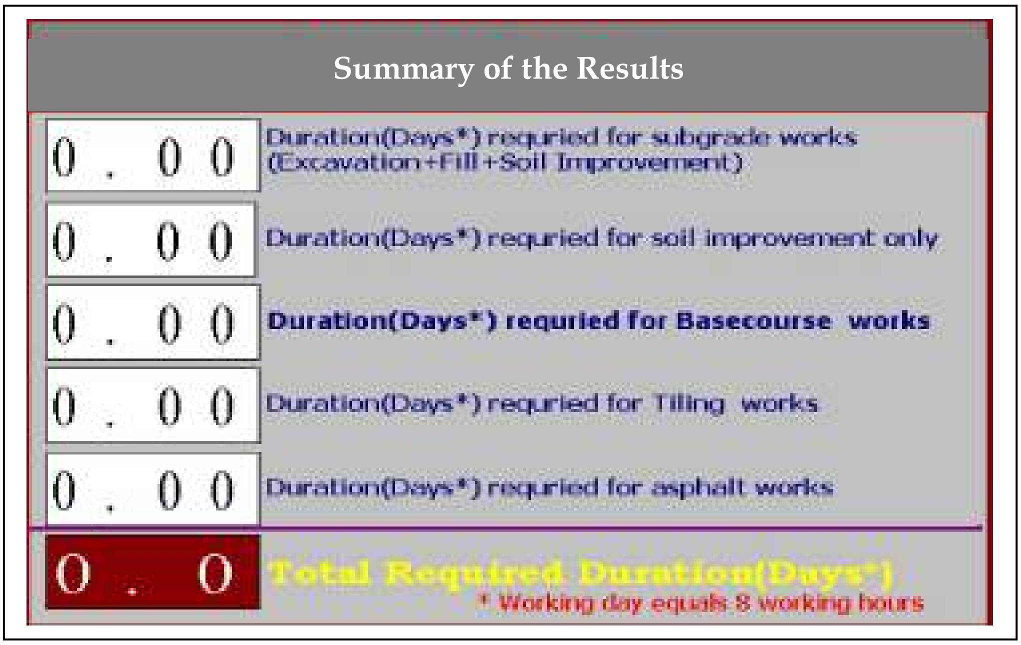


Figure 6.16 Output screen

The total duration required to complete all activities of a road construction project is also given.

For other results (i.e. resources utilization, process times, statistics on resources and processes, etc.); Arena generates detailed output files that assist Arena users in drafting the proper decision once needed by the job time.

6.5 Probability Distribution Functions for Pavement works

6.5.1 Introduction

In this module, same procedure followed (previously explained in sewer module) to create probability distribution functions for different templates of pavement module. Different statistical observations were made to record production rates of different construction processes at different construction projects. These records were used to develop the probability distribution functions.

These distributions will be used as a tool to generate the random numbers required for the simulation inputs.

6.5.2 Beta (PDF) for Processes Durations of Pavement Module

All data required to simulate different construction processes were collected by direct site observation. Observations were made to find the area of work (for different processes) executed during each 8 working hours. The processes include all sub-grade works, base course works and paving works including tiles and asphalt. The concept of the observation depends on estimating the total area of work done in 8 working hours, and then calculating from these values the duration required to execute 500 m^2 of the same work.

Example:

For base course spreading works, it was found (for example) that an area of 2500 m^2 was executed in 8 working hours.

So duration required to execute 500 m^2 of same works = (8*500)/2500=1.6 hours.

Tables 7.4 shows a sample of the data recorded. All Beta distribution function for different processes is summarized in the following table. See Table 6.5.

Appendix A summarized the data records for all processes.

Table 6.4
Observations records of watering and compaction process for sub-grade works in 8 working hours.

Production rates for watering and compaction process for sub-grade works		
Process: Watering ,Compaction and F.D test		
No.	Production rate (m^2 /8 hr)	Time required for each 500 m^2(hour)
1	3,250.00	1.23
2	2,600.00	1.54
3	2,500.00	1.60
4	3,250.00	1.23
5	2,800.00	1.43
6	2,900.00	1.38
7	2,950.00	1.36
8	2,750.00	1.45
9	2,600.00	1.54
10	3,250.00	1.23
11	3,150.00	1.27
12	3,000.00	1.33
13	2,900.00	1.38
14	3,200.00	1.25
15	2,400.00	1.67
16	3,450.00	1.16
17	2,650.00	1.51
18	2,950.00	1.36
19	3,600.00	1.11
20	2,590.00	1.54
21	2,950.00	1.36
22	3,000.00	1.33
23	2,850.00	1.40
24	2,450.00	1.63
25	2,750.00	1.45
26	4,000.00	1.00
27	3,500.00	1.14
28	2,950.00	1.36
29	2,450.00	1.63
30	2,500.00	1.60
31	3,250.00	1.23

After all required data was collected and converted to the required shape (duration per 500 m^2), Arena input analyzer software (statistical software) was used to calculate all Beta distribution functions for different templates (processes).

Table 6.5 shows all Beta distribution functions for different templates (construction processes).

Table 6.5 Beta distribution functions for different templates in the pavement module

No	Template name (As in Arena)	Segment of area to be executed	Beta Distribution Function
		Sub-grade Works	
1	Excavation of 500 m^2 (depth 20 cm)	Excavation of (area of 500 m^2)	1.21 + 0.791 * BETA(2.2, 1.74)
2	Sub grade leveling for 500 m^2	Leveling (area of 500 m^2)	0.999 + 0.741 * BETA(1.04, 1.36)
3	Watering and compaction for 500 m^2	Watering and compaction (area of 500 m^2)	0.999 + 0.741 * BETA(1.93, 1.85)
4	Fill of 500 m^2 (depth 20 cm)	Filling (area of 500 m^2)	1.05 + 0.68 * BETA(2.18, 2.56)
5	Sub grade leveling (filling layer) for 500 m^2	Leveling (area of 500 m^2)	0.999 + 0.741 * BETA(1.04, 1.36)
6	Watering and compaction (filling layer) for 500 m^2	Compaction and watering (area of 500 m^2)	1.02+ 0.741 * BETA(1.63, 1.85)
7	For each20 cm layer area of 500 m^2 in soil improvement	Soil improvement (area of 500 m^2)	1.05 + 0.68 * BETA(2.18, 2.56)
8	leveling for 500 m^2 in soil improvement	Soil improvement of 500 m^2	0.999 + 0.52 * BETA(1.14, 1.65)
9	Watering and compaction for 500 m^2 in soil improvement	Soil improvement (area of 500 m^2)	1.09 + 0.841 * BETA(1.93, 1.65)
		Base Course Works	
10	Spreading of BC first layer for area of 500 m^2	Base course work (area of 500 m^2)	1.05 + 0.64 * BETA(4.45, 5.21)
11	Leveling of BC first layer for area of 500 m^2	Base course work (area of 500 m^2)	1.15 + 0.64 * BETA(2.16, 2.64)
12	watering and compaction of BC 1	Base course work (area of 500 m^2)	1.05 + 0.64 * BETA(2.26, 2.64)
		Paving Works	
13	Tilling Process for 100 m^2	Tiling work (area of 100 m^2)	1.69 + 1.07 * BETA(2.14, 3.2)
14	Spreading of MC2 material for area of 500 m^2	Asphalt work (area of 500 m^2)	0.69 + 1.75 * BETA(3.22, 3.78)
15	spreading of first layer of asphalt for area of 500 m^2	Asphalt work (area of 500 m^2)	1.03 + 0.95 * BETA(2.07, 2.92)

6.6 Development of Visual Basic Interface for Pavement Module

6.6.1 Introduction

Visual Basic for Applications (VBA) was used to develop a simple interface for data entry of the module. The interface screen was divided into six groups each one is required for certain input data.

6.6.2 Pavement Works Module Interface

Visual Basic programming language was used to build an interactive user friendly interface for data entry. This interface facilitates data entry for the module. The user needs only run the model (play) to activate the interface screen. The Data required by the user is divided into six groups, as shown in Figure 6.17 and 6.18. These groups are:

1. Road Excavation
2. Fill Data
3. Soil Improvement Data
4. Data of Base Course Area
5. Asphalt Works
6. Tiling Works

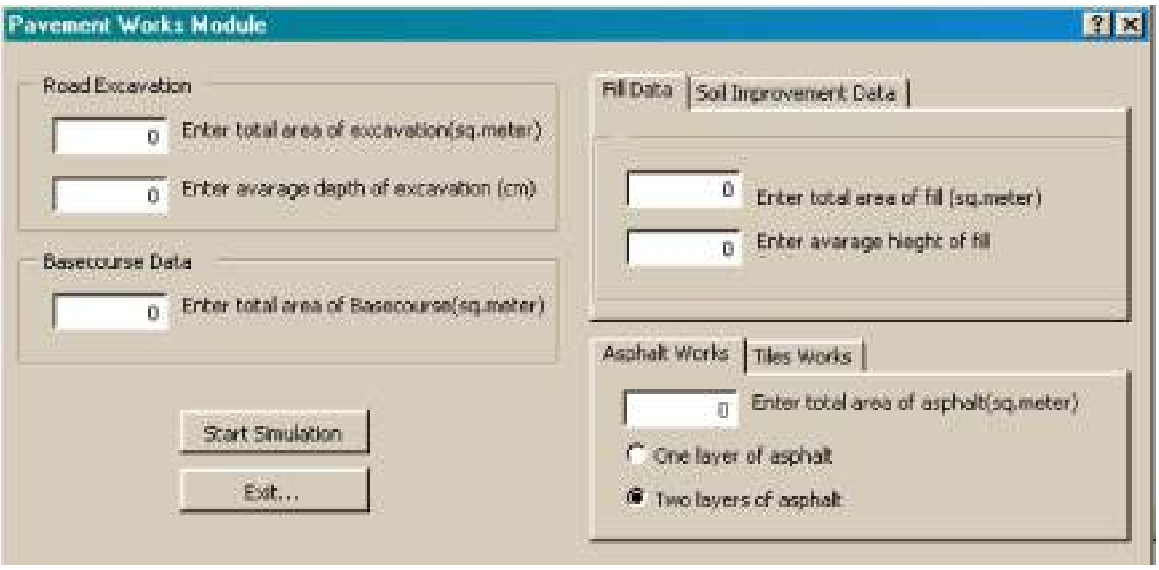


Figure 6.17 Pavement works main module interface

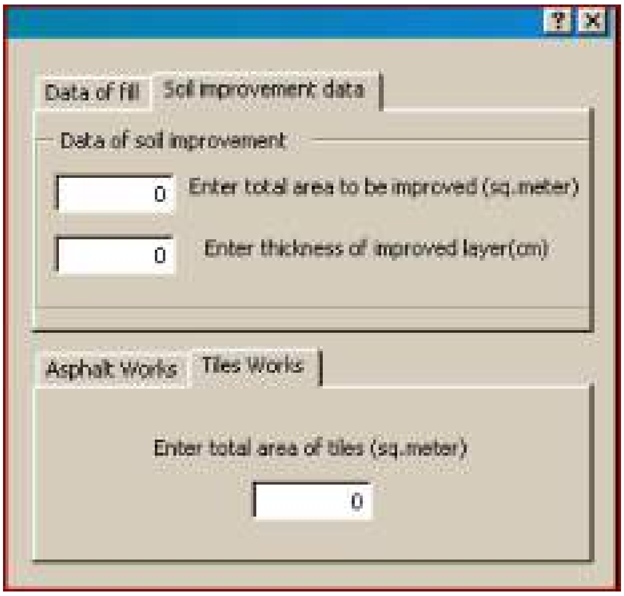


Figure 6.18 Pavement works module interface (Soil Improvement and tiles works)

The details of the six groups of data entry can be summarized in the followings:

1. *Road Excavation*

As shown in Figure 6.17, the user should define the total area of road excavation as well as the calculated average road depth based on number of stations.

The following example explains the procedure for depth calculation:

Example: if a road contains three stations and the depths of excavation at these stations are (in cm): 20, 30, 40, the average depth of excavation = ((20+30+40)/3) =30 cm.

2. *Fill Data*

In this group, the user should define the total area of road that required to be backfilled (for road levels lower than the designed) and to input the calculated average height of filling. The same procedure used in calculating the average excavation depth can be used to calculate the average fill height.

3. *Soil Improvement Data*

In this group, the user should define the total area of road that required soil improvement works (this activity needed when natural soil is weak to resist highway stresses).

Also, it is required to calculate the average depth of improved soil by the same procedure.

4. *Data of Base Course*

In this group, the user should define the total area of road that required base course layers (it assumes that work of base course will be done in two layers).

5. *Asphalt Works*

Here it is required to insert total area of road that designed to be paved by asphalt. Also, it is required to select number of layer required (one or two layers)

6. *Tiling works*

This group designed to insert the total area of road to be paved with tiles.

All source codes used in programming the visual basic interface is given at Appendix B.

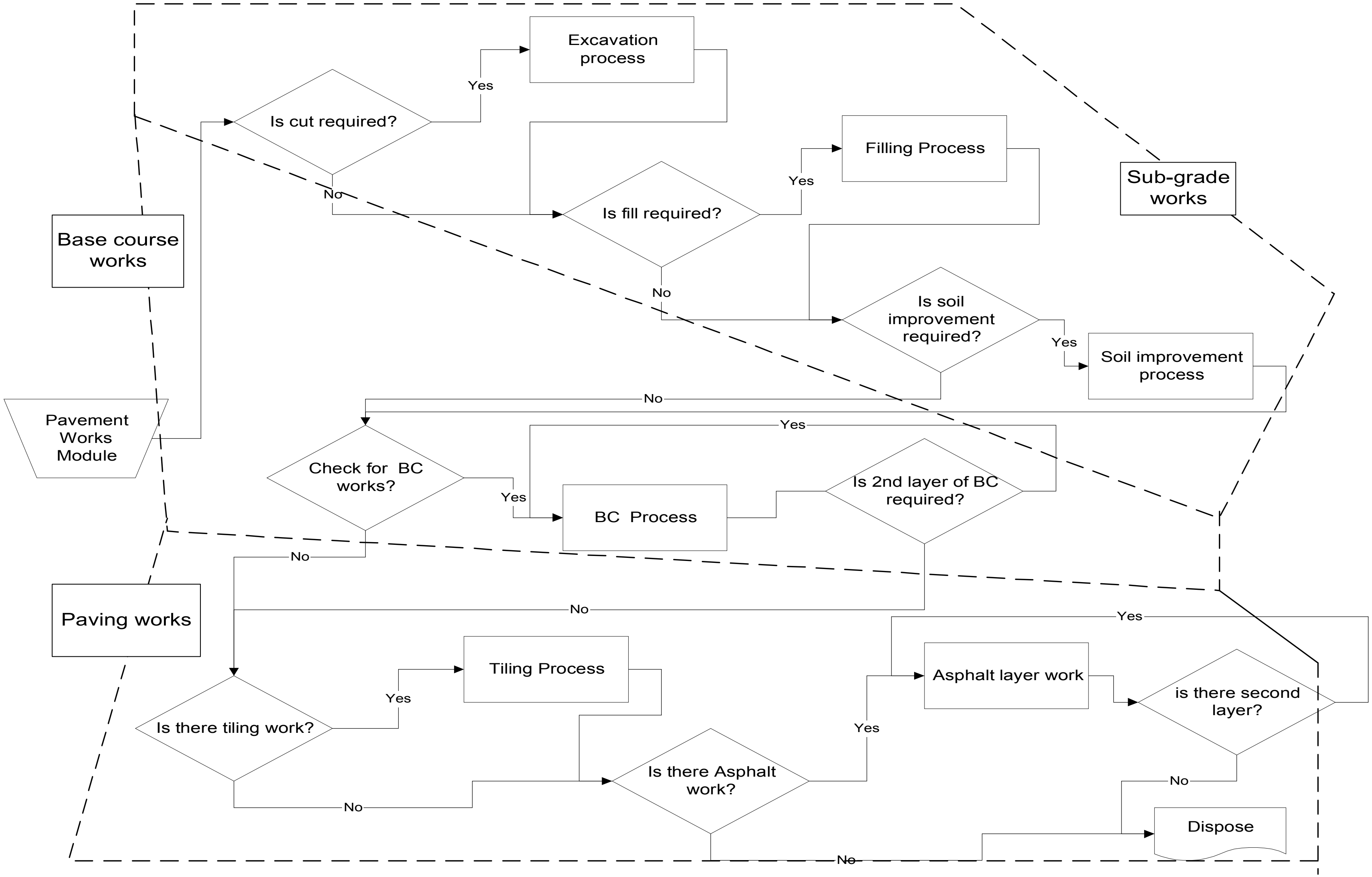


Figure 6.1 Pavement Works Module Flowchart

7 DEVELOPMENT of the OVERALL INTEGRATED MODEL

7.1 Introduction

This chapter demonstrates how to develop the overall simulation model using the sewer and pavement modules based on the approach developed in Chapter 4.

7.2 Applying the Approach

As explained earlier (in Chapter 4), the first step in creating an infrastructure simulation model is the definition of project levels. Infrastructure simulation model involves four sequential levels: model, sub-model, module, and templates. Each one of these levels represents certain level in real infrastructure project, see Figure 7.1.

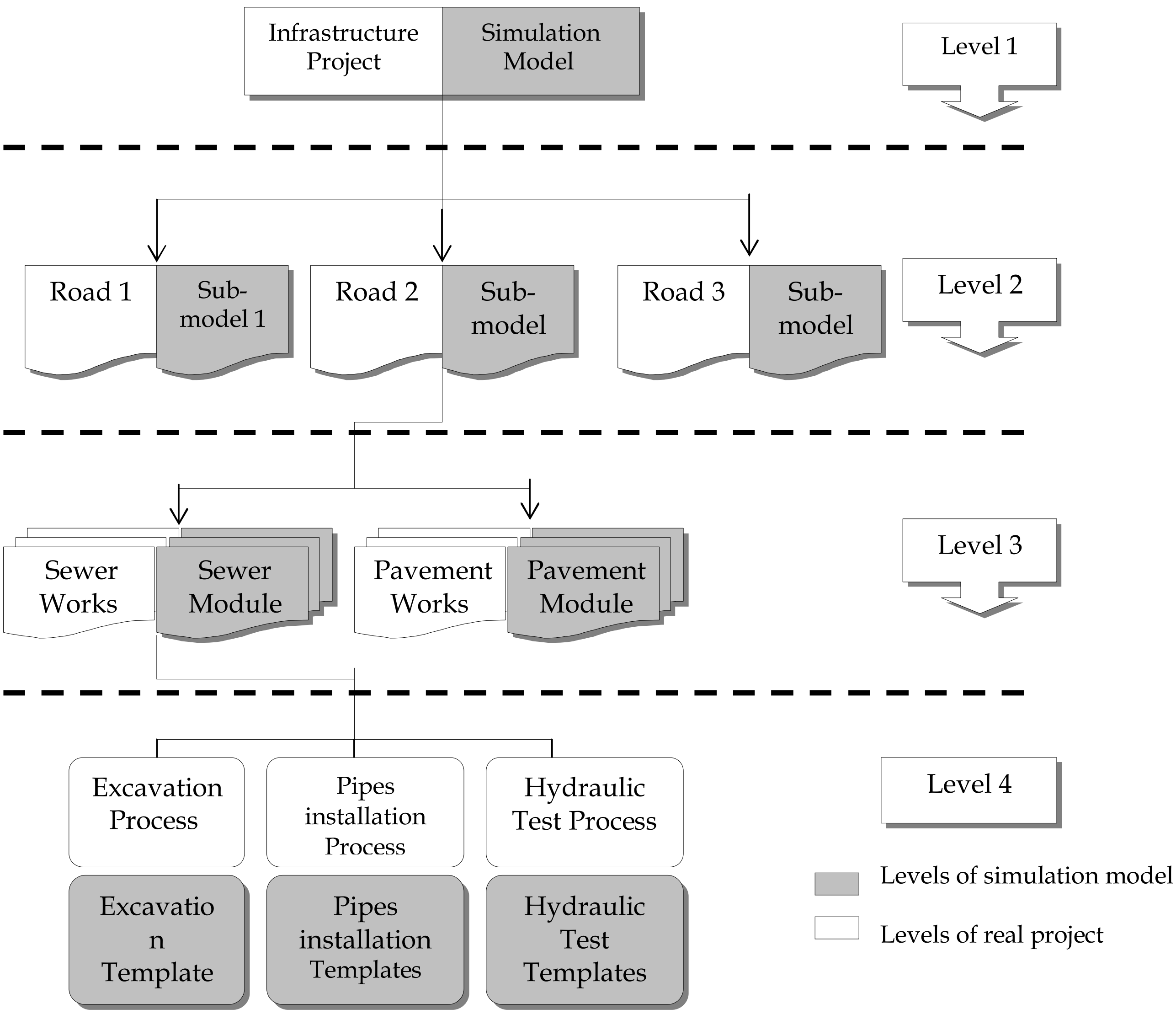


Figure 7.1 Representation of real project levels and simulation model levels

After dividing the project into these levels, it is required to prepare the project scenarios (work plans). The project scenarios identify the overall and integrated relationships between the project components. Infrastructure project scenarios can be prepared using bar chart technique. The scenario is required to identify where the activities of the road construction start and where they finish, and it identifies the relations between different activities inside these roads. Figure 7.2 represents a general example of using the bar-chart to prepare a project scenario.

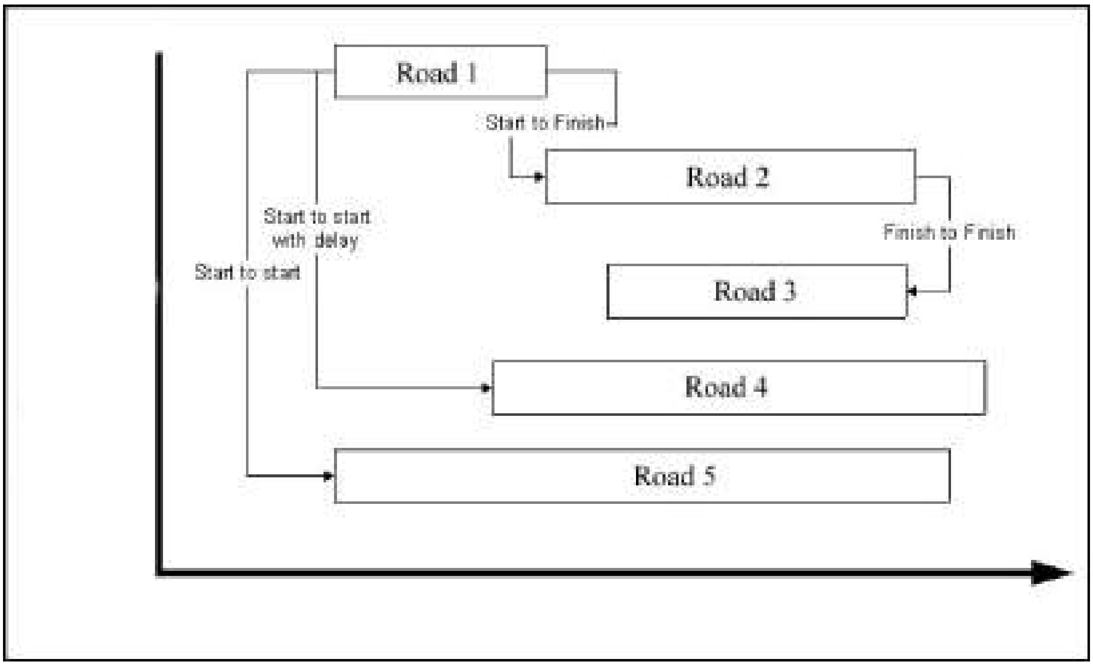


Figure 8.2 Using bar-chart in preparing a general scenario for an infrastructure project.

After preparing the project scenarios, the approach develpoed in chapter 4 can be used to create the overall model.

7.3 Infrastructure Simulation Model Building

This step will be done using Arena software. The building of the overall model starts from level 3 (modules level), as shown in Figure 7.1. The Sewer and Pavement modules (previously designed in Chapters 5 and 6) will be stored in Arena as built-in simulation elements. These two elements will be used in building a sub-model (sub-project), which is a road in infrastructure projects. The user may add many sewer and pavement modules to simulate all roads activities in a project. Also, the user can connect these modules in any manner according to his scenarios to create start to start relationships or start to finish relationships or any desired relationships. Figure 7.3 demonstrates the concept of using these module elements to create the model.

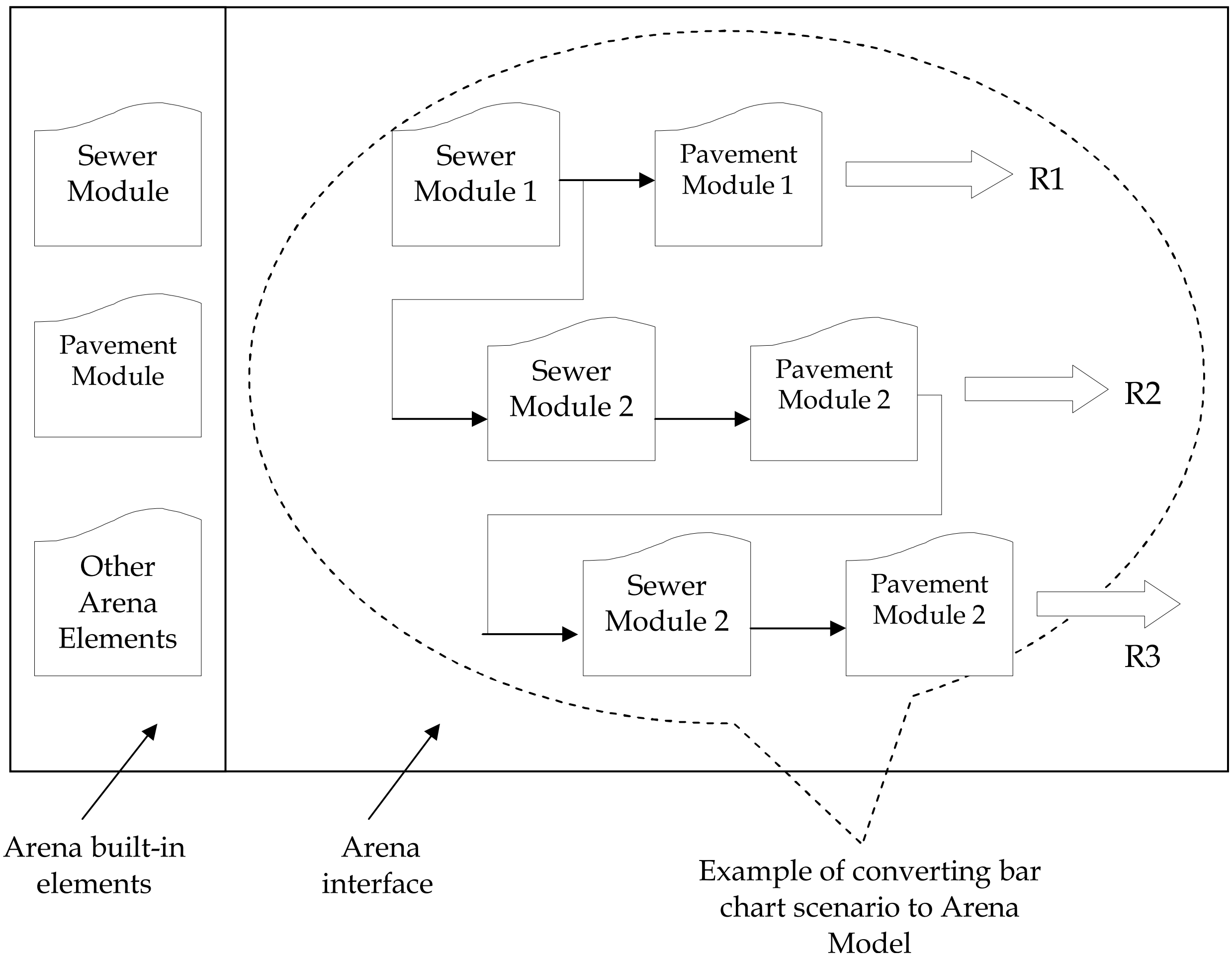


Figure 7.3 Using Arena built-in Module elements to create Arena Infrastructure model

The previous procedure of building the Arena model could not be applied fully in this research because of the deficiency of the available version of Arena software.
The available version of Arena is the academic version which differs from the professional version. The function of converting customized modules to built-in elements is available only in the professional version of Arena and not in the available academic version. This limitation may not be considered a major problem, because in case that the professional version is made available, it will be easy to follow the procedure outlined in this thesis and create the model.

7.4 Unanticipated Events

Most construction projects encounter some unanticipated events during the construction phase. Examples of thee events are sever weather conditions, strikes, subsurface conditions, change orders, etc. Here in Gaza, closure of crossing points is the most essential reason because the delay of delivering raw materials required for executing the projects and thus affecting the project durations.

To allow for these unanticipated events in building the model, an element created by Arena can be used to simulate these events. This element can be placed in the built in elements window with other modules elements as shown in Figure 7.4. A delay element, as an example, will allow for additional project duration as well as allowing changes in resources and cost.

This element will be flexible in both value and position. The value of this delay element depends on the planner (a value inserted by the user), the value of delay depends on similar events occurred to similar projects. Also, the user will have the capability to insert this element at any place in the model as shown in Figure 7.4. The model may contain more than one delay element.

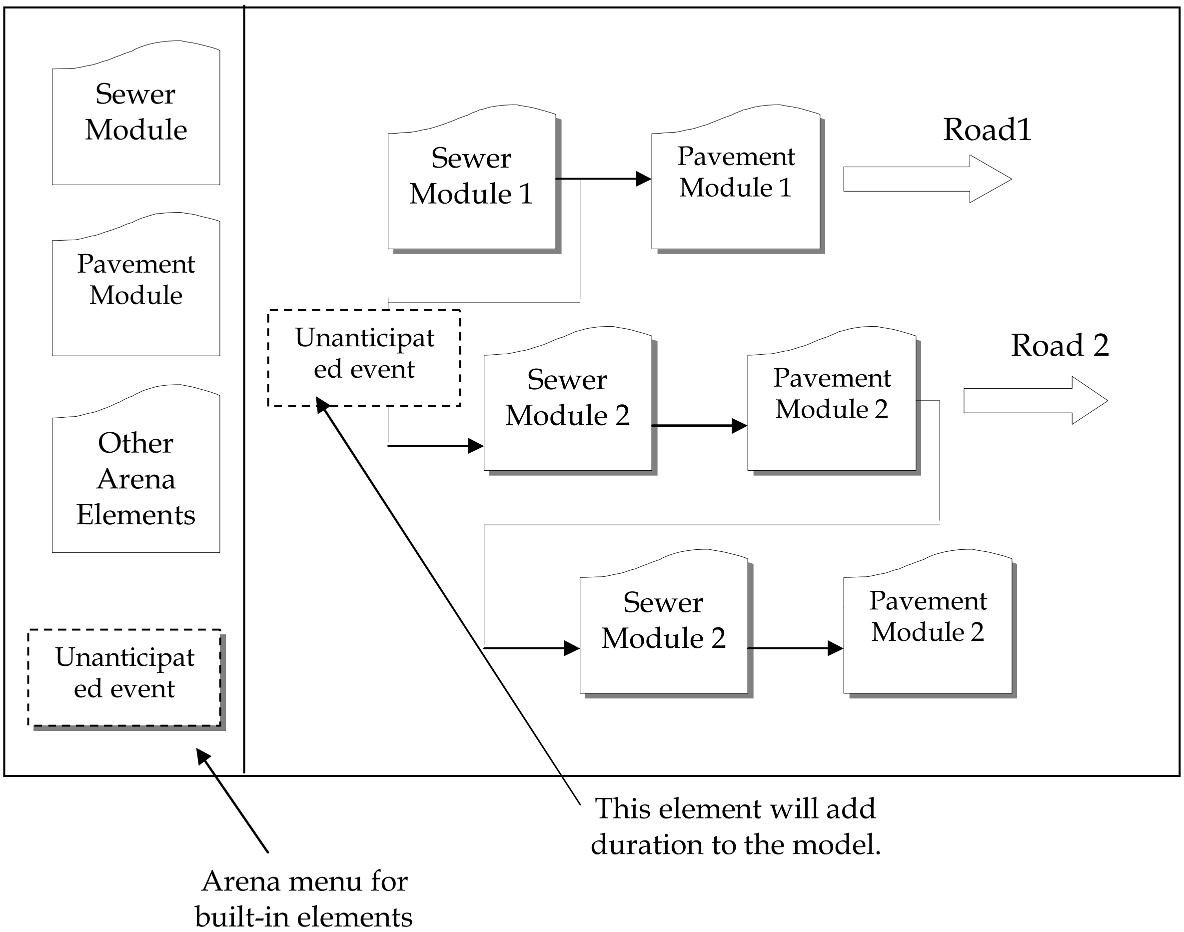


Figure 7.4 Unanticipated events in Arena model.

7.5 Benefits of the Modules

Although the available version of Arena (academic) prevents us from creating the overall model, these modules are still helpful. These modules were designed in a flexible manner to work either separately without integrating with each other or in an integrated manner.

For example, the user may separate the works of the project into two parts; sewer and pavement. Each part can be considered as a separated project. So, these modules can be activated individually, and the user is required to prepare the input data for each module. The output results (simulated durations) will then be obtained from each module individually.

8 VERIFICATION AND VALIDATION OF THE MODULES

8.1 Introduction

After developing the simulation models, verification and validation processes needed to be done before the simulation output results can be used (Valentin and Verbraeck 2002).

This chapter demonstrates the verification and validation processes applied to the simulation modules. Each segment of the modules was checked solely and the integrated modules were checked jointly.

8.2 Verification Process

Verification is to check whether the model is programmed right. It is very easy to make a mistake either in the logic or in the syntax. While the compiler typically detects syntax errors, it is the model developer's responsibility to ensure that the logic is correct.

The verification process was executed by applying specific known data (this data will give known output results) for a specific segment of the module, then comparing the results. If these results are close, then the templates, logical relationships and probability distribution functions are correctly designed for that segment and the process then continue with all other segments.

8.2.1 Verification of the Sewer Module

Each part of the sewer module was separately verified (during designing of the module). This verification process was performed by making a comparison between two different values, actual duration (from past project) required to execute 60 meter of pipes in certain site conditions and the simulated duration estimated by the module using same site conditions.

Verification Example:

The duration required to execute 60 meter of 10" diameter pipes in sandy soil at depth of 2.5 m is:

- The actual duration estimated from past executed project = 7.0 hours.
- The simulated duration using a segment of the sewer module = 7.84 hours.

Comparing between the two results, it is clear that this segment gives sound results and the difference appeared between the two values occurred due to the probability distribution functions.

All other variables (work conditions) were checked by the same procedure to ensure that each part of module logic is designed correctly.

8.2.2 Verification of the Pavement Module

Also here, each part of pavement module was separately verified. This verification process was done by comparing the duration required to execute different areas of road works (activities) in different conditions.

Verification Example:

Duration required to excavate 2000 m^2 of a road segment with average depth of 20 cm (work includes; excavation process, removal of surplus material, leveling, watering, compaction and field density test):

- The actual duration estimated from past executed project = 4.5 hours.
- The simulated duration using a segment of the sewer module = 4.12 hours.

Comparing between the two results, it is clear that this segment gives sound results. All other conditions were tested by the same manner to ensure that the module logic is designed correctly.

8.3 Validation Process

Validation is to check whether the operation is modeled accurately. In a simulation model, validation is related to both the input data and the model network (Banks 1998). So, validation should be done for the entire model. This process can be performed by selecting an integrated infrastructure project (previously executed) and prepare all input data required for this project. By running the model, it will give simulation results (durations for each activity and duration for the entire project) and these results are to be compared with what actual project durations.

In this thesis, the validation for an integrated model could not be achieved, because building an integrated model required the professional version of Arena which is not available. To overcome this obstacle, the validation process was made for the modules which later form the integrated model as shown in the sections below.

8.3.1 Modules Validation Using One Segment of the Project (Sewer Modules)

The validation process for the sewer module was executed using actual data of a past performed project. This project is located in the northern part of Gaza (Jabalia region). One part of the project (road) was selected for the validation process as follows:

- A road with total length of 3600 meter was selected.
- Sewer pipelines with different three diameters 8", 10" and 12" were used.
- Type of soil was sand.

Table 8.1 summarizes the input data for this segment.

Table 8.1 Summary information about the executed pipeline

No	Depth Category (meter)	Length (m)	Diameter (in.)	Actual Durations (days)
1	1.5<d<2.0	1000.0	Less than 16"	13.5
2	2.0<d<3.0	1500.0	Less than 16"	25.5
3	3.0<d<4.0	1100.0	Less than 16"	31.0
Total length		*3600.0*	*Total Duration*	*70 .0*

Using the previous data as an input data for the sewer module, the following results were obtained as shown in Table 8.2. It is worth mentioning that the activities durations used were the beta distribution functions fitted durations.

Table 8.2 Summary module outputs (simulated durations)

No.	Depth Category (meter)	Length (m)	Diameter (in.)	Simulated Durations (days)
1	1.5<d<2.0	1000.0	Less than 16"	12.6
2	2.0<d<3.0	1500.0	Less than 16"	27.7
3	3.0<d<4.0	1100.0	Less than 16"	29.1
Total length		*3600.0*	*Total Duration*	*69.4*

Figure 8.1 shows the difference between the two results.

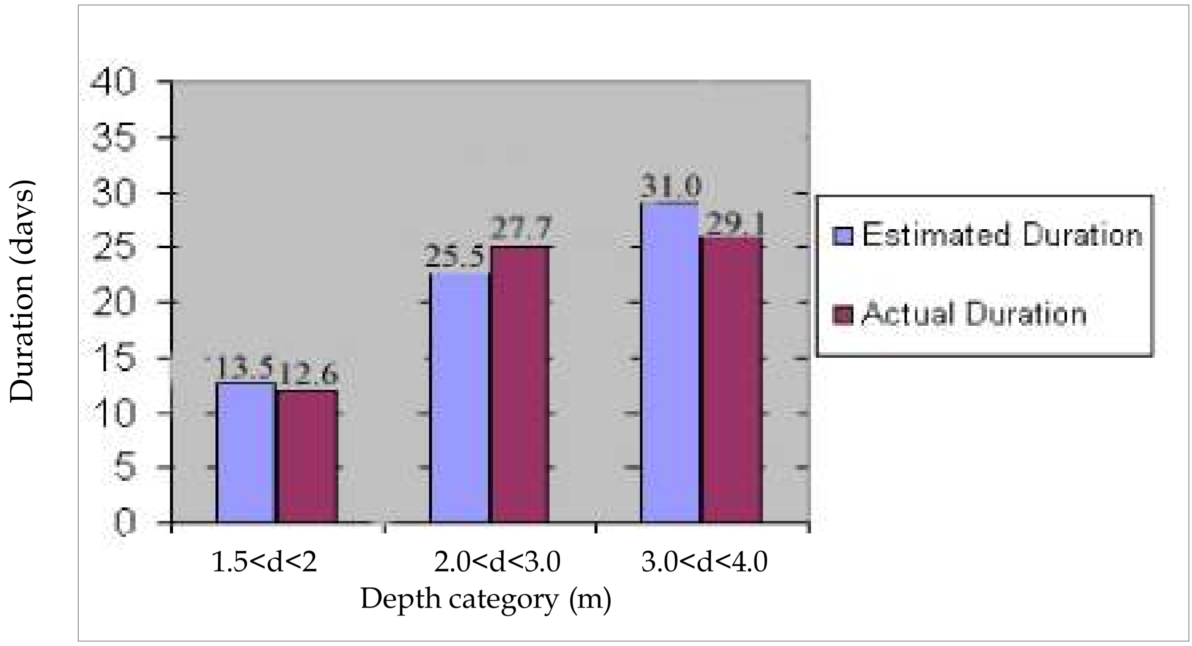


Figure 8.1 Actual durations vs. simulated durations of the sewer segment

From the chart it is clear that the differences between the module results and the actual durations are relatively small (3-5%). This indicates that the module networks and templates were designed properly.

8.3.2 Validation Using One Segment of a Project (Pavement Module)

The validation process for the pavement module was performed using actual data of a past executed project. The project is located also in the northern part of Gaza (Beit Lahia town). This project included the construction of a number of roads. Part of that project (road) was selected for the validation process. A road with total area of 20,000 m^2 was selected; it was required to pave the main street with asphalt and the sidewalks with interlocks tiles.

The work included many activities; excavation, base course, and paving work including many processes like compaction, leveling, field density tests, etc.

Table 8.3 represents the specifications, quantities of executed works and the actual durations of the project activities.

Table 8.3 Summery information about the executed road activity

No	Type of Activity	Area (m^2)	Actual Durations (days)
1	Excavation for average depth of 25cm.Works includes all required processes (leveling, watering, compaction, etc).	20,000.0	32.0
2	Base course works for two layer of 30 cm. Works include all required processes (leveling, watering compaction, etc).	12500.0	24.0
3	Asphalt works for two layer of 8cm. Works include all required processes (compaction, testing, etc).	12500.0	23.0
4	Tiling Works for sidewalks. Works include all required processes (Base course layer, spreading of sand, compaction, etc).	7500.0	15.0

By using the previous information as input data for the pavement module, and running the module. The following results were obtained, see Table 8.4.

Table 8.4 Summery information about module outputs (simulated durations)

No.	Type of Activity	Area (m^2)	Simulated Durations (days)
1	Excavation for average depth of 25cm.Works includes all required processes (leveling, watering, compaction, etc).	20,000.0	30.9
2	Base course works for two layer of 30 cm. Works include all required processes (leveling, watering compaction, etc).	12,500.0	26.2
3	Asphalt works for two layer of 8cm. Works include all required processes (compaction, testing, etc).	12,500.0	20.0
4	Tiling Works for sidewalks. Works include all required processes (Base course layer, spreading of sand, compaction, etc).	7,500.0	18.7

These two different data can be used in the comparison between; actual durations consumed by every activity of the road construction project and simulated durations got by the pavement module. The durations for different activities in both cases were converted to a chart, this chart represent how the results of the module outputs were close to the actual one. See Figure 8.2.

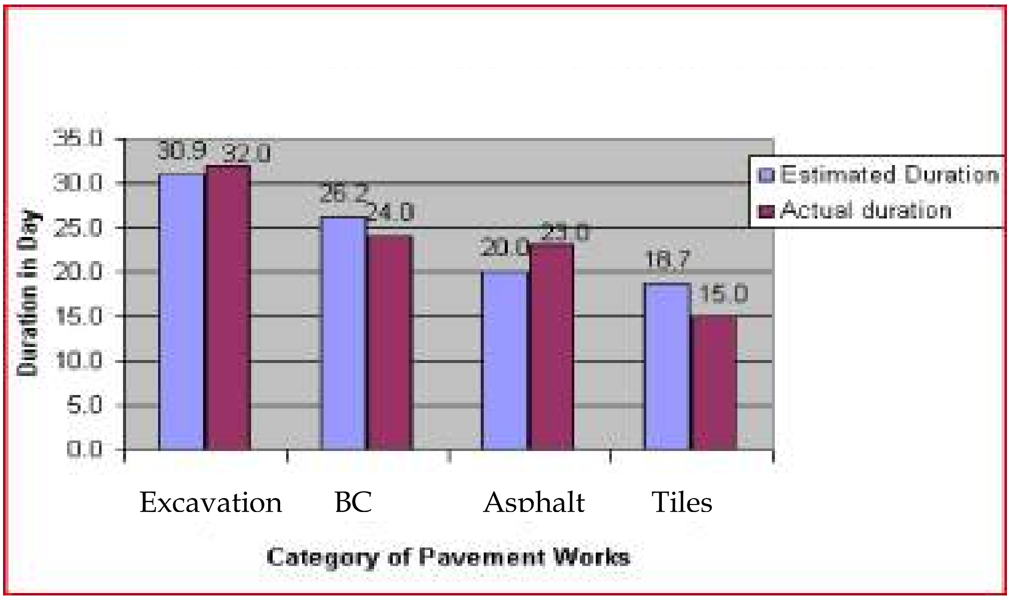


Figure 8.2 Comparison between actual durations and simulated durations of the road construction project.

9 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

9.1.1 Literature Review

Simulation is considered as a good tool in the field of construction management. Most benefits of simulation appear in projects with repetitive processes. Two types of simulation approaches are available, physical and mathematical. Construction projects models require the mathematical approach.

Simulation strategy is the conceptual framework that guides model development; it determines how the modeler will represent the system being modeled. The two main simulation strategies are; process interaction (PI) and activity scanning (AS). PI strategy is used for construction project modeling.

Simulation specialist's efforts can be reduced by applying the concept of re-usable models. This concept intends to design models which can be used for several projects. Interactive simulation system was suggested to provide easy access and easy manipulating environment for studying and analyzing real systems. This system uses an attractive graphical user interface to overcome potential resistance by the user to simulation as an analytical tool. Arena software is considered one of the most advanced tools used in simulation. It combines the ease of use found in high level simulators with the flexibility of simulation languages. Therefore, it is used in building the model in this thesis.

9.1.2 Infrastructure Simulation Model

The purpose of the infrastructure simulation model is to estimate the durations required to execute an infrastructure project during the planning phase. A general approach was developed to be applied in creating the infrastructure simulation model. The concept of the approach depends on dividing the construction project into four sequential levels.

These levels were proposed to facilitate the modeling of project activities. This approach was examined by applying it to both infrastructure and building projects. It was proven that this approach is applicable for such type of projects.

Two separated modules were deigned, sewer and pavement. The sewer module was designed to simulate installation of the activities of sewer pipes. Visual Basic interface was designed to facilitate the data entry of the sewer module. This interface is used to input many variables related to site conditions and type of work. The pavement module was designed to simulate the activities of roads construction. It involves earth activity (excavation, filling, and soil improvement processes), the base course activity and the paving activity (asphalt and tiles). Visual Basic interface was designed to insert variables related to these activities in an easy manner.

All processes required to execute these activities were represented and simulated using Arena software. For all of the assigned processes, site observations were made to get records regarding different construction processes durations. These records were used to create probability distribution functions for each process. Beta distribution function was found as the most suitable function for these construction processes.

The final shape of the model could not be achieved, because converting the designed modules into built-in elements in Arena required a professional version which is not currently available. The designed models were verified and validated. The verification process was executed to ensure that no syntax or logical errors exist in the templates. The validation process was executed to check whether the whole module work well or not. The results of the verification and validation processes demonstrated that these modules work properly and they gave sound output results.

9.2 Recommendations

- The simulation technique should be considered by the Palestinian planners and decision makers, as it was proven that simulation is a powerful tool in forecasting the behavior of projects.
- An effort should be paid in introducing the engineers with the value of simulation technique. User's interface is an idea that it could facilitate the use of simulation software.
- More research should be conducted to create multi-use simulation models for different kinds of construction projects.
- This research focused on developing multi-use models to be used during the planning phase, other research should proceed in this area to produce multi-use models which are suitable for contracting companies (i.e. multi-use models that consider higher number of variables during the construction phase).
- Professional version of Arena must be furnished for universities or municipalities to be used in developing different types of simulation models.

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11 APPENDICES

Appendix A:

1.Production rates for different depths of excavation, type of soil and diameter group of pipes (sewer works).

2.Production rates for sub-grade works.

3.Production rates for base course activities (pavement works).

4.Production rates for paving activities (pavement works).

Appendix B:

1. Visual Basic Source Code for user interface (Sewer module).
2. Visual Basic Source Code for user interface (Pavement).

APPENDIX A

1. Production Rates for different depths of excavation, type of soil and diameter of pipes (sewer works)

Production rates for pipe excavation, bidding ,pipe installation and backfilling		
Depth of excavation(1.5-2.0m)		
Diameter of pipe less than 16" Type of soil: Clay		
Se. No.	Production Rate (Lm/8 hr)	Time req. for each 30 m (unit is hr)
1	88.00	2.73
2	84.00	2.86
3	96.00	2.50
4	66.00	3.64
5	81.00	2.96
6	75.00	3.20
7	86.50	2.77
8	77.00	3.12
9	78.00	3.08
10	85.00	2.82
11	92.00	2.61
12	64.00	3.75
13	82.00	2.93
14	89.00	2.70
15	95.00	2.53
16	96.00	2.50
17	91.00	2.64
18	86.00	2.79
19	85.00	2.82
20	78.00	3.08
21	84.00	2.86
22	76.00	3.16
23	75.00	3.20
24	99.00	2.42
25	96.00	2.50
26	86.00	2.79
27	85.00	2.82
28	78.00	3.08
29	84.00	2.86
30	76.00	3.16
31	75.00	3.20
32	99.00	2.42
33	96.00	2.50
34	78.00	3.08
35	85.00	2.82

Production rates for pipe excavation, bidding ,pipe installation and backfilling		
Depth of excavation(1.5-2.0m)		
Diameter of pipe more than or equal 16" Type of soil: Clay		
Se. No.	Production Rate (Lm/8 hr)	Time req. for each 30 m (unit is hr)
1	87.00	2.76
2	80.00	3.00
3	98.00	2.45
4	64.00	3.75
5	79.00	3.04
6	76.00	3.16
7	85.00	2.82
8	75.00	3.20
9	75.00	3.20
10	80.00	3.00
11	93.00	2.58
12	60.00	4.00
13	81.00	2.96
14	89.00	2.70
15	94.00	2.55
16	94.00	2.55
17	90.00	2.67
18	84.00	2.86
19	85.00	2.82
20	75.00	3.20
21	80.00	3.00
22	75.00	3.20
23	74.00	3.24
24	100.00	2.40
25	94.00	2.55
26	94.00	2.55
27	90.00	2.67
28	84.00	2.86
29	85.00	2.82
30	75.00	3.20
31	80.00	3.00
32	75.00	3.20
33	74.00	3.24
34	100.00	2.40
35	94.00	2.55

Production rates for pipe excavation, bidding ,pipe installation and backfilling		
Depth of excavation(1.5-2.0m)		
Diameter of pipe less than 16" Type of soil: Sand		
Se. No.	Pro. Rate (Lm/8 hr)	Time req. for each 30 m (unit is hr)
1	90.00	2.67
2	87.00	2.76
3	84.00	2.86
4	75.00	3.20
5	95.00	2.53
6	87.00	2.76
7	84.00	2.86
8	65.00	3.69
9	80.00	3.00
10	95.00	2.53
11	84.00	2.86
12	75.00	3.20
13	72.00	3.33
14	99.00	2.42
15	95.00	2.53
16	87.00	2.76
17	66.00	3.64
18	80.00	3.00
19	68.00	3.53
20	45.00	5.33
21	90.00	2.67
22	83.00	2.89
23	78.00	3.08
24	79.00	3.04
25	85.00	2.82
26	99.00	2.42
27	95.00	2.53
28	87.00	2.76
29	66.00	3.64
30	80.00	3.00
31	68.00	3.53
32	45.00	5.33
33	90.00	2.67
34	83.00	2.89
35	78.00	3.08

Production rates for pipe excavation, bidding ,pipe installation and backfilling		
Depth of excavation(1.5-2.0m)		
Diameter of pipe more than or equal 16" Type of soil: Sand		
Se. No.	Pro. Rate (Lm/8 hr)	Time req. for each 30 m (unit is hr)
1	85.00	2.82
2	88.00	2.73
3	79.00	3.04
4	71.00	3.38
5	91.00	2.64
6	85.00	2.82
7	81.00	2.96
8	62.00	3.87
9	79.00	3.04
10	92.00	2.61
11	81.00	2.96
12	74.00	3.24
13	70.00	3.43
14	95.00	2.53
15	92.00	2.61
16	85.00	2.82
17	62.00	3.87
18	79.00	3.04
19	66.00	3.64
20	55.00	4.36
21	86.00	2.79
22	79.00	3.04
23	75.00	3.20
24	74.00	3.24
25	86.00	2.79
26	92.00	2.61
27	85.00	2.82
28	62.00	3.87
29	79.00	3.04
30	66.00	3.64
31	55.00	4.36
32	86.00	2.79
33	79.00	3.04
34	75.00	3.20
35	74.00	3.24

Production rates for pipe excavation, bidding ,pipe installation and backfilling		
Depth of excavation(2.0-3.0m)		
Diameter of pipe less than 16" Type of soil: Clay		
Se. No.	Pro. Rate (Lm/8 hr)	Time req. for each 30 m (unit is hr)
1	65.00	3.69
2	66.00	3.64
3	50.00	4.80
4	53.00	4.53
5	54.00	4.44
6	45.00	5.33
7	68.00	3.53
8	70.00	3.43
9	52.00	4.62
10	55.00	4.36
11	55.00	4.36
12	60.00	4.00
13	63.00	3.81
14	65.00	3.69
15	49.00	4.90
16	55.00	4.36
17	66.00	3.64
18	60.00	4.00
19	63.00	3.81
20	52.00	4.62
21	55.00	4.36
22	64.00	3.75
23	61.00	3.93
24	59.00	4.07
25	66.00	3.64
26	49.00	4.90
27	55.00	4.36
28	66.00	3.64
29	60.00	4.00
30	63.00	3.81
31	52.00	4.62
32	55.00	4.36
33	64.00	3.75
34	61.00	3.93
35	59.00	4.07

Production rates for pipe excavation, bidding ,pipe installation and backfilling		
Depth of excavation(2.0-3.0m)		
Diameter of pipe more than or equal 16" Type of soil: Clay		
Se. No.	Pro. Rate (Lm/8 hr)	Time req. for each 30 m (unit is hr)
1	60.00	4.00
2	52.00	4.62
3	51.00	4.71
4	50.00	4.80
5	51.00	4.71
6	44.00	5.45
7	65.00	3.69
8	65.00	3.69
9	50.00	4.80
10	52.00	4.62
11	53.00	4.53
12	62.00	3.87
13	60.00	4.00
14	60.00	4.00
15	45.00	5.33
16	53.00	4.53
17	65.00	3.69
18	59.00	4.07
19	52.00	4.62
20	60.00	4.00
21	60.00	4.00
22	62.00	3.87
23	59.00	4.07
24	53.00	4.53
25	55.00	4.36
26	44.00	5.45
27	65.00	3.69
28	65.00	3.69
29	50.00	4.80
30	52.00	4.62
31	53.00	4.53
32	62.00	3.87
33	60.00	4.00
34	60.00	4.00
35	45.00	5.33

Production rates for pipe excavation, bidding ,pipe installation and backfilling		
Depth of excavation(2.0-3.0m)		
Diameter of pipe less than 16" Type of soil: Sand		
Se. No.	Pro. Rate (Lm/8 hr)	Time req. for each 30 m (unit is hr)
1	63.00	3.81
2	55.00	4.36
3	69.00	3.48
4	72.00	3.33
5	52.00	4.62
6	55.00	4.36
7	62.00	3.87
8	65.00	3.69
9	56.00	4.29
10	63.00	3.81
11	68.00	3.53
12	59.00	4.07
13	52.00	4.62
14	65.00	3.69
15	62.00	3.87
16	59.00	4.07
17	52.00	4.62
18	62.00	3.87
19	67.00	3.58
20	59.00	4.07
21	63.00	3.81
22	64.00	3.75
23	49.00	4.90
24	43.00	5.58
25	62.00	3.87
26	69.00	3.48
27	72.00	3.33
28	52.00	4.62
29	55.00	4.36
30	62.00	3.87
31	65.00	3.69
32	56.00	4.29
33	63.00	3.81
34	68.00	3.53
35	59.00	4.07

Production rates for pipe excavation, bidding ,pipe installation and backfilling		
Depth of excavation(2.0-3.0m)		
Diameter of pipe more than or equal 16" Type of soil: Sand		
Se. No.	Pro. Rate (Lm/8 hr)	Time req. for each 30 m (unit is hr)
1	58.00	4.14
2	56.00	4.29
3	60.00	4.00
4	55.00	4.36
5	65.00	3.69
6	35.00	6.86
7	66.00	3.64
8	69.00	3.48
9	54.00	4.44
10	45.00	5.33
11	45.00	5.33
12	35.00	6.86
13	50.00	4.80
14	60.00	4.00
15	61.00	3.93
16	55.00	4.36
17	59.00	4.07
18	58.00	4.14
19	52.00	4.62
20	56.00	4.29
21	58.00	4.14
22	55.00	4.36
23	33.00	7.27
24	56.00	4.29
25	45.00	5.33
26	55.00	4.36
27	65.00	3.69
28	35.00	6.86
29	66.00	3.64
30	69.00	3.48
31	54.00	4.44
32	45.00	5.33
33	45.00	5.33
34	35.00	6.86
35	50.00	4.80

Production rates for pipe excavation, bidding ,pipe installation and backfilling		
Depth of excavation(3.0-4.0m)		
Diameter of pipe less than 16" Type of soil: Clay		
Se. No.	Pro. Rate (Lm/8 hr)	Time req. for each 30 m (unit is hr)
1	40.00	6.00
2	42.00	5.71
3	52.00	4.62
4	39.00	6.15
5	30.00	8.00
6	19.00	12.63
7	26.00	9.23
8	45.00	5.33
9	49.00	4.90
10	48.00	5.00
11	51.00	4.71
12	52.00	4.62
13	28.00	8.57
14	34.00	7.06
15	41.00	5.85
16	40.00	6.00
17	48.00	5.00
18	51.00	4.71
19	34.00	7.06
20	29.00	8.28
21	42.00	5.71
22	50.00	4.80
23	43.00	5.58
24	41.00	5.85
25	39.00	6.15
26	52.00	4.62
27	39.00	6.15
28	30.00	8.00
29	19.00	12.63
30	26.00	9.23
31	45.00	5.33
32	49.00	4.90
33	48.00	5.00
34	51.00	4.71
35	52.00	4.62

Production rates for pipe excavation, bidding ,pipe installation and backfilling		
Depth of excavation(3.0-4.0m)		
Diameter of pipe more than or equal 16" Type of soil: Clay		
Se. No.	Pro. Rate (Lm/8 hr)	Time req. for each 30 m (unit is hr)
1	38.00	6.32
2	39.00	6.15
3	50.00	4.80
4	42.00	5.71
5	42.00	5.71
6	29.00	8.28
7	32.00	7.50
8	41.00	5.85
9	42.00	5.71
10	43.00	5.58
11	49.00	4.90
12	49.00	4.90
13	26.00	9.23
14	29.00	8.28
15	38.00	6.32
16	38.00	6.32
17	45.00	5.33
18	48.00	5.00
19	42.00	5.71
20	32.00	7.50
21	39.00	6.15
22	36.00	6.67
23	41.00	5.85
24	39.00	6.15
25	35.00	6.86
26	41.00	5.85
27	42.00	5.71
28	43.00	5.58
29	49.00	4.90
30	49.00	4.90
31	26.00	9.23
32	29.00	8.28
33	38.00	6.32
34	38.00	6.32
35	45.00	5.33

Production rates for pipe excavation, bidding ,pipe installation and backfilling		
Depth of excavation(3.0-4.0m)		
Diameter of pipe less than 16" Type of soil: Sand		
Se. No.	Pro. Rate (Lm/8 hr)	Time req. for each 30 m (unit is hr)
1	25.00	9.60
2	36.00	6.67
3	42.00	5.71
4	41.00	5.85
5	30.00	8.00
6	30.00	8.00
7	35.00	6.86
8	32.00	7.50
9	31.00	7.74
10	32.00	7.50
11	35.00	6.86
12	36.00	6.67
13	39.00	6.15
14	36.00	6.67
15	36.00	6.67
16	45.00	5.33
17	40.00	6.00
18	25.00	9.60
19	50.00	4.80
20	34.00	7.06
21	39.00	6.15
22	32.00	7.50
23	37.00	6.49
24	35.00	6.86
25	42.00	5.71
26	31.00	7.74
27	32.00	7.50
28	35.00	6.86
29	36.00	6.67
30	39.00	6.15
31	36.00	6.67
32	36.00	6.67
33	45.00	5.33
34	40.00	6.00
35	25.00	9.60

Production rates for pipe excavation, bidding ,pipe installation and backfilling		
Depth of excavation(3.0-4.0m)		
Diameter of pipe more than or equal 16" Type of soil: Sand		
Se. No.	Pro. Rate (Lm/8 hr)	Time req. for each 30 m (unit is hr)
1	30.00	8.00
2	32.00	7.50
3	41.00	5.85
4	40.00	6.00
5	40.00	6.00
6	29.00	8.28
7	31.00	7.74
8	30.00	8.00
9	29.00	8.28
10	29.00	8.28
11	34.00	7.06
12	35.00	6.86
13	36.00	6.67
14	32.00	7.50
15	35.00	6.86
16	42.00	5.71
17	42.00	5.71
18	30.00	8.00
19	45.00	5.33
20	32.00	7.50
21	35.00	6.86
22	30.00	8.00
23	35.00	6.86
24	32.00	7.50
25	35.00	6.86
26	35.00	6.86
27	36.00	6.67
28	32.00	7.50
29	35.00	6.86
30	42.00	5.71
31	42.00	5.71
32	30.00	8.00
33	45.00	5.33
34	32.00	7.50
35	35.00	6.86

2. Production Rates for Sub grade activities (Pavement works)

Production rates for cutting in Sub grade works(sand or clay)		
Depth of cutting 20cm (layer of thickness 20 cm)		
S/N	Pro. Rate (m^2 per8 working hr)	Time required for each 500 m^2(in hour)
1	2,500.00	1.60
2	2,450.00	1.63
3	2,600.00	1.54
4	2,122.00	1.89
5	2,300.00	1.74
6	2,900.00	1.38
7	2,100.00	1.90
8	2,000.00	2.00
9	2,250.00	1.78
10	3,100.00	1.29
11	2,050.00	1.95
12	2,500.00	1.60
13	2,600.00	1.54
14	2,800.00	1.43
15	2,400.00	1.67
16	2,300.00	1.74
17	2,540.00	1.57
18	2,635.00	1.52
19	2,555.00	1.57
20	2,350.00	1.70
21	2,150.00	1.86
22	2,650.00	1.51
23	2,500.00	1.60
24	2,500.00	1.60
25	2,900.00	1.38
26	2,500.00	1.60
27	2,635.00	1.52
28	2,330.00	1.72
29	2,400.00	1.67
30	2,200.00	1.82
31	2,100.00	1.90

Production rates for Filling Sub grade works(sand or clay)		
Depth of cutting 20cm (layer of thickness 20 cm)		
S/N	Pro. Rate (m^2 per8 working hr)	Time required for each 500 m^2(in hour)
1	3,000.00	1.33
2	2,900.00	1.38
3	2,800.00	1.43
4	3,200.00	1.25
5	3,600.00	1.11
6	3,250.00	1.23
7	2,500.00	1.60
8	2,600.00	1.54
9	2,400.00	1.67
10	3,100.00	1.29
11	3,200.00	1.25
12	3,000.00	1.33
13	2,900.00	1.38
14	2,950.00	1.36
15	2,800.00	1.43
16	3,400.00	1.18
17	3,100.00	1.29
18	3,200.00	1.25
19	3,600.00	1.11
20	2,590.00	1.54
21	2,547.00	1.57
22	2,450.00	1.63
23	2,800.00	1.43
24	3,200.00	1.25
25	3,140.00	1.27
26	3,250.00	1.23
27	2,900.00	1.38
28	2,800.00	1.43
29	2,850.00	1.40
30	2,950.00	1.36
31	2,100.00	1.27

Production rates for Production rates for leveling of subgrade		
(layer of thickness 20 cm)		
S/N	Pro. Rate (m^2 per8 working hr)	Time required for each 500 m^2(in hour)
1	2,500.00	1.60
2	2,900.00	1.38
3	2,650.00	1.51
4	2,850.00	1.40
5	3,200.00	1.25
6	3,500.00	1.14
7	3,600.00	1.11
8	3,920.00	1.02
9	3,450.00	1.16
10	3,100.00	1.29
11	2,950.00	1.36
12	3,600.00	1.11
13	2,900.00	1.38
14	3,200.00	1.25
15	2,400.00	1.67
16	3,450.00	1.16
17	2,650.00	1.51
18	2,950.00	1.36
19	3,600.00	1.11
20	2,590.00	1.54
21	2,900.00	1.38
22	2,400.00	1.67
23	2,900.00	1.38
24	3,500.00	1.14
25	3,260.00	1.23
26	4,000.00	1.00
27	3,500.00	1.14
28	2,950.00	1.36
29	2,550.00	1.57
30	2,400.00	1.67
31	3,100.00	1.29

Production rates for Production rates for Watering ,compaction and Field density test		
(layer of thickness 20 cm)		
S/N	Pro. Rate (m^2 per8 working hr)	Time required for each 500 m^2(in hour)
1	3,250.00	1.23
2	2,600.00	1.54
3	2,500.00	1.60
4	3,250.00	1.23
5	2,800.00	1.43
6	2,900.00	1.38
7	2,950.00	1.36
8	2,750.00	1.45
9	2,600.00	1.54
10	3,250.00	1.23
11	3,150.00	1.27
12	3,000.00	1.33
13	2,900.00	1.38
14	3,200.00	1.25
15	2,400.00	1.67
16	3,450.00	1.16
17	2,650.00	1.51
18	2,950.00	1.36
19	3,600.00	1.11
20	2,590.00	1.54
21	2,950.00	1.36
22	3,000.00	1.33
23	2,850.00	1.40
24	2,450.00	1.63
25	2,750.00	1.45
26	4,000.00	1.00
27	3,500.00	1.14
28	2,950.00	1.36
29	2,450.00	1.63
30	2,500.00	1.60
31	3,250.00	1.23

3. Production Rates for Base Course activities (Pavement works)

Production rates for spreading 1st layer of BC		
Spreading of 1st layer of BC		
S/N	Pro. Rate (m^2 per8 working hr)	Time required for each 500 m^2(in hour)
1	3,000.00	1.33
2	3,150.00	1.27
3	3,250.00	1.23
4	2,900.00	1.38
5	2,950.00	1.36
6	2,900.00	1.38
7	2,950.00	1.36
8	3,000.00	1.33
9	2,600.00	1.54
10	3,250.00	1.23
11	3,150.00	1.27
12	3,000.00	1.33
13	2,900.00	1.38
14	3,200.00	1.25
15	2,900.00	1.38
16	3,450.00	1.16
17	2,650.00	1.51
18	2,950.00	1.36
19	3,600.00	1.11
20	2,850.00	1.40
21	2,950.00	1.36
22	3,000.00	1.33
23	2,850.00	1.40
24	2,450.00	1.63
25	2,750.00	1.45
26	3,200.00	1.25
27	3,200.00	1.25
28	3,100.00	1.29
29	2,850.00	1.40
30	2,900.00	1.38
31	3,000.00	1.33

Production rates for spreading 2nd layer of BC		
Spreading of 2nd layer of BC		
S/N	Pro. Rate (m^2 per8 working hr)	Time required for each 500 m^2(in hour)
1	3,000.00	1.33
2	3,150.00	1.27
3	3,250.00	1.23
4	2,900.00	1.38
5	2,950.00	1.36
6	2,900.00	1.38
7	2,950.00	1.36
8	3,000.00	1.33
9	2,600.00	1.54
10	3,250.00	1.23
11	3,150.00	1.27
12	3,000.00	1.33
13	2,900.00	1.38
14	3,200.00	1.25
15	2,900.00	1.38
16	3,450.00	1.16
17	2,650.00	1.51
18	2,950.00	1.36
19	3,600.00	1.11
20	2,850.00	1.40
21	2,950.00	1.36
22	3,000.00	1.33
23	2,850.00	1.40
24	2,450.00	1.63
25	2,750.00	1.45
26	3,200.00	1.25
27	3,200.00	1.25
28	3,100.00	1.29
29	2,850.00	1.40
30	2,900.00	1.38
31	3,000.00	1.33

Production Rates for paving activities
(Pavement works)

Production rates for Spreading of MCO material		
S/N	Pro. Rate (m^2 per8 working hr)	Time required for each $1000m^2$ (in hour)
1	5,500.00	1.45
2	6,500.00	1.23
3	6,000.00	1.33
4	5,000.00	1.60
5	4,500.00	1.78
6	7,500.00	1.07
7	3,500.00	2.29
8	4,500.00	1.78
9	5,400.00	1.48
10	5,000.00	1.60
11	6,000.00	1.33
12	6,500.00	1.23
13	7,500.00	1.07
14	3,900.00	2.05
15	4,000.00	2.00
16	5,900.00	1.36
17	6,500.00	1.23
18	5,800.00	1.38
19	9,500.00	0.84
20	4,500.00	1.78
21	5,500.00	1.45
22	5,000.00	1.60
23	6,000.00	1.33
24	5,500.00	1.45
25	6,800.00	1.18
26	4,900.00	1.63
27	4,800.00	1.67
28	5,600.00	1.43
29	5,900.00	1.36
30	5,000.00	1.60
31	4,500.00	1.78

Production rates for Spreading of Asphalt layer and compaction		
S/N	Pro. Rate (m^2 per8 working hr)	Time required for each $500m^2$ (in hour)
1	2,500.00	1.60
2	2,600.00	1.54
3	2,900.00	1.38
4	3,500.00	1.14
5	3,250.00	1.23
6	3,000.00	1.33
7	2,900.00	1.38
8	2,500.00	1.60
9	2,600.00	1.54
10	2,400.00	1.67
11	2,500.00	1.60
12	3,250.00	1.23
13	3,200.00	1.25
14	3,000.00	1.33
15	3,100.00	1.29
16	3,600.00	1.11
17	3,000.00	1.33
18	2,900.00	1.38
19	2,800.00	1.43
20	2,500.00	1.60
21	2,550.00	1.57
22	3,400.00	1.18
23	3,100.00	1.29
24	2,900.00	1.38
25	2,500.00	1.60
26	2,400.00	1.67
27	2,110.00	1.90
28	3,450.00	1.16
29	2,600.00	1.54
30	2,500.00	1.60
31	3,100.00	1.29

Production rates for tiling process		
S/N	Pro. Rate(m^2 per8 working hr)	Time required for each 100 m^2 (in hour)
1	350.00	2.29
2	410.00	1.95
3	410.00	1.95
4	430.00	1.86
5	350.00	2.29
6	390.00	2.05
7	300.00	2.67
8	320.00	2.50
9	350.00	2.29
10	450.00	1.78
11	410.00	1.95
12	400.00	2.00
13	420.00	1.90
14	415.00	1.93
15	320.00	2.50
16	390.00	2.05
17	390.00	2.05
18	360.00	2.22
19	350.00	2.29
20	380.00	2.11
21	370.00	2.16
22	390.00	2.05
23	390.00	2.05
24	450.00	1.78
25	390.00	2.05
26	360.00	2.22
27	390.00	2.05
28	410.00	1.95
29	400.00	2.00
30	390.00	2.05
31	330.00	2.42

APPENDIX B
1) Visual Basic Source Code for user interface(Sewer module)

```
Private sub commandButton1_Click()
Dim m As Model
Dim theMod As Module
     Dim i As Long

         Set m = ThisDocument.Model
     i = m.Modules.Find(smFindTag, "Process)
     Set theMod = m.Modules(i(
     theMod.Data("Value") = TextBox1.value

'  for the new depth
Dim mm As Model
Dim theMod1 As Module
     Dim ii As Long

  Set mm = ThisDocument.Model
     ii = mm.Modules.Find(smFindTag, "Process1)
     Set theMod1 = mm.Modules(ii(
     theMod1.Data("Value") = TextBox2.value

'  for the new depth(3 to 4(
Dim k As Model
Dim Mod1 As Module
     Dim ll As Long

  Set k = ThisDocument.Model
     ll = k.Modules.Find(smFindTag, "Process111")
    Set Mod1 = k.Modules(ll)
     Mod1.Data("Value") = TextBox5.value

'  for the type of soil

 Dim mmm As Model
Dim theMod11 As Module
     Dim iii As Long

  Set mmm = ThisDocument.Model
     iii = mmm.Modules.Find(smFindTag, "Process)
     Set theMod11 = mmm.Modules(iii)
     theMod11.Data("Value") = TextBox3.value

'  for the distance between manholes
```

```
'  Dim mmmm As Model
'Dim theMod111 As Module
'      Dim iiii As Long

'  Set mmmm = ThisDocument.Model
'      iiii = mmmm.Modules.Find(smFindTag, "Process3)
'      Set theMod111 = mmmm.Modules(iiii)
'      theMod111.Data("Value") = TextBox4.value

=============================================================='
'  for the dim of pipes

  Dim mmmm As Model
Dim theMod111 As Module
      Dim iiii As Long

  Set mmmm = ThisDocument.Model
      iiii = mmmm.Modules.Find(smFindTag, "Process)
      Set theMod111 = mmmm.Modules(iiii)
      theMod111.Data("Value") = TextBox4.value

'  ask if you want to quit
 Dim kk As Model
Dim Mod11 As Module
      Dim lll As Long

  Set kk = ThisDocument.Model
      lll = kk.Modules.Find(smFindTag, "Process111)
      Set Mod11 = kk.Modules(lll)
      Mod11.Data("Value") = 1
Me.Hide

  End Sub

Private Sub CommandButton2_Click()
Me.Hide
exist.Show

End Sub

Private Sub OptionButton2_Click()

End Sub

Private Sub k_Click()

End Sub

Private Sub less_Click()
```

```
If less.value = -1 Then TextBox4.value = 2
End Sub

Private Sub OptionButton1_Click()

End Sub

Private Sub more_Click()
If more.value = 1 Then TextBox4.value = 1
End Sub

Private Sub sand_Click()
'for the type of soil

 If sand.value = -1 Then TextBox3.value = 2
  End Sub

Private Sub clay_Click()
If clay.value = 1 Then TextBox3.value = 1
End Sub

Private Sub TextBox1_Change()
End Sub

Private Sub TextBox2_Change()
End Sub

Private Sub TextBox3_Change()
End Sub

Private Sub TextBox4_Change()
End Sub

Private Sub TextBox5_Change()
End Sub

Private Sub TextBox6_Change()
End Sub
```

2) Visual Basic Source Code for user interface(Pavement module)

```
Private Sub CommandButton1_Click()
'ask if you want to quit
 Dim kk As Model
Dim Mod11 As Module
     Dim lll As Long

  Set kk = ThisDocument.Model
     lll = kk.Modules.Find(smFindTag, "Process1111")
     Set Mod11 = kk.Modules(lll)
     Mod11.Data("Value") = 2

'for area of cut
Dim a As Model
Dim b As Module
     Dim c As Long

         Set a = ThisDocument.Model
     c = a.Modules.Find(smFindTag, "areaofcut")
     Set b = a.Modules(c)
     b.Data("Value") = TextBox1.value

  'for depth of cut
 Dim aa As Model
Dim bb As Module
     Dim cc As Long

  Set aa = ThisDocument.Model
     cc = aa.Modules.Find(smFindTag, "depthofcut")
     Set bb = aa.Modules(cc)
     bb.Data("Value") = TextBox2.value

 'for area of fill
 Dim aaa As Model
Dim bbb As Module
     Dim ccc As Long

  Set aaa = ThisDocument.Model
     ccc = aaa.Modules.Find(smFindTag, "areaoffill")
     Set bbb = aaa.Modules(ccc)
     bbb.Data("Value") = TextBox3.value


  'for hight of fill
 Dim aaaa As Model
Dim bbbb As Module
     Dim cccc As Long
```

```
  Set aaaa = ThisDocument.Model
     cccc = aaaa.Modules.Find(smFindTag, "hightoffill")
     Set bbbb = aaaa.Modules(cccc)
     bbbb.Data("Value") = TextBox4.value

  'for area of tiles
Dim d As Model
Dim e As Module
     Dim f As Long

        Set d = ThisDocument.Model
     f = d.Modules.Find(smFindTag, "A T")
     Set e = d.Modules(f)
     e.Data("Value") = TextBox5.value

  'for area of asphalt
Dim aa1 As Model
Dim bb1 As Module
     Dim cc1 As Long

  Set aa1 = ThisDocument.Model
     cc1 = aa1.Modules.Find(smFindTag, "A A")
     Set bb1 = aa1.Modules(cc1)
     bb1.Data("Value") = TextBox6.value


'for area of basecourse
Dim aa11 As Model
Dim bb11 As Module
     Dim cc11 As Long

  Set aa11 = ThisDocument.Model
     cc11 = aa11.Modules.Find(smFindTag, "T A R")
     Set bb11 = aa11.Modules(cc11)
     bb11.Data("Value") = TextBox7.value

'for number of layer of asphalt
Dim aa111 As Model
Dim bb111 As Module
     Dim cc111 As Long

  Set aa111 = ThisDocument.Model
     cc111 = aa111.Modules.Find(smFindTag, "N L")
     Set bb111 = aa111.Modules(cc111)
     bb111.Data("Value") = TextBox10.value

'for number of area of soil improvement
Dim aaa111 As Model
Dim bbb111 As Module
```

```
    Dim ccc111 As Long

  Set aaa111 = ThisDocument.Model
    ccc111 = aaa111.Modules.Find(smFindTag, "A S I")
    Set bbb111 = aaa111.Modules(ccc111)
    bbb111.Data("Value") = TextBox11.value

'for thickness of soil improvement layer
Dim aaa1111 As Model
Dim bbb1111 As Module
    Dim ccc1111 As Long

  Set aaa1111 = ThisDocument.Model
    ccc1111 = aaa1111.Modules.Find(smFindTag, "T O I")
    Set bbb1111 = aaa1111.Modules(ccc1111)
    bbb1111.Data("Value") = TextBox12.value

Me.Hide

End Sub

Private Sub CommandButton2_Click()
Me.Hide
exist.Show

End Sub

Private Sub Frame1_Click()

End Sub

Private Sub Frame3_Click()

End Sub

Private Sub OptionButton1_Click()
'Private Sub sand_Click()
'for number of layer

 If OptionButton1.value = -1 Then TextBox10.value = 2
End Sub

Private Sub OptionButton2_Click()
'Private Sub sand_Click()
'for number of layer

 If OptionButton2.value = 1 Then TextBox10.value = 1

End Sub
```