Engineering process simulation model

Electrical Systems and Projects Engineering Process

ABB Marine & Cranes

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ABSTRACT

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ABSTRACT

The background for this thesis is formed by two documents:

- 3AFV6036386 Engineering Process Description.
- 3AFV6041649 Engineering Process Flow Chart.

The purpose of the first mentioned document is to describe the project engineering process. The document focuses on engineering actions to meet the technical requirements of the customer and the man-hour budget of a project, on using standard products and system solutions and on supporting commissioning.

The second document is a graphical representation of the engineering process steps described in the first document. It was used as a basis for the simulation model. Both documents were needed to understand the complete engineering process.

The aim of this thesis was to build up a simulation model of the proposed engineering process, and to define adjustable attributes for all the tasks. The process was modelled in appropriate detail to allow for the identification and calculation of the extra time invested by the resources.

The engineering process was modelled using commercial discrete-event simulation software. The model was created in two phases; first the complete process was modelled based on existing documents, and then it was refined based on the interviews with the person of contact in the Electrical Systems and Projects Engineering Process department. Once the simulation model is finished, resources will be sized to reduce the extra-time invested in the engineering process.

Therefore, the model itself is the main result of this thesis, because it allows for testing the complete process, and it acts as important validation for the department if any modification in the engineering process is applied in the future.

Keywords simulation, engineering, process, model, Simul8.

Pages 117 p. + appendices 0 p.

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1 INTRODUCTION

1.1 Commissioning organisation

ABB is a global leader in power and automation technologies that enable utility and industry customers to improve their performance while lowering environmental impact. With a global presence in more than a hundred countries and headquarter in Zurich, Switzerland, ABB's employees are developing new products and services with the latest technological advancements that meet the needs of their customers. (ABB Group 2013.)

The implementation of this thesis work was conducted with the Electrical systems and Projects Engineering Process department at ABB Marine & Cranes division located in Helsinki, Finland. ABB Marine Systems develop electrification and automation solutions for the marine industry and a leading manufacturer of electric power and propulsion systems for ships. As a global maritime organization, it is providing innovative, reliable, safe and environmentally-friendly solutions and qualified services to reduce operational costs and ensure optimum vessel lifecycle for its wide range of customers. (ABB Marine 2013.)

Due to a strong drive from leadership to improve quality, reduce engineering lead-time and improve cost efficiency, the need to simulate the engineering process so as to achieve the required aim is unavoidable. Project engineering process is the phase in the project's lifecycle which includes tasks and activities after the project is handed over to the project engineering department by sales department until the project is handed over to the warranty team. The activities executed in this department include purchasing support, power plant engineering, propulsion system hardware engineering, propulsion control software application engineering, product and software application testing, and other technical supports that may be required by customers and/or other stakeholders.

Project activities are dependent on the scope and nature of a project. Generally only standard solutions shall be used, some options are available. The applicability of different tasks and workflow may differ per projects. Several tasks are performed simultaneously and repeatedly throughout the project's execution process. (Kuttila 2012, 3.)

1.2 Aim of thesis

The aim of this thesis was to build up a simulation model of the proposed engineering process, and to define adjustable attributes for all tasks.

The process was modelled in appropriate detail to allow for the identification and calculation of the extra time invested by the resources.

1.3 Scope of simulation model

The simulation model varies as to the information according to the duration of each step in the engineering process. This variability is based on a different complexity level of each project type.

The proposed engineering process is a simplified version of the current process, so the interdependencies between the different steps need to undergo a deep analysis in order to make a correct connection between them.

Furthermore, there is a lack of information about the relationship and communication between the personnel. This is an issue worth considering because an office simulation model includes the people behaviour as its main resource.

1.4 Research methods

The engineering process was modelled using commercial discrete-event simulation software. The model was created in two phases; first the whole process was modelled based on existing documents, and then refined based on the interviews with the person of contact in the Electrical Systems and Projects department.

Once the simulation model is finished, resources will be sized to reduce the extra-time invested in the engineering process.

Therefore, this model itself is the main result of the thesis, because it allows testing and checking the whole process, and it acts as important validation for the department if any modification in the engineering process is applied in the future.

2 QUANTITATIVE TOOL IN A DYNAMIC SYSTEM

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Through the development of the simulation model, the engineering process flow chart was modified several times until an appropriate flow to represent in the simulation software was reached. As explained below, drafting flow charts in the process modelling is a key step before the representation in the simulation program.

2.1 Process modelling

Flow charts are an exceptionally good source for simulation logic, since they provide more information on the parallel and sequential nature of sub-processes than work instructions. The same logic works both ways; a flow chart can be extracted from the simulation model.

Conceptual process designs must be tested before they are implemented. It is possible for the design to be flawed or to simply not deliver the intended outcomes. The testing can be done through implementation of pilot projects, but it is generally an expensive way to perform an initial assessment of the process performance. It also takes quite some time before enough data are available from the pilot to make a sound judgment of the effects of the new design.

Therefore, it is an attractive alternative use process modelling and quantitative tools for the initial testing. Among the available modelling tools, the most flexible and in many respects the most powerful (although not always the most appropriate one) is simulation.

The advantage of using quantitative models to test the process designed is that it is much cheaper and faster than the pilot implementation approach. Simulation offers freedom in testing new ideas and to arrive at better process designs. The drawback is that any model, by definition, is an approximation of reality, although it can never capture all aspects of it. Particularly hard to model are behavioural issues, which have to do with attitudes, resistance to change, and work behaviour (all factors that to a large extent are unknown before the implementation).

Therefore, process modelling and simulation can never completely replace pilot testing and vice versa. To finalize the design and explore behavioural issues, pilot testing is often a worthwhile step before moving on to a full-implementation.

In general terms, simulation means “to mimic reality in some way”. Simulation in the context of process modelling actually refers to discrete computer event simulation. This is a technique that allows the representation of processes, people, and technology in a dynamic computer model. Process modelling and simulation as a concept consist of the following basic steps.

1. Building a simulation model of the process.
2. Running the simulation model.
3. Analyzing the performance measures.
4. Evaluating alternative scenarios.

The simulation model mimics the operations of business process. This is accomplished by stepping through the event in compressed time, often while displaying an animated picture of the flow. While stepping through the events, the simulation software accumulates data related to the model elements, including capacity utilization of resources, number of jobs, and waiting times in buffer. The performance of the process can then be evaluated through statistical analysis of the collected output data. (Laguna & Marklund 2004, 94.)

2.2 Quantitative tool

One of the major strengths of simulation modelling as a tool for business process design is that it can help reduce the risks inherent in any type of change. The use of scenario-based what-if analysis enables to test various alternatives and choose the best one.

With regards to what-if analysis, the main advantages of simulation modelling over test performed on the real system are that:

1. It is done “off-line” without disturbing current operations.
2. Time is compressed in a simulation run.

In a redesign effort, an existing process is observed and strategies are developed to change it to enhance performance. Testing such strategies on the real system would disturb daily operations and negatively impact results. In a simulation model, any strategy can be tested safely without upsetting the environment. Time compression can be used because in a simulation model, events are accelerated. By only considering the discrete events when something happens in the system, simulation can compress time and “advance the clock” much faster than it would occur in real time, enabling the analyst to examine longer time horizons. Depending on the size of the model and the computer’s capabilities, several years can be simulated in minutes or even seconds.

Another risk that simulation can help mitigate is that of sub-optimization. As simulation model encompasses various processes, analysts can study how these processes interact and how changing on process impacts the others.

In relation to other quantitative tools, a major strength of simulation modelling is its ability to capture systems dynamics. Random events such as equipment breakdowns and customer arrivals are modelled by using probability distributions. As the simulation advances in time, the embedded distributions are sampled through the use of random-number generators. Hence, the dynamic interaction among systems elements is captured.

Another interesting aspect of simulation that is directly related to the simulation software available today is its ability to provide animation to help visualize the process operations. Through the use of animation, ideas come alive. Equally important are the multitude of other graphical tools enabling dynamic reporting of results and trends. Time series, histograms, and pie charts are some of the dynamic reporting features of most simulation software packages today. These features help simulation modelling enhance communication. At the same time, the quantitative nature of simulation reporting brings objectivity into the picture. Improvement initiatives can be compared and prioritized. (Laguna & Marklund 2004, 95.)

2.3 Stochastic model

A simple process model assumes that activity times and demand are deterministic and constant, but in reality, and element of variability will always exist in the time it takes to perform a certain task and in the demand for service. In situations where the variability is small, deterministic models might be an adequate way of describing a process. However, in situations with more accentuated variability, these models do not suffice. In fact, the variability itself is often one of the most important characteristics to capture in the model of a process.

Variability makes it difficult to match demand and capacity in such a way that queues are avoided.

The models of business processes that incorporate variability are known in the literature as stochastic models. These models enable to evaluate how the process design decisions affect waiting times, queue lengths, and service levels.

An important difference compared to the deterministic models is that in the stochastic models the waiting time is no longer an input parameter; it is the result of the specified process time and the demand pattern. Because eliminating non-value-adding waiting time is an important objective when designing a new business process, the usefulness of stochastic models in process design is obvious. (Laguna & Marklund 2004, 171-172.)

Therefore, it is important to understand why variability in process parameters is such an important issue from an operational and an economic perspective.

2.3.1 Variability under an operational perspective

From an operational perspective, the main problem with variability in processing times, demands, and capacity is that it leads to an unbalanced use of resources over time, causing the information of waiting lines. This will be referred to loosely as a capacity-planning problem. The core of this problem is that queues (or waiting lines) can arise at any given time when the demand for services exceeds the resource capacity for providing the service. This means that even if the average demand falls well below the average capacity, high variability will lead to instances when the demand for services exceeds the capacity and a queue starts to form.

On the other hand, in some instances the capacity to provide service will greatly exceed the demand for service. This causes the queue to decrease. Moreover, even if a no queue exists at all, the resource providing the service will be idle. At this point, it is important to recognize that queues concern individuals as well as documents, products, or intangible jobs. (Laguna & Marklund 2004, 172.)

2.3.2 Variability under an economical perspective

From an economic perspective, the capacity-planning problem caused by high variability in demand and process times comes down to balancing the cost of having too much capacity on certain occasions against the cost associated with long waiting lines at other times. The cost of delays and waiting can take on many different forms including the following.

- The cost of lost customers who go elsewhere because of inadequate service.
- The cost of discounts because of late deliveries.
- The cost of goodwill loss and bad reputation affecting future sales.
- The cost of idle employees who have to wait for some task to be completed before they can continue their work.

Ultimately, these costs will affect the organization, even though the impact sometimes might be hard to quantify. The cost of excessive capacity is usually easier to identify. Primarily, it consists of the fixed and variable costs of additional and unused capacity, including increased staffing levels.

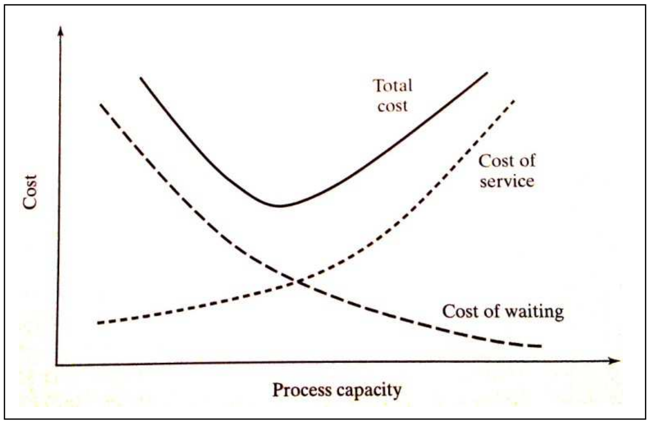


Figure 1 Economic trade-off of between service capacity and waiting time (Laguna & Marklund 2004, 173.)

Figure 1 depicts the economic trade-off associated with the capacity-planning problem. The x-axis represents the service capacity expressed as the number of jobs per unit of time the system can complete on average. The y-axis represents the total costs associated with waiting and providing service. The waiting cost reflects the cost of having too little service capacity, and the service cost reflects the cost of acquiring and maintaining a certain service capacity.

It follows that in order to arrive at design decisions that will minimize the total costs; the first step is to quantify the delay associated with a certain capacity decision. Second, this delay needs to be translated into monetary terms to compare this to the cost of providing a certain service capacity. (Laguna & Marklund 2004, 173.)

2.4 Introduction to simulation

Because many business processes are cross functional and characterized by complex structure and variability patterns, a more flexible modelling tool is needed. Simulation offers this flexibility and represents a powerful approach for analysis and quantitative evaluation of business processes.

In general, to simulate means to mimic reality in some way. Simulation can be done, for example, through physical models such as wind tunnels, simulators where pilots or astronauts train by interacting with a computer in a virtual or artificial reality, or through computer-based models for evaluation of a given technical system or process design. In the latter case, simulation software is used to create a computer model that mimics the behaviour of the real-world process.

The rapid development of computer hardware and software in recent years has made computer simulation an effective tool for process modelling and an attractive technique for predicting the performance of alternative process designs. It also helps in optimizing their efficiency. Simulation is useful in the context because business process design is a decision-making problem for which the following is true.

- Developing analytical mathematical models in many cases might be too difficult or perhaps even impossible.
- The performance of a process design typically depends heavily on the ability to cope with variability in inter-arrival and processing times (implying for a modelling tool that can incorporate several random variables).
- The dynamics are often extremely complex.
- The behaviour over a period of time must be observed to validate the design.
- The ability to show an animation of the operation is often an important way to stimulate the creativity of the design teams.

Despite its many virtues, simulation is sometimes met by scepticism from practitioners and managers. Much of the reluctance toward using simulation stems from the misconception that simulation is extremely costly and time-consuming. This is despite the many success stories showing that the savings from using simulation to improve process designs has far exceeded its costs. (Laguna & Marklund 2004, 223.)

In fact with the advanced modelling tools that are currently available, the model development and experimentation phase might take only a few days or weeks, representing only a small fraction of the overall project development time (Harrell and Tumay, 1995).

One of the most resource-consuming efforts that go into building a valid simulation model understands how the process operates. However, as discussed before, this process understanding is a necessity for achieving an effective process design and must be done whether or not simulation is used. (Laguna & Marklund 2004, 223.)

2.4.1 Computer-based simulation models

Simulation models in general and computer-based models in particular can be classified in three ways according to their attributes.

- Static or dynamic.
- Deterministic or stochastic.
- Discrete or continuous.

A static model is used when time does not play a role in the actual system. For example, a model of a bridge does not depend on time. A deterministic model is such that the outputs are fully determined after the inputs are known. Take a computer model for calculating the water pressure of a pipe networks as an example. The pressure is known once the designer selects the pipe diameters for all the pipe segments. A discrete model considers that individual units (i.e., the transient entities of the system) are important. Most manufacturing, service, and business processes are discrete. Business processes in general are represented as computer-based dynamic, stochastic, and discrete simulation models.

A computer-based simulation model is an abstraction of the actual business process, represented in the computer as a network of connected activities and buffers (or equivalent, a network of basic queuing systems) through which jobs or customers flow. To provide a correct representation of the process, the model also must capture the resources and various inputs needed to perform the activities.

Because process modelling is only one application area for simulation modelling, a more general terminology for describing a simulation model is to refer to it as an abstraction of a system rather than a process. Conceptually, a system is defined as a collection of entities that interact with a common purpose according to sets of laws and policies. Entities are either transient or resident. In the process terminology, transient entities are jobs that flow through the system, and the resident entities are the buffers, workstations, and resources that make up the process network. Laws are not under the process designer’s control. Laws generally are represented by parameters. Sensitivity analysis is the experimentation used to determine the effect of changes in parameter values. Policies, on the other hand, are under the designer’s control. A policy typically is implemented by changing input factors. Design is the experimentation used to determine the effect of changes in input factors and system structure.

In process design models are used to study the behaviour of a process. A process can be modelled symbolically, analytically, or with simulation. These models include process activity charts, process diagrams, and flowcharts. Symbolic models are quick and easy to develop, and are easily understood by others. The main disadvantage of symbolic models is that they fail to capture the dynamics of the process. If their underlying assumptions were valid for a system under study, these models would be a convenient way to evaluate quantitatively different process designs. The main disadvantage is that these underlying assumptions are often restrictive. Furthermore, because these tools offer no obvious graphical representation, they might appear abstract to the process designer.

Modern simulation software in a sense combines the descriptive strength of the symbolic models with the quantitative strength of the analytical models. It offers graphical representation of the model through graphical interfaces, as well as graphical illustration of the system dynamics through plots of output data and animation of process operations. At the same time, it enables estimation of quantitative performance measures through statistical analysis of output data. The main disadvantage of simulation is the time spent learning how to use the simulation software and how to interpret the results.

To summarize, the following are some of the main attributes that make simulation powerful.

- Simulation, like analytical modelling, provides a quantitative measure of performance (e.g. resource utilization or average waiting time).
- Simulation, unlike analytical and symbolic models, is able to take into consideration any kind of complex system variation and statistical interdependencies.
- Simulation is capable of uncovering inefficiencies that usually go undetected until the system is in operation.

Therefore, simulation software packages are used as what-if tools. This means that given a simulation model, the designer would experiment with alternative designs and operating strategies in order to measure system performance. Consequently, in such an environment, the model becomes an experimental tool that is used to find an effective design. (Laguna & Marklund 2004, 224-225.)

2.4.2 Discrete event simulation

Business processes usually are modelled as computer-based, dynamic, stochastic, and discrete simulation models. The most common way to represent theses models in the computer using discrete-event simulation. In simple terms, discrete-event simulation describes how a system with discrete flow units or jobs evolves over time. Technically, this means that the computer tracks how and when state variables such as queue lengths and resource availabilities change over time. The state-variables change as a result of an event (or discrete event) occurring in the system. A characteristic is that discrete-event models focus only on the time instances when these discrete events occur. This feature allows for significant time compression because it makes it possible to skip through all time segments between events when the state of the system remains unchanged. Therefore, in a short period of time, the computer can simulate a large number of events corresponding to a long real-time span. (Laguna & Marklund 2004, 226.)

The key reason for using discrete-event simulation is the need to model processes that are subject to variability and that are interconnected, which leads to complexity. Variability can be thought of in terms of predictable variability (e.g. shift changeovers) and unpredictable variability (e.g. patient arrival patterns and consultation times). Given that most processes are subject to a range of sources of variability, which are interconnected (e.g. arrival profiles, to triage times, to initial consultation times, etc.), the process becomes complex. As a result, the performance of the process is difficult to predict; hence the need for simulation. Complexity arises not just from the scale of the process under investigation, but also through the dynamic interaction and feedback between elements of the process. Meanwhile, queues emerge between process steps as a result of the complex interaction of individual processes which are subject to variability. Hence the key assumptions of discrete-event simulation are that processes are subject to variability, they are interconnected and complex; queues emerge within the process and process performance (process flow) is difficult, or indeed impossible, to predict without simulation.

Discrete-event simulation is primarily used as a means for testing whether a proposed performs as expected and to look for means of improving a process. The common benefits of using discrete event simulation in a manufacturing context are risk reduction, greater understanding, operating cost reduction, lead time reduction, faster plant changes, capital cost reduction and improved customer service. These benefits can easily be translated to other context such as services. (Robinson, Radnor, Burgess & Worthington 2012, 7-8.)

To illustrate the mechanics of a discrete-event simulation model, consider an information desk with a single server. Assume that the objective of the simulation is to estimate the average delay of a customer. The simulation then must have the following state variables.

- Status of the server (busy or idle).
- Number of customers in the queue.
- Time of arrival of each person in the queue.

As the simulation runs, two events can change the value of these state variables: the arrival of a customer or the completion of service. The arrival of a customer either changes the status of the server from idle to busy or increases the number of customers in the queue. The completion of service, on the other hand, either changes the status of the server from busy to idle or decreases the number of customers in the queue.

Because the state variables change only when an event occurs, a discrete-event simulation model examines the dynamics of the system from one event to the next. That is, the simulation moves the “simulation clock” from one event to the next and considers that the system does not change in any way between two consecutive events. For example, if a single customer is waiting in line at grocery store and the next event is the completion of service of the customer who is currently paying for his groceries, then discrete-event simulation does not keep track of how the customer in the line spends her waiting time. In other words, the simulation keeps track of the time when each event occurs but assumes that nothing happens during the elapsed time between two consecutive events.

Figure 2 summarizes the steps associated with a discrete-event simulation. The simulation starts with initializing the current state of the system and an event list. The initial state of the system, for example, might include some jobs in several queues as specified by the analyst. It also could specify, for instance, the availability of some resources in the process. The most common initial state is to consider that no jobs are in the process and that all resources are currently available and ready. The event list indicates the time when the next event will occur. For example, the event list initially might include the time of the first arrival to the process. Other events might be scheduled initially, as specified by the analyst.

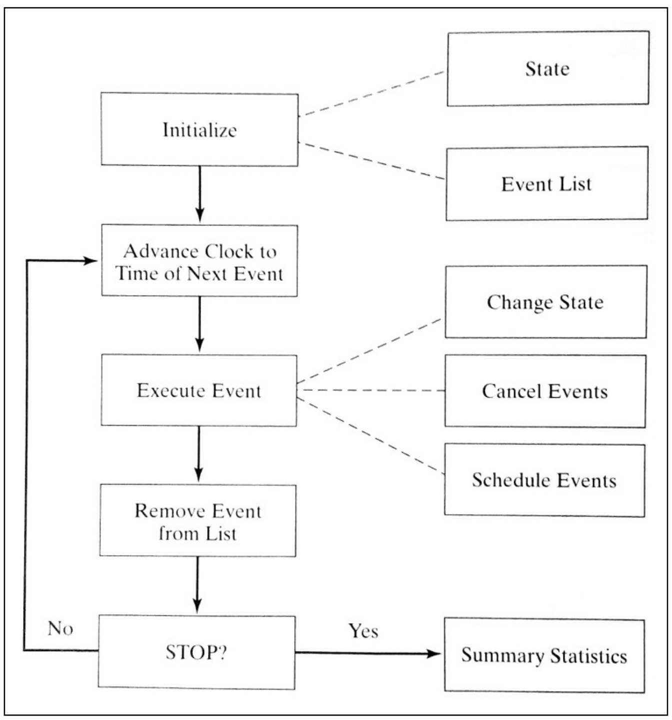


Figure 2 Discrete-event simulation. (Laguna & Marklund 2004, 227.)

Once the initialization step is completed, the clock is advanced to the next event in the event list. The next event is then executed. Three activities are triggered by the execution of an event. First, the current state of the system must be changed. For example, the execute event might be a job arriving to the process. If all the servers are busy, then the state change consists of adding the arriving job to a queue. Other state changes might require deleting a job from a queue or making a server busy.

The execution of an event might cause the cancellation of other events. For example, if the executed event consists of a machine breakdown, then this event forces the cancelation of the processing of jobs that are waiting for the machine. Finally, the execution of an event may cause the scheduling of future events. For example, if a job arrives and is added to a queue, a future event is also added to the event list indicating the time that the job will start processing.

When an event is executed, the event is removed from the event list. Then the termination criterion is checked. If the criterion indicates that the end of the simulation has been reached, then raw data along with summary statistics are made available to the analyst. On the other hand, if the termination criterion indicates that the simulation has not finished (for example, because more events remain in the event list), then the clock is advanced to the time of the next event. (Laguna & Marklund 2004, 226-227.)

Data analysis is a key element of computer simulation. Without analysis of input data, a simulation model cannot be built and validated properly. Likewise, without appropriate analysis of simulation output data, valid conclusions cannot be drawn and sound recommendations cannot be made. In other words, without input data analysis, there is no simulation model, and without output data analysis, a simulation model is worthless. (Laguna & Marklund 2004, 326.)

2.5 Input data analysis

Input data analysis is needed because business processes are rarely deterministic. Factors such as arrival rates and processing times affect the performance of a process, and they are typically nondeterministic (i.e., stochastic). For instance, the time elapsed between the arrival of one job and the next generally follows a nondeterministic pattern that needs to be studied and understood in order to build a simulation model that accurately represents the real process. In addition, building a simulation model of a process entails the re-creation of the random elements in the real process. Therefore, three main activities are associated with the input data necessary for building a valid simulation model.

1. Analysis of input data.
2. Random number generation.
3. Generation of random varieties.

Input data are analyzed to uncover patterns such as those associated with inter-arrival times or processing times. After the analysis is performed, the patterns are mimicked using a stream of random numbers. The stream of random numbers is generated using procedures that are based on starting the sequence in a so-called seed value. Because the patterns observed in the real process may be diverse (e.g. a pattern of inter-arrival times might be better approximated with an Exponential distribution, and a pattern of processing times might follow a uniform distribution), some random numbers need to be transformed in a way such that the observed patterns can be approximated during the execution of the simulation model. This transformation is referred to as the generation of random varieties. (Laguna & Marklund 2004, 326.)

2.5.1 Dealing with randomness

One option for mimicking the randomness of a real process is to collect a sufficient amount of data from the process and then use the data as the input values for the simulation model.

However, this approach has several shortcomings. First, field data (also called real data) typically are limited in quantity because in most processes, the collection of data is expensive. Therefore, the length of the simulation would be limited to the amount of available data. Second, field data are not available for processes that are not currently in operation. However, an important role of simulation is to aid in the design of processes in situations where an existing process is not available. Field data can be used on a proposed redesign of an existing process, but it is likely that the problem of not having enough data to draw meaningful conclusions would be encountered. Third, the lack of several scenarios represented by field data would prevent one from performing sensitivity analysis to disclose the behaviour of the process under a variety of conditions. Finally, real data may not include extreme values that might exist but that do not appear in the data set collected. Probability distributions functions include these extreme values in the tails.

Although field data are not useful for gaining a full understanding of the behaviour of a process, they are useful for model validation. Validating a model entails checking that the model behaves like the actual process when both are subject to exactly the same data patterns. Model validation is necessary before the model can be used for analysis and prediction.

Due to these limitations, simulation models are typically built to run with artificially generated data. These artificial data are generated according to a set of specifications in order to imitate the pattern observed in the real data; that is, the specifications are such that the characteristics of the artificially generated data are essentially the same as those of the real data. The procedure for creating representative artificial data is as follows.

1. A sufficient amount of field data is collected to serve as a representative sample of the population. The collection of the data must observe the rules for sampling a population so the resulting sample is statistically valid.
2. Statistical analysis of the sample is performed in order to characterize the underlying probability distribution of the population from which the sample was taken. The analysis must be such that the probability distribution function is identified and the appropriate values of the associated parameters are determined. In other words, the population

must be fully characterized by probability distribution after the analysis is completed.

3. A mechanism is devised to generate an unlimited number of random varieties from the probability distribution identified in step 2.

The analyst performs step 1 by direct observation of the process or by gathering data using historical records including those stored in databases. Some software packages provide distribution-fitting tools to perform step 2. These tools compare the characteristics of the sample data to theoretical probability distributions. The analyst can choose the probability distribution based on how well each of tested distributions fits the empirical distribution drawn from the sample data. (Laguna & Marklund 2004, 327-328.)

Most of the simulation software packages provide a tool for performing the third step. These tools are designed to give users the ability to choose the generation of random varieties from an extensive catalogue of theoretical probability distributions.

2.5.2 Probability distribution of field data

A probability distribution function (PDF), or if the data values are continuous, a probability density function, is a model to represent the random patterns in field data. A probability distribution is a mathematical function that assigns a probability value to a given value or range of values for a random variable. The processing time, for instance, is a random variable in most business processes. (Laguna & Marklund 2004, 328.)

Researchers have empirically determined that many random phenomena in practice can be characterized using a fairly small number of probability distribution and density functions. This small number of PDFs seems to be sufficient to represent the most commonly observed patterns occurring in systems with randomness. This observation has encouraged mathematicians to create PDF structures that can be used to represent each of the most commonly observed random phenomena. The structures are referred to as theoretical in nature; they are inspired by patterns observed in real systems. An example of a best-know distribution is Uniform distribution, Figure 3 shows its characteristics.

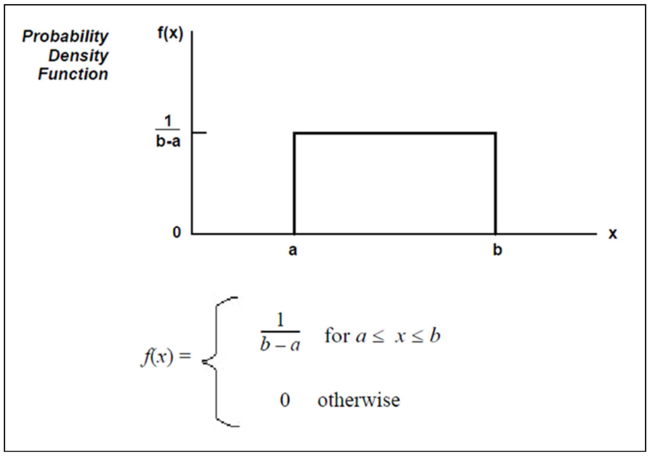


Figure 3 Uniform distribution (Arena User’s Guide 2005, 123.)

The Uniform distribution is used when all values over a finite range are considered to be equally likely. It is sometimes used when no information other than the range is available. The uniform distribution has a larger variance than other distributions that are used when information is lacking. (Arena User’s Guide 2005, 123.)

Some of the other best-know distributions are Triangular, Normal, Exponential, Binomial, Poisson, Erlang, Weibull, Beta, and Gamma. The structures of these distributions are well established, and guidelines exist to match a given distribution to specific applications.

To facilitate the generation of random varieties, it is necessary to identify a PDF that can represent the random patterns associated with a real business process appropriately. It is also desirable to employ a known theoretical PDF if one can be identified as a good approximation of the field data. At this stage of the analysis, several PDFs must be considered while applying statistical methods to assess how well the theoretical distributions represent the population from which the sample data were taken. (Laguna & Marklund 2004, 329.)

2.6 Output data analysis

One of the main goals of this analysis is to determine the characteristics of key measures of performance such as cycle time or throughput for given input conditions such as changes in resource availability or demand volume. This can be used to either understand the behaviour of an existing process or to predict the behaviour of a suggested process. Another important goal associated with the analysis of output data is to be able to compare the results from several simulated scenarios and determine the conditions under which the process is expected to perform efficiently. (Laguna & Marklund 2004, 326.)

The previous sections have addressed the issues associated with the modelling of process uncertainty using discrete-event simulation. The stochastic behaviour of the output of a process is due to inputs (e.g. the uncertainty in the arrival of jobs) and internal elements (e.g. the uncertainty of processing times, the routing of jobs in the process, or the availability of resources). Hence, the output of a simulation model also should be treated as set of random variables. For example, the waiting time of jobs is a random variable that depends on the inputs to the simulation model as well as the model's internal elements. Other random variables that are outputs of process simulations are cycle time and work-in-process.

In the context of business process design, simulation studies are performed for the following reasons.

1. To estimate the characteristics (e.g. mean and standard deviation) of output variables (e.g. cycle times) given some input conditions and values of key parameter settings. This estimation helps one understand the behaviour of an existing business process or predict the behaviour of a proposed process design.
2. To compare the characteristics (e.g. minimum and maximum) of outputs variables (e.g. resource utilization) given some input conditions and values of key parameter settings. These comparisons help one choose the best design out of a set of alternative process configurations. Also, the comparisons can be used to determine the best operating conditions for a proposed process design.

Statistical analysis of simulation output is necessary in order to draw valid conclusions about the behaviour of a process. When performing statistical analysis, one must deal with the issues related to sampling and sample sizes. These issues cannot be ignored, because valid conclusions cannot be drawn from single simulation run of arbitrary length. (Laguna & Marklund 2004, 349.)

Various authors and manuals stress the importance of comprehensive simulation model verification and validation before the results that are generated by a simulation run can be accepted as representative of the simulated scenario. Verification is the process of determining that a model operates as intended. Throughout the verification process, we try to find and remove unintentional errors in the logic of the model. This activity is commonly referred to as debugging the model. In contrast, validation is the process of reaching an acceptable level of confidence that the inferences drawn from the model are correct and applicable to the real-world system being represented. Through validation, we try to determine whether the simplifications and omissions of detail, which we have knowingly and deliberately made in our model, have introduced unacceptably large errors in the results. (Albertyn 2005, 140.)

3 SIMULATION ENGINEERING PROCESS

The previous sections are mainly the theory applied in the present thesis. This theory establishes a connection with the thesis background and answers about what a simulation is and what are the key elements of it.

As explained at the beginning of the present document, the aim of this thesis was to build up engineering process simulation model and define adjustable attributes for all tasks.

Therefore, discrete-event simulation theory has been defined previously to understand the commercial discrete-event simulation software that allows the modelling of the proposed engineering process.

In the commercial market, there are different simulation programs. To choose one or other depends on the simulation objectives, the key parameters to simulate and how the results will be shown. Once all of these key elements are evaluated, the comparison between simulation programs is more accurate, and to obtain a proper choice is easier.

3.1 Simulation objectives

In the present thesis, the simulation objectives were defined by the Electrical Systems and Project department personnel of ABB Marine and Cranes. The main objectives to simulate the proposed engineering process were the following:

- Simulation software that allows defining adjustable attributes for each engineering process step.
- Simulation model that represents the engineering process.
- Customized results that show the usage of the resources and the operation times of each engineering process step.
- Link to Microsoft Office Excel to analyze the customized results.

These objectives were the guideline of the simulation modelling. In the simulation model were accomplished in a proper way.

3.1.1 Given inputs

The inputs of the engineering process simulation model were related with the variability explained in the previous chapters. The Electrical Systems and Project department personnel of ABB Marine and Cranes established the desire of a simulation model, easy to use and adjustable parameters that affect directly the performance of the engineering process.

Mainly, the given inputs of the simulation model were the following:

- Input data on the entry of the different projects.
- Operation time of each engineering process step.
- Percentages to get the different approvals.
- Number of resources available in the engineering process.
- Time data of the simulation model.

These given inputs were defined in the simulation model in a more detail dialogs that make easier the introduction of the data.

3.1.2 Desired outputs

According with the aim of the Electrical Systems and Project department personnel of ABB Marine and Cranes, the desired output is to improve the engineering process efficiency cutting 10% of engineering hours.

It means customized results that show engineering lead time and utilization of the resources. Another important issue is to offer a document that allows a link with Microsoft Office Excel to analyze the information collected.

The following data appears in the customized results when the simulation is finished:

- Number of completed jobs through the engineering process.
- Working percentage of each engineering process steps.
- Average queuing time in the simulation model.
- Utilization percentage of the different resources.
- Re-work percentage in the denied approval of the projects.

In the simulation model these customized results are shown in a deeply detail offering a clear view of the data collected. And to make a quick comparison between them is easier.

3.2 Selection of a suitable tool

As explained before, there are several commercial software programs that can simulate the process, one of the main differences to choose one or another was to identify the key parameters to simulate.

The present thesis is about an engineering process simulation model where the work item is documentation, and the main environment is the office. Therefore, the proposed engineering process faced a complex service in a dynamic system. And to simulate it, discrete-event simulation software was needed.

A correct approach to compare the different simulation programs was classifying them according with their main applications:

- Complex system design evaluation: AnyLogic, Arena, AutoMod, SIMPROCESS, Simul8.
- Service systems: Arena, ExtendSim, Simul8.
- Supply chain management: AnyLogic, Arena, Flexsim, SAS simulation Studio.
- De-bottlenecking: Plant Simulation, ShowFlow, Simul8.
- What if scenarios: Arena, Enterprise Dynamics, SIMPROCESS, Simul8.
- Business process reengineering and workflows: Arena, Flexsim, ProModel, Simcad Pro, SIMPROCESS, Simul8.

- Manufacturing systems: AutoMod, Flexsim, GoldSim, Plant Simulation, ProModel, Simcad Pro, Simul8.

The previous classification shows the main programs existing that are used to simulate the different applications. A quick conclusion was that Arena and Simul8 are used in the most of the applications. It means that both programs offer a flexible simulation modelling and common tools to simulate different scenarios and processes.

Therefore, the selection of a suitable tool was focused in a comparison between both commercial software packages.

3.2.1 Arena & Simul8 comparison

The comparison was based on the requirements specified previously according with the given inputs and desired outputs. Table 1 shows the information.

Table 1 Arena vs. Simul8 (Albertyn 2005, 160.)

Attribute	Arena	Simul8
Acquisition cost	14	1
Annual licensing fees	2	None
Graphics capability	More advanced	More basic
Modelling environment complexity	More complex	More simplistic
Simulation modelling capability	More capable	Adequate
Simulation model ease of use	More difficult	More easy
Link with Excel	Yes	Yes
Link with Visio	Yes	Yes
Logic programming language accessibility	Less accessible (VBA)	More accessible (VL)

The acquisition cost and annual licensing fees of the simulation software packages change over time because the developers adjust prices to accommodate software upgrades and inflation. Therefore the values for acquisition cost and annual licensing fees that are presented in the Table 1 are only representative and not absolute.

A basic design philosophy of the generic simulation modelling methodology is to use the most basic of the standard simulation software package building blocks whenever possible. This approach supports the design criteria of compact simulation model size and short simulation runtimes. Therefore, user can find in Simul8, a modelling environment simpler than

Arena, and also Simul8 uses a basic graphics that make easier to understand, since the first usage. (Albertyn 2005, 160-161.)

The ability to read input variables from, or to write output variables to, an external file is seen as one of the basic capabilities that is needed to support the user-friendliness design criterion of the generic methodology. Both simulation packages allow the link with Microsoft Excel, to import and export data, and Microsoft Visio to import flow chart previously designed. This easy link allows to the user reduce the time to learn the similar applications that these programs offer.

The Arena simulation model uses WKS files as the output mechanism for the results that are generated by a simulation run. The Simul8 simulation model uses spreadsheets variables as the input and output mechanisms of the simulation model. In Simul8 every variable that is used by the simulation model is defined in the Information Store. A variable is called a Global Data Item and may be defined as a spreadsheet. This is very useful feature because it allows easy manipulation of variables and simplifies the import and export of values into and out of the simulation model. It creates an easy link with Microsoft Excel.

The generic simulation modelling methodology presents a structured approach that renders simulation models with the following characteristics:

- Short development time.
- Short maintenance time.
- User-friendliness.
- Short simulation runtimes.
- Compact size.
- Robustness.
- Accuracy.
- Preferably a single software application.

Both the Arena and Simul8 simulation software packages conform to all these characteristics. In both packages short development and maintenance times are achieved through the use of the high-level blocks. Both packages allow hierarchical modelling (through the use of sub-models in the arena environment and sub-processes in the Simul8 environment) and support user-friendliness with their input and output mechanisms (through the use of input and output files in the Arena environment and spreadsheets variables in the Simul8 environment). These inputs mechanisms allow fast and easy access to input and output variables. Acceptable simulation runtimes and compact simulation model sizes are achievable with both packages. Both packages produce accurate simulation models (proved through verification and validation) and allow the whole simulation model to be accommodated in a single software application. (Albertyn 2005, 124-129.)

3.2.2 Arena evaluation

The strengths of the Arena simulation software package are a more advanced graphics capability and additional modelling capabilities, like transporters, conveyors, etc. These additional capabilities do not feature in the generic simulation modelling methodology, but could be important for users when seen in the broader perspective of general simulation modelling applications.

The weaknesses of the Arena simulation software package are higher acquisition cost, annual licensing fees, more complex modelling environment (and thus more difficult to learn and use), no internal logic programming language, larger simulation model size and longer simulation runtime. (Albertyn 2005, 161-162.)

3.2.3 Simul8 evaluation

The strengths of the Simul8 simulation software package are lower acquisition cost, no annual licensing fees, more simplistic modelling environment (and thus easier to learn and use), inclusion of an internal logic programming language, smaller simulation model size and shorter simulation runtime. The use of spreadsheet variables as input and output mechanisms enhance user-friendliness and therefore the ease of use of Simul8 simulation models is also strength.

The weaknesses of the Simul8 simulation software package are a more basic graphics capability and less modelling capabilities. But the inclusion of Visual Logic allows great modelling freedom and creativity. (Albertyn 2005, 162.)

3.2.4 Comparison conclusion

Once the comparison was done and the information of both simulation programs was analyzed, the selection of a suitable tool was justified under the simulation objectives according with the given inputs and desired outputs.

Therefore, the simulation software package that was more suitable to represent the proposed engineering process was Simul8. In relation with the selection, there were some key reasons that Simul8 was chosen:

1. Simul8 acquisition cost is lower than Arena. It has got more simplistic modelling environment, smaller simulation model size, and an easier link with Microsoft Office Excel.
2. The simulation model faces an engineering process where people behaviour has to be modelled. Using Arena environment with basic building blocks is not enough to represent it. Simul8 environment consists primarily of a block of Visual Logic (VL) code, and it offers a very detailed logic to control the operation of the simulation.

3. Previously in ABB Marine and Cranes, Simul8 simulation software package has been used and the existing experience is positive.
4. HAMK UAS has got an educational license that allows a free use of the simulation software.

3.3 Simul8 concepts

Once Simul8 was selected to simulate the engineering process, is necessary to explain the main elements used in the simulation modelling.

A Simul8 simulation model is made up of objects in a structure. Work items (work to be done in the operation) travel through the structure with objects controlling their flow. The structure is represented on the screen by a number of objects and lines joining these objects. A great deal of detail can be placed behind this structure. This makes it possible to use Simul8 at a strategic level, and at a detailed tactical level, as required. (Hauge & Paige 2001, 53.)

Therefore there are two fundamental concepts underlie most model building in Simul8: Objects and Work Items. Objects are entities that create the structure of the simulation, these entities process or provide services to work items.

3.3.1 Work Item

A “Work Item” is the work which is done in the organization being simulated. Work items flow through the simulation, and they are stored or processed in different objects. Each work item is of a “Type” known as “Work Item Type”. For example, patients in a hospital, invoices in an account department or products in a factory. (Hauge & Paige 2001, 56.)

In the simulation described, work items are mainly documents. They start out as orders from “Sales Department”, pass through the engineering process steps, and finish in the “Warranty Process”.

3.3.2 Start Point

A “Start Point” is a work generator object. It is the place where work to be done first appears in the simulation. Usually it simply describes the average time between items of work entering the model. But it can, for example, contain a list of work stored in a spreadsheet. (Hauge & Paige 2001, 57.)

“Sales Department” is represented by this object. Simul8 allows to give different values to the same work item using labels, in this point of the simulation is where in “Actions” option is defined this setting label values, these values are according with the complexity level of the projects.

3.3.3 Queue

A “Queue” is a place where work to be done can wait until appropriate resources or activities are available. It is one of the fundamental objects that make up the simulation structure and due to the internal workings of the simulation program queues are needed as buffers between activities. Otherwise when simulating some processes, queue can act as an activity that can contain many work items (storage bin). (Hauge & Paige 2001, 61.)

In the simulation, the engineering process flow establishes a direct connection between activities and all the queues do not hold work items by default. Therefore, waiting time is generated by the interdependencies between activities, and the availability of the resources. Before some activities “Travel Time” is considered. It represents the time that engineers spend travelling to one location before to work on the activity.

3.3.4 Activity

An “Activity” is a place where work takes place on work items. Work done at activities usually takes up time and sometimes requires the availability of resources. At an activity a work item may be transformed in some way (perhaps by changing one or more of its labels). After the work is done the work item may be sent on to another simulation object, or one of a number of different simulation objects depending on routing rules that can be specified. (Hauge & Paige 2001, 60.)

Activities represent the engineering process steps of the proposed engineering process in the simulation. Work item is processed in each activity; operation time and resources required are defined according with the complexity level of the project.

3.3.5 End Point

An “End Point” is a place where work that is complete, or otherwise finished, leaves the simulation. At the point in time when each work item leaves, data is recorded about how long it has spent in the simulation (from the time when it entered through a “Start Point”). (Hauge & Paige 2001, 64.)

“Warranty Process” is represented by this object in the simulation. It represents the last step of the engineering process.

3.3.6 Routing

“Routing” controls the path taken by each individual work item through the simulation model. Routing arrows are divided in routing-out and routing-in arrows, and are used to connect simulation objects. The most used routing-in rules in the described simulation are “Collect” and “Priority”.

- "Collect" method of routing work items into a work centre allows the collection of a number of work items before the work centre will start work. In this collection, the work items are assembled into one work item, this assembly is according with the label values.
- "Priority" method selects a work item from the first place in the list of objects which feed this work centre. (Hauge & Paige 2001, 97.)

The most used routing-out rules in the present simulation are "Circulate" and "Percent".

- "Circulate" means that the first work item will go to the first destination in the list, the second work item to the second, the nth work item to the nth destination on the list. By default "Ignore Blocked Routes" option in Simul8 is checked, for this simulation this option has to be unchecked.
- "Percent" method means that the destination work centre is decided randomly (like "Uniform") except that the exact percentage going to each destination can be specified. (Hauge & Paige 2001, 106.)

In this simulation most of the activities use "Priority" routing-in and "Circulate" routing-out. The reason to used "Collect" routing-in is because some activities literally have to collect several documents previous its performance. The "Percent" routing-out is used in the two approvals that the engineering process has to face, the percentages are according to get the approval or not.

3.3.7 Resource

"Resources" are items in the simulation model which are required at work centres in order for the work centre to work on a work item. Work centre cannot start work until both a work item is available and the specified resources are also available. Resources are shared between all the work centres which used them. (Hauge & Paige 2001, 68.)

In this simulation "Resources" are considered engineers. There are seven different engineering specialities. Six of these specialities have got three different experience levels each of them. Table 2 shows the specialities and their experience levels that are considered in the simulation model.

Table 2 Engineering specialties with their respective experience levels.

Cabling Engineer Document Controller Drive Engineer Lead Engineer Power plant engineer Software Engineer	Three experience levels: - Low experience - Medium experience - High experience
Project Manager	One experience level

3.3.8 Group

A “Group” is a collection of simulation objects. It is used to limit the number of work items which can be in one area of the process and to control the results of the collection. (Hauge & Paige 2001, 157.)

In the simulation there are seven groups according with the seven engineering specialities. Each engineering speciality works on activities, some of them are done at the same time with other specialties. Groups collect the activities and queues that each engineering speciality must work. The results of the collection is shown in the customize results when the simulation is finished.

3.3.9 Component

“Components” are pre-build sections of a simulation, they are intended to help build simulation in two ways, reducing the need to re-build certain elements of a simulation over and over, and reducing development time of more complex elements. (Hauge & Paige 2001, 319.)

In this simulation components were created to make easier the interaction with the simulation model. In the “ABB_Project Engineering Process_Office.S8” file there are nine components and they are linked with dialogs that make easier the introduction of data.

3.3.10 Label

“Labels” can be attached to any “Work Item” going through the simulation. Labels can contain either text or numbers, can be used to tell work centres which distribution to use for sampling work times, can be also used to route work item, to collect data and for a number of other purposes. (Hauge & Paige 2001, 111.)

In the simulation one label was created to identify the different projects according with their complexity level that enter in the engineering process simulated.

3.3.11 Distribution

All timing and number information in Simul8 is given in terms of “Distribution”. Statistical distributions provide a method of simulating the variations that occur in timing (and other numbers) in any process involving people or machines or anything in nature. Simul8 allows to create own distributions. (Hauge & Paige 2001, 139.)

In this simulation a new distribution was created based on the different complexity levels of the projects that enter in the engineering process simulated. This distribution is related with the label created in the described simulation.

3.3.12 Information Store

The “Information Store” holds data which is used in the simulation. It allows selecting the type of item to create and change the starting, or reset value as well as monitoring the current value contained in the item. All information store items are “Global” (anywhere in the model that they are referenced will find the same value in them). This differs from labels which have different values depending on the “Work Item” is being referenced. (Hauge & Paige 2001, 178.)

Global data item could be single variables or “Spreadsheets” of data. Simul8 spreadsheets are not designed to replace spreadsheet packages, they are storage places for data, or places where can be created reports. Global data items are normally used from Visual Logic but they can also be referenced directly from Simul8 timing boxes. Table 3 shows the global data item existing in the simulation model.

Table 3 Global data item used in the simulation model.

Number of items	Item type	Data
14 items	Number	Variable
2 items	Spreadsheet	Spreadsheet
6 items	Text	Variable
5 items	Time	Variable

3.3.13 Dialog

Custom “Dialogs” allow Simul8 to be tailored to the specific needs of a business, can appear when “Components” are clicked (replacing their properties dialogs), as new menu items when simulation is opened, or any time driven by Visual Logic. Custom dialogs can display Simul8 information store data and allow information store data to be changed by the user. This makes it very easy for someone to use simulation on a daily basis without any understanding of how to build simulations (and without the simulation builder having to use external packages like Visual Basic or Excel). (Hauge & Paige 2001, 184.)

In the present simulation there are nineteen dialogs that allow an easy interaction and data introduction to the user since the simulation is started. Table 4 shows the number of dialogs according with their purpose in the simulation model.

Table 4 Dialogs used in the simulation model.

Number of dialogs	Purpose
4 dialogs	Informative
15 dialogs	Informative & Data introduction

3.3.14 Visual Logic

Visual Logic (VL) is the internal programming language. VL does not appear as one large stream of code. It is structured and divided into appropriate places with simply access. Most VL is not typed. It is chosen from menus, but menus which are structures to make the choosing much faster than typing, and much easier than remembering what to type. VL code is blocked in a hierarchy, so even large amounts of VL can be reviewed and understood quickly. (Hauge & Paige 2001, 214.) Table 5 shows the locations where the code is placed in the simulation model.

Table 5 Visual Logic locations used in the simulation model.

Visual Logic location	Purpose
"On Simulation Open"	Show dialogs in the user's view when simulation is opened.
"On OK Dialog"	In some dialogs, to click on "OK" button makes the code running and execute different actions (i.e. open a dialog or display a spreadsheet).
"Before Selecting"	Before "Work Item" is selected by an "Activity", the code written assigns the resources according with the label value.
"After Loading Work"	Once "Work Item" is selected by an "Activity" the code written establishes the operation time according to the label value.
"On Work Complete"	When the work is done in the "Activity", the code written resets the operation time.
"On Stop Run"	When the simulation is finished all the data referenced in the code is collected and introduced in the spreadsheet shown in the user's view.
"Before Reset"	Previous "Reset", some data referenced in the code time is changed to be in a proper format for the next simulation
"On Reset"	On "Reset", the code is running and it shows some dialogs in the user's view.

The number of codes used in the simulation model is based on the locations where the code is located. For example, "On OK Dialog" is located in six dialogs, and in the simulation model there are nineteen of them. Other codes only are located in one location, but "Before Selecting", "After Loading Work", and "On Work Complete" are located in most of the activities of the engineering process simulated. It represents the complex and dynamic system that is faced in the present simulation model.

3.4 Data sources

Once the Simul8 concepts have been explained, previous the simulation modelling of the engineering process, a deep analysis of the background of the present simulation model was necessary. As explained at the beginning, the engineering process simulated is formed by two documents:

- 3AFV6036386 Engineering Process Description.
- 3AFV6041649 Engineering Process Flow Chart.

The engineering process represents the work flow in the Electrical Systems and Project department. And all the activities described have been performed previously.

The main reason of the present simulation model is to improve the engineering process efficiency cutting 10% of engineering hours. The extra time identification of the process was analyzed in the “Project Manager” course collaborating with the same Electrical Systems and Project department personnel of ABB Marine and Cranes. The aim of this course was to find a proper way to implement “Lean Office” in the proposed engineering process. The deep analysis of the main documents and to be part of the “Project Manager” course offered a more clear understanding of the whole process to simulate, and extra information that was used to make possible the simulation done.

3.4.1 Engineering Process Description

This document describes the engineering process simulated. This process begins when a project team is nominated by the “Engineering Manager” and ends when the project close-out meeting has been held by the “Project Manager”.

In this document all the engineering process steps are explained. In each explanation the objective of the step and its description are defined, also the engineers involved in the activity are specified. There are two tables in most of the explanations that indicate the input and output documents of each step and the responsible people. The information described in this document defines the connection between the engineers and the interdependencies as to the engineering process steps. This document is a complement of the flow chart and vice versa.

3.4.2 Engineering Process Flow Chart

The graphical representation of the engineering process allows an easy understanding of the work flow, but the description document is necessary to understand the interdependencies between the steps. The flow chart allows a quick representation in the simulation software, and with the description of each step the whole process flow is redefined.

After several versions of the engineering process using Simul8, a flow chart improvement was necessary. The main reason for the improvement was a need to combine the “Description” document with the “Flow Chart” document. The new flow chart connects all the activities and makes it easier to understand the connections between engineers and interdependencies between steps.

In a quick comparison with the original flow chart, the new one offers a clearer graphic design. It highlights different flows according to the approval and re-work, and identifies using different images important engineering process steps.

3.4.3 Project Manager Course

"Project Manager" course was developed at HAMK UAS with the collaboration of ABB Marine and Cranes personnel. It was mainly focused on defining a way to implement "Lean Office" in the same proposed engineering process. To analyze the process, members of the course were divided into different teams to study different issues. One of the most relevant findings to be considered at the end of this project was the work developed by "Lead Time" team. This team identified five different "Non-Value Added Time" issues.

Once the engineering process was simulated, all of these "Non-Value Added Time" issues appeared in the simulation results. This meant that the work completed during the course was correct and the simulation model showed proper customized results.

3.4.4 Assumptions & Estimations

As explained earlier in the scope of this simulation study there was a lack of information of the operation times of each engineering process step and in general of all the times involved in the process. All the simulation tests were conducted using assumptions and estimations of the real data. The Electrical Systems and Project department personnel of ABB Marine and Cranes made it clear since the beginning of the present thesis that no real data had to be used to develop the simulation model. Through the time invested into the simulation modelling, not much real data was given. This data was used to refine the simulation model in some aspects.

Therefore, the simulation model was developed so that data with logic limitations could be introduced. For example, one logic limitation was that the number of engineers cannot be -1, it must always be equal to or higher than 0. Most of the assumptions and estimations were solved using Visual Logic in Simul8. All this code is explained in detail in the following chapters.

4 SIMULATION MODEL MANUAL

Once all the information collected was analyzed and the simulation software concepts were understood, the simulation modelling of the proposed engineering process was performed. Simul8 offers a friendly interface to build a new process quickly. Using the building blocks predefined in the simulation program allows an easy way to build the process and using connection tools allows the connection between activities.

Depends on the process to simulate, it could be simple and easy, but in this case with the lack of information and human being simulated in the process, it became a complex dynamic system. This was the reason that the main simulation performance is in the Visual Logic, using language programming is possible to represent the behaviour of the resources, the time of the projects according with their complexity level, and different interactions that allow an easy usage and understanding of the simulation model. In this thesis two simulation models were created:

- ABB_Project Engineering Process_Office.
- ABB_Project Engineering Process_Work Flow.

Both of them represent the same engineering process. The main difference is the access that the user has to their simulation objects. The "Work Flow" file allows an unlimited interaction with the objects, and the possibility to modify the whole simulation model. The "Office" file offers a limited version to interact with the elements and to modify the simulation model, but a more friendly and easy interface to get the simulation results.

4.1 Nomenclature

In the present thesis both simulation model files are based in the same structure and have the same nomenclature for each simulation object and work item. In both files "Work Item" is named as "Document". Table 6 shows this information.

Table 6 Work Item Type nomenclature in the simulation model.

Work Item	Nomenclature
Work Item Type	Document

The work item name can be modified in "Work Item Type" option in "Advanced" section of Simul8. Figure 4 shows this option.

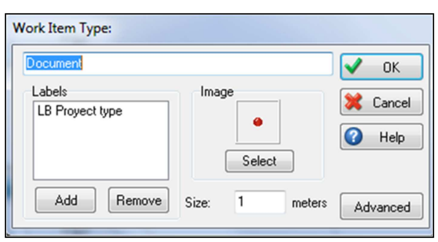


Figure 4 Work Item Type options.

This option allows connecting the work item type to a "Label".

4.1.1 Simulation elements

In the simulation was created one label to identify the different types of projects that enter in the engineering process from sales process. This “Label” was named as “LB Project type”, and has got “Number” type. It means that number data are considered as label values. Table 7 shows this information.

Table 7 Label nomenclature in the simulation model.

Simulation element	Nomenclature	Type
Label	LB Project type	Number

Figure 5 shows the “Label Properties” option in “Data and Rules” section of Simul8 where the label name and its properties can be modified.

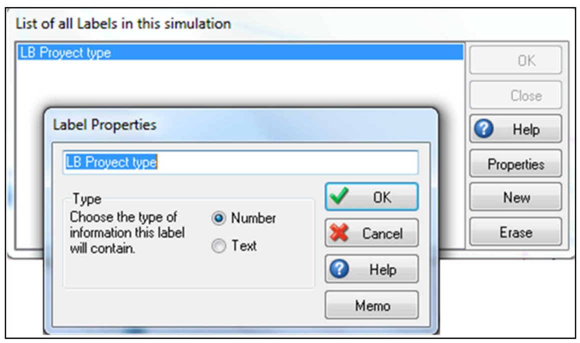


Figure 5 Label Properties options.

In the simulation a distribution was attached to this label where is introduced the input percentage according with the number of projects of each type. This “Distribution” was named as “ProjectType%” and it was created as a new probability profile distribution. Table 8 shows this information.

Table 8 Distribution nomenclature in the simulation model.

Simulation element	Nomenclature	Type
Distribution	ProjectType%	Probability Profile Distribution

In the following Figure 6 shows “Distributions” option in “Data and Rules” section of Simul8 where the distribution name and its properties can be modified.

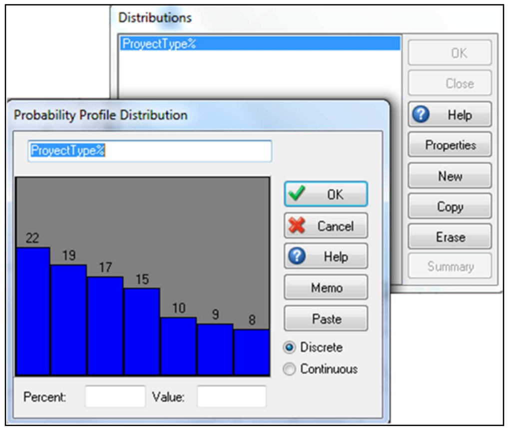


Figure 6 Probability Profile Distribution options.

This distribution was located at the beginning of the simulation model, specifically in the “Start Point”.

4.1.2 Simulation objects

In the simulation model “Start Point” was named as “Sales process”, this is the start of the engineering process steps until the “End Point” that was named as “Warranty process”. Table 9 shows this nomenclature.

Table 9 Start and end point nomenclature in the simulation model.

Simulation object	Nomenclature
Start Point	Sales process
End Point	Warranty process

Between these two simulation objects all the “Activities” and “Queues” of the engineering process steps were modelled. Table 10 shows some examples of these simulation objects and their nomenclature.

Table 10 Examples of the activities and queues nomenclature in the simulation model.

Simulation object	Nomenclature	
Engineering Process Steps	Activity	Queue
2.1 Technical Handover from Sales	S 1	Queue for S 1
2.2 Prepare external kick-off meeting memo	S 2_1	Queue for S 2_1
2.2 Customer kick-off meeting	S 2_2	Queue for S 2_2

To modify the name of any activity, queue, start point or end point, there is a “Name” option on the top toolbar that appears when any of these simulation objects is clicked. Figure 7 show this option, it is located in “General” information of “File” section of Simul8. Besides, it allows introducing a memo to add a more detail simulation object description.

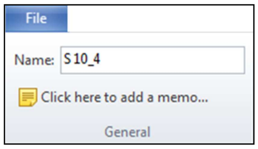


Figure 7 General information options.

Also, the name can be changed in “Activity Properties” and “Queue Properties”, in these windows there are different options with default values that are used in the simulation model, only the options explained in the present thesis were changed. To organize and control better the customized results of the simulation objects, groups were created.

As explained in the previous chapters, “Groups” were created to control the work item in relation with the engineers work, each of them has to work or to be part on different activities as are explained in the” Engineering Process” description and “Flow Chart” documents. Therefore the groups were created under these documents and are shown in the Table 11.

Table 11 Groups nomenclature in the simulation model.

Engineering Process Steps	Groups nomenclature
2.3 / 2.19 / 2.26 / 2.27	Cabling Engineer EPS
2.3 / 2.5 / 2.7 / 2.8 / 2.21 / 2.26 / 2.27	Document Controller EPS
2.3 / 2.16 / 2.17 / 2.18 / 2.22 / 2.24 / 2.26 / 2.27	Drives Engineer EPS
2.1 / 2.2 / 2.3 / 2.4 / 2.5 / 2.6 / 2.7 / 2.8 / 2.9 / 2.10 / 2.11 / 2.13 / 2.15 / 2.16 / 2.18 / 2.20 / 2.22 / 2.23 / 2.24 / 2.25 / 2.26 / 2.27 / 2.28	Lead Engineer EPS
2.3 / 2.13 / 2.14 / 2.15 / 2.22 / 2.24 / 2.26 / 2.27	Power plant Engineer EPS
2.1 / 2.2 / 2.3 / 2.4 / 2.6 / 2.9 / 2.10 / 2.11 / 2.13 / 2.15 / 2.16 / 2.18 / 2.22 / 2.23 / 2.25 / 2.27 / 2.28	Project manager EPS
2.3 / 2.9 / 2.10 / 2.11 / 2.12 / 2.22 / 2.24 / 2.25 / 2.26 / 2.27	Software Engineer EPS

The previous table shows the engineering process steps involved in each group. Activities and queues that represent these steps can be changed in “Groups” option in “Objects” section of Simul8. Figure 8 shows this option.

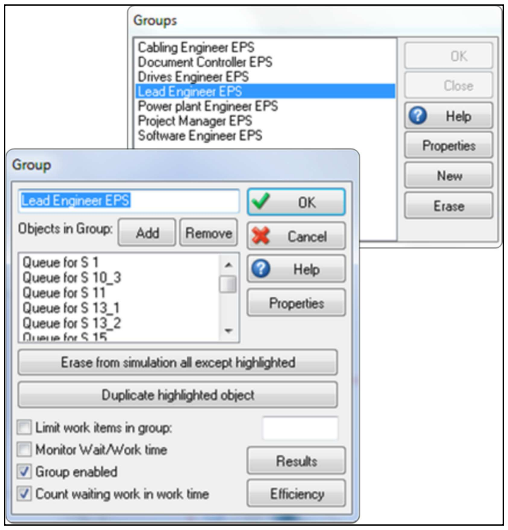


Figure 8 Group options.

In most of the activities, resources are needed to perform them. According to the label value of the work item type, resources are established. As explained before, resources are considered engineers. There are seven different engineering specialities. Six of these specialities have got three different experience levels each of them. In the Table 12 are shown the nomenclature of the resources used.

Table 12 Resources nomenclature in the simulation model.

Resources	Nomenclature
Cabling Engineer (low experience) Cabling Engineer (medium experience) Cabling Engineer (high experience)	CE_1 CE_2 CE_3
Document Controller (low experience) Document Controller (medium experience) Document Controller (high experience)	DC_1 DC_2 DC_3
Drives Engineer (low experience) Drives Engineer (medium experience) Drives Engineer (high experience)	DE_1 DE_2 DE_3
Lead Engineer (low experience) Lead Engineer (medium experience) Lead Engineer (high experience)	LE_1 LE_2 LE_3
Power plant Engineer (low experience) Power plant Engineer (medium experience) Power plant Engineer (high experience)	PE_1 PE_2 PE_3
Project Manager (one experience level)	PM
Software Engineer (low experience) Software Engineer (medium experience) Software Engineer (high experience)	SE_1 SE_2 SE_3

The resource's name can be modified in the "Resource Properties" options that is located when the simulation object is double clicked. Figure 9 shows this window. Also, the name can be modified in the "Name" option on the top toolbar that appears when it is clicked.

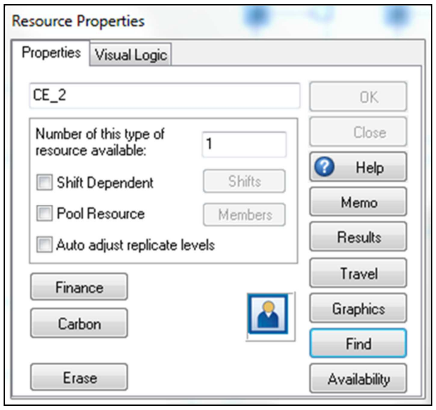


Figure 9 Resource Properties options.

4.1.3 Global Data Item

Simul8 offers the possibility to create new variables that allow a better control of the work item and of the customize results. In the Table 13 are shown all the variables used in the simulation and their main purposes are explained.

Table 13 Variables nomenclature in the simulation model.

Name	Type	Purpose
VAR High entry	Number	Distribution Upper Bound
VAR Level 1A (1)	Number	Input percentage Level 1 (> 4th vessel)
VAR Level 1A (2)	Number	Input percentage Level 1(3rd vessel)
VAR Level 1A (3)	Number	Input percentage Level 1 (2nd vessel)
VAR Level 2 (4)	Number	Input percentage Level 2 (1st vessel)
VAR Level 3A (5)	Number	Input percentage Level 3 (High technology)
VAR Level 3A (6)	Number	Input percentage Level 3 (Very high technology)
VAR Level 3A (7)	Number	Input percentage Level 3 (Extremely high technology)
VAR Low entry	Number	Distribution Lower Bound
VAR Percentage noC	Number	No % in Approval from Classification
VAR Percentage noSY	Number	No % in Approval from Shipyard
VAR Percentage yesC	Number	Yes % in Approval from Classification
VAR Percentage yesSY	Number	Yes % in Approval from Shipyard
VAR Simulation speed	Number	Percentage simulation speed
VAR Engineering Process RESULTS	Spreadsheet	Engineering Process custom results
VAR Operation Time EPS	Spreadsheet	Operation time of each Engineering Process Step
VAR AC fail	Text	Message: "Percentages in Approval C

		not correct”
VAR ASY fail	Text	Message: “Percentages in Approval SY not correct”
VAR Distribution fail	Text	Message: “Probability profile not correct”
VAR Time fail	Text	Message: “Simulation time must be higher than Warm up period”
VAR noC	Text	Message: “No approval from Classification”
VAR noSY	Text	Message: “No approval from Shipyard”
VAR Simulation time	Time	Hours of simulation time
VAR Travel time 10_3	Time	Hours of travel time to “Interface meeting”
VAR Travel time 22	Time	Hours of travel time to “FATs”
VAR Travel time 2_2	Time	Hours of travel time to “Customer kick-off meeting”
VAR Warm up period	Time	Hours of warm up period

These data can be modified in the “Information Store” options located in “Data and Rules” section of Simul8. Figure 10 shows this information.

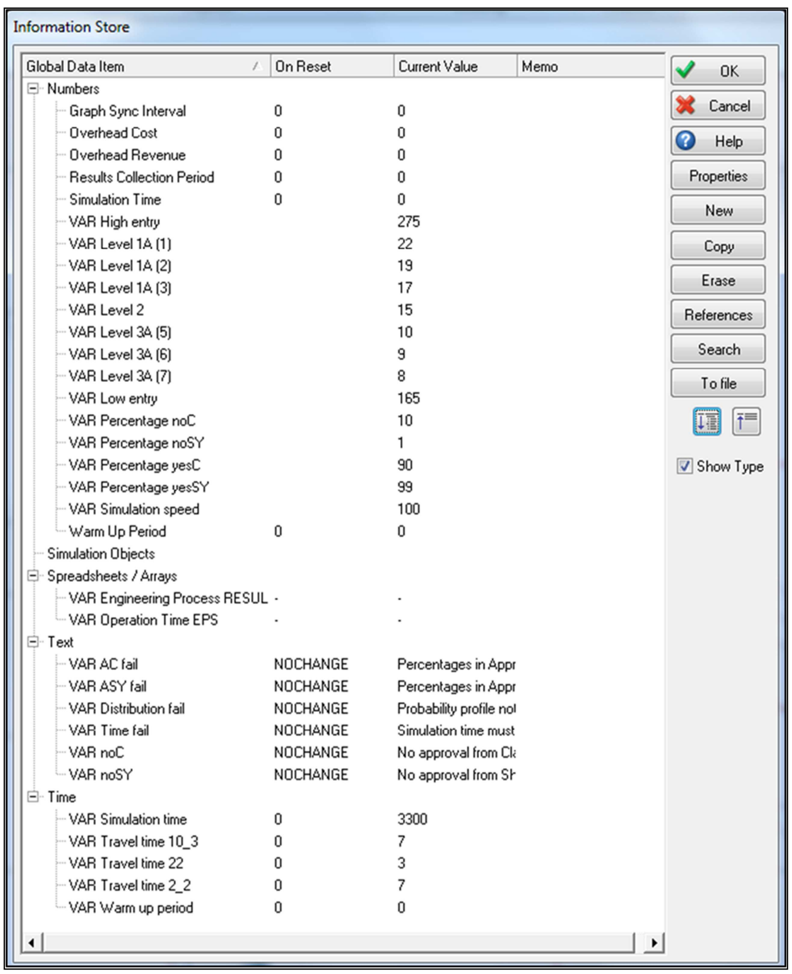


Figure 10 Information Store options.

The name of each variable can be modified in "Properties" option.

4.2 Work flow

As explained in the previous chapters, engineering process flow chart was modified and improved to represent the work flow in the simulation software. This new work flow chart offers a clearer graphic design. It highlights different flows according with the approval and re-work, and identifies with different images important engineering process steps. Figure 11 shows the representation of the work flow in the simulation software.

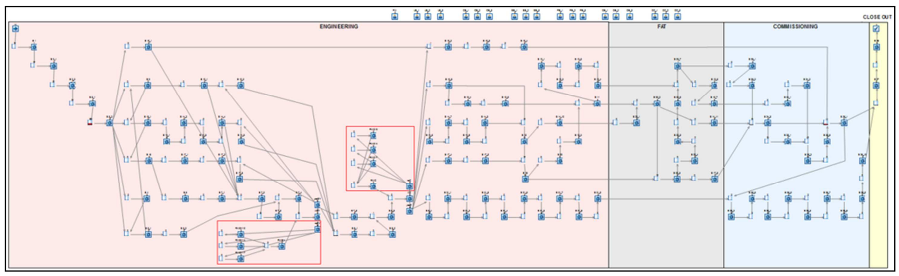


Figure 11 Work Flow of "ABB_Project Engineering Process_Work Flow" file.

In the simulation model engineering process steps were represented by activities. One queue is needed before each activity to hold the work when the resources are idle in other activities or to collect a specific number of documents before to start the work.

New activities were created to represent the re-work when one project is not approved in the approvals. These new activities represent the re-work in the engineering process step 2.10, 2.14 and 2.17. In the "ABB_Project Engineering Process_Work Flow" file the re-work is highlighted inside a red square. Another activity with its respective queue is needed to collect all the work items of the re-work before are introduced again in the work flow. Table 14 shows this information.

Table 14 New activities to represent the re-work in the proposed engineering process simulation model.

New activities purpose	Nomenclature	
Definition	Activity	Queue
Get the Approval from Shipyard	yesSY	Queue for yesSY
Approval denied from Shipyard	noSY	Queue for noSY
Collection of the re-work done by the engineers to get the approval from Shipyard	RWSY	Queue for RWSY
Software engineer(s) re-work to get the approval from Shipyard	RWSY10	Queue for RWSY10
Power plant engineer(s) re-work to get the approval from Shipyard	RWSY14	Queue for RWSY14

Drives engineer(s) re-work to get the approval from Shipyard	RWSY17	Queue for RWSY17
Get the Approval from Classification	yesC	Queue for yesC
Approval denied from Classification	noC	Queue for noC
Collection of the re-work done by the engineers to get the approval from Classification	RWC	Queue for RWC
Software engineer(s) re-work to get the approval from Classification	RWC10	Queue for RWC10
Power plant engineer(s) re-work to get the approval from Classification	RWC14	Queue for RWC14
Drives engineer(s) re-work to get the approval from Classification	RWC17	Queue for RWC17

Figure 12 shows the re-work in Approval from Shipyard, and Figure 13 shows the re-work in Approval from Classification.

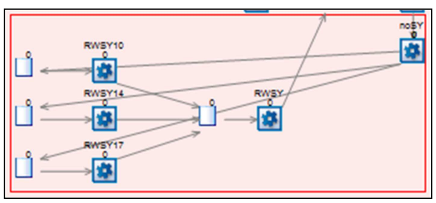


Figure 12 Re-work simulation objects in the Approval from Shipyard.

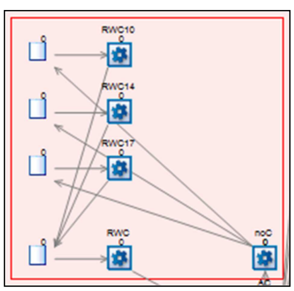


Figure 13 Re-work simulation objects in the Approval from Classification.

The work flow in the “ABB_Project Engineering Process_Office” file is the same. The differences are that some simulation objects are represented by components that make easier the interaction with the simulation model. Start point, resources, approval and re-work simulation objects are the components of this file, the rest of the activites and queues are included in a sub-window. Figure 14 shows this sub-window content of the “ABB_Project Engineering Process_Office” file.

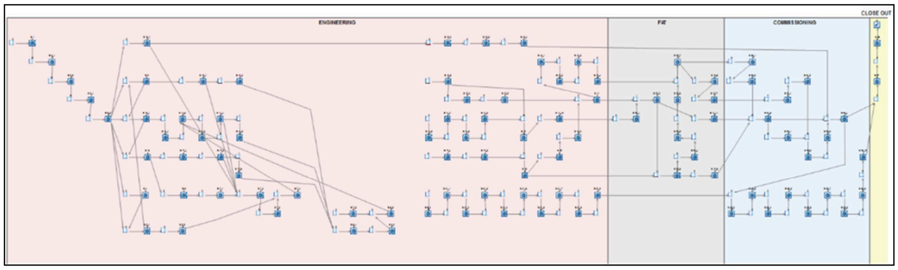


Figure 14 Sub-window of the "ABB_Project Engineering Process_Office" file.

In both files, activities and queues are connected using routing arrows. As explained previously, in this simulation there are different ways to connect the objects, routing-in uses "Priority" and "Collect" method, and routing-out uses "Circulate" and "Percent" method.

4.2.1 Routing In

Routing-in using "Priority" method was established in the "Routing In" option inside each "Activity Properties". Figure 15 shows it, using activity "S 10_4" as an example.

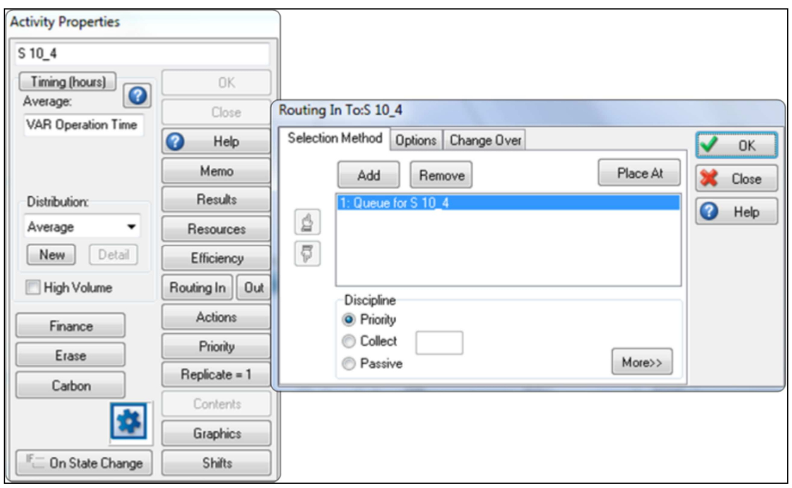


Figure 15 Routing-in to "S 10_4" using "Priority" method.

This routing-in method is used in most of the activities of the engineering process simulation model. "Priority" method selects a work item from the first place in the list of objects which feed this work centre, the work start until all the resources are available.

Routing-in using "Collect" method was established in the "Routing In" option inside each "Activity Properties". Figure 16 shows it, using activity "S 16" as an example.

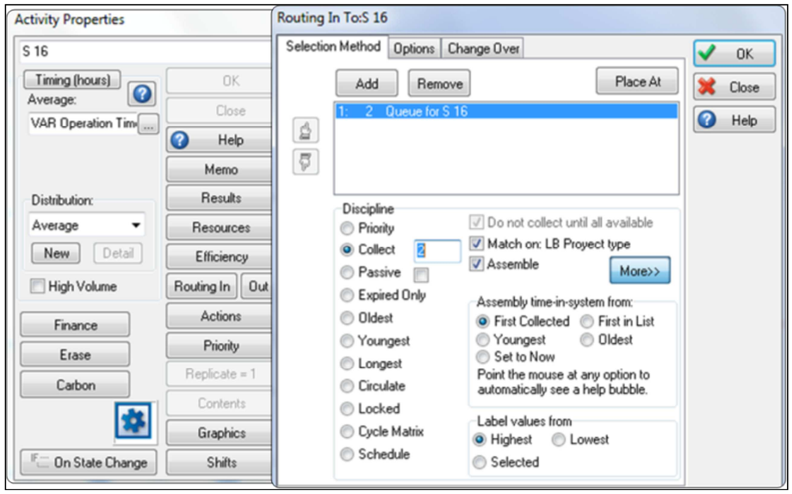


Figure 16 Routing in to “S 16” using “Collect” method.

This method of “routing” work items into a work centre allows the collection of a number of work items before the work centre will start work. In this collection, the work items are assembled into one work item, using “Assemble” option, this assembly is according with the label values selecting “Match on: LB Project Type”.

In all the activities there are two codes inside “Routing In” option. “Before selecting” code based on the operation time and “After Loading Work” code based on the resources.

4.2.2 Before Selecting

As explained in the previous chapters there are seven different complexity levels and the operation time of each engineering process step is based on them. The label created in the simulation model “LB Project type” has got seven different numerical values that represent the complexity levels. “Level 2 Time” was established as the main reference to calculate the other times. Table 15 shows the relation between times according to the complexity level.

Table 15 Operation times according to the complexity level.

Project type	Complexity	Level	Label	Time
Repeat project	> 4th vessel 3rd vessel 2nd vessel	Level 1A Level 1A Level 1A	1 2 3	t – t * 75% t – t * 50% t – t * 25%
Prototype project	1st vessel	Level 2	4	t
New technology	High Very high Extremely high	Level 3A Level 3A Level 3A	5 6 7	t + t * 25% t + t * 50 % t + t * 75%

To represent it in the simulation model, Visual Logic was used. In the “Routing In” of each activity was written a code. This code establishes the operation time of the engineering process step according to the complexity level. Figure 17 shows how to access to "Before Selecting" Visual Logic location.

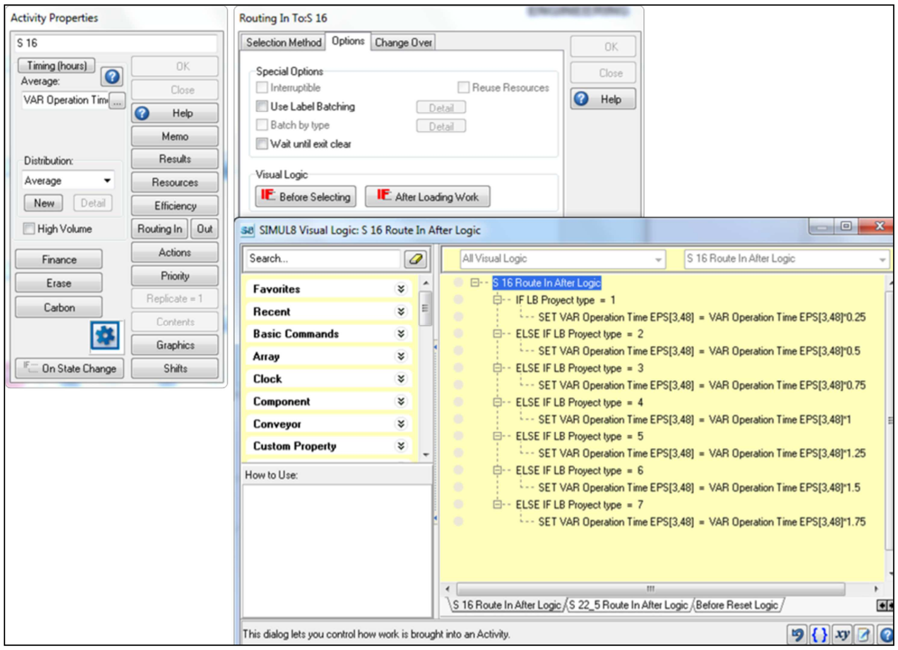


Figure 17 "Before Selecting" location of "S 16" activity.

This Visual Logic location is placed in "Options" of "Routing In" window of each activity. The following code, using activity "S 16" as an example, shows this logic.

```
VL SECTION: S 16 Route In After Logic

  IF LB Project type = 1
    SET VAR Operation Time EPS[3,48] = VAR Operation Time
EPS[3,48]*0.25
  ELSE IF LB Project type = 2
    SET VAR Operation Time EPS[3,48] = VAR Operation Time
EPS[3,48]*0.5
  ELSE IF LB Project type = 3
    SET VAR Operation Time EPS[3,48] = VAR Operation Time
EPS[3,48]*0.75
  ELSE IF LB Project type = 4
    SET VAR Operation Time EPS[3,48] = VAR Operation Time
EPS[3,48]*1
  ELSE IF LB Project type = 5
    SET VAR Operation Time EPS[3,48] = VAR Operation Time
EPS[3,48]*1.25
  ELSE IF LB Project type = 6
    SET VAR Operation Time EPS[3,48] = VAR Operation Time
EPS[3,48]*1.5
  ELSE IF LB Project type = 7
    SET VAR Operation Time EPS[3,48] = VAR Operation Time
EPS[3,48]*1.75
```

The operation time is selected in the spreadsheet “VAR Operation Time EPS”. Figure 18 shows how this time data is selected from the spreadsheet.

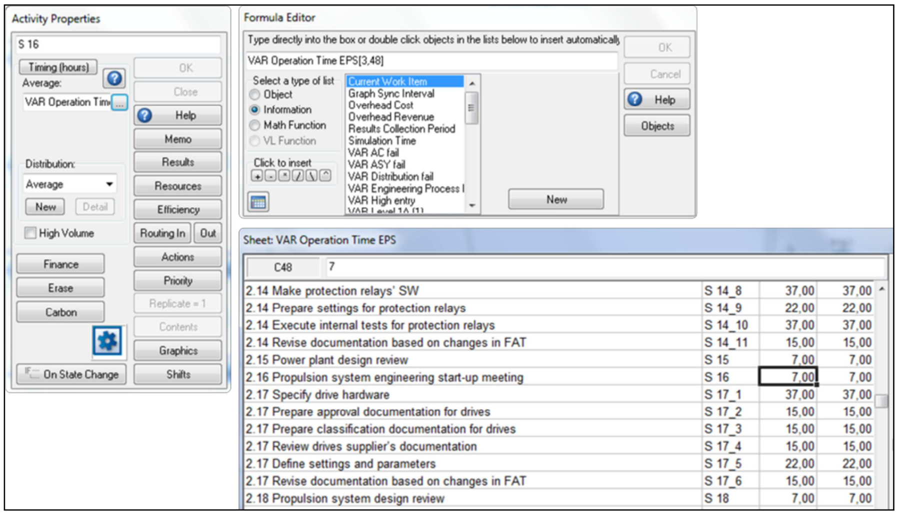


Figure 18 Operation times selected from “VAR Operation Time EPS” spreadsheet.

Next to the space where the operation time can be introduced, there is a button that opens “Formula Editor”. In this window there are different data types, in this case “Information” is checked, and all the data collected in “Information Store” is shown. Simul8 offers an option to access easily to the spreadsheet.

According to the code written, it selects the data time of the “Time” column and calculates the time according with the label number of “LB Project type”. For example, if work item has got 3 of label value, the operation time is multiplied by 0.75, it means less 25% of the “Prototype” project time. Table 16 shows the numbers that each operation time is multiplied according to the complexity level.

Table 16 Operation time calculation in Visual Logic.

Level	Label	Time	Operation time multiply by
Level 1A Level 1A Level 1A	1 2 3	t – t * 75% t – t * 50% t – t * 25%	0.25 0.5 0.75
Level 2	4	t	1
Level 3A Level 3A Level 3A	5 6 7	t + t * 25% t + t * 50 % t + t * 75%	1.25 1.5 1.75

After this code, operation time is adjusted to the new time, and then the work item goes to the next code, “After Loading Work” Visual Logic location.

4.2.3 Routing Out

Routing-out using “Circulate” method was established in the “Routing Out” option inside of “Activity Properties”. Figure 19 shows it, using “S 16” activity as an example.

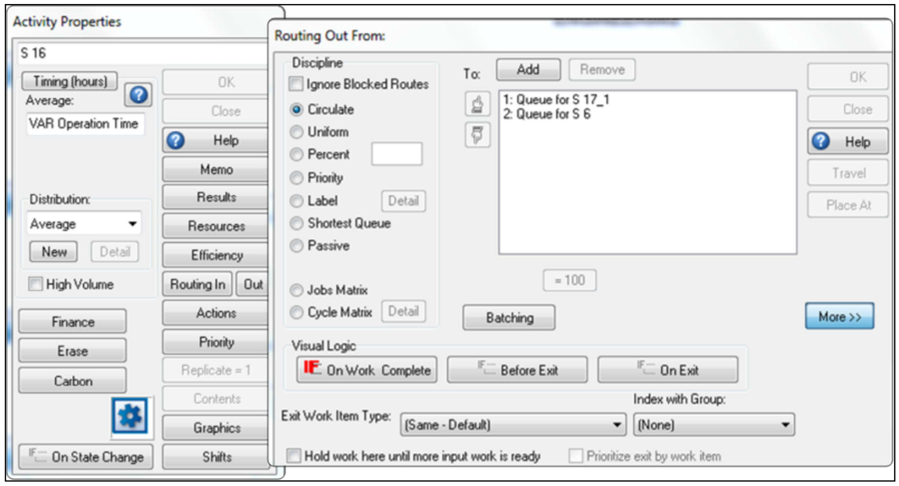


Figure 19 Routing-out from “S 16” activity using “Circulate” method.

This method is used in most of the activities. “Circulate” means that the first work item will go to the first destination in the list, the second work item to the second, the nth work item to the nth destination on the list. By default “Ignore Blocked Routes” option in Simul8 is checked, for this simulation this option has to be unchecked.

Most of the activities have got only one routing-out arrow, therefore they have got only one batch. But some of the activities have got several routing-out arrows so batching size depends on the number of connections with other activities. In the previous example, “S 16” activity has got two routing-out arrows, so the batching size is two. This data can be modified in “Batching” option. Figure 20 shows it.

Figure 20 Batching option inside “Routing Out” options.

Routing-out using “Percent” method was established in “Routing Out” option inside “Activity Properties”. Figure 21 shows it, using “ASY” activity as an example.

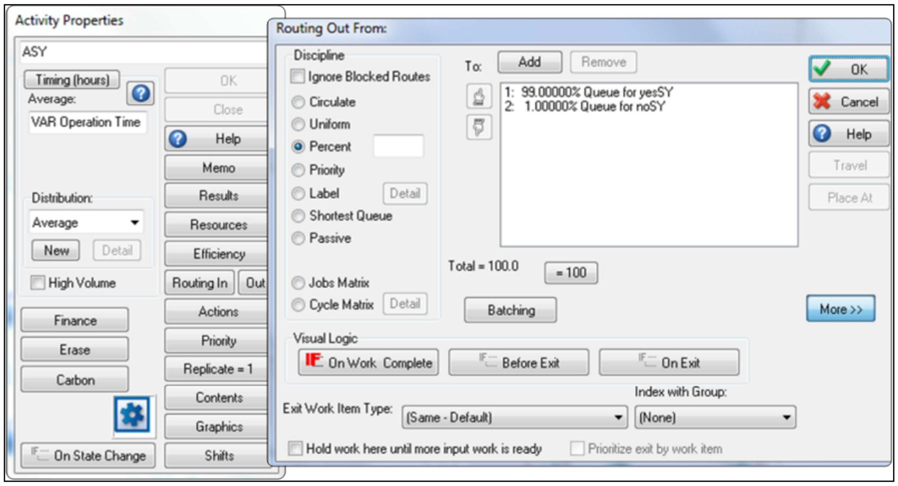


Figure 21 Routing-out from “ASY” activity using “Percent” method.

This method is used only in the activities that represent approval from shipyard and approval from classification.

Previous figure shows the routing-out of approval from shipyard. It has got 99% probability to get the approval and 1% probability to not get the approval.

These percentages can be changed directly when the simulation is started in one dialog or directly in the “Routing Out” options shown in the previous figure.

Both approvals consider the unit in the batching size.

4.2.4 On Work Complete

As defined previously, when the work item enters in an activity, operation time is multiplied by a number according to the complexity level.

Therefore, previous the work item leaving from the activity, operation time must be the same as at the beginning to continue with the work flow.

In most of the activities there is a code in the Visual Logic place “On Work Complete” Visual Logic location. Figure 22 shows the location of this option.

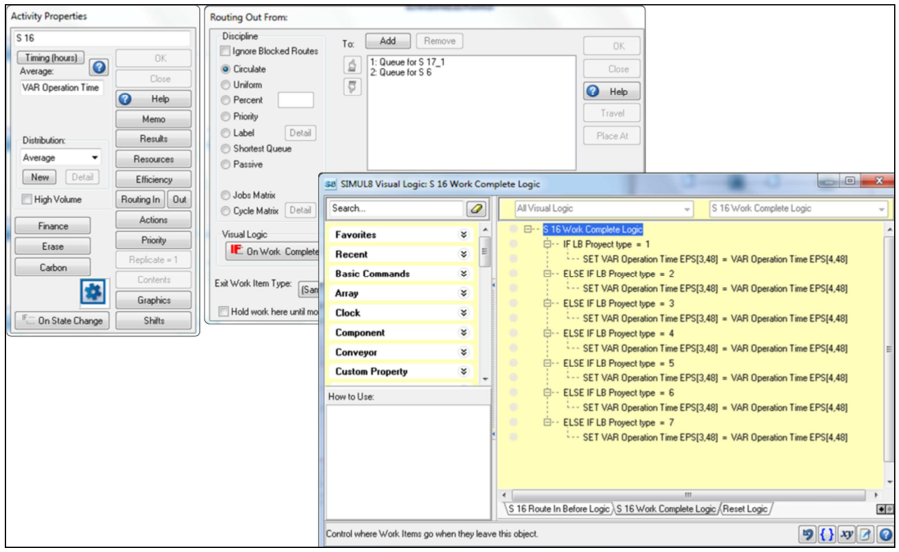


Figure 22 “On Work Complete” location of “S 16” activity.

This Visual Logic location is placed in “More” button of “Routing Out” window of each activity. The following code shows the adjustment of the operation time, using “S 16” activity as an example.

```
VL SECTION: S 16 Work Complete Logic

  IF LB Project type = 1
    SET VAR Operation Time EPS[3,48] = VAR Operation Time
EPS[4,48]
  ELSE IF LB Project type = 2
    SET VAR Operation Time EPS[3,48] = VAR Operation Time
EPS[4,48]
  ELSE IF LB Project type = 3
    SET VAR Operation Time EPS[3,48] = VAR Operation Time
EPS[4,48]
  ELSE IF LB Project type = 4
    SET VAR Operation Time EPS[3,48] = VAR Operation Time
EPS[4,48]
  ELSE IF LB Project type = 5
    SET VAR Operation Time EPS[3,48] = VAR Operation Time
EPS[4,48]
  ELSE IF LB Project type = 6
    SET VAR Operation Time EPS[3,48] = VAR Operation Time
EPS[4,48]
  ELSE IF LB Project type = 7
    SET VAR Operation Time EPS[3,48] = VAR Operation Time
EPS[4,48]
```

The operation time is selected in the spreadsheet “VAR Operation Time EPS” and the code written chooses the time data of the “On Reset” column. As explained further, when the simulation is started, one dialog asks to the user to introduce time data in this spreadsheet. Another dialog specifies that the time data in “Time” column must be the same than in “On Reset” column. Figure 23 shows part of this spreadsheet.

Engineering Process Steps			
Activity	EPS	Time	On Reset
2.1 Technical Handover from Sales	S 1	7,00	7,00
2.2 Prepare external kick-off meeting memo	S 2_1	15,00	15,00
2.2 Customer kick-off meeting	S 2_2	7,00	7,00
2.3 Prepare SMDL	S 3_1	22,00	22,00
2.3 Internal kick-off meeting	S 3_2	7,00	7,00
2.4 Schedule engineering tasks and provide input to PA	S 4	22,00	22,00
2.5 Create project folder structure in ECM	S 5_1	22,00	22,00

Figure 23 Some operation time data in the spreadsheet of the simulation model.

This spreadsheet allows the introduction of all the operation times of the engineering process steps. Time data in both columns are the same at the beginning, only "Time" column data changes through the simulation, as explained in "Before Selecting" Visual Logic location.

To facilitate several simulation runs avoiding the introduction of the time data every simulation, "On Reset" column was created.

Therefore, the code written in this Visual Logic location establishes the "On Reset" data time to continue with the next activity of the work flow.

As explained in the previous chapters, new activities were created to represent the re-work that engineers have to do if one project is not approved.

In the present simulation model a message appears when a project is not approved from Shipyard. Figure 24 shows this message.

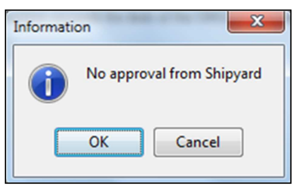


Figure 24 Informative message established by "VAR noSY" variable.

It is related with the variable "VAR noSY" in "Global Data Item". Another message appears when a project is not approved from Classification. Figure 25 shows this message.

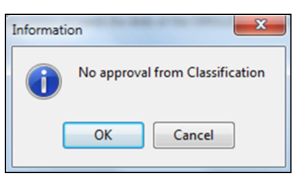


Figure 25 Informative message established by "VAR noC" variable.

It is related with the variable "VAR noSY" in "Global Data Item".

Table 17 shows the information of both variables and their type and purpose.

Table 17 Variables that show informative messages in the no approvals.

Name	Type	Purpose
VAR noSY	Text	Message: “No approval from Shipyard”
VAR noC	Text	Message: “No approval from Classification”

To show these messages through the simulation, Visual Logic was used. The following codes represent the “On Work Complete” logic of “noSY” activity and “noC” activity respectively.

```
VL SECTION: noSY Work Complete Logic
  Display Message    VAR noSY

VL SECTION: noC Work Complete Logic
  Display Message    VAR noC
```

These messages appear every time when the engineering process simulation model runs and there is not approval.

4.3 Use of Resources

As explained previously, resources are considered engineers. There are seven different engineering specialities. Six of these specialities have got three different experience levels each of them. In the present simulation model each resource can work only in one activity at the same time and has got 100% of availability. This data can be modified in “Resource Properties” options. Figure 26 shows this information.

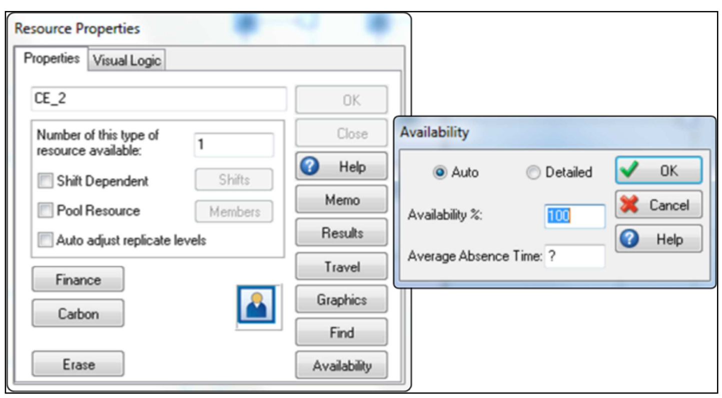


Figure 26 Availability in “Resource Properties” options.

To assign the resources to the different activities, Visual Logic was used, because it is a complex responsibility distribution of each engineer in relation with the complexity level of the project.

4.3.1 Responsibilities

The use of the resources is according to the complexity level of the project. Table 18 shows the responsible to the different projects according with the complexity level.

Table 18 Engineers responsibilities

Project type	Level	Label	Responsible
Repeat project	Level 1	≤ 3	Low experience Medium experience High experience
Prototype project	Level 2	= 4	Medium experience High experience
New technology	Level 3	≥ 5	High experience

The work to do of each engineer is a list of pending activities. The order of these activities is defined by the work item through the work flow. The first engineer that is free represents the first resource to perform the first pending activity.

4.3.2 After Loading Work

To simulate the complex responsibility distribution of each engineer in Visual Logic, a code was written in "After Loading Work" location. Figure 27 shows where this code is located.

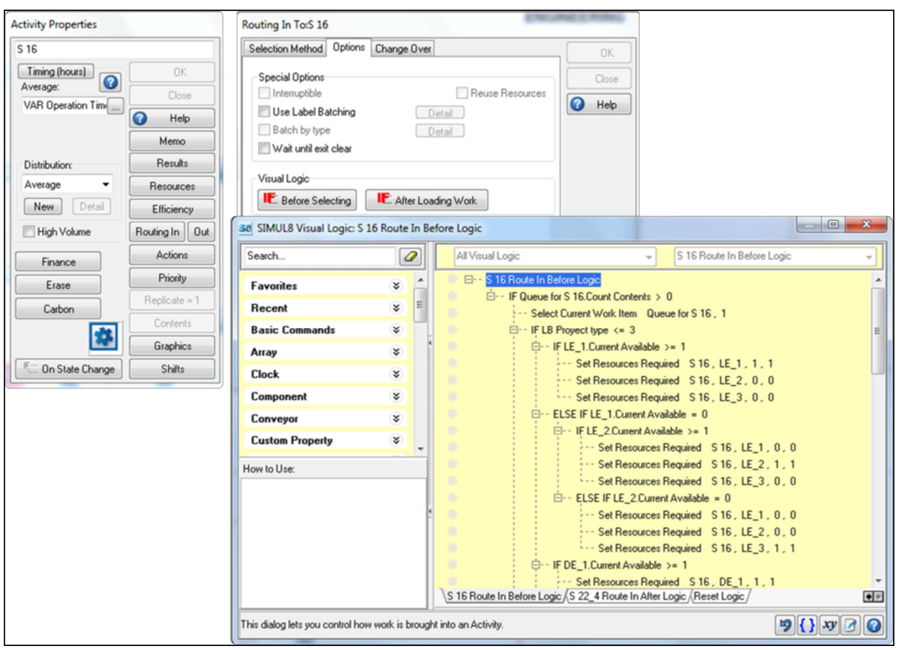


Figure 27 "After Loading Work" location of "S 16" activity.

This Visual Logic location was placed in "Options" of "Routing In" window of each activity. The code written establishes the resources according with the complexity level defined with the label number. In the following code of “S 10_4” activity shows this logic.

```
VL SECTION: S 10_4 Route In Before Logic

  IF Queue for S 10_4.Count Contents > 0
    Select Current Work Item    Queue for S 10_4, 1

    IF LB Project type <= 3
      IF SE_1.Current Available >= 1
        Set Resources Required    S 10_4, SE_1, 1, 1
        Set Resources Required    S 10_4, SE_2, 0, 0
        Set Resources Required    S 10_4, SE_3, 0, 0
      ELSE IF SE_1.Current Available = 0
        IF SE_2.Current Available >= 1
          Set Resources Required    S 10_4, SE_1, 0, 0
          Set Resources Required    S 10_4, SE_2, 1, 1
          Set Resources Required    S 10_4, SE_3, 0, 0
        ELSE IF SE_2.Current Available = 0
          Set Resources Required    S 10_4, SE_1, 0, 0
          Set Resources Required    S 10_4, SE_2, 0, 0
          Set Resources Required    S 10_4, SE_3, 1, 1

    ELSE IF LB Project type = 4
      IF SE_2.Current Available >= 1
        Set Resources Required    S 10_4, SE_1, 0, 0
        Set Resources Required    S 10_4, SE_2, 1, 1
        Set Resources Required    S 10_4, SE_3, 0, 0
      ELSE IF SE_2.Current Available = 0
        Set Resources Required    S 10_4, SE_1, 0, 0
        Set Resources Required    S 10_4, SE_2, 0, 0
        Set Resources Required    S 10_4, SE_3, 1, 1

    ELSE IF LB Project type >= 5
      Set Resources Required    S 10_4, SE_1, 0, 0
      Set Resources Required    S 10_4, SE_2, 0, 0
      Set Resources Required    S 10_4, SE_3, 1, 1
```

In the previous code the resource availability is checked from the low until high experience level. There are three possible cases according with the complexity level:

First case, if work item has got ≤ 3 label number, engineer(s) availability of low experience is checked, in this case “SE_1” resource.

- If it is available, “SE_1” does the work. Else if not, engineer(s) availability of medium experience is checked, in this case “SE_2” resource.
- If it is available, “SE_2” does the work. Else if not, engineer(s) availability of high experience is checked, in this case “SE_3” resource.
- If it is available, “SE_3” does the work. Else if not, queue holds the work item until one of them will be free.

Second case, if work item has got = 4 label number, engineer(s) availability of medium experience is checked, in this case “SE_2” resource.

– If it is available, “SE_2” does the work. Else if not, engineer(s) availability of high experience is checked, in this case “SE_3” resource.
– If it is available, “SE_3” does the work. Else if not, queue holds the work item until one of them will be free.

Third case, if work item has got ≥ 5 label number, engineer(s) availability of high experience is checked, in this case “SE_3” resource.

– If it is available, “SE_3” will do the work. Else if not, queue holds the work item until will be free.

This logic is followed to assign the resources in the activities where more than one engineering speciality is involved. Next code using “S 16” activity shows how three different engineering specialities are called to perform the activity.

```
VL SECTION: S 16 Route In Before Logic

  IF Queue for S 16.Count Contents > 0
    Select Current Work Item    Queue for S 16, 1

    IF LB Project type <= 3
      IF LE_1.Current Available >= 1
        Set Resources Required    S 16, LE_1, 1, 1
        Set Resources Required    S 16, LE_2, 0, 0
        Set Resources Required    S 16, LE_3, 0, 0
      ELSE IF LE_1.Current Available = 0
        IF LE_2.Current Available >= 1
          Set Resources Required    S 16, LE_1, 0, 0
          Set Resources Required    S 16, LE_2, 1, 1
          Set Resources Required    S 16, LE_3, 0, 0
        ELSE IF LE_2.Current Available = 0
          Set Resources Required    S 16, LE_1, 0, 0
          Set Resources Required    S 16, LE_2, 0, 0
          Set Resources Required    S 16, LE_3, 1, 1
      IF DE_1.Current Available >= 1
        Set Resources Required    S 16, DE_1, 1, 1
        Set Resources Required    S 16, DE_2, 0, 0
        Set Resources Required    S 16, DE_3, 0, 0
      ELSE IF DE_1.Current Available = 0
        IF DE_2.Current Available >= 1
          Set Resources Required    S 16, DE_1, 0, 0
          Set Resources Required    S 16, DE_2, 1, 1
          Set Resources Required    S 16, DE_3, 0, 0
        ELSE IF DE_2.Current Available = 0
          Set Resources Required    S 16, DE_1, 0, 0
          Set Resources Required    S 16, DE_2, 0, 0
          Set Resources Required    S 16, DE_3, 1, 1
      Set Resources Required    S 16, PM, 1, 1

    ELSE IF LB Project type = 4
      IF LE_2.Current Available >= 1
        Set Resources Required    S 16, LE_1, 0, 0
        Set Resources Required    S 16, LE_2, 1, 1
        Set Resources Required    S 16, LE_3, 0, 0
      ELSE IF LE_2.Current Available = 0
        Set Resources Required    S 16, LE_1, 0, 0
```

```
      Set Resources Required    S 16, LE_2, 0, 0
      Set Resources Required    S 16, LE_3, 1, 1
    IF DE_2.Current Available >= 1
      Set Resources Required    S 16, DE_1, 0, 0
      Set Resources Required    S 16, DE_2, 1, 1
      Set Resources Required    S 16, DE_3, 0, 0
    ELSE IF DE_2.Current Available = 0
      Set Resources Required    S 16, DE_1, 0, 0
      Set Resources Required    S 16, DE_2, 0, 0
      Set Resources Required    S 16, DE_3, 1, 1
    Set Resources Required    S 16, PM, 1, 1

  ELSE IF LB Project type >= 5
    Set Resources Required    S 16, LE_1, 0, 0
    Set Resources Required    S 16, LE_2, 0, 0
    Set Resources Required    S 16, LE_3, 1, 1
    Set Resources Required    S 16, DE_1, 0, 0
    Set Resources Required    S 16, DE_2, 0, 0
    Set Resources Required    S 16, DE_3, 1, 1
    Set Resources Required    S 16, PM, 1, 1
```

Once the code was introduced in this Visual Logic location, the resources are established in the activity. They can be checked in “Resources Required” option of each “Activity Properties”. Figure 28 shows this options.

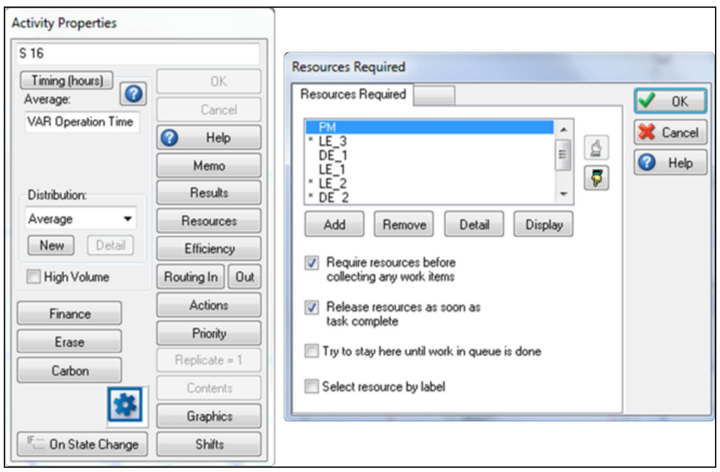


Figure 28 “Resources Requires” options of the “S 16” activity.

Also in this window there are more options that can modify the behaviour of the resources. By default two options are checked:

- Require resources before collecting any work item.
- Release resources as soon as task complete.

In the present simulation model they are used. Another way to check where resources are used is in “Where is resource used” option of “Resource Properties”. Figure 29 shows this information.

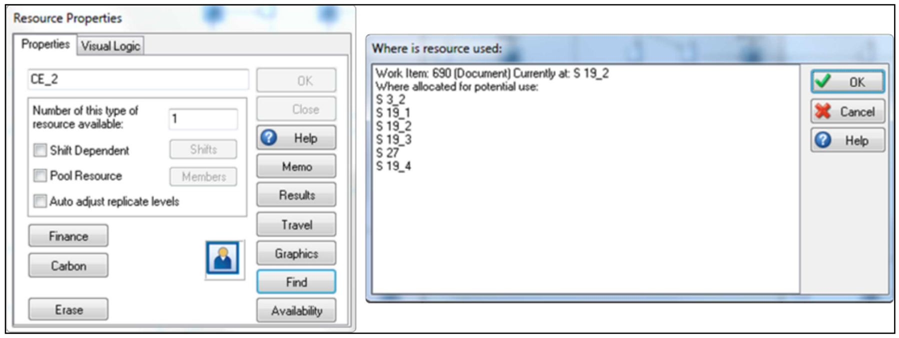


Figure 29 “Where resource is used” option in “Resource Properties”.

As explained previously, each engineer can work only in one activity at the same time. This was the reason that the code written establishes one engineer as a minimum number and also as a maximum number of resources to perform each activity.

The number of engineer(s) can be modified when the simulation is started in the dialogs according to the different engineering specialities or in the simulation object than represents the resource in the “Number Available” option. Figure 30 shows the last option in “Availability” section of Simul8.

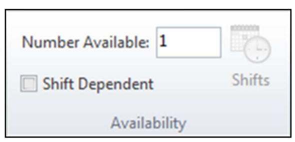


Figure 30 “Number Available” in “Availability” section of Simul8.

4.3.3 Travel Time

Simul8 calculates travel times before activities, and they are defined by the distance between them. In the present simulation model, the main scenario is an office environment, and the distances between activities are not considered, but some activities require that engineers travel previous the activity performance.

ABB personnel specified three existing travel times in the engineering process. The following Table 19 shows these travel times of the engineer(s) before to perform the activity and the references of them in the simulation model.

Table 19 Travel times in the engineering process simulation model.

Travel time	Before	Reference
Travel to “Customer kick-off ” meeting	S 2_2	VAR Travel time 2_2
Travel to “Interface” meeting	S 10_3	VAR Travel time 10_3

Travel to "FATs"	S 22_1 S 22_2 S 22_3 S 22_4 S 22_5 S 22_6 S 22_7	VAR Travel time 22

As shown in the previous Table 19, one travel time is considered before "Customer kick-off" meeting, and another travel time before "Interface" meeting. In the travel to "FATs" one travel time is considered before seven different activities, it means that the travel time is the same before each FAT. In relation with the lack of information of these travel times, in the present simulation model an average of travel times before FATs was considered.

To represent the travel time in the engineering process simulation model, Visual Logic was used. The following code, using "S 10_3" activity, shows how the travel time is added in the operation time of the activity.

```
VL SECTION: S 10_3 Route In After Logic

  IF LB Project type = 1
    SET VAR Operation Time EPS[3,24] = [VAR Operation Time
EPS[3,24]*0.25]+VAR Travel time 10_3
  ELSE IF LB Project type = 2
    SET VAR Operation Time EPS[3,24] = [VAR Operation Time
EPS[3,24]*0.5]+VAR Travel time 10_3
  ELSE IF LB Project type = 3
    SET VAR Operation Time EPS[3,24] = [VAR Operation Time
EPS[3,24]*0.75]+VAR Travel time 10_3
  ELSE IF LB Project type = 4
    SET VAR Operation Time EPS[3,24] = [VAR Operation Time
EPS[3,24]*1]+VAR Travel time 10_3
  ELSE IF LB Project type = 5
    SET VAR Operation Time EPS[3,24] = [VAR Operation Time
EPS[3,24]*1.25]+VAR Travel time 10_3
  ELSE IF LB Project type = 6
    SET VAR Operation Time EPS[3,24] = [VAR Operation Time
EPS[3,24]*1.5]+VAR Travel time 10_3
  ELSE IF LB Project type = 7
    SET VAR Operation Time EPS[3,24] = [VAR Operation Time
EPS[3,24]*1.75]+VAR Travel time 10_3
```

The code written in "Before Selecting" Visual Logic location was modified to include the travel time in the operation time of the activity. The following code shows "S 22_5" activity related to the FATs and the travel time added.

```
VL SECTION: S 22_5 Route In After Logic
  IF LB Project type = 1
    SET VAR Operation Time EPS[3,82] = [VAR Operation Time
EPS[3,82]*0.25]+VAR Travel time 22
  ELSE IF LB Project type = 2
    SET VAR Operation Time EPS[3,82] = [VAR Operation Time
EPS[3,82]*0.5]+VAR Travel time 22
  ELSE IF LB Project type = 3
```

```
    SET VAR Operation Time EPS[3,82] = [VAR Operation Time
EPS[3,82]*0.75]+VAR Travel time 22
  ELSE IF LB Project type = 4
    SET VAR Operation Time EPS[3,82] = [VAR Operation Time
EPS[3,82]*1]+VAR Travel time 22
  ELSE IF LB Project type = 5
    SET VAR Operation Time EPS[3,82] = [VAR Operation Time
EPS[3,82]*1.25]+VAR Travel time 22
  ELSE IF LB Project type = 6
    SET VAR Operation Time EPS[3,82] = [VAR Operation Time
EPS[3,82]*1.5]+VAR Travel time 22
  ELSE IF LB Project type = 7
    SET VAR Operation Time EPS[3,82] = [VAR Operation Time
EPS[3,82]*1.75]+VAR Travel time 22
```

The “VAR Travel time 22” was added in the same way in the rest of the activities related to the FATs.

4.4 Use of Data

In the previous chapters the main simulation objects and elements have been explained, also their main purpose and actions. This chapter explains how the data is performed through them.

In both simulation model files the performance is the same, only the user interface is the main difference between them.

4.4.1 Preferences

Simul8 establishes by default different options related with the simulation performance.

In the present simulation most of the default options are used, only some options were changed in “Distance” section.

Figure 31 shows the information of this section.

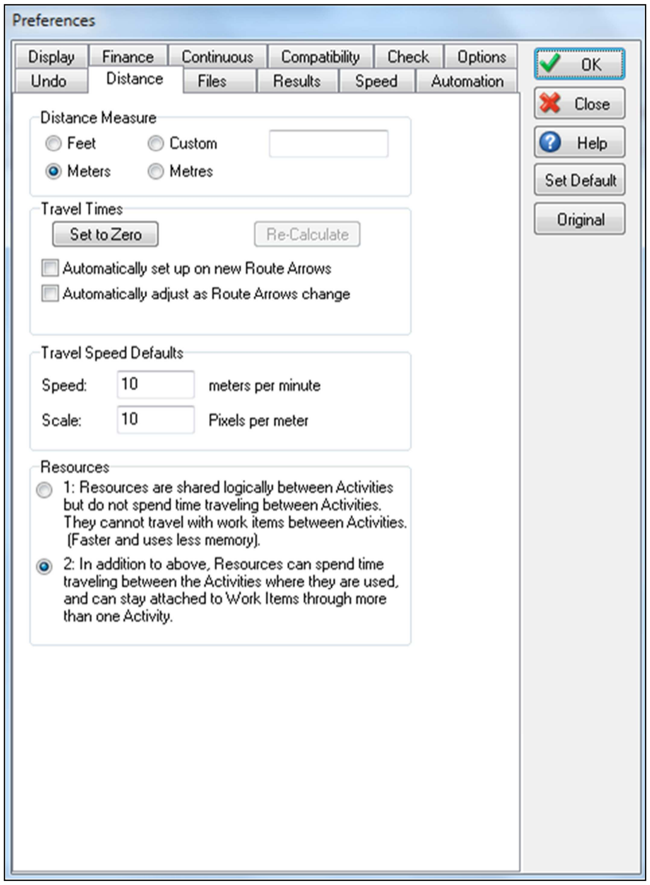


Figure 31 Distance section of “Preferences” option.

By default “Automatically set up on new Route Arrows” and “Automatically adjust as Route Arrows change” options are checked, and they are related with “Travel times”. As explained previously, in the present simulation model travel times between activities were not considered, only three specific travel times.

Therefore, to unchecked these options “Set to Zero” is selected, one message appears informing that once a travelling time is set to zero, only travel time can be introduced in routing-out option of each activity.

4.4.2 Clock Properties

The present simulation model performs in hours. Therefore, all the time data introduced must be in hours. The personnel of ABB Marine and Cranes established the working time of the department in 7.5 hours per day, and 220 days per year. This information was introduced in the simulation model using “Clock Properties” option which is located in “Clock” section of Simul8. Figure 32 shows the information of this options.

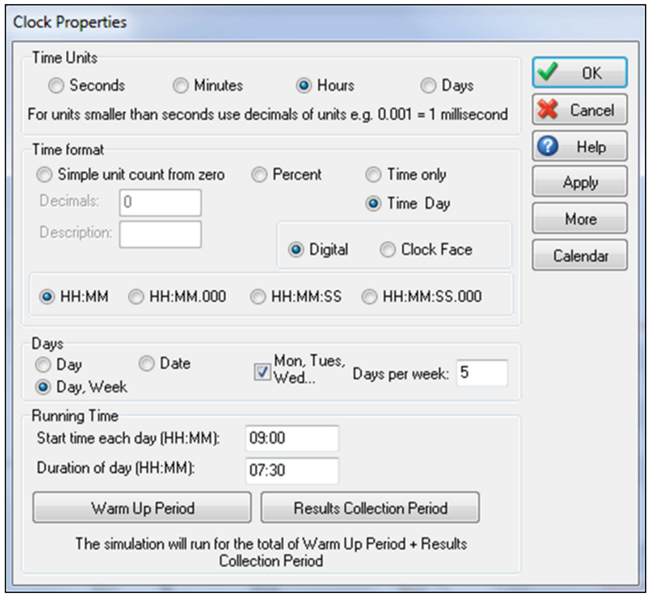


Figure 32 “Clock Properties” options of the simulation model.

Previous figure shows the time data used in the simulation model and Figure 33 shows the user’s view of this time data introduced.

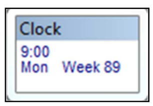


Figure 33 User’s view of the clock time data.

Simul8 allows introducing “Warm Up Period”, it means previous working time. Most of the processes don’t start since zero. They have some work going when the simulation runs. In the present simulation model this time can be considered. In that case, simulation time must be higher than warm up period, because the total time that Simul8 simulates follows the next rule:

Time to simulate = Simulation time – Warm up period

For example, if we want to simulate 2 years, and a warm up period of 5 years, the simulation time will be 7 years (2 = 7 – 5). This time data can be introduced in “Clock Properties” option or in a dialog when the simulation model is opened.

4.4.3 Start Point Properties

As explained previously, in the present simulation model “LB Project type” label was created to identify seven project types. To this label “ProjectType%” distribution was attached, it is a discrete distribution where the input percentage of each project type is established. Figure 34 shows the connection of these two simulation elements in the “Start Point” simulation object.

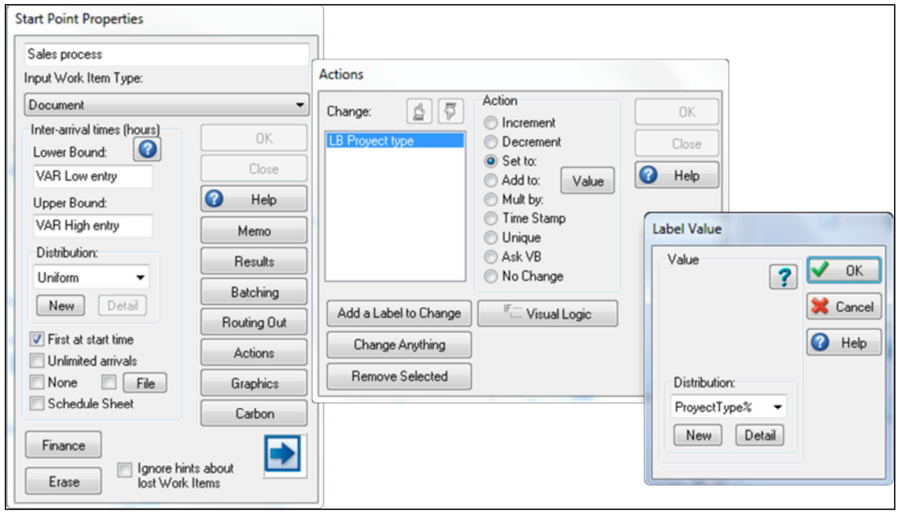


Figure 34 “Start Point Properties” options.

The label was applied in “Actions” option of “Start Point Properties”. To link it with the distribution created, “Set to” option was selected, “Label Value” window was opened and in “Distribution” option “ProjectType%” was established. This distribution establishes the input percentages of the project types.

As shown in the previous figure ”First at start time” option is checked, it means that a first work item enters in the work flow when the simulation model is started.

The time between work item entries was specified in “Start Point Properties”, to establish this inter-arrival times a “Uniform” distribution was selected. There is a low bound defined by “VAR Low entry” and upper bound defined by ”VAR High entry”, these data can be changed in this option or in a dialog when the simulation model is started.

4.4.4 Links

Activities and queues are the main simulation objects used in the present simulation model. They create all the relevant data collected in the results.

As explained previously, these two simulation objects were connected using routing-in and routing-out. In relation with the engineering process steps the routing uses one or another method.

Simul8 offers an option to facilitate the routing between activities. This option is also a browser of the routing arrows. Figure 35 shows the option where all the connections between activities and queues are shown.

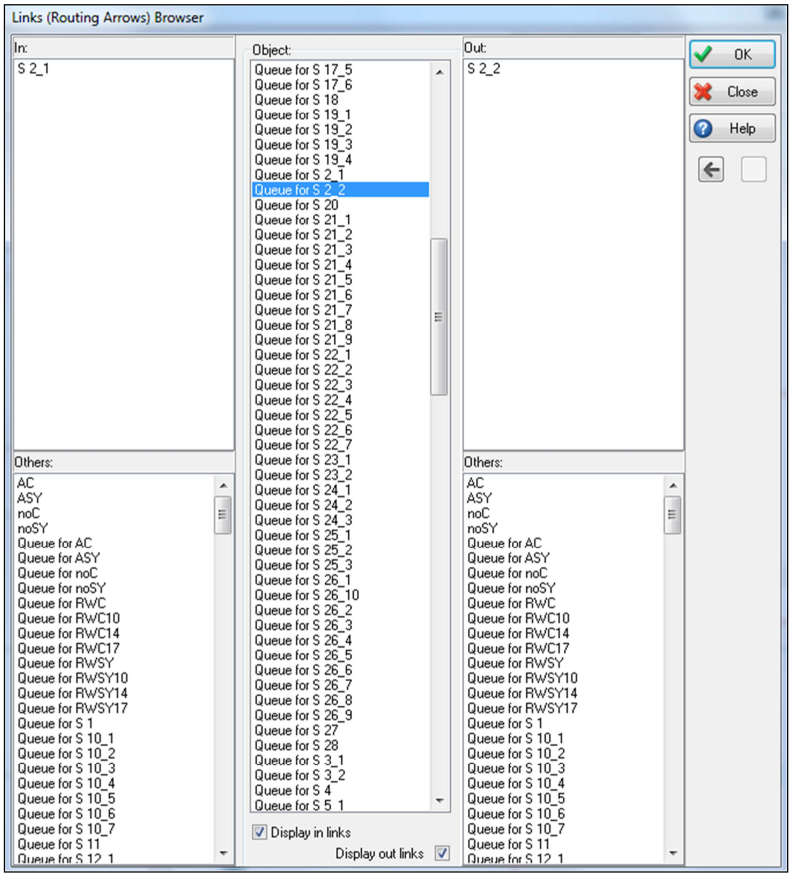


Figure 35 Links option in the simulation model

Once the routing arrows were created and they connected activities and queues, this option was useful to ensure these connections.

4.4.5 Components

In the present thesis two simulation model files were created. There are two main differences between them. The "ABB_Project Engineering Process_ Office" file reduces scale problems and user interface is easier and more intuitive than the "ABB_Project Engineering Process_ Work Flow" file.

Components facilitate these two main differences. The model is large and to reduce scale problems, components were created to join different simulation objects in one. And to make an easy and intuitive user interface, components allow a direct link with dialogs where data can be changed easily. The main view of the "ABB_Project Engineering Process_ Office" file is shown in the Figure 36.

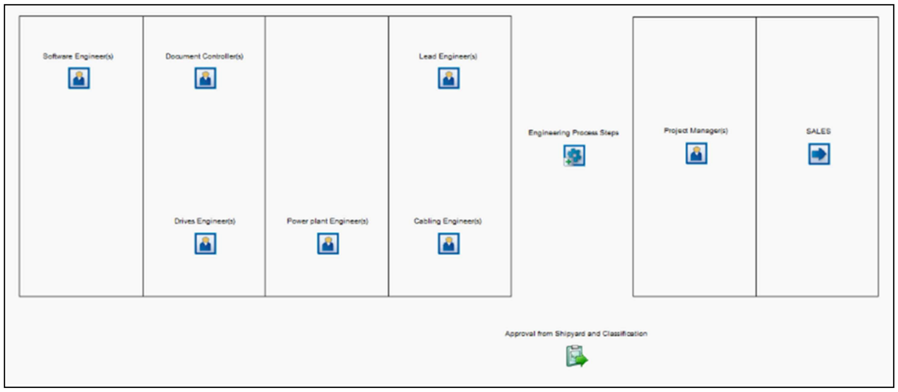


Figure 36 Main view of the “ABB_Project Engineering Process_ Office” file.

As shown in the previous figure, there are nine components and one sub-window. Start point, resources and re-work simulation objects are the components of this file, the rest of the activities and queues were included in a sub-window. Table 20 shows the simulation objects included and the dialogs linked to each component.

Table 20 Simulation objects included and dialogs linked to each component.

Component	Simulation Object	Dialog
Approval from Shipyard and Classification	AC Queue for AC yesC Queue for yesC NoC Queue for noC RWC Queue for RWC RWC10 Queue for RWC10 RWC14 Queue for RWC14 RWC17 Queue for RWC17 ASY Queue for ASY yesSY Queue for yesSY NoSY Queue for noSY RWSY Queue for RWSY RWSY10 Queue for RWSY10 RWSY14 Queue for RWSY14 RWSY17 Queue for RWSY17	Percentage to get the APPROVAL

Cabling Engineer(s)	CE_1 CE_2 CE_3	Cabling Engineer (CE)
Document Controller(s)	DC_1 DC_2 DC_3	Document Controller (DC)
Drives Engineer(s)	DE_1 DE_2 DE_3	Drives Engineer (DE)
Lead Engineer(s)	LE_1 LE_2 LE_3	Lead Engineer (LE)
Power plant Engineer(s)	PE_1 PE_2 PE_3	Power plant Engineer (PE)
Project Manager(s)	PM	Project Manager (PM)
SALES	Sales process	DISTRIBUTION of the projects
Software Engineer(s)	SE_1 SE_2 SE_3	Software Engineer (SE)

As shown in the previous table, start point, resources, approval and rework simulation objects are the components. “Dialogs” option in “Component Properties” links the dialog to each component. Figure 37 shows this option.

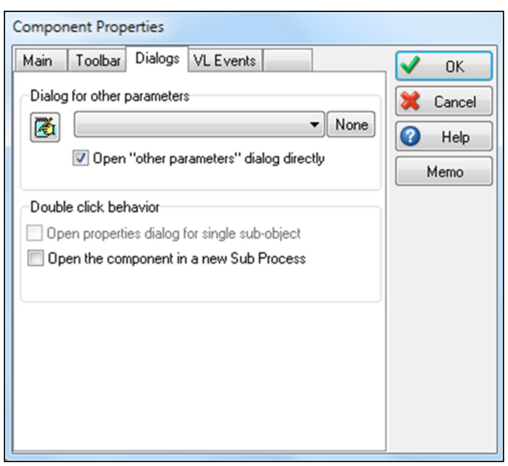


Figure 37 Dialogs option in “Component Properties”.

When the dialog of each component was selected, there is the option “Open other parameters dialog directly” that allows open directly the dialog when the component is selected. In the “ABB_Project Engineering Process_ Office” file this option was checked for all the components. It offers a quick interaction with the simulation model, but at the same time, it limits the possibility to change the properties of the simulation objects included in the components.

4.5 Custom Dialogs

In the two simulation model files created there are nineteen dialogs, four are only informative, fifteen are informative and they allow introducing data. Simul8 allows an easy interface to create and modify dialogs. Figure 38 shows this option that is located in "Dialogs" section of Simul8.

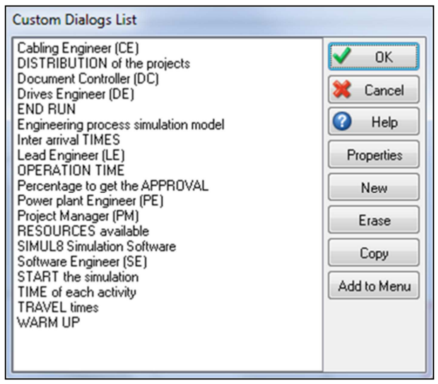


Figure 38 "Custom Dialogs List" option.

All the dialogs created in the present simulation model appear in this window. Below, these dialogs are explained following the order that they appear when the simulation is started.

4.5.1 Simul8 Simulation Software

Once the simulation is started, a first informative dialog appears with the information shown in the Figure 39.

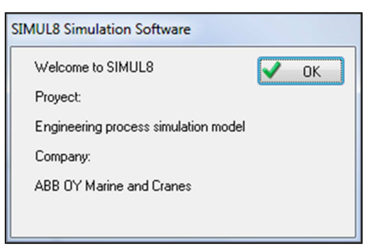


Figure 39 "Simul8 Simulation Software" dialog.

It is a welcome message to the simulation. The project name and company are shown in it. In this dialog only was used "Title" option that allows introducing text. When "OK" button is clicked next dialog is shown.

4.5.2 Engineering process simulation model

The information included in this dialog shows the main fields where user has to introduce data. Figure 40 shows this informative dialog.

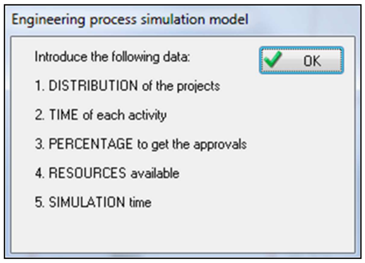


Figure 40 “Engineering process simulation model” dialog.

These fields are explained with more detail in following dialogs. In this dialog only was used “Title” option that allows introducing text. When “OK” is clicked next dialog is shown.

4.5.3 Distribution of the projects

“Distribution of the projects” dialog allows introducing the input percentages of the different project types based on their complexity level. Figure 41 shows this dialog.

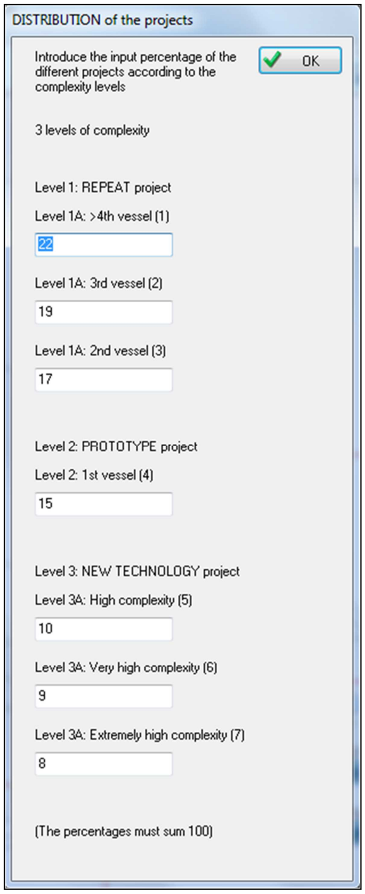


Figure 41 “Distribution of the project” dialog.

To create this dialog "Title" option was used to introduce the text, and "Data Field" option was used to create blank spaces where user can introduce the data asked. To link these data introduced with the "Global Data Item", "Formula Editor" was opened, "Information" type was selected, and the variables related with the data introduced in the blank spaces were selected. Figure 42 shows this link.

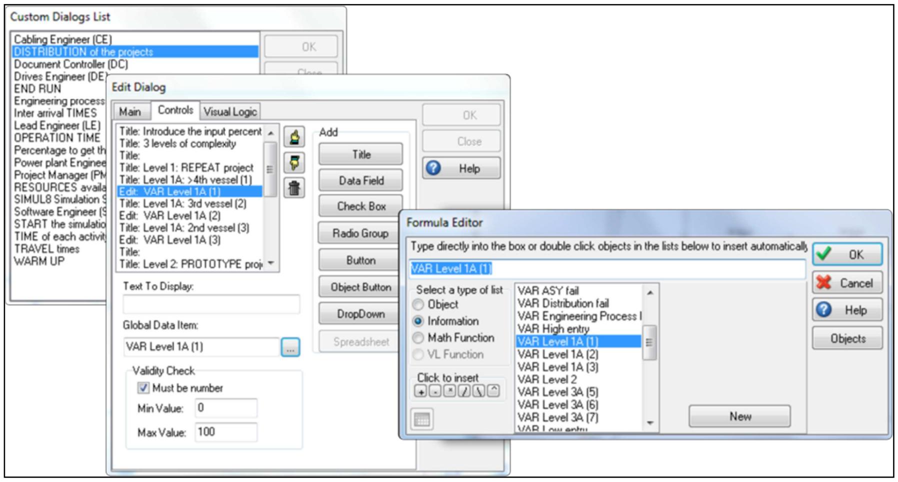


Figure 42 Link between data introduced and "Global Data Item".

In this case, there are seven blank spaces based on the seven input percentages. Table 21 shows the variables linked with the data introduced in the blank spaces.

Table 21 Variables linked with input percentages introduced.

Name	Type	Data introduced
VAR Level 1A (1)	Number	Input percentage Level 1 (> 4th vessel)
VAR Level 1A (2)	Number	Input percentage Level 1(3rd vessel)
VAR Level 1A (3)	Number	Input percentage Level 1 (2nd vessel)
VAR Level 2 (4)	Number	Input percentage Level 2 (1st vessel)
VAR Level 3A (5)	Number	Input percentage Level 3 (High technology)
VAR Level 3A (6)	Number	Input percentage Level 3 (Very high technology)
VAR Level 3A (7)	Number	Input percentage Level 3 (Extremely high technology)

These input percentages must be numbers and with a minimum value of 0 and with a maximum value of 100. These limitations were established in "Validity Check" option, as shown in the previous figure. When the "OK" button is clicked and the data introduced don't accomplish these limitations, one message appears informing that the percentages are not correct. Figure 43 shows this message.

Figure 43 Informative message established by "VAR Distribution fail" variable.

This message is established by "VAR Distribution fail" variable and it appears every time that the input percentages are wrong. Table 22 shows the variable linked with the informative message.

Table 22 Variable linked with informative message about input percentages.

Name	Type	Message
VAR Distribution fail	Text	"Probability profile not correct"

To apply all these actions in the simulation model, Visual Logic was used. In "Visual Logic" section of "Edit Dialog" option a code was introduced in "On OK Dialog" Visual Logic location. Figure 44 shows the location of this code.

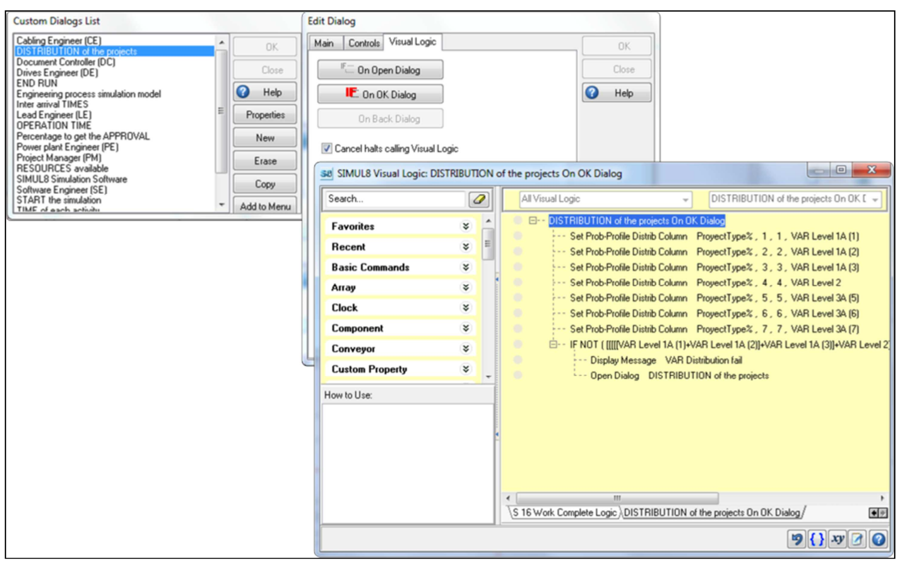


Figure 44 Code in "On OK Dialog" location of "Distribution of the projects" dialog.

The code written establishes the input percentages in "ProjectType%" distribution and checks that the total sum of all the percentages is 100.

```
VL SECTION: DISTRIBUTION of the projects On OK Dialog

  Set Prob-Profile Distrib Column      ProjectType%, 1, 1,
VAR Level 1A (1)
  Set Prob-Profile Distrib Column      ProjectType%, 2, 2,
VAR Level 1A (2)
  Set Prob-Profile Distrib Column      ProjectType%, 3, 3,
VAR Level 1A (3)
```

```
  Set Prob-Profile Distrib Column      ProjectType%, 4, 4,
VAR Level 2
  Set Prob-Profile Distrib Column      ProjectType%, 5, 5,
VAR Level 3A (5)
  Set Prob-Profile Distrib Column      ProjectType%, 6, 6,
VAR Level 3A (6)
  Set Prob-Profile Distrib Column      ProjectType%, 7, 7,
VAR Level 3A (7)

  IF NOT ( [[[[[VAR Level 1A (1)+VAR Level 1A (2)]+VAR Lev-
el 1A (3)]+VAR Level 2]+VAR Level 3A (5)]+VAR Level 3A
(6)]+VAR Level 3A (7)  =  100 )

    Display Message    VAR Distribution fail
    Open Dialog    DISTRIBUTION of the projects
```

Once the percentages are numbers between 0 and 100 and all of them sum 100, next dialog appears.

4.5.4 Inter arrival Times

In this dialog user has to introduce the inter-arrival times between projects. It is defined by a “Uniform” distribution that has got two limits, “Lower Bound” and “Upper Bound”. Figure 45 shows this dialog.

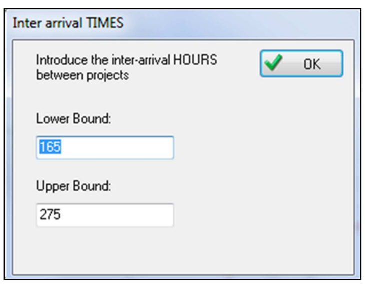


Figure 45 “Inter arrival Times” dialog.

To link these data introduced with the “Global Data Item”, “Formula Editor” was opened, “Information” type was selected, and the variables related with the data introduced in the blank spaces were selected. Figure 46 shows this link.

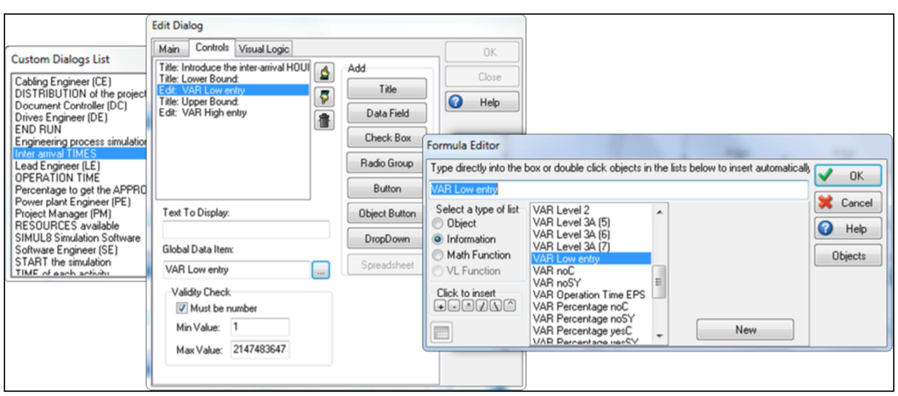


Figure 46 Link between data introduced and “Global Data Item”.

Table 23 shows the variables linked with the data introduced in the blank spaces.

Table 23 Variables linked with the “Uniform” distribution bounds.

Name	Type	Purpose
VAR High entry	Number	Distribution Upper Bound
VAR Low entry	Number	Distribution Lower Bound

The data introduced must be numbers and with 1 as minimum value. These specifications were established in “Validity Check” option, as shown in the previous figure. “Upper Bound” data must be higher than the “Lower Bound” data, and the next dialog will not appear until this rule will be true. To establish these actions, Visual Logic was used. Figure 47 shows the location of the code written.

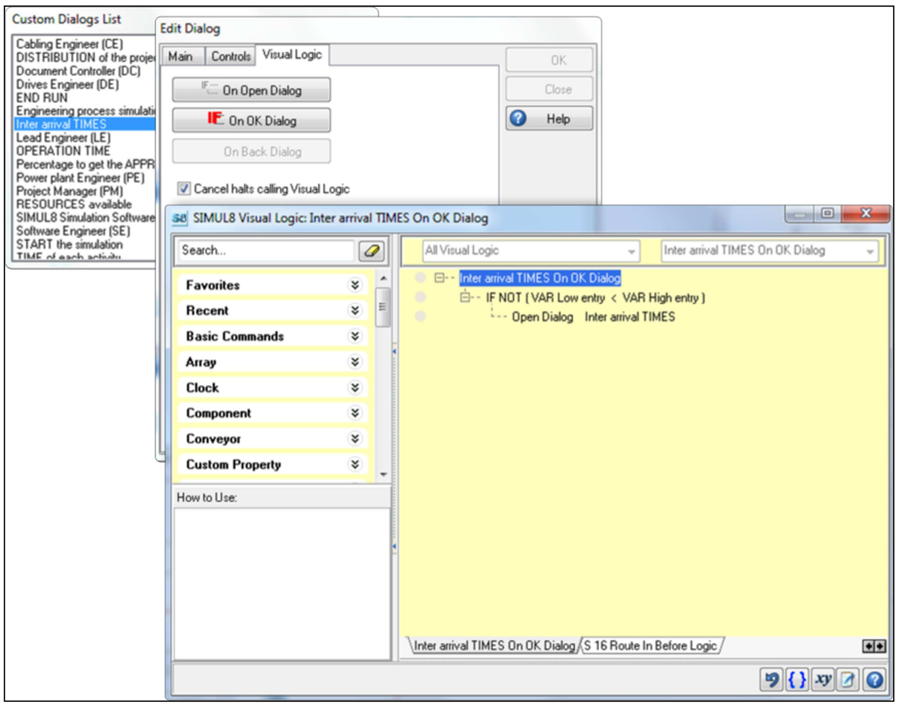


Figure 47 Code in “On OK Dialog” location of “Inter arrival Times” dialog.

This code establishes that the data introduced in “Lower Bound” must be lower than the data introduced in “Upper Bound”.

```
VL SECTION: Inter arrival TIMES On OK Dialog

  IF NOT (VAR Low entry < VAR High entry)
    Open Dialog    Inter arrival TIMES
```

If this logic is not accomplished, inter arrival times dialog is shown. When this logic is true, next dialog appears.

4.5.5 Time of each activity

Operation time information is shown in this dialog, and how the present simulation model calculates this time according with the complexity level of each project type. Figure 48 shows this dialog.

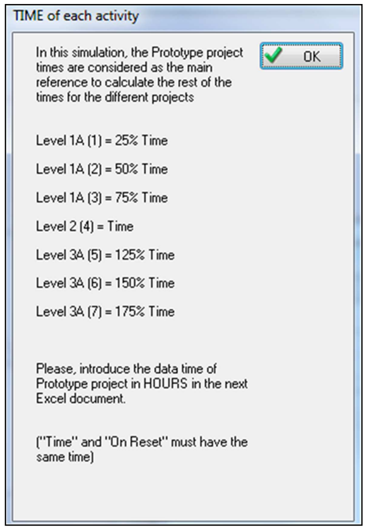


Figure 48 “Time of each activity” dialog.

Table 24 explains the information shown in the dialog with the information explained in previous sections.

Table 24 Time information of the “Time of each activity” dialog.

Level	Label	Time	Dialog information
Level 1A Level 1A Level 1A	1 2 3	t – t * 75% t – t * 50% t – t * 25%	Level 1A (1) = 25% Time Level 1A (2) = 50% Time Level 1A (3) = 75% Time
Level 2	4	t	Level 2 (4) = Time
Level 3A Level 3A Level 3A	5 6 7	t + t * 25% t + t * 50 % t + t * 75%	Level 3A (5) = 125% Time Level 3A (6) = 150% Time Level 3A (7) = 175% Time

When “OK” button of this informative dialog is clicked, next dialog appears.

4.5.6 Operation Time

The present dialog has got a link with the spreadsheet “VAR Operation Time EPS”. Therefore, user can introduce all the operation times according with the engineering process steps. As explained in the previous chapters “Time” and “On Reset” column must have the same time. This dialog is shown in Figure 49.

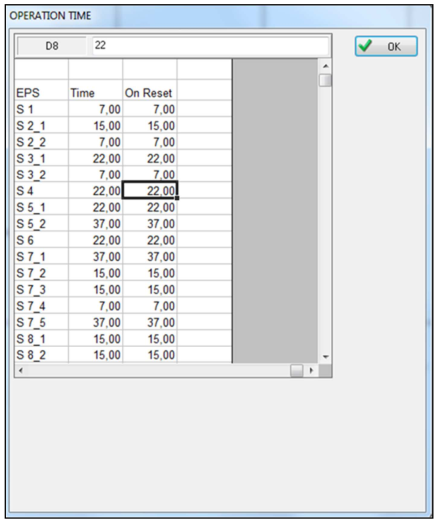


Figure 49 “Operation Time” dialog.

Simul8 offers the “Spreadsheet” option that creates a direct link to any spreadsheet created in “Global Data Item”. Figure 50 shows how this link was established.

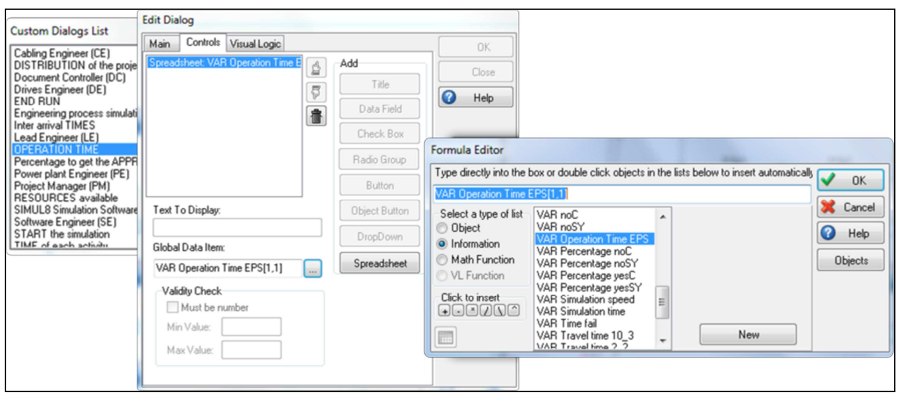


Figure 50 Link between “Operation Time” dialog and spreadsheet.

To link the spreadsheet “Formula Editor” was opened, “Information” type was selected, and the variable related with the spreadsheet was selected. Table 25 shows the variable linked with the spreadsheet.

Table 25 Variables linked with the “VAR Operation Time EPS” spreadsheet.

Name	Type	Purpose
VAR Operation Time EPS	Spread-sheet	Operation time of each Engineering Process Step

Once all the operation times are introduced, “OK” button is clicked and next dialog is shown.

4.5.7 Percentage to get the Approval

The percentages to get the different approvals were introduced in this dialog. The Electrical Systems and Project department personnel of ABB Marine and Cranes established the following criteria to get the approvals:

- Shipyard is interested in size and weight of products, and approves 99% of the products because they are defined based on customer requirements. If a product is not approved, it may need to be changed to other type or re-design.
- Classification is interested in safety and inspects the system functionality and protection logic. 90% of cases, it approves the design on first round. If not, the system is re-designed.

Figure 51 shows the dialog created to allow the introduction of the data explained above.

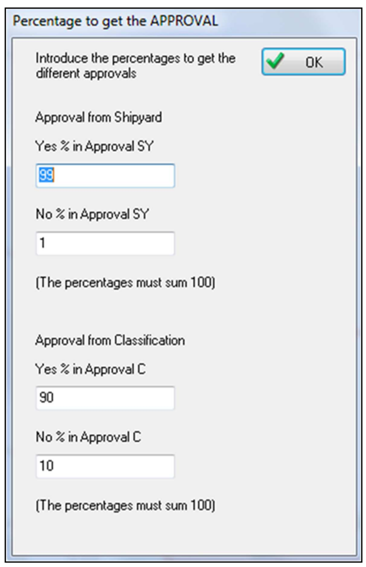


Figure 51 “Percentage to get the Approval” dialog.

The data introduced was connected with the routing-out option in both approvals represented by “ASY” activity and “AC” activity. To link these data introduced with the “Global Data Item”, “Formula Editor” was opened, “Information” type was selected, and the variables related with the data introduced in the blank spaces were selected. Figure 52 shows this link.

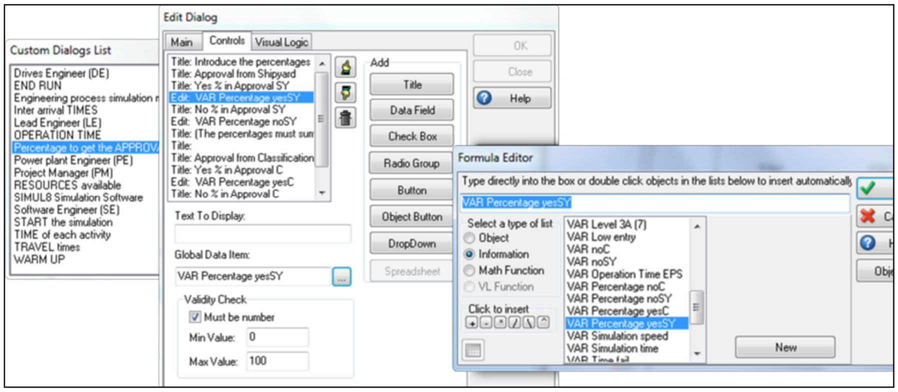


Figure 52 Link between data introduced and “Global Data Item”.

Table 26 shows the variables linked with the data introduced in the blank spaces.

Table 26 Variables linked with percentages introduced.

Name	Type	Data introduced
VAR Percentage noC	Number	No % in Approval from Classification
VAR Percentage noSY	Number	No % in Approval from Shipyard
VAR Percentage yesC	Number	Yes % in Approval from Classification
VAR Percentage yesSY	Number	Yes % in Approval from Shipyard

These percentages must be numbers and with a minimum value of 0 and with a maximum value of 100. These limitations were established in “Validity Check” option, as shown in the previous figure. In the present dialog there is a sentence between parentheses informing that the percentages introduced in “Approval from Shipyard” must sum 100, if not, a message informing about an error appears. Figure 53 shows this message.

Figure 53 Informative message established by “VAR ASY fail” variable.

This message is established by “VAR ASY fail” variable and it appears every time that the percentages are wrong. The same logic is applied in “Approval from Classification”. Figure 54 shows the message.

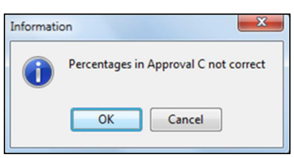


Figure 54 Informative message established by “VAR AC fail” variable.

This message is established by “VAR AC fail” variable and it appears every time that the percentages are wrong. Table 27 shows the variables linked with the informative messages.

Table 27 Variables linked with the informative messages about the wrong percentages to get the approvals.

Name	Type	Message
VAR AC fail	Text	“Percentages in Approval C not correct”
VAR ASY fail	Text	“Percentages in Approval SY not correct”

To apply all these actions in the simulation model, Visual Logic was used. In “Visual Logic” section of “Edit Dialog” option a code was introduced in “On OK Dialog” Visual Logic location. Figure 55 shows the location of this code.

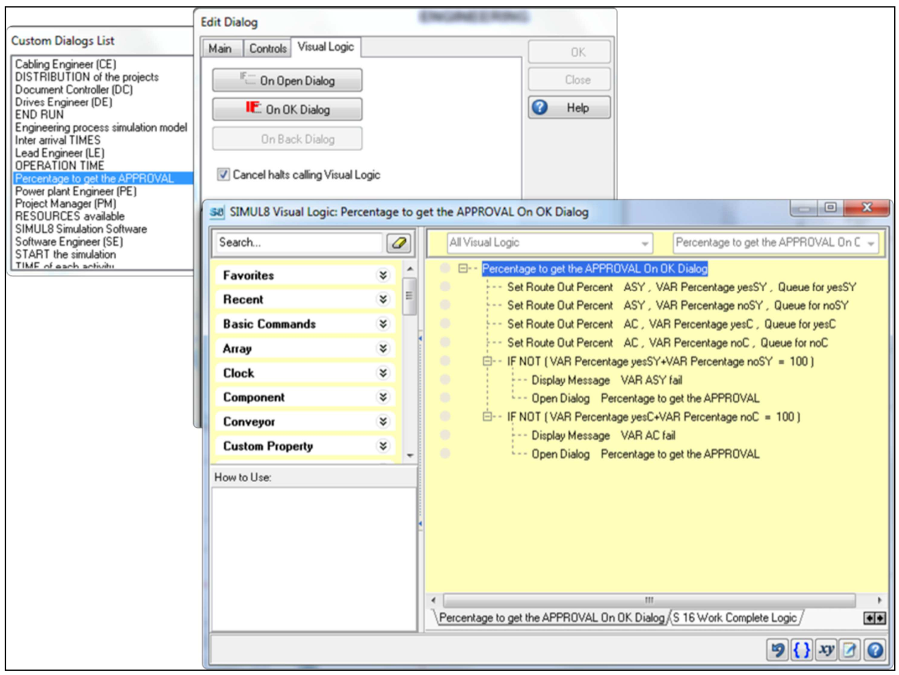


Figure 55 Code in “On OK Dialog” location of “Percentage to get the Approval” dialog.

This code sets the routing-out percent to “Queue for yesSY” and to “Queue for noSY” from “ASY” activity. Also it sets the routing-out percentage to “Queue for yesC” and to “Queue for noC” from “AC” activity.

```
VL SECTION: Percentage to get the APPROVAL On OK Dialog

  Set Route Out Percent    ASY, VAR Percentage yesSY, Queue
for yesSY
  Set Route Out Percent    ASY, VAR Percentage noSY, Queue
for noSY
  Set Route Out Percent    AC, VAR Percentage yesC, Queue
for yesC
  Set Route Out Percent    AC, VAR Percentage noC, Queue
for noC
```

```
IF NOT (VAR Percentage yesSY+VAR Percentage noSY = 100)
  Display Message    VAR ASY fail
  Open Dialog    Percentage to get the APPROVAL

IF NOT (VAR Percentage yesC+VAR Percentage noC = 100)
  Display Message    VAR AC fail
  Open Dialog    Percentage to get the APPROVAL
```

If the percentages introduced in the approval from Shipyard do not sum 100, the message established by "VAR ASY fail" variable appears. Also in the approval from Classification, if the percentages introduced do not sum 100, the message was established by "VAR AC fail" variable appears. When both logics are true, next dialog appears.

4.5.8 Resources available

"Resources available" dialog explains the different engineering specialities that are available in the present simulation model, and the different experience levels that are considered. Figure 56 shows this dialog which is an introduction of a consecutive dialogs where user can introduce the number of engineer(s).

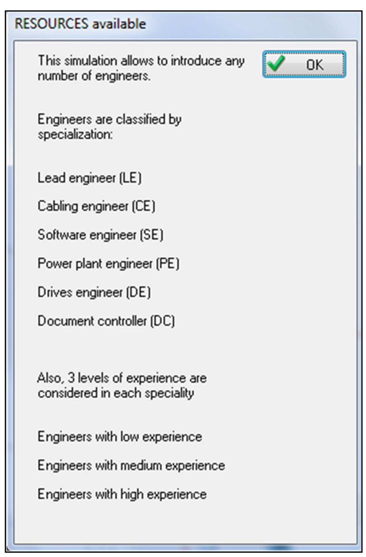


Figure 56 "Resources available" dialog.

The order of appearance of the following dialogs is described in the previous dialog information.

4.5.9 Lead Engineer

In the present dialog, data introduced is the number of engineer(s) of lead engineering speciality according with the experience. Figure 57 shows it.

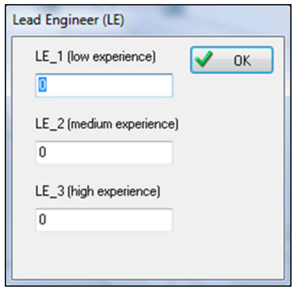


Figure 57 “Lead Engineer” dialog.

In the next dialog is explained how the data introduced in the blank spaces was connected with the resources used in the simulation model.

4.5.10 Cabling Engineer

Figure 58 shows the dialog where data introduced is the number of engineer(s) of cabling engineering speciality according with the experience.

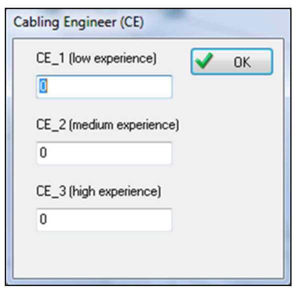


Figure 58 “Cabling Engineer” dialog.

To link these data with the number of resources available to simulate, “Formula Editor” was opened, “Object” type was selected, and the simulation objects related with the data introduced in the blank spaces were selected. Figure 59 shows this link.

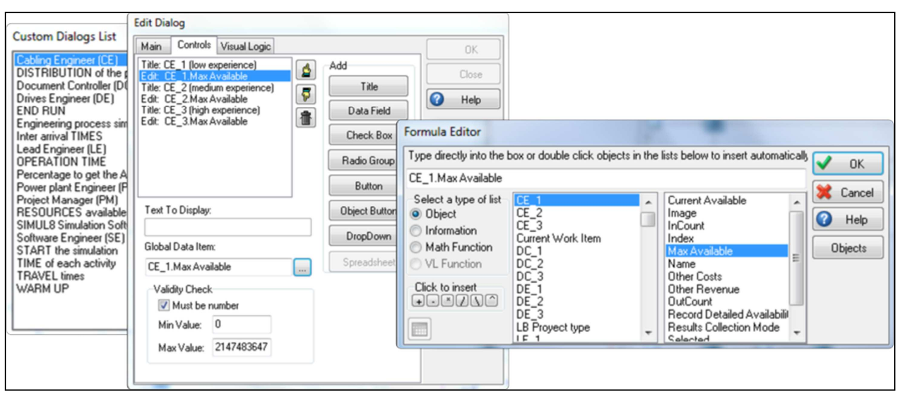


Figure 59 Link between data introduced and resources.

The simulation objects selected are according with the resources created in the present simulation model. Once the resource was selected, “Max Available” option has to be selected as well.

The data introduced must be numbers and with 0 as minimum value. These limitations were established in “Validity Check” option, as shown in the previous figure. All the dialogs related with resources follow this structure. When data is introduced in the blank spaces, “OK” button is clicked and next dialog appears.

4.5.11 Software Engineer

In the present dialog, data introduced is the number of engineer(s) of software engineering speciality according with the experience. Figure 60 shows it.

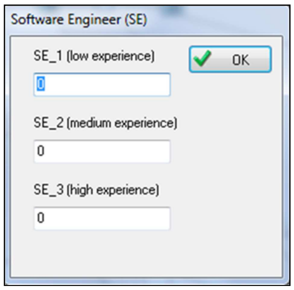


Figure 60 “Software Engineer” dialog.

When data is introduced in the blank spaces, “OK” button is clicked and next dialog appears.

4.5.12 Power plant Engineer

In the present dialog, data introduced is the number of engineer(s) of power plant engineering speciality according with the experience. Figure 61 shows it.

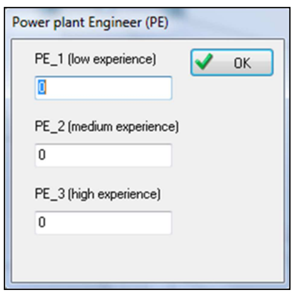


Figure 61 “Power plant Engineer” dialog.

When data is introduced in the blank spaces, “OK” button is clicked and next dialog appears.

4.5.13 Drives Engineer

In the present dialog, data introduced is the number of engineer(s) of drives engineering speciality according with the experience. Figure 62 shows it.

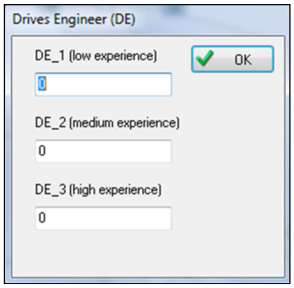


Figure 62 “Drives Engineer” dialog.

When data is introduced in the blank spaces, “OK” button is clicked and next dialog appears.

4.5.14 Document Controller

In the present dialog, data introduced is the number of engineer(s) of document controller engineering speciality according with the experience. Figure 63 shows it.

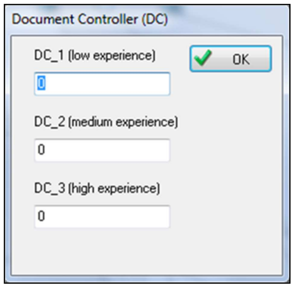


Figure 63 “Document Controller” dialog.

When data is introduced in the blank spaces, “OK” button is clicked and next dialog appears.

4.5.15 Project Manager

The present simulation model considers one experience level of project manager engineering speciality. This information is explained in the dialog, and the data introduced is the number of engineer(s) of this speciality. Figure 64 shows it.

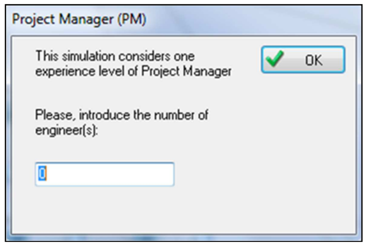


Figure 64 “Project Manager” dialog.

When data is introduced in the blank spaces, “OK” button is clicked and next dialog appears.

4.5.16 Travel times

Travel times explained in previous sections. The present dialog defines the three existing travel times in the simulation model and explains that the time data must be in hours. Figure 65 shows this dialog.

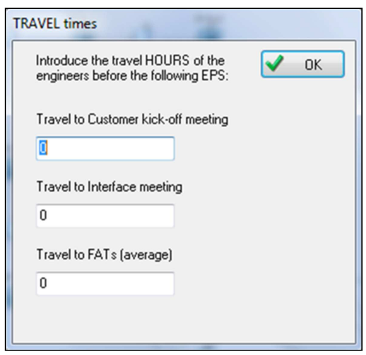


Figure 65 “Travel times” dialog.

To link the data introduced with the “Global Data Item”, “Formula Editor” was opened, “Information” type was selected, and the variables related with the data introduced in the blank spaces were selected. Figure 66 shows this link.

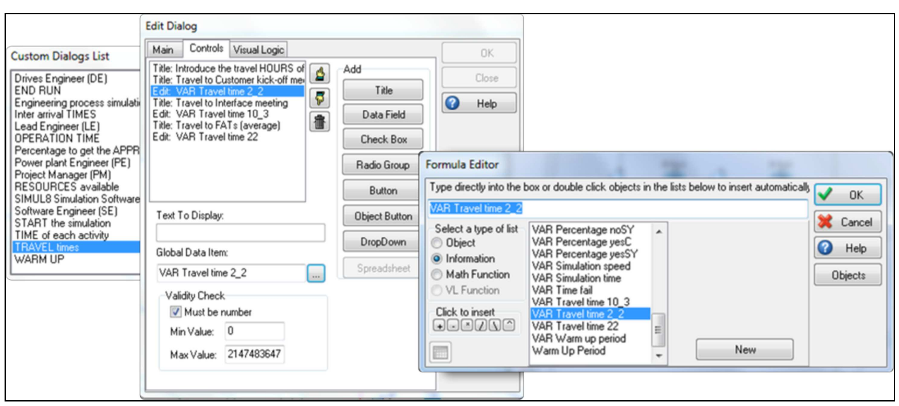


Figure 66 Link between data introduced and travel times variables.

Table 28 shows the variables linked with the data introduced in the blank spaces.

Table 28 Variables linked with the travel time data introduced.

Name	Type	Purpose
VAR Travel time 2_2	Time	Hours of travel time to “Customer kick-off meeting”
VAR Travel time 10_3	Time	Hours of travel time to “Interface meeting”
VAR Travel time 22	Time	Hours of travel time to “FATs”

The data introduced must be numbers and with 0 as a minimum value. These specifications were established in “Validity Check” option, as shown in the previous figure. Once the travel times are introduced, “OK” button is clicked and next dialog is shown.

4.5.17 Warm Up

Warm up period allows starting the simulation with the process running. It means that most of the processes don’t start since zero. Figure 67 shows the dialog that allows the introduction of warm up period.

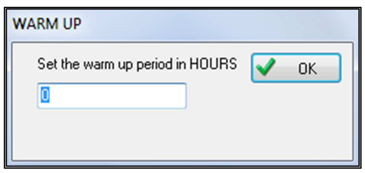


Figure 67 “Warm Up” dialog.

To link the data introduced with the “Global Data Item”, “Formula Editor” was opened, “Information” type was selected, and the variable related with the data introduced in the blank space was selected. Figure 68 shows this link.

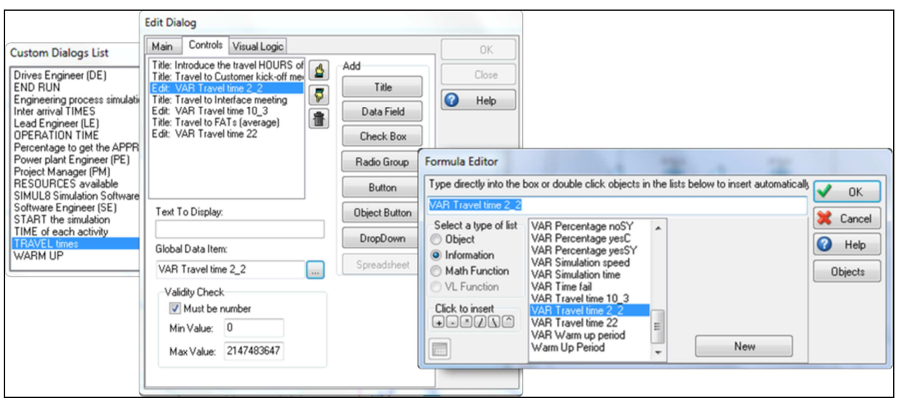


Figure 68 Link between data introduced and warm up variable.

Table 29 shows the variable linked with the data introduced in the blank space.

Table 29 Variable linked with the warm up period introduced.

Name	Type	Purpose
VAR Warm up period	Time	Hours of warm up period

The data introduced must be numbers and with 0 as a minimum value. These specifications were established in “Validity Check” option, as shown in the previous figure. To establish the warm up period introduced in the simulation model, Visual Logic was used. Figure 69 shows where the code written is located.

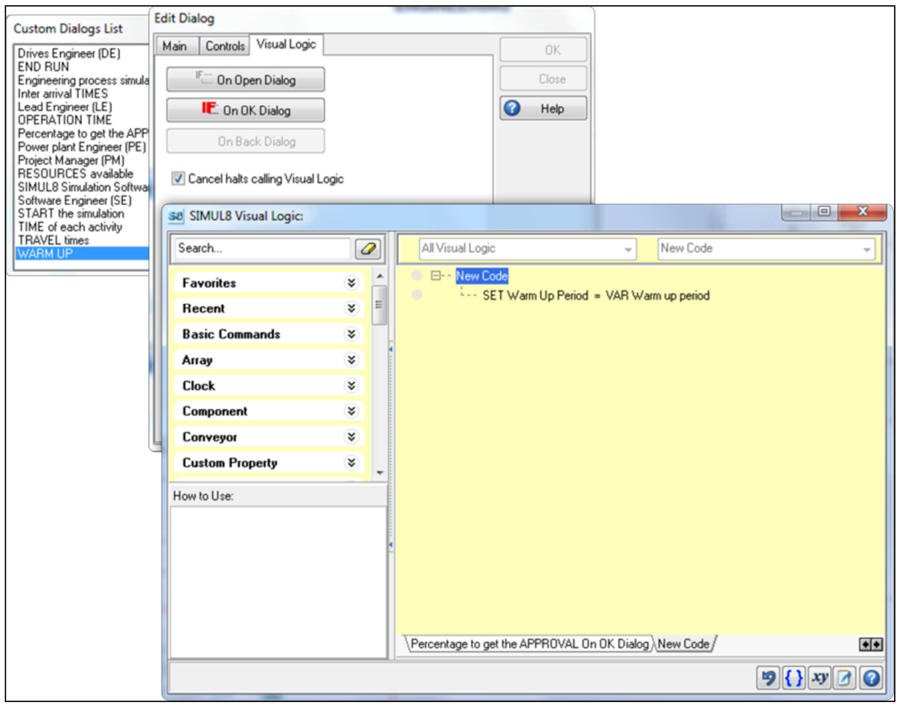


Figure 69 Code in “On OK Dialog” location of “Warm Up” dialog.

The code written sets the warm up period introduced in the “Warm Up Period” option of the simulation model.

```
VL SECTION: New Code

  SET Warm Up Period = VAR Warm up period
```

Once the warm up period is introduced, “OK” button is clicked and next dialog is shown.

4.5.18 Start the simulation

The “Start the simulation” dialog represents the last dialog before the simulation starts. In this dialog the time to be simulated and the simulation speed are defined. Figure 70 shows it.

Figure 70 “Start the simulation” dialog.

To link these data with the “Global Data Item”, “Formula Editor” was opened, “Information” type was selected, and the variables related with the data introduced in the blank spaces were selected. Figure 71 shows this link.

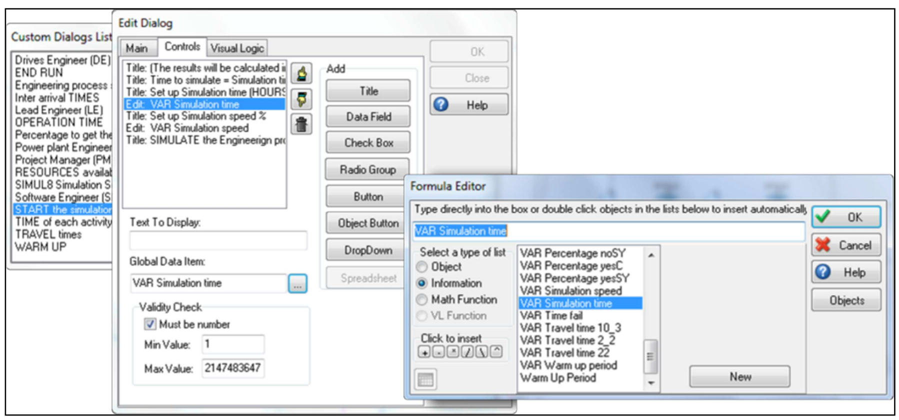


Figure 71 Link between data introduced and “Global Data Item”.

Table 30 shows the variables linked with the data introduced in the blank spaces.

Table 30 Variables linked with data introduced.

Name	Type	Purpose
VAR Simulation time	Time	Hours of simulation time
VAR Simulation speed	Number	Percentage simulation speed

Simulation time data is in hours and simulation speed data is in percent. These data must be numbers and with 1 as minimum value of simulation time and 0 as minimum value of simulation speed. These specifications were established in “Validity Check” option, as shown in the previous figure.

The dialog explains that the “Time to simulate” is equal to the difference between “Simulation time” and “Warm up period”. Therefore, simulation time data must be higher than warm up period data, if not, an informative message appears. Figure 72 shows this dialog.

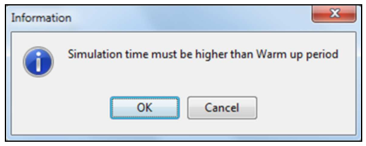


Figure 72 Informative message established by “VAR Time fail” variable.

This message is established by “VAR Time fail” variable and it appears every time that the time data is wrong. Table 31 shows the variable linked with the informative message.

Table 31 Variables linked with the informative messages about time to simulate.

Name	Type	Message
VAR Time fail	Text	“Simulation time must be higher than Warm up period”

To apply all these actions in the simulation model, Visual Logic was used. In “Visual Logic” section of “Edit Dialog” option a code was introduced in “On OK Dialog” Visual Logic location. Figure 73 shows the location of this code.

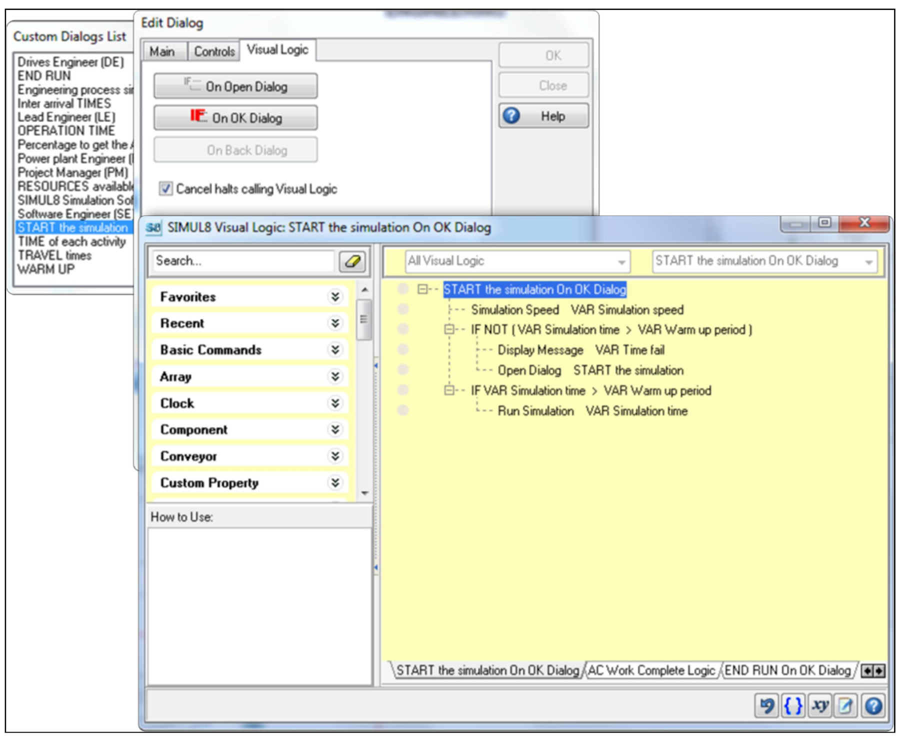


Figure 73 Code in “On OK Dialog” location of “Start the simulation” dialog.

The code written establishes the “Simulation Speed” and checks if simulation time data is higher than warm up period data.

```
VL SECTION: START the simulation On OK Dialog
```

```
Simulation Speed    VAR Simulation speed

IF NOT (VAR Simulation time > VAR Warm up period)
  Display Message    VAR Time fail
  Open Dialog    START the simulation

IF VAR Simulation time > VAR Warm up period
  Run Simulation    VAR Simulation time
```

If simulation time data is not higher than warm up period data, the message established by “VAR Time fail” variable appears, and this dialog is shown until this logic is true.

Once the data introduced follows the logic, “OK” button is clicked and the simulation starts.

4.5.19 End Run

Once the simulation ends, “End Run” dialog is shown. Figure 74 shows this informative dialog.

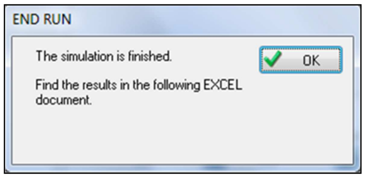


Figure 74 “End Run” dialog.

When “OK” button is clicked the customized results in the “VAR Engineering Process RESULTS” spreadsheet are shown.

Table 32 shows the variable linked with the spreadsheet.

Table 32 Variable linked with the spreadsheet of the customized results.

Name	Type	Purpose
VAR Engineering Process RESULTS	Spreadsheet	Engineering Process customized results

To apply this action in the simulation model, Visual Logic was used. In “Visual Logic” section of “Edit Dialog” option a code was introduced in “On OK Dialog” Visual Logic location.

Figure 75 shows the location of this code.

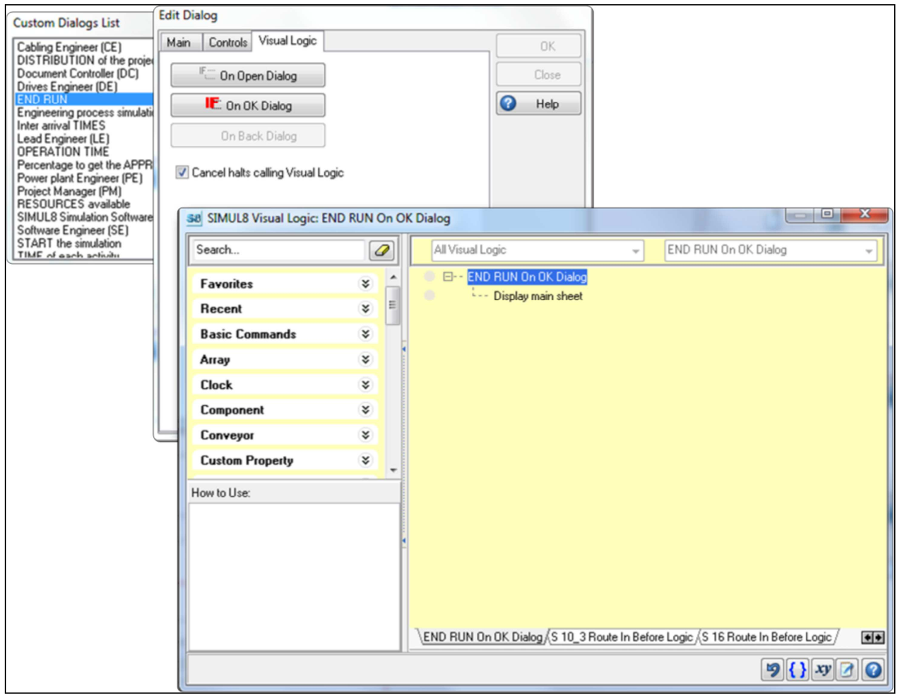


Figure 75 Code in “On OK Dialog” location of “End Run” dialog.

This code displays the “Main Sheet”, in this case is the “VAR Engineering Process RESULTS” spreadsheet.

```
VL SECTION: END RUN On OK Dialog

  Display main sheet
```

This spreadsheet contains the customized results.

4.6 Visual Logic

In the simulation model there are four codes according to the simulation performance, these codes show the dialogs created, establish the operation time on reset and create the customized results. There were divided in two groups, ”Time Based” and ”Action Based” codes. ”Time Based” codes are located in ”Before Reset” and ”On Reset” Visual Logic locations. Figure 76 shows the locations of this codes.

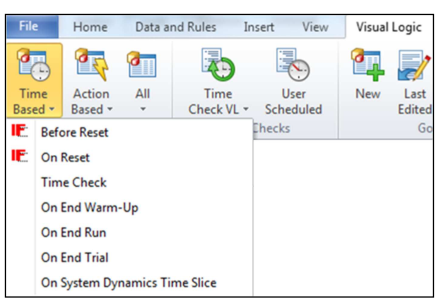


Figure 76 “Time Based” codes.

”Action Based” codes are located in ”On Stop Run” and ”On Simulation open” Visual Logic locations. Figure 77 shows the locations of this codes.

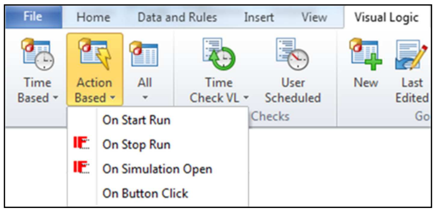


Figure 77 “Action Based” codes.

Below ”On Simulation open”, ”Before Reset”, and ”On Reset” codes are explained in detail. ”On Stop Run” code is explained in ”Customize Results” section.

4.6.1 On Simulation open

The main purpose of the code written in this Visual Logic location is to show the dialogs created in the present simulation model. Below this code is shown:

```
VL SECTION: On Simulation Open Logic

  Open Dialog    SIMUL8 Simulation Software
  Open Dialog    Engineering process simulation model
  Open Dialog    DISTRIBUTION of the projects
  Open Dialog    Inter arrival TIMES
  Open Dialog    TIME of each activity
  Open Dialog    OPERATION TIME
  Open Dialog    Percentage to get the APPROVAL
  Open Dialog    RESOURCES available
  Open Dialog    Lead Engineer (LE)
  Open Dialog    Cabling Engineer (CE)
  Open Dialog    Software Engineer (SE)
  Open Dialog    Power plant Engineer (PE)
  Open Dialog    Drives Engineer (DE)
  Open Dialog    Document Controller (DC)
  Open Dialog    Project Manager (PM)
  Open Dialog    TRAVEL times
  Open Dialog    WARM UP
  Open Dialog    START the simulation
```

The code establishes the order in which the dialogs are shown when the simulation is started.

4.6.2 Before Reset

The following code shows some examples about how it establishes the operation time of each activity before the simulation is reset.

```
VL SECTION: Before Reset Logic
```

```
  SET  VAR  Operation  Time  EPS[3,3]  =  VAR  Operation  Time
EPS[4,3]
  SET  VAR  Operation  Time  EPS[3,4]  =  VAR  Operation  Time
EPS[4,4]
  SET  VAR  Operation  Time  EPS[3,5]  =  VAR  Operation  Time
EPS[4,5]
  SET  VAR  Operation  Time  EPS[3,6]  =  VAR  Operation  Time
EPS[4,6]
```

The operation time is selected from “On Reset” column of the “VAR Operation Time EPS” spreadsheet.

4.6.3 On Reset

The code written in this Visual Logic location is different from the files created in Simul8. In the “ABB_Project Engineering Process_ Work Flow” file the following code is written:

```
VL SECTION: Reset Logic

  Open Dialog    DISTRIBUTION of the projects
  Open Dialog    Inter arrival TIMES
  Open Dialog    TIME of each activity
  Open Dialog    OPERATION TIME
  Open Dialog    Percentage to get the APPROVAL
  Open Dialog    RESOURCES available
  Open Dialog    Lead Engineer (LE)
  Open Dialog    Cabling Engineer (CE)
  Open Dialog    Software Engineer (SE)
  Open Dialog    Power plant Engineer (PE)
  Open Dialog    Drives Engineer (DE)
  Open Dialog    Document Controller (DC)
  Open Dialog    Project Manager (PM)
  Open Dialog    TRAVEL times
  Open Dialog    WARM UP
  Open Dialog    START the simulation
```

In the “ABB_Project Engineering Process_ Office” file the following code is written:

```
VL SECTION: Reset Logic

  Open Dialog    TIME of each activity
  Open Dialog    OPERATION TIME
  Open Dialog    TRAVEL times
  Open Dialog    WARM UP
  Open Dialog    START the simulation
```

As shown the main purpose of these codes is to show the dialogs created when the simulation is reset. The difference between the codes is that in the ”Office” file there are less dialogs than in the “Work Flow” file.

As explained in the previous chapters, in the “Office” file components are created to make the user interface easier and more intuitive than in the “Work Flow” file. The start point, resources and re-work simulation objects are the components created, and they are linked with the dialogs that are not written into the “Office” file code.

4.7 Customized Results

Simul8 offers the “Results Manager” option to visualize and compare all the relevant data of the simulation results. The Electrical Systems and Project department personnel of ABB Marine and Cranes specified that all these results have to be included into a document which allows for an easy link with Microsoft Office Excel.

In the present simulation model, the “VAR Engineering Process RESULTS” spreadsheet was created to include all the customized results with an easy link to Microsoft Office Excel. Therefore, when the simulation stops this spreadsheet is filled with all the relevant data of the simulation results. On order to apply all these actions a code was written in “On Stop Run” Visual Logic location. Below some examples of this code are shown:

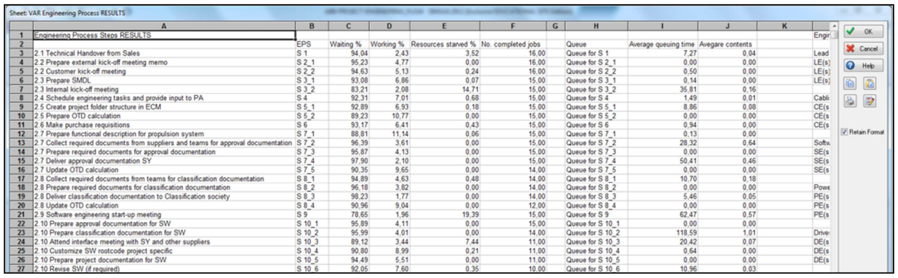
```
VL SECTION: Stop Run Logic

  Get  Result      VAR  Engineering  Process  RESULTS[3,3]  ,
Current Run ,  S 1: Waiting %
  Get  Result      VAR  Engineering  Process  RESULTS[4,3]  ,
Current Run ,  S 1: Working %
  Get  Result      VAR  Engineering  Process  RESULTS[5,3]  ,
Current Run ,  S 1: Resource Starved %
  SET VAR Engineering Process RESULTS[6,3]   =   S 1.Number
Completed Jobs
  SET VAR Engineering Process RESULTS[9,3]  =  Queue for S
1.Average Queueing Time
  SET VAR Engineering Process RESULTS[10,3]  =  Queue for S
1.Average Contents
  Get  Result      VAR  Engineering  Process  RESULTS[3,4]  ,
Current Run ,  S 2_1: Waiting %
  Get  Result      VAR  Engineering  Process  RESULTS[4,4]  ,
Current Run ,  S 2_1: Working %
  Get  Result      VAR  Engineering  Process  RESULTS[5,4]  ,
Current Run ,  S 2_1: Resource Starved %
  SET VAR Engineering Process RESULTS[6,4]  =  S 2_1.Number
Completed Jobs
  SET VAR Engineering Process RESULTS[9,4]  =  Queue for S
2_1.Average Queueing Time
  SET VAR Engineering Process RESULTS[10,4]  =  Queue for S
2_1.Average Contents

  Get  Result      VAR  Engineering  Process  RESULTS[13,3]  ,
Current Run ,  Lead Engineer EPS: Waiting %
  Get  Result      VAR  Engineering  Process  RESULTS[14,3]  ,
Current Run ,  Lead Engineer EPS: Working %
  Get Percent Utilization over Interval    LE_1 ,  VAR Warm
up period ,  VAR Simulation time ,  VAR Engineering Process
RESULTS[15,4]
  Get Percent Utilization over Interval    LE_2 ,  VAR Warm
up period ,  VAR Simulation time ,  VAR Engineering Process
RESULTS[15,5]
```

```
  Get Percent Utilization over Interval    LE_3 ,  VAR Warm
up period ,  VAR Simulation time ,  VAR Engineering Process
RESULTS[15,6]
  Get  Result      VAR  Engineering  Process  RESULTS[13,8]  ,
Current Run ,  Cabling Engineer EPS: Waiting %
  Get  Result      VAR  Engineering  Process  RESULTS[14,8]  ,
Current Run ,  Cabling Engineer EPS: Working %
  Get Percent Utilization over Interval    CE_1 ,  VAR Warm
up period ,  VAR Simulation time ,  VAR Engineering Process
RESULTS[15,9]
  Get Percent Utilization over Interval    CE_2 ,  VAR Warm
up period ,  VAR Simulation time ,  VAR Engineering Process
RESULTS[15,10]
  Get Percent Utilization over Interval    CE_3 ,  VAR Warm
up period ,  VAR Simulation time ,  VAR Engineering Process
RESULTS[15,11]

  Get  Result      VAR  Engineering  Process  RESULTS[13,35]  ,
Current Run ,  ASY: Waiting %
  Get  Result      VAR  Engineering  Process  RESULTS[14,35]  ,
Current Run ,  ASY: Working %
  Get  Result      VAR  Engineering  Process  RESULTS[13,36]  ,
Current Run ,  RWSY10: Waiting %
  Get  Result      VAR  Engineering  Process  RESULTS[14,36]  ,
Current Run ,  RWSY10: Working %
  SET   VAR   Engineering   Process   RESULTS[15,36]      =
RWSY10.Number Completed Jobs+" projects"
  Get  Result      VAR  Engineering  Process  RESULTS[13,37]  ,
Current Run ,  RWSY14: Waiting %
  Get  Result      VAR  Engineering  Process  RESULTS[14,37]  ,
Current Run ,  RWSY14: Working %
  SET   VAR   Engineering   Process   RESULTS[15,37]      =
RWSY14.Number Completed Jobs+" projects"
  Get  Result      VAR  Engineering  Process  RESULTS[13,38]  ,
Current Run ,  RWSY17: Waiting %
  Get  Result      VAR  Engineering  Process  RESULTS[14,38]  ,
Current Run ,  RWSY17: Working %
  SET   VAR   Engineering   Process   RESULTS[15,38]      =
RWSY17.Number Completed Jobs+" projects"

  Open Dialog    END RUN
```

The code written establishes the following relevant data of the simulation results in the spreadsheet.

- Waiting and working percentage of the activities and resources.
- Utilization percentage of the resources.
- Resources starved percentage of the activities.
- Average queuing time.
- Number of completed jobs of the activities.
- Average contents of the queues.
- Number of completed jobs in the re-work to get the approvals.

These data is collected through the time simulated. Once the code ends, “End Run” dialog is opened and informs that the simulation is finished. Figure 78 shows part of the “VAR Engineering Process RESULTS” spreadsheet that appears when “OK” button of this dialog is clicked.



Sheet: VAR Engineering Process RESULTS

	A	B	C	D	E	F	G	H	I	J	K	
1	Engineering Process Steps RESULTS											Engir
2		EPS	Waiting %	Working %	Resources starved %	No. completed jobs		Queue	Average queuing time	Avegare contents		
3	2.1 Technical Handover from Sales	S 1	94,04	2,43	3,52	16,00		Queue for S 1	7,27	0,04		Lead
4	2.2 Prepare external kick-off meeting memo	S 2_1	95,23	4,77	0,00	16,00		Queue for S 2_1	0,00	0,00		LE(s)
5	2.2 Customer kick-off meeting	S 2_2	94,63	5,13	0,24	16,00		Queue for S 2_2	0,50	0,00		LE(s)
6	2.3 Prepare SMDL	S 3_1	93,08	6,86	0,07	15,00		Queue for S 3_1	0,14	0,00		LE(s)
7	2.3 Internal kick-off meeting	S 3_2	83,21	2,08	14,71	15,00		Queue for S 3_2	35,81	0,16		
8	2.4 Schedule engineering tasks and provide input to PA	S 4	92,31	7,01	0,68	15,00		Queue for S 4	1,49	0,01		Cabli
9	2.5 Create project folder structure in ECM	S 5_1	92,89	6,93	0,18	15,00		Queue for S 5_1	8,86	0,08		CE(s
10	2.5 Prepare OTD calculation	S 5_2	89,23	10,77	0,00	15,00		Queue for S 5_2	0,00	0,00		CE(s
11	2.6 Make purchase requisitions	S 6	93,17	6,41	0,43	15,00		Queue for S 6	0,94	0,00		CE(s
12	2.7 Prepare functional description for propulsion system	S 7_1	88,81	11,14	0,06	15,00		Queue for S 7_1	0,13	0,00		
13	2.7 Collect required documents from suppliers and teams for approval documentation	S 7_2	96,39	3,61	0,00	15,00		Queue for S 7_2	28,32	0,64		Softw
14	2.7 Prepare required documents for approval documentation	S 7_3	95,87	4,13	0,00	15,00		Queue for S 7_3	0,00	0,00		SE(s
15	2.7 Deliver approval documentation SY	S 7_4	97,90	2,10	0,00	15,00		Queue for S 7_4	50,41	0,46		SE(s
16	2.7 Update OTD calculation	S 7_5	90,35	9,65	0,00	14,00		Queue for S 7_5	0,00	0,00		SE(s
17	2.8 Collect required documents from teams for classification documentation	S 8_1	94,89	4,63	0,48	14,00		Queue for S 8_1	10,70	0,18		
18	2.8 Prepare required documents for classification documentation	S 8_2	96,18	3,82	0,00	14,00		Queue for S 8_2	0,00	0,00		Powe
19	2.8 Deliver classification documentation to Classification society	S 8_3	98,23	1,77	0,00	14,00		Queue for S 8_3	5,46	0,05		PE(s
20	2.8 Update OTD calculation	S 8_4	90,96	9,04	0,00	12,00		Queue for S 8_4	0,00	0,00		PE(s
21	2.9 Software engineering start-up meeting	S 9	78,65	1,96	19,39	15,00		Queue for S 9	62,47	0,57		PE(s
22	2.10 Prepare approval documentation for SW	S 10_1	95,89	4,11	0,00	15,00		Queue for S 10_1	0,00	0,00		
23	2.10 Prepare classification documentation for SW	S 10_2	95,99	4,01	0,00	14,00		Queue for S 10_2	118,59	1,01		Drive
24	2.10 Attend interface meeting with SY and other suppliers	S 10_3	89,12	3,44	7,44	11,00		Queue for S 10_3	20,42	0,07		DE(s
25	2.10 Customize SW rootcode project specific	S 10_4	90,80	8,99	0,21	11,00		Queue for S 10_4	0,64	0,00		DE(s
26	2.10 Prepare project documentation for SW	S 10_5	94,49	5,51	0,00	11,00		Queue for S 10_5	0,00	0,00		DE(s
27	2.10 Revise SW (if required)	S 10_6	92,05	7,60	0,35	10,00		Queue for S 10_6	10,96	0,03		

Figure 78 Part of the spreadsheet with the customize results.

Simul8 offers the option to save this spreadsheet with Microsoft Office Excel extension (.xls) in “Edit Formats” option of the spreadsheet. Once the spreadsheet is saved with this extension, the document can be visualized in Microsoft Office Excel, and all the data collected can be represented using this powerful tool.

Once the results are obtained and the simulation program is closed, a message appears to confirm if all data introduced and changes done in the simulation model are saved or not. Figure 79 shows this message.

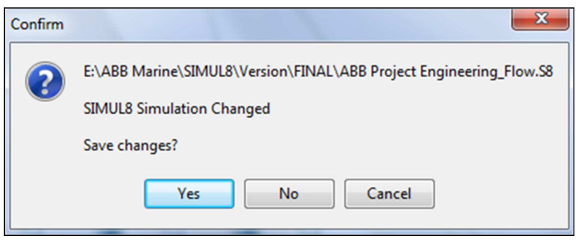


Figure 79 Message to confirm if changes are saved or not.

The file has to be saved with different name if there is a desire to keep the original simulation model.

5 CONCLUSION

Simulation models are formulaic, mathematical and logical representations that define the idealization of system of interest. Today simulation models are evaluated with computers, using tools selected from a wide range of general and simulation-specific programming languages, spreadsheets software and specialized commercial simulation software.

Simul8 was chosen after a comparison between two of the most used commercial simulation software related with the proposed engineering process. Simul8 concepts were introduced to provide a basis for understanding the modelling solutions that were later described. The model was built mainly of activities and queues that represent the engineering process steps. Other simulation elements of this software were used to make an easier and more interactive usage of the simulation model.

The simulation modelling started with numerous simulation exercises not related to the proposed engineering process. These exercises continued to some extent during the modelling of the actual process, mainly to test different modelling approaches to practical problems encountered while modelling the proposed engineering process.

According with the aim of the Electrical Systems and Project department personnel of ABB Marine and Cranes, the desired output of the present thesis is to improve the engineering process efficiency cutting 10% of engineering hours.

The simulation model developed is the main result of this thesis, and it allows testing and checking the whole process. The customized results are useful to improve the efficiency and an important validation for the department if any modification in the engineering process is applied in the future.

Once the simulation model was finished and presented in ABB Marine & Cranes installations in Helsinki, the commissioner evaluated the work done positively and with an excellent grade in the utility of the thesis, business importance.

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