SEVENTH FRAMEWORK PROGRAMME

VIT
Vision for Innovative Transport

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SP4-Capacities - Research for SMEs

REPORT ON THE SIMULATOR PROTOTYPE

Deliverable D6.2

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About the Document

This document reports technical details of the final version of the simulation software, the content of the developed software modules, some numerical deliverables of the simulation model and the documentation about how to use it. Also it refers to the activity of Task 6.2 Classification of events coming from the vision system, Task 6.3 Logic Layers and Task 6.4 Reliability Modelling and Prediction inside the Workpackage WP6: System security and data management.

The document has been produced by the collaboration of the workpackage WP6, the participants of the workpackage have all duly contributed to the activity of the workpackage and the production of this document and they endorse the final version as the conclusion of the workpackage.

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INTRODUCTION

The main objective of this work package is to evaluate and analyse the risk connected with the information coming from the vision systems. All the possible failure events must be analysed and classified and a set of recovery actions must be defined.

A stochastic simulation model of the terminal has been built to simulate the handling logic, the failures of the various vision devices and the ensuing repair actions.

Scenarios which simulate both standard and critical conditions have been run to ensure the plant safety; the primary goal of the scenarios analysis is to investigate the effects of the failures on the final reliability level and on the terminal correct operability in accordance with the targets and the constraints imposed by the SMEs.

It is possible for a user to change the input failures parameters (frequency and duration) easily through an excel input file in order to build and run a new scenario and evaluate the results of the simulation.

In detail, the final outputs of this WP are:

- A report which contains a classification of all the events/information/failures coming from the vision systems and a definition of the recovery actions for these events
- A stochastic simulation model of the terminal which simulates both the material handling processes and the vision system events
- The numeric deliverables of the simulation analysis which permit to compare different scenarios

Structure of the report

The present report is structured as follows:

1. **Overview:** this section reports a summary of the main objectives of the WP6
2. **Summary of events classification coming from the vision system:** this section reports a summary of the analysis and classification of the events originated by the vision systems related to task T6.2. (See D6.1 for more details)
3. **Summary of the logic layers:** this section reports a summary about the design and the prototyping of the logic layers and procedures which permit to define the recovery actions consequently to the events coming from the vision systems. It is related to task T6.3. (See D6.1 for more details)
4. **The simulation model:** this section contains:
   - A description of all the main features of the final version of the simulation model of the terminal
   - A description of the "**XL_Input_Terminal_FinalRelease.xls**" excel file interface
   - The numerical results of the most important scenarios, defined with the help of the SME's and of the developers of the other WPs
5. **Final release simulation software User's Guide:** this section contains a small guide to help the user to feed the simulation model with a new configuration, run the new scenario and see the simulation results. It also refers to a training video uploaded on the web site.
6. **Final review with respect to user requirements:** this section contains a summary of the achieved objectives with respect to user requirements
7. **State of simulator with respect to Metrocargo:** this section contains the state of the simulation model with respect to Metrocargo and it reports some possible future developments and implementations.

AUDIENCE

The present deliverable is filed as Confidential, as it contains critical information for the VIT project and also for the Metrocargo system.

Therefore the audience of the document is restricted the project participants --- the SME's who will find the technical details following their user requirements and the RTD performers who will use the present report as a guideline of their research and development activity.

1. Overview

The main objectives of the WP are formalized in tasks T6.2, T6.3, T6.4. In the following we relate the main objectives of the tasks with the sections of this report.

T 6.2 Classification of events coming from the vision system

- **Analysis and classification of the events originated by the vision system, in relation to the system structure:** a summary is reported in section 2. A complete account of the research carried out was presented in Deliverable D6.1

T 6.3 Logic layer

- **Design and prototyping of the logic layer and procedures that permit to define the actions consequently to the events coming from the vision systems: a** summary is reported in section 3. A complete account of the research carried out was presented in Deliverable D6.1

T 6.4 Reliability modeling and prediction

- **A stochastic simulator will permit to estimate the reliability level resulting from the defined architecture and procedures:** section 4 reports the final release of the simulator, including details on how to interface with it. A detailed description of a set of simulations run in consideration of various scenarios is also reported. A summary of the reliability level of the system concludes the section.

2. Summary of events classification coming from the vision system

In order to implement the stochastic failure logics in the simulator, a detailed analysis of all the events originated by the vision devices has been developed in T6.2, as reported in Deliverable D6.1

The disturbances have been classified into categories at several levels leading to various actions when experienced during operations; first of all, failure events have been categorized according to their type and frequency.

Figure 1 shows the complete template table which collects and classifies all the possible failure events analysed with the help of the developers of the WP3, WP4 and WP5. (***See D 6.1 for details about the fields description and the events classification***).

WP	Devices	Failure Description	Frequency	Failure Type	Count	Percentage	Up Time	Up Time Units
WP3	Cameras For Automatic Positioning for Load / Unload	Cameras breaking off.	Rare					
	Cameras For Automatic Positioning for Load / Unload	Failure during the container loading	Daily	Percentage		0.5		
	Cameras For Automatic Positioning for Load / Unload	Failure during the container unloading	Daily	Percentage		0.5		
WP4	Cameras For Reconstruction of the train profile	Cameras breaking off.	Rare					
	Cameras For Reconstruction of the train profile	Wrong Train	Rare					
	Cameras For Reconstruction of the train profile	Wrong List	Frequent	Time			TRIA(25,30,35)	Days
	Cameras For Reconstruction of the train profile	Ownership code not recognized on train arriving	Remarkable	Percentage		0.001		
	Cameras For Reconstruction of the train profile	Ownership code not recognized on train leaving	Remarkable	Percentage		0.001		
	Cameras For Reconstruction of the train profile	Wrong recognition of the empty spaces	Daily	Percentage		2		
WP5	Cameras For People Security	Cameras breaking off.	Rare					
	Cameras For People Security (Terminal Area)	Cameras don't recognize a human operator who is passing	Daily	Percentage		3		
	Cameras For People Security (Terminal Area)	Cameras recognize a human operator who is not passing	Daily	Percentage		8		
	Cameras For People Security (Loading Area)	Cameras don't recognize a human operator who is passing	Remarkable	Percentage		1		
	Cameras For People Security (Loading Area)	Cameras recognize a human operator who is not passing	Remarkable	Percentage		5		

Figure 1 – Vision system failures in standard conditions

Figure 2 shows the complete template table which collects all the possible failure events according to their importance.

WP	Devices	Failure Description	Importance	Down Time	Down Time Units
WP3	Cameras For Automatic Positioning for Load / Unload	Cameras breaking off.	Significant	NORM(20,5)	Minutes
	Cameras For Automatic Positioning for Load / Unload	Failure during the container loading	Minor	NORM(1,0.2)	Minutes
	Cameras For Automatic Positioning for Load / Unload	Failure during the container unloading	Minor	NORM(1,0.2)	Minutes
WP4	Cameras For Reconstruction of the train profile	Cameras breaking off.	Significant	NORM(15,3)	Minutes
	Cameras For Reconstruction of the train profile	Wrong Train	Significant	NORM(10,3)	Minutes
	Cameras For Reconstruction of the train profile	Wrong List	Significant	TRIA(4,5,6)	Minutes
	Cameras For Reconstruction of the train profile	Ownership code not recognized on train arriving	Minor	DISC(0.2,0.5,1.0,5)	Minutes
	Cameras For Reconstruction of the train profile	Ownership code not recognized on train leaving	Significant		
	Cameras For Reconstruction of the train profile	Wrong recognition of the empty spaces	Minor	TRIA(1.5,2,2.5)	Minutes
WP5	Cameras For People Security	Cameras breaking off.	Significant	NORM(10,3)	Minutes
	Cameras For People Security (Terminal Area)	Cameras don't recognize a human operator who is passing	Significant		
	Cameras For People Security (Terminal Area)	Cameras recognize a human operator who is not passing	Minor		
	Cameras For People Security (Loading Area)	Cameras don't recognize a human operator who is passing	Critical		
	Cameras For People Security (Loading Area)	Cameras recognize a human operator who is not passing	Significant	NORM(15,3)	Minutes

Figure 2 – Failures importance

3. Summary of the logic layers

With the terms “logic layers” we refer to the definition of the recovery actions consequently to the events coming from the vision system.

When a vision device is exposed to disturbances and disruptions occur, it is crucial to understand how the operation returns to normal and how fast the strategy can be implemented; for this reason, is very important to define the ensuing repair action for each failure event.

Figure 3 shows the complete template table which collects all the possible recovery actions analyzed with the help of the SME's and of the developers of the WP3, WP4 and WP5. (***See D 6.1 for details** about the definition of the recovery actions*).

WP	Devices	Failure Description	Recovery Actions Description	Notes
WP3	Cameras For Automatic Positioning for Load / Unload	Cameras breaking off.	Camera replacement with human operator intervention	Two cameras on the same side must be failed simultaneouslly to not perform loading/unloading operations. This is a really rare event. The failed camera can be replaced when there are no trains in the terminal
	Cameras For Automatic Positioning for Load / Unload	Failure during the container loading	Alert and human operator intervention	The position of the wagon's pin is determined by using two sonars, placed on opposite turrets.
	Cameras For Automatic Positioning for Load / Unload	Failure during the container unloading	Alert and human operator intervention	Sensors give alerts if the container's twist locks are not centered
WP4	Cameras For Reconstruction of the train profile	Cameras breaking off.	Camera replacement with human operator intervention	
	Cameras For Reconstruction of the train profile	Wrong Train	Alert	A wrong train arrives into the MC terminal. This is a really exceptional case
	Cameras For Reconstruction of the train profile	Wrong List	Alert and human operator intervention for the right list searching	The list doesn't match with the arriving train's profile. (A train arrives before or after its schedule time)
	Cameras For Reconstruction of the train profile	Ownership code not recognized on train arriving	**20%** Alert and a human operator recognizes the code viewing the camera's image **80%** Alert and a human operator recognizes the code viewing the container directly	
	Cameras For Reconstruction of the train profile	Ownership code not recognized on train leaving	Notification to the general control System	A human intervention is not possible because the recognition occurs when the train is leaving and it can't be stopped.
	Cameras For Reconstruction of the train profile	Wrong recognition of the empty spaces		This event causes a delay in the loading/unloading operations because the automated devices (shuttle and turrets) can't find the right position
WP5	Cameras For People Security	Cameras breaking off.	Camera replacement with human operator intervention	
	Cameras For People Security (Terminal Area)	Cameras don't recognize a human operator who is passing		This is a not given alert (False Negative). It is not a critical event because these type of cameras are monitoring the terminal area where human presence is normal
	Cameras For People Security (Terminal Area)	Cameras recognize a human operator who is not passing	An alert is sent to the camera for loading area's security (about 2 seconds)	This is a false alert (False Positive)
	Cameras For People Security (Loading Area)	Cameras don't recognize a human operator who is passing		**This is a critical event (False Negative)**
	Cameras For People Security (Loading Area)	Cameras recognize a human operator who is not passing	Warning sound alarm and terminal block	**This is a critical event (False Positive)**

Figure 3 – Logic Layers

4. The Simulation Model

A simulation model has been built to model all the terminal logics (both the handling logics and the vision systems failure logics) and to run and compare different scenarios.

The terminal is modeled as a set of platforms, which are served by a number of cranes and automated transfer equipment (shuttles and turrets). The train arrivals and the patterns of trucks arrivals for ITU are statistically modeled. During the simulation, various statistics are gathered to asses the performance of the terminal equipment (both of the automated transfer devices and of the vision system), the train residence time, and the terminal throughput.

The simulation software has been implemented as a discrete-event simulation model, using Rockwell Arena.

This section contains:

- A detailed description of the simulation model final release;
- A detailed description of the interface (an excel input file);
- The numerical results (outputs) coming from the simulations of different scenarios (runs of both standard and critical scenarios)

4.1 Simulation module final release

The final simulation model includes:

- **Stochastic Containers Arrival Patterns (from trucks):** a create module generates containers arriving at the terminal by trucks with a specified rail destination. For each containers the terminal logics must (*see Figure 4*):
    - o accept the incoming ITU;
    - o search in the DB the first free position on a scheduled train through a VBA routine;
    - o assign a resource (crane) and a buffer area to each ITU according to its destination and its train position;
    - o move the ITU into the correct storage areas;
    - o release the crane;

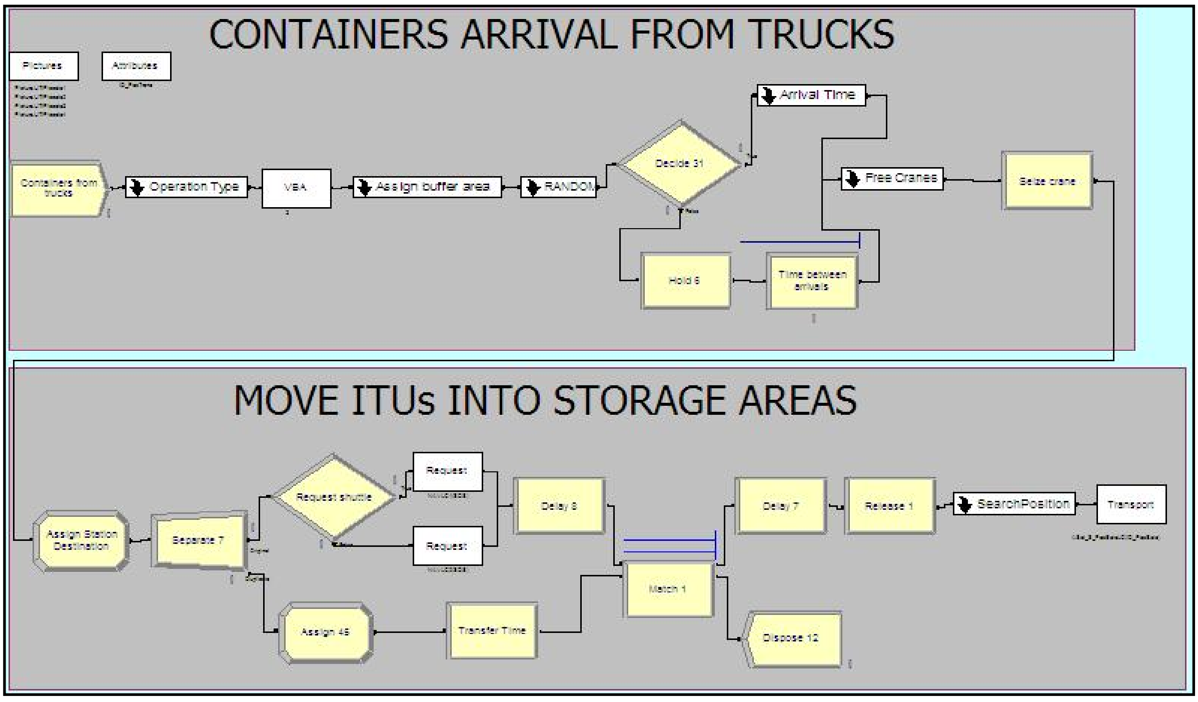


Figure 4 – Containers Arrival Logic

- **Trains Arrival Patterns:** a <u>create</u> module generates trains arriving at the terminal to be loaded/unloaded and an Access DB table is automatically created (with a record for each position on the train). The configuration of the wagons is stochastic (wagons on a train are created according to a discrete "wagontype" distribution); each train has a different number of containers to be unloaded. For each train the terminal logics must (*see Figure 5*):
    - accept the incoming train;
    - recognize the ITUs that must be unloaded;
    - determine the areas where ITUs must be stored;
    - allocate resources (shuttles and turrets) for the loading/unloading operations;
    - perform the loading/unloading operations;
    - tell the train to depart the terminal when it has been unloaded;

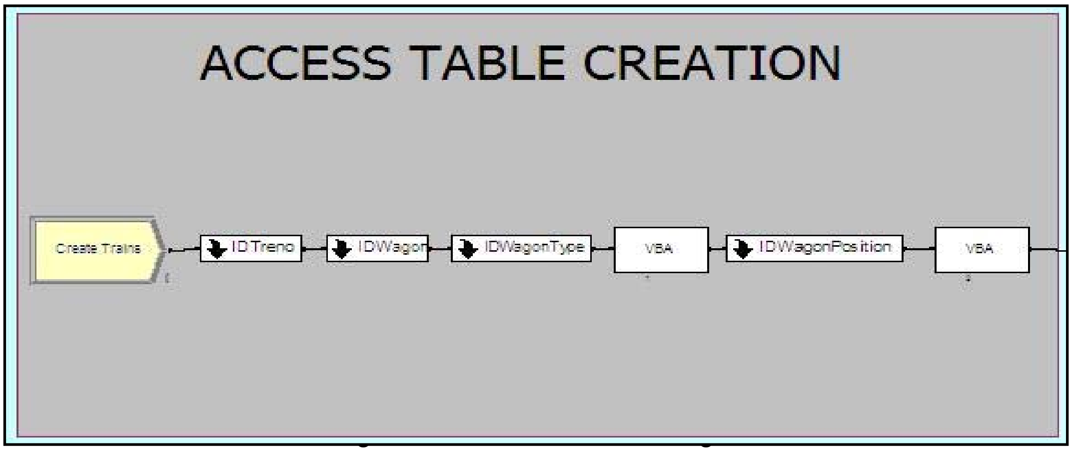


Figure 5 – Trains Table Creation

- **Containers Handling Logic (for loading/unloading operations):** the simulation model includes all the transfer devices; the train loading/unloading operations occur via the robots supported by the vision systems. Each position in the buffer area is assigned to a specific couple of shuttles. The train loading/unloading process starts as soon as possible, that is, when the train is on the platform. The possible operations are (*see Figure 6*):
    - searching an ITU on the train;
    - unloading an ITU from a wagon of an entering train on a specific buffer area, according to its destination;
    - searching an ITU in the buffer areas;
    - loading an ITU on a wagon of a departing train from the buffer area;

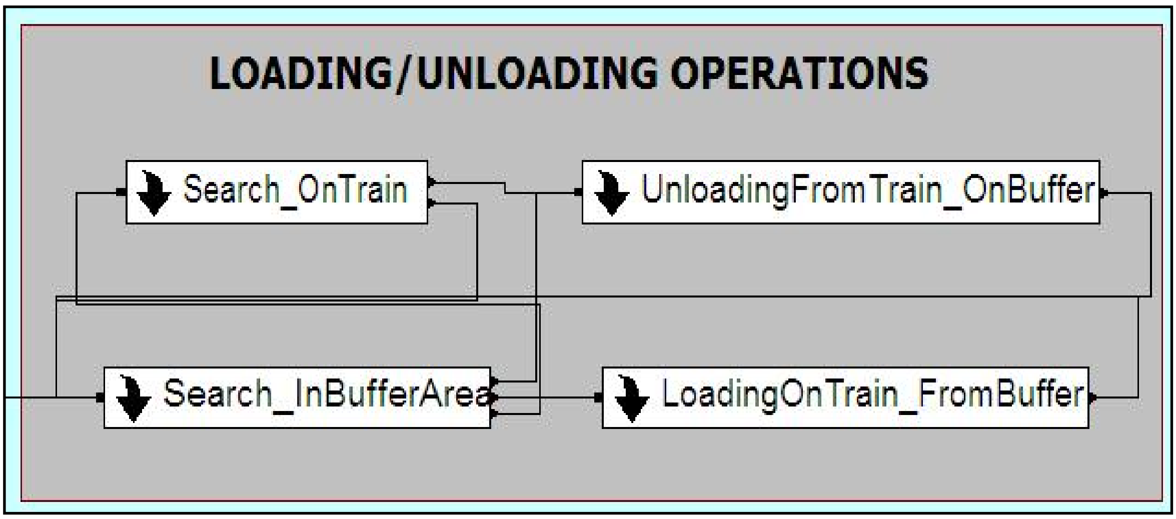


Figure 6 – Containers Handling Logic

- **Failure logic for vision system and recovery actions:** some modules have been introduced to simulate vision system and their failure conditions (according to the templates described in the previous sections); *figure 7* shows the logics implemented for failures which occur during the containers unloading operations (twist lock not centred) and for a wrong recognition of the empty spaces on the train:
    - o two "decide" modules contain the failure stochastic percentages (as they have been defined in the template tables);
    - o two "process" modules simulate the delays caused by the failure events (delays for supervisor intervention) and allocate a human operator for the recovery operations;
    - o two "record" modules collect statistic about the number of the failures (and alerts) which are really observed in the simulation period (percentages are stochastic and not deterministic elements)

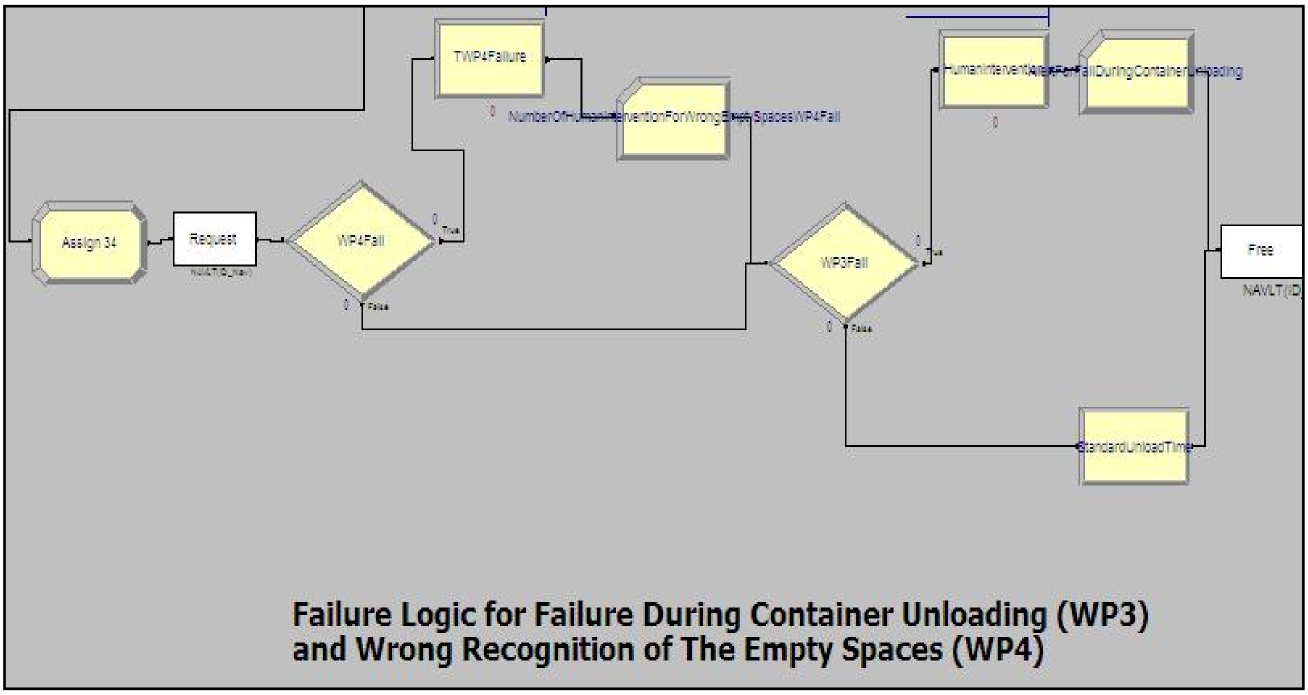


Figure 7 – An example of the failure logics related to WP3 and WP4

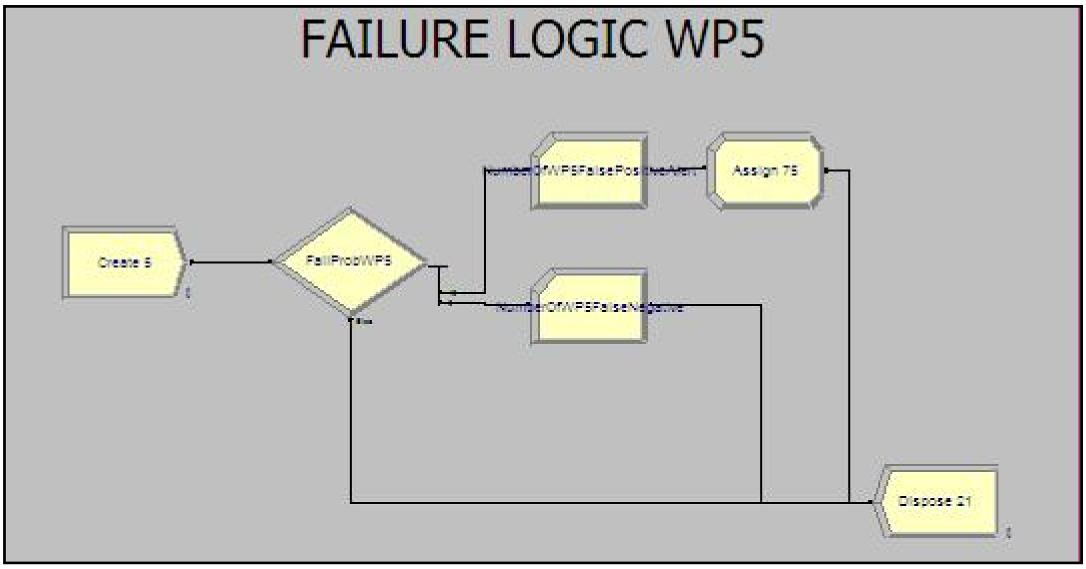


Figure 8 – An example of the failure logics related to WP5

- **Model Outputs (Terminal KPIs):** two different types of outputs are defined in the simulation model (KPIs concerning the functionality of the terminal and KPIs about the plant safety and the people security). Outputs for "rare" failure events have not been defined; if the final field tests will give different results for these events, specific outputs will be defined.

  The most important outputs of the simulator are:
  - "**TimeInTerminal**" output; it reports the average time in terminal per train (time for the train scanning and the loading/unloading operations). It must be compared with the temporal constraint of 40 – 45 minutes
  - **"LoadedContainer**" output; it collects the total number of the loaded containers during the simulation time
  - "**UnloadedContainer**" output; it collects the total number of the unloaded containers during the simulation time
  - "**MovedFromTruckToBufferPerHour**" output; it reports the cranes' hourly productivity
  - "**LoadedContainerPerHour**" output; it reports the average number of loaded containers per hour
  - "**UnloadedContainerPerHour**" output; it reports the average number of loaded containers per hour
  - **"TerminalUtilization**" output; it is determined from taking the utilization at each instant and the calculating a time-weighted average.
  - "**NumberOfWP5FalseNegative**" output; it collects the total number of the false negatives for WP5 cameras of the terminal area during the simulation time;
  - "**NumberOfWP5FalsePositiveAlert**" output; it collects the total number of the false positives and alerts sent by the WP5 cameras of the terminal area during the simulation time;
  - "**NumberOfWP5FalseNegativeWA**" output; it collects the total number of the false negatives for WP5 cameras of the work area during the simulation time;
  - "**NumberOfWP5FalsePositiveAlertWA**" output; it collects the total number of the false positives and alerts sent by the WP5 cameras of the work area during the simulation time;
  - "**AlertForFailDuringContainerUnloading**" output; it collects the total number of the alerts sent by the vision system for errors during containers' unloading operations
  - "**AlertForFailDuringContainerLoading**" output; it collects the total number of the alerts sent by the vision system for errors during the containers' loading operations
  - "**HumanInterventionForWrongEmptySpaces**" output; it collects the total number of the human interventions caused by a failure in the reconstruction of train profile
  - "**HumanInterventionForWrongCode**" output; it collects the total number of the human interventions caused by a failure in the recognition of the ownership code

- **The infrastructures** modelled in the terminal simulator are:
  - Automated buffer areas for the storage of the ITUs;
  - Cranes for the handling of the ITUs from the storage area to trucks and from trucks to the storage area;
  - All the transfer devices, which include shuttles and turrets.

An Access database is used to store information on trains. When a train arrives at the terminal, a table called trainsettings is created. It contains a record for each train position and it includes the fields below:

- TRAINSETTINGS_IDTrain: a progressive number which identifies trains in the simulation model
- TRAINSETTINGS_IDDirection: a number (from 1 to 4) which identifies the right destination for each train

- TRAINSETTINGS_IDWagon: a number which identifies the wagon on the train (from 1 to the maximum number of wagons for each train)
- TRAINSETTINGS_IDPosOnWagon: a number which identifies the containers' position on the wagon (1 or 2)
- TRAINSETTINGS_IDPosition: a number which identifies the containers' position on the wagon (from 1 to 2*Maximum Number Of Wagons)
- TRAINSETTINGS_IDContainer: a progressive number which identifies containers in the simulation model
- TRAINSETTINGS_IDContainerType: a number which identifies the type of each container (1 or 2)
- TRAINSETTINGS_IDUnloading: a number which identifies the type of operation:
  - 1. The container must be unloaded or the position is empty
  - 2. The container remains on the train
- TRAINSETTINGS_Assigned: It is a Boolean value:
  - 0. The position is not assigned
  - 1. The position is assigned

4.2 Interface

In the present work the simulation model has been integrated with Microsoft Office for input/output functionalities: a specific input data file has been performed to introduce and change different project parameters easily, by using VBA routines.

An user interface has been built to facilitate the use of the simulator; the input data file (.xls) allows to feed the simulation module with a possible configuration. Acting on this input data file the user can modify the terminal definition. In particular, the user can modify the failures parameters and he can run a new scenario.

The input data file is named "**XL_Input_Terminal_FinalRelease**" and it is placed in the same folder of the simulation model.

In particularly, it contains:

- A "Trains" spreadsheet, which allows the user to change some trains parameters such as the number of wagons per train (from 1 to 33) and the wagons configuration distribution.
- A "Trucks" spreadsheet, which allows the user to change some trucks parameters such as the time between arrivals and the direction probability distribution for the incoming ITUs;
- A "Times" spreadsheet, which allows the user to change the time for loading/unloading operations for all the terminal equipments (cranes, turrets and shuttles); transfer times are obtained by the combination of distances with velocities, which are already set in the simulation model
- A "***Failures Parameters***" spreadsheet, which allows the user to change the failure probability and the failure recovery time for each vision device.

4.3 Run of scenarios

Note: this paragraph refers to field test performed between month 15 and month 18.

The outputs coming from critical scenarios must be analysed in order to understand the real influence of perturbations on system security and terminal productivity and they must be compared with the outputs coming from the standard scenario and with the desired service level.

The simulation model of the terminal has been fed by the SME's experts through the use of the input data excel file with a suitable configuration ("Trains", "Trucks" and "Times"); the different scenarios refer to different "**FailureParameters**"

The numerical results of the following scenarios are reported:

- **"Standard Scenario"** with no failure events coming from the vision system
- **"Standard Failure Scenario"** with standard vision systems failures added. The frequency of the failure events is changed according to the field tests. Only events with "daily" frequency are modelled.
- **"Critical Weather Conditions Scenario"** in which critical weather conditions are simulated. The frequency of the failure events is changed according to the field tests. Only events with "daily" frequency are modelled.
- **"Maximum Failure Standard Scenario"** with maximum error percentage in standard conditions added. Only "daily" or "critical" events are modelled
- **"Maximum Failure Critical Weather Conditions Scenario"** with maximum error percentage in critical weather conditions added. Only "daily" or "critical" events are modelled.

The last two scenarios have been run to evaluate the maximum resulting risk and to understand if it is acceptable by the SME's.

For each scenario 7 days are simulated (replication length) and 10 simulation runs are executed (number of replications).

Figure 9 shows an example of the Arena's outputs in Crystal Report. Taking in account a SME's experts requirement, all the simulation results have been collected in a "**VIT_TerminalSimulationResults**" Excel file (so results are more intelligible and it is easier to compare different scenarios).

Time Persistent

Time Persistent	Average	Half Width	Minimum Average	Maximum Average
LoadedContainerPerHour	15.6856	0.18	15.2561	16.1500
MovedFromTruckToBufferPerHour	16.5070	0.20	16.0185	17.0371
UnloadedContainerPerHour	16.0270	0.24	15.5318	16.7407

Figure 9 – An example of Crystal Report's outputs

For each scenario, results are collected in a table which contains a row for each output and four different columns (*Figure 10, Figure11, Figure 12*):

- An **"Average"** field; it reports the average of the replication averages;
- An **"Half Width"** field; this statistic is included to determine the reliability of the simulation results. This value may be interpreted by saying "in 95% of repeated trials, the sample mean would be reported as within the interval sample mean ± half width". The half width can be reduced by running the simulation for a longer period of time.
- A **"Minimum Average"** field; it contains the smallest average across all replications
- A **"Maximum Average"** field; it contains the largest average across all replications

Standard Scenario	Average	Half Width	Minimum Average	Maximum Average
TimeInTerminal	*43.01 Minutes*	*0.33 Minutes*	*42.09 Minutes*	*43.60 Minutes*
LoadedContainers per we-ek	2751	36.47	2667	2815
UnloadedContainers per week	3895	30.48	3828	3968
Moved From Trucks To Buffer Per Hour	16.54	0.30	15.73	17.35
Loaded Containers Per Hour	15.73	0.29	14.92	16.48
Unloaded Containers Per Hour	22.36	0.25	21.85	22.90
Terminal Utilization	*35.42%*	*0.04%*	*34.66%*	*35.91%*
Human Operator Utiliza-tion	0%	0%	0%	0%
Number Of WP5 False Ne-gative (Terminal Area) per week	0	0	0	0
Number Of WP5 False Po-sitive Alerts (Terminal A-rea) per week	0	0	0	0
Number Of WP5 False Ne-gative (Work Area) per week	0	0	0	0
Number Of WP5 False Po-sitive Alerts (Work Area) per week	0	0	0	0
Alerts For Fail During Container Unloading per week	0	0	0	0
Alerts For Fail During Container Loading per we-ek	0	0	0	0
Human Intervention For Wrong Empty Spaces per week	0	0	0	0
Human Intervention For Wrong Recognition of the Code per week	0	0	0	0

Figure 10 – Outputs of the Standard Scenario

Standard Failure Scenario	Average	Half Width	Minimum Average	Maximum Average
TimeInTerminal	***43.51 Minutes***	***0.71 Minutes***	***42.11 Minutes***	***45.27 Minutes***
LoadedContainers per we-ek	2744	28.64	2668	2783
UnloadedContainers per week	3892	32.78	3801	3975
Moved From Trucks To Buffer Per Hour	16.59	0.16	16.28	16.93
Loaded Containers Per Hour	15.76	0.15	15.45	16.06
Unloaded Containers Per Hour	22.39	0.22	21.97	22.87
Terminal Utilization	***35.83%***	***0.06%***	***34.68%***	***37.28%***
Human Operator Utiliza-tion	**2.58%**	**0.06%**	**2.28%**	**3.20%**
Number Of WP5 False Ne-gative (Terminal Area) per week	10.90	3.15	5	16
Number Of WP5 False Po-sitive Alerts (Terminal A-rea) per week	24.60	3.44	14	30
Number Of WP5 False Ne-gative (Work Area) per week	0.18	0.35	0	1
Number Of WP5 False Po-sitive Alerts (Work Area) per week	1.20	0.66	0	3
Alerts For Fail During Container Unloading per week	9.20	1.50	6	14
Alerts For Fail During Container Loading per we-ek	7.40	1.85	4	11
Human Intervention For Wrong Empty Spaces per week	120.20	10.27	103	152
Human Intervention For Wrong Recognition of the Code per week	4.60	1.23	2	7

Figure 11 – Outputs of the Standard Failure Scenario

Critical Weather Conditions Scenario	Average	Half Width	Minimum Average	Maximum Average
TimeInTerminal	*44.86 Minutes*	*0.61 Minutes*	*43.96 Minutes*	*46.51 Minutes*
LoadedContainers per we-ek	2754	39.87	2669	2839
UnloadedContainers per week	3894	28.76	3851	3982
Moved From Trucks To Buffer Per Hour	16.61	0.29	16.08	17.19
Loaded Containers Per Hour	15.78	0.28	15.26	16.32
Unloaded Containers Per Hour	22.36	0.22	21.97	22.94
Terminal Utilization	*36.94%*	*0.06%*	*36.19%*	*38.30%*
Human Operator Utiliza-tion	7.34%	0.06%	7.05%	7.65%
Number Of WP5 False Ne-gative (Terminal Area) per week	16.20	3.25	8	21
Number Of WP5 False Po-sitive Alerts (Terminal A-rea) per week	39.70	4.37	27	50
Number Of WP5 False Ne-gative (Work Area) per week	0.20	0.30	0	1
Number Of WP5 False Po-sitive Alerts (Work Area) per week	1.80	1.34	0	6
Alerts For Fail During Container Unloading per week	16.60	2.37	11	21
Alerts For Fail During Container Loading per we-ek	12.70	1.85	7	16
Human Intervention For Wrong Empty Spaces per week	342.50	8.03	331	363
Human Intervention For Wrong Recognition of the Code per week	20.90	2.89	13	28

Figure 12 – Outputs of the Critical Weather Conditions Scenario

NOTE*: For the wrong reconstruction of the train profile the maximum acceptable error percentage has been considered. The results of the field tests in critical wind condition suggest that a new hardware device is needed. (See WP4 for details)*

Maximum Failure Standard Scenario	Average	Half Width	Minimum Average	Maximum Average
TimeInTerminal	*44.03 Minutes*	*0.48 Minutes*	*42.80 Minutes*	*44.97 Minutes*
LoadedContainers per we-ek	2744	34.62	2685	2819
UnloadedContainers per week	3902	25.52	3858	3983
Moved From Trucks To Buffer Per Hour	16.58	0.25	16.09	17.17
Loaded Containers Per Hour	15.75	0.25	15.31	16.3
Unloaded Containers Per Hour	22.43	0.21	21.93	22.84
Terminal Utilization	*36.25%*	*0.05%*	*35.25%*	*37.04%*
Human Operator Utiliza-tion	4.68%	0.06%	4.12%	5.11%
Number Of WP5 False Ne-gative (Terminal Area) per week	17.40	2.19	11	20
Number Of WP5 False Po-sitive Alerts (Terminal A-rea) per week	41.30	3.85	31	48
Number Of WP5 False Ne-gative (Work Area) per week	0.20	0.30	0	1
Number Of WP5 False Po-sitive Alerts (Work Area) per week	1.30	1.26	0	6
Alerts For Fail During Container Unloading per week	18.10	3.19	10	25
Alerts For Fail During Container Loading per we-ek	14.60	2.87	7	18
Human Intervention For Wrong Empty Spaces per week	171.50	7.10	154	188
Human Intervention For Wrong Recognition of the Code per week	73.60	8.17	57	89

Figure 13 – Outputs of the Maximum Failure Standard Scenario

Maximum Failure Critical Weather Conditions Scenario	Average	Half Width	Minimum Average	Maximum Average
TimeInTerminal	*45.04 Minutes*	*0.57 Minutes*	*44.16 Minutes*	*46.93 Minutes*
LoadedContainers per we-ek	2725	35.86	2630	2805
UnloadedContainers per week	3883	28.61	3817	3961
Moved From Trucks To Buffer Per Hour	16.45	0.25	15.9	17.02
Loaded Containers Per Hour	15.62	0.25	15.07	16.13
Unloaded Containers Per Hour	22.37	0.22	21.83	22.94
Terminal Utilization	*37.09%*	*0.05%*	*36.36%*	*38.65%*
Human Operator Utiliza-tion	*9.46%*	*0.06%*	*8.96%*	*10.15%*
Number Of WP5 False Ne-gative (Terminal Area) per week	21.30	2.96	13	28
Number Of WP5 False Po-sitive Alerts (Terminal A-rea) per week	49.70	5.66	39	65
Number Of WP5 False Ne-gative (Work Area) per week	0.30	0.35	0	1
Number Of WP5 False Po-sitive Alerts (Work Area) per week	4.60	0.97	2	7
Alerts For Fail During Container Unloading per week	36.60	4.27	28	45
Alerts For Fail During Container Loading per we-ek	25.90	2.93	19	33
Human Intervention For Wrong Empty Spaces per week	345.40	13.56	327	384
Human Intervention For Wrong Recognition of the Code per week	155.80	7.46	137	169

Figure 14 – Outputs of the Maximum Failure Critical Weather Conditions Scenario

The discrete stochastic simulator of the terminal has been integrated with failure mode effects and critical scenarios analysis to establish the risk of catastrophic failures, to estimate the final reliability both for plant safety and for correct terminal operability.

The most frequent events are:

- A wrong recognition of the empty spaces on the train;
- A false positive alert coming from cameras monitoring the terminal area;

These events are not critical; they have no risks for people security, and they have not an important influence on system productivity.

In fact, analysing the results with the help of the SME's, it is possible to note that also in critical weather conditions the very strict temporal constraints of 40 – 45 minute for trains' loading/unloading is met, considering a tolerance of two minutes

The terminal utilization varies between 35.32% and 37.5% , that corresponds to 8-9 operating hours per day (with 12 arriving trains per day).

For the considerations above we can say that the correct terminal operability is ensured both in standard and in critical conditions.

The only critical event for human safety is a false negative event from the work area cameras; the simulation results report that it is a very rare event in any condition; in fact, both the terminal area cameras and the work area cameras must fail to not detect a human presence in the loading area. Note that a human presence event is not a critical events if it doesn't occur during loading/unloading operations.

Besides, it's very important to understand that these results are referred to a **"not constrained terminal"** without any limited access point where common people can move freely around the terminal area. These results don't take into account that:

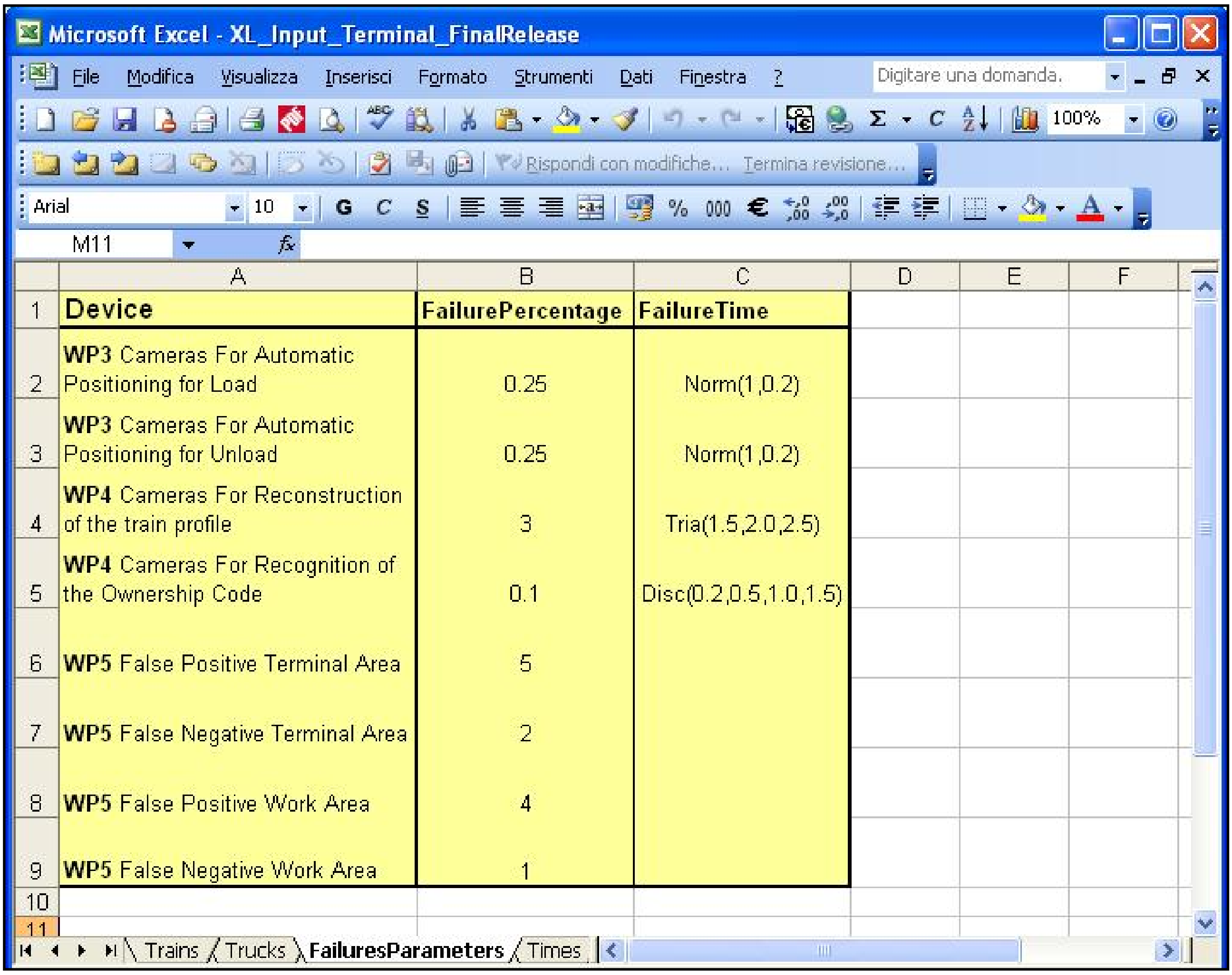
- The plant is installed within a port or inter-port area, that has its own fencing and security controls against intrusion of people not connected with the operations.
- The plant itself has fencing with limited access points, and plant personnel will be stationed in a position having general visibility of the site.
- Plant personnel are highly trained technicians.
- Presence of personnel in the work area is not necessary and prohibited, and will be immediately remarked by plant control personnel and/or plant supervisor.

NOTE: The outputs coming from the analysed scenarios have been discussed by the SME's experts and they have been validated. Obviously other scenarios can be tested by using the simulation model.

5. Final release simulation software User's Guide

As a first action, the user must extract all the files from the folder "**VIT_SimModelFinalRelease**" in order to use the simulation model. Then following the steps below:

1. To feed the simulation model with a new configuration, open the "**XL_Input_Terminal_FinalRelease",** change the desired parameters, save and close the file.



Device	FailurePercentage	FailureTime
WP3 Cameras For Automatic Positioning for Load	0.25	Norm(1,0.2)
WP3 Cameras For Automatic Positioning for Unload	0.25	Norm(1,0.2)
WP4 Cameras For Reconstruction of the train profile	3	Tria(1.5,2.0,2.5)
WP4 Cameras For Recognition of the Ownership Code	0.1	Disc(0.2,0.5,1.0,1.5)
WP5 False Positive Terminal Area	5	
WP5 False Negative Terminal Area	2	
WP5 False Positive Work Area	4	
WP5 False Negative Work Area	1	

Figure 15 – Failure Parameters Update

2. To open the simulation model, double-click on the "**TerminalModel_FinalRelease.doe**" icon; then click on the "Update Input Data" command button to automatically update changed parameters in the simulation model

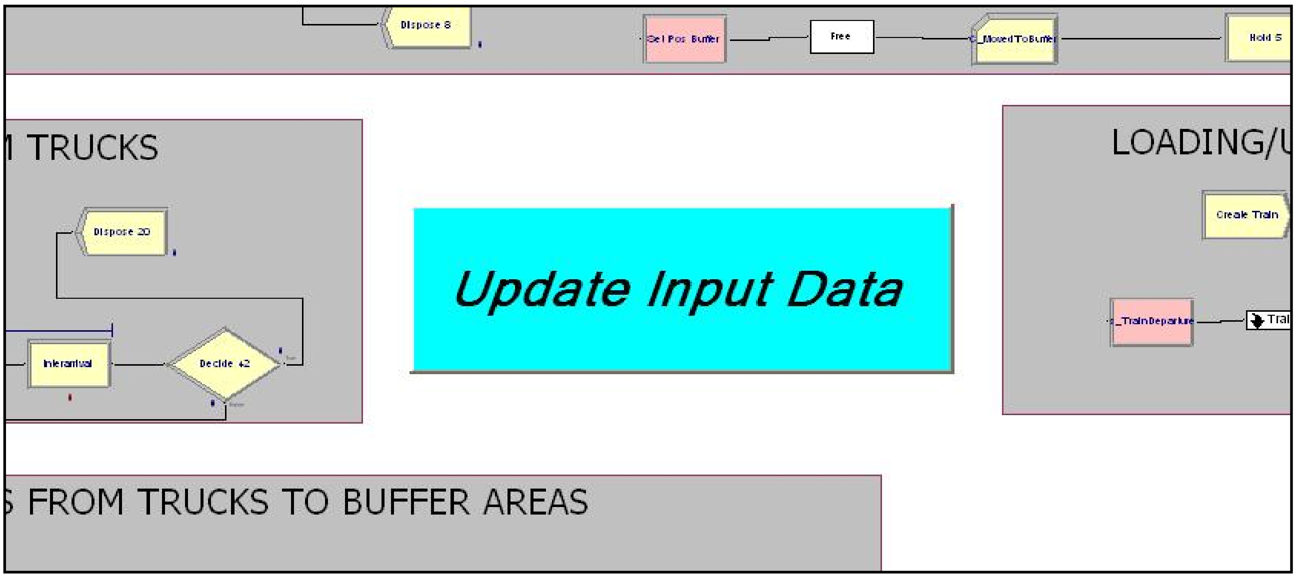


Figure 16 – The Update Input Data Command Button

3. To run the model, click on the "***Go***" button or the "***Fast-Forward***" button (for a faster simulation) on the "***Standard Toolbar***"

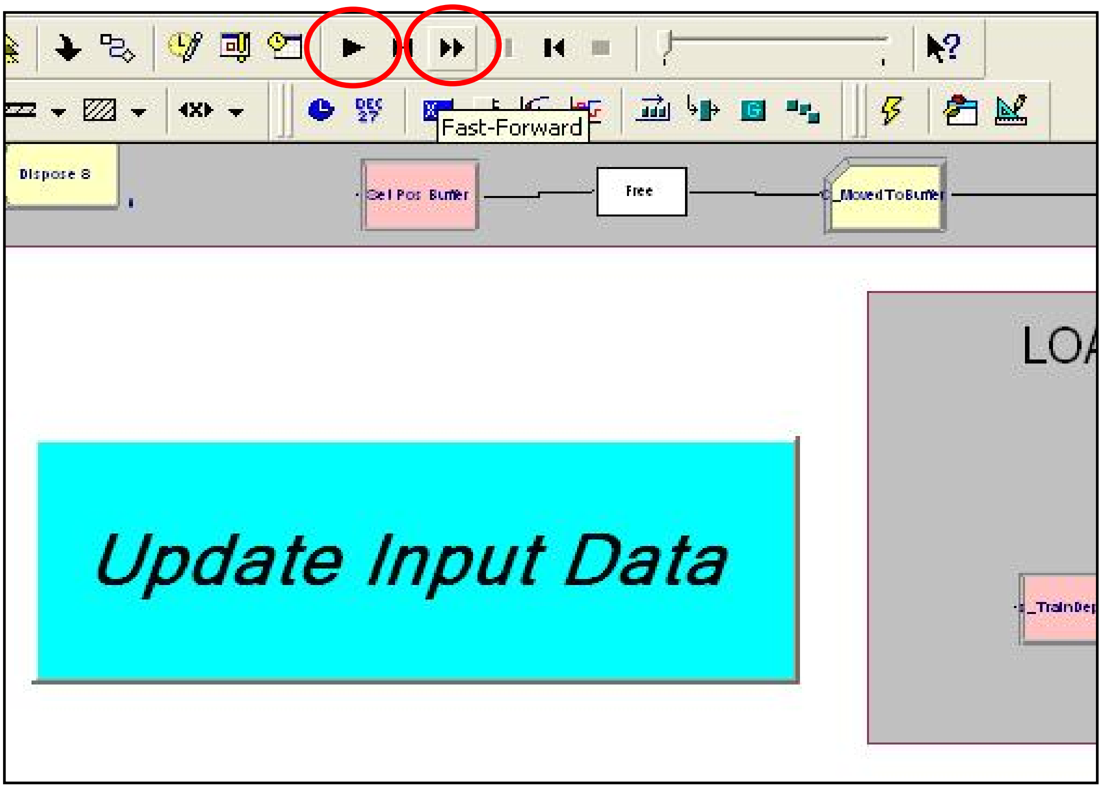


Figure 17 – The "Go" and the "Fast-Forward" button

4. To view the model outputs after the simulation click on the "Yes" button.

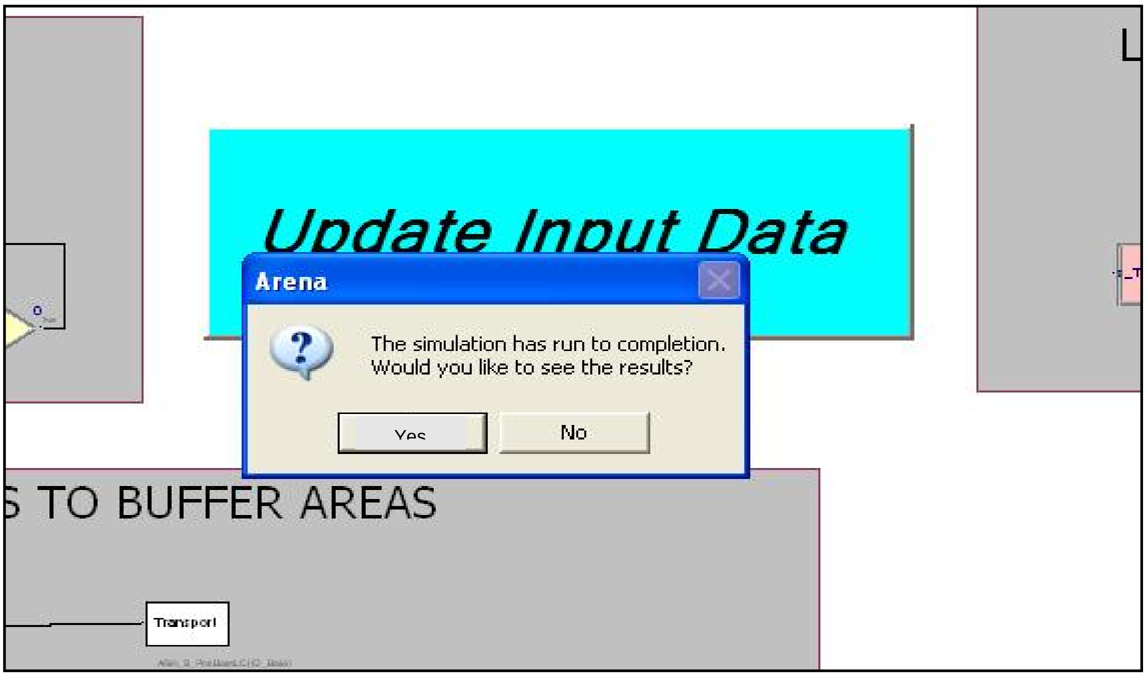


Figure 18 – Click "Yes" to see the simulation results

NOTE: *A training video has been recorded to help the user to perform the step above and it has been uploaded on the web site*

6. Final review with respect to user requirements

Requirements

- **To define the basic logic of the terminal, modeling trains/trucks arrivals and the loading/unloading operations by using a simulator**
  - All the basic terminal logic have been studied and analyzed; a stochastic simulator has been developed to model trains/trucks arrivals and the loading/unloading operations.
  - All the terminal devices (cranes, shuttles and turrets) and the buffer areas have been modeled. *(See paragraph 4.1 of this document for a detailed description of the simulator)*.
- **To analyze and classify the events originated by the vision systems with the help of the vision experts**
  - Meeting with the leaders of the other RTD WPs have been organized to collect data about the failure events of the vision system.
  - All the possible events have been listed, collected in a form (excel template file) and classified according to their importance and their frequency. *(See section 2 of this document for the excel template file)*
- **to evaluate the risks connected with errors in the information coming from the vision systems**
  - Some modules have been introduced in the terminal model to simulate all the significant events and the failures influence on the terminal KPIs has been analyzed. *(See paragraph 4.1 and 4.3 of this document for details)*
- **to define the recovery actions deriving from the events originated by the vision systems with the help of SME's**
  - For each vision device and for each failure the actions that are needed when the failure event occurs have been defined with the help of SME's and developers of the WP3, WP4 and WP5.
  - All the recovery actions have been collected in a form (excel template file) and they have been simulated in the stochastic model of the terminal. *(See section 3 of this document for the excel template file)*
- **to define plant safety and terminal operability KPIs for the simulation model**
  - Both terminal safety and terminal productivity KPIs have been defined in order to analyse the overall system performance *(See paragraph 4.2 of this document for a wider description of all the KPIs)*
- **to predict the reliability level by using the simulation model (both in standard and anomalous conditions)**
  - Different failure scenarios have been defined with the help of the other WPs developers; they have been run to predict the reliability level of the system in different conditions. *(See paragraph 4.3 of this document for details)*
- **to compare the outputs coming from the simulation model with the desired service level (or defined constraints)**
  - The model outputs of each simulated scenario have been analysed and compared with the desired service level and with the constraints defined by the SMEs. *(See paragraph 4.3 of this document for details)*
- **to design the hardware architecture and the high level logic in such a way as to manage the plant in safe conditions and guarantee a correct operability. (This shall include a devices redundancy policy to counter critical conditions)**

- Scenarios which simulate critical stochastic conditions have been run; simulation has given feedback about all the control logics and the defined recovery actions have been monitored and evaluated. *(See paragraph 4.3 of this document for details).*

- o **to evaluate the final reliability level resulting from the defined architecture and procedures**
  - Through the scenarios analysis, the final reliability level resulting from the defined architecture has been evaluated. Obviously, in the future, with very small changes to the simulation model will be possible to evaluate other hardware solutions.

Constraints

- o **The system security and data management will take into consideration all the features of the vision systems defined in the preceding WPs**
  - All the features of the vision systems defined by the developers of the other WPs have been studied and their functionalities have been simulated. *(See paragraph 4.1 of this document for details)*
- o **The system security and data management will take into consideration the different extreme conditions assumed in the preceding WPs**
  - Both standard and critical scenarios have been run; in particularly, extreme weather conditions have been simulated as perturbations (higher failure frequency coming from the results of the field tests). *(See paragraph 4.3 of this document for details)*

Measurable objectives

In the scenarios analysis all the measurable objectives of the other WPs have been considered; the simulation model has been fed with the maximum error percentages defined in D2.1 (both in standard and in extreme conditions) to evaluate the resulting risk and to understand if it is acceptable by the SME's.

The various scenarios have been run and the simulation results have been analysed; in particularly, the most important operational constraint, which is the very strict temporal constraint of 40 – 45 minutes (with a tolerance of 2 minutes), to load and unload a train is always met. *(See paragraph 4.3 of this document for details)*

7. State of simulator with respect to Metrocargo

A decision support system is a very important tool for the management of an intermodal container terminal. Among problems to be solved are the allocation of containers in the buffer areas, the allocation of the transfer devices, the scheduling of terminal activities and operations to maximize the performance of the overall system and the evaluation of the reliability level for plant safety and operability.
All the main features of a Metrocargo terminal have been implemented in the simulation model; in particularly all the lifting equipments, the transfer devices and the sorting buffer platforms have been modelled; vision systems developed by the other WPs and their failure have been analysed and added to the model to see the whole terminal in its complexity, considering the multiple interactions of the various concurrent processes.
After the implementation, test scenarios have been run and, simulation results have been analysed by the SME's experts and the model has been validated.
The discrete-event simulation tool based on the process-oriented paradigm provides a test bed for checking the validity and robustness of the suggested solutions.
In the future developments the simulation model of the intermodal Metrocargo terminal may be integrated with a planner and a scheduler for optimising all the terminal activities (loading/unloading operations, buffer areas operations, trucks arrivals, etc…).
It also will be possible to feed the simulation model with data about failures of the automated lifting equipments to predict their effects on terminal productivity and to estimate the correct number of each transfer device for every new Metrocargo installation.