Industrial Engineering Ph.D.

MODELING & SIMULATION APPLIED TO DESIGN AND MANAGEMENT OF PRODUCTION AND LOGISTIC SYSTEMS

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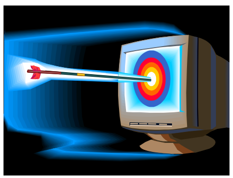
INTRODUCTION AND THESIS OBJECTIVES

- The Doctorate is concerned with *Modeling & Simulation* (discrete event simulation) applied to manufacturing systems and logistic systems
- No other works had been developed in this specific area at Industrial Plant chair of University of Calabria

OBJECTIVES



- Modeling & Simulation to achieve new scientific results in the specific area of interest.
- Innovative ways to use Modeling & Simulation as well as innovative approaches to classic problems using Modeling & Simulation.

STARTING POINT (*Industrial Engineering Sector definition*)

“The sector studies the methodologies and the general criteria related to production systems planning, designing and management. The sector groups the following scientific areas: production systems analysis and design, [….] production systems management, production systems internal and external logistic, including material handling […….]”

RESEARCH AREAS IDENTIFICATION AND Ph.D. ACTIVITIES

1. *Production Systems Management*

Short period production planning (in particular refer to stochastic scheduling problems of manufacturing systems) and plant lay-out analysis and optimization (looking also to material handling systems as fundamental elements for an efficient plant lay-out) as part of *production systems management*.

2. *External Logistic*

Logistic and transportations analysis, inventory/store management and security in supply chains as part of *external logistic*

The Doctorate activities have been subdivided in three parts:

1. Training activities
2. State of art overview
3. Research activities

TRAINING & RESEARCH ACTIVITIES – STATE OF ART OVERVIEW

University of Calabria	• M&S general principles – eM-Plant, Minitab, Simple++, Visual Basic;
University of Genoa	• M&S (VV&A, DOE and ANOVA) – Creator, Vega, C++;
State University of New Jersey (Rutgers University)	• M&S (input data analysis, ANOVA) – Anylogic, Minitab, JAVA.

- The state of art overview has been made reading several books, international journal papers and conferences papers.

PRODUCTION SYSTEM MANAGEMENT

- 2 cases study concerning with short period production planning
- 2 cases study concerning plant lay-out and optimization

EXTERNAL LOGISTIC

- 3 cases study concerning logistic, transportation, inventory/store management (supply chain management)
- 1 case study concerning supply chain security

PRODUCTION SYSTEMS MANAGEMENT (*Short Period Production Planning*)

Demand Market

↓

Shop Orders

↓

Scheduling on available resources

- Stochastic process times
- Stochastic setup times
- Preemption
- Machines failures
- Manpower unavailable
- Machines duplication
- A Shop Order can simultaneously occupy more than one machine
- Non-negligible transportation times
- Limited interoperation buffer capability
- ……..

The research on short period production planning focalizes jobs scheduling problem in manufacturing systems.

The state of art overview: restrictive assumptions on stochastic nature of production systems (deterministic approach) and restrictive assumptions on starting hypotheses (avoiding highly complex and computationally intractable problems)

↓

Several and different analytical models have been proposed. These models can be used to define scenarios useful to gain confidence and knowledge about the system but, as very often happens, the results cannot be applied to real systems.

CASE STUDY: MASTINO (**M**odeling, **A**nalysis & **S**imulation of **T**ube manufacturing process and **IN**dustrial **O**peration control)

Modeling & Simulation to recreate systems complexity and delete restrictive assumptions

→

Good assumptions to have good models – No interest in easy solvable problem from a theoretical/analytical point of view.

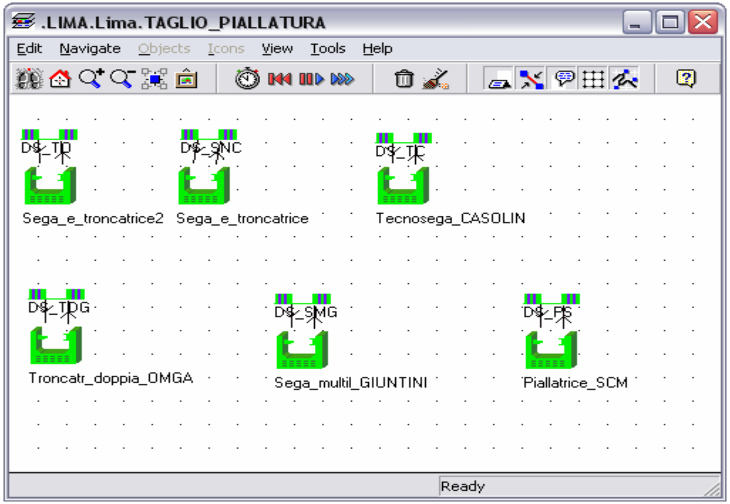
We don't aim to obtain results with general validity but to obtain result that can be easily transferred to the real systems.

ALFAGOMMA
Alfatechnology S.r.l

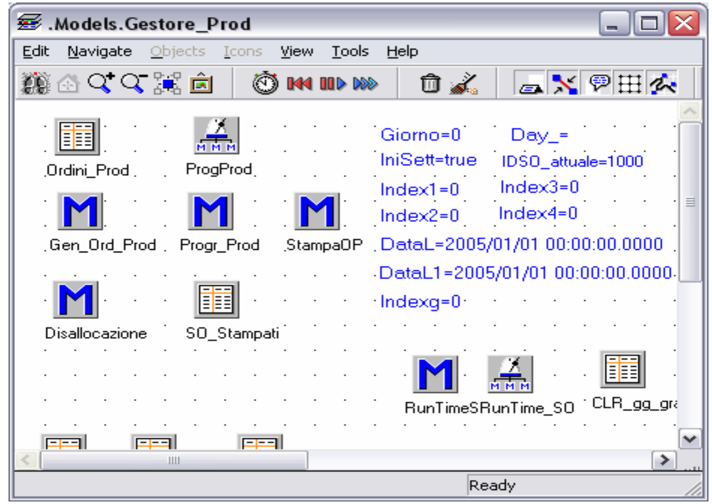
- The case study has been developed with a medium enterprise working on hydraulic hoses manufacturing
- **Objective**: a powerful and flexible tool (a simulator) that can be completely integrated in the company management system to support the shop orders scheduling (short period production planning)
- In addition we propose a particular way to use a discrete event simulation software.

CASE STUDY: MASTINO (Modeling, Analysis & Simulation of Tube manufacturing process and INdustrial Operation control)

Modeling phase traditional approach



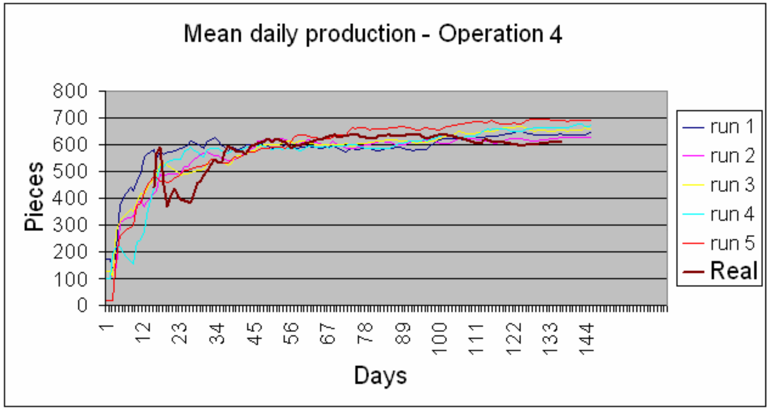
Modeling phase advanced approach

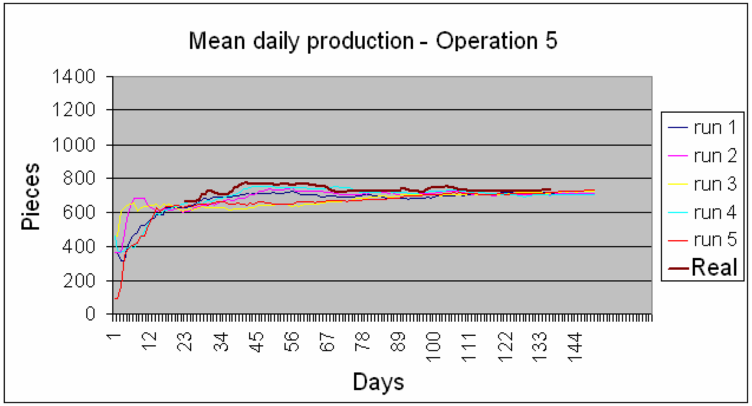


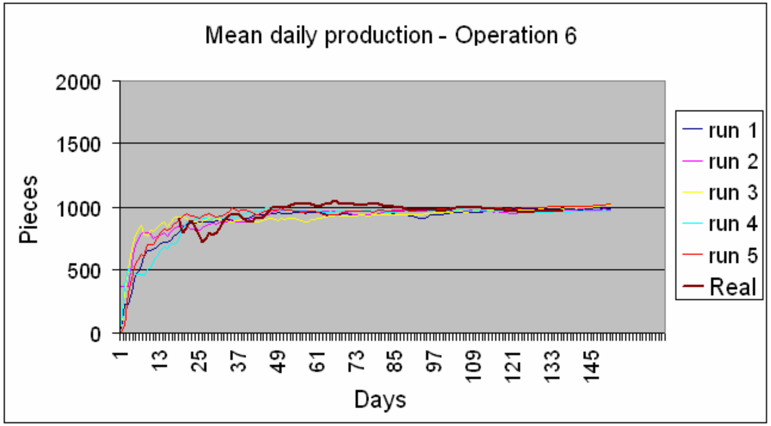
- The modeling phase traditional approach in terms of library objects and entities is characterized by two problems: huge difficulties in modeling complex scenarios, too many entities cause computational heavy models.
- The new approach uses only the events controller object, the architecture is completely based on programming code, tables and events generators.
- The outcome is a very flexible simulator (in fact every object can be accessed and modified by means of code) and easy for what concern the computation (the physical flow of entities is replaced by information flows stored in tables).

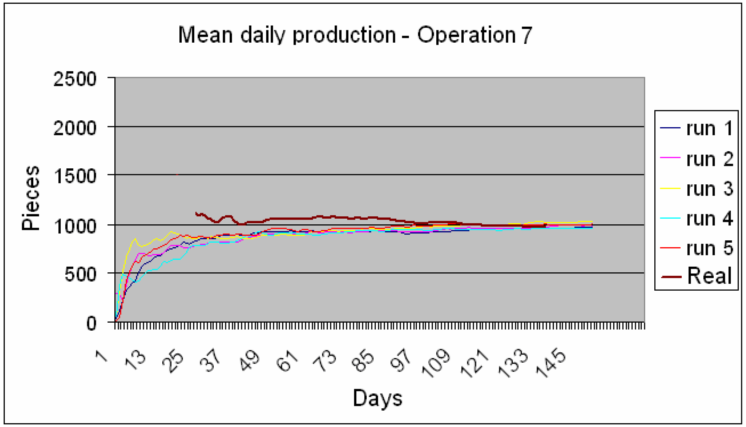
CASE STUDY: MASTINO (**M**odeling, **A**nalysis & **S**imulation of **T**ube manufacturing process and **IN**dustrial **O**peration control)

Validation, Verification & Accreditation (VV&A) – *Face Validation*









CASE STUDY: MASTINO (Modeling, Analysis & Simulation of Tube manufacturing process and INdustrial Operation control)

As before mentioned the simulator has to be integrated in the company informative system to support jobs scheduling and short period production planning. The step just before the integration was the simulator potential tests.

Scheduling rules (decision tools)

- Short Production time (SPT);
- Due Date (DD);
- Longest Production time (LPT);
- Number In Next Queue (NINQ);

Performance Indexes

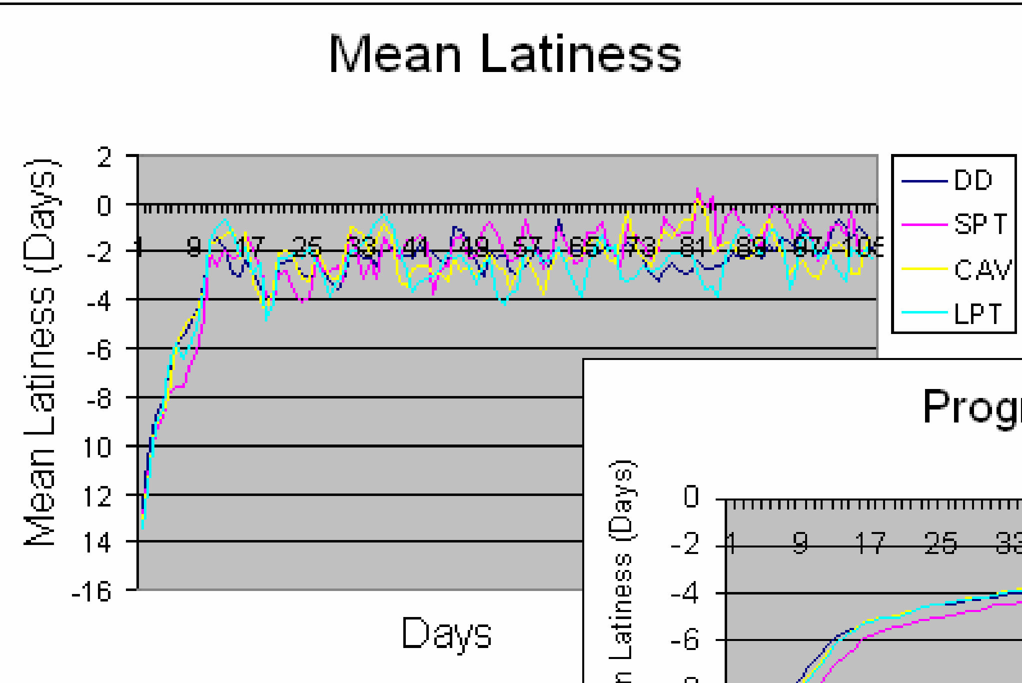
- d_i, Shop Order Due Date
- I_i, Shop Order entrance Date
- C_i, Shop Order Completion Time
- t, time
- n_t, number of Shop Order completed
- *Lateness*, $L_i = C_i - d_i$
- *Tardiness*, T_i = max (0, Latiness)
- *FlowTime*, $F_i = C_i - I_i$

$$LM = \frac{\sum_{i=1}^{n_t} L_i}{n_t}$$ *Mean Latiness*

$$TM = \frac{\sum_{i=1}^{n_t} T_i}{n_t}$$ *Mean Tardiness*

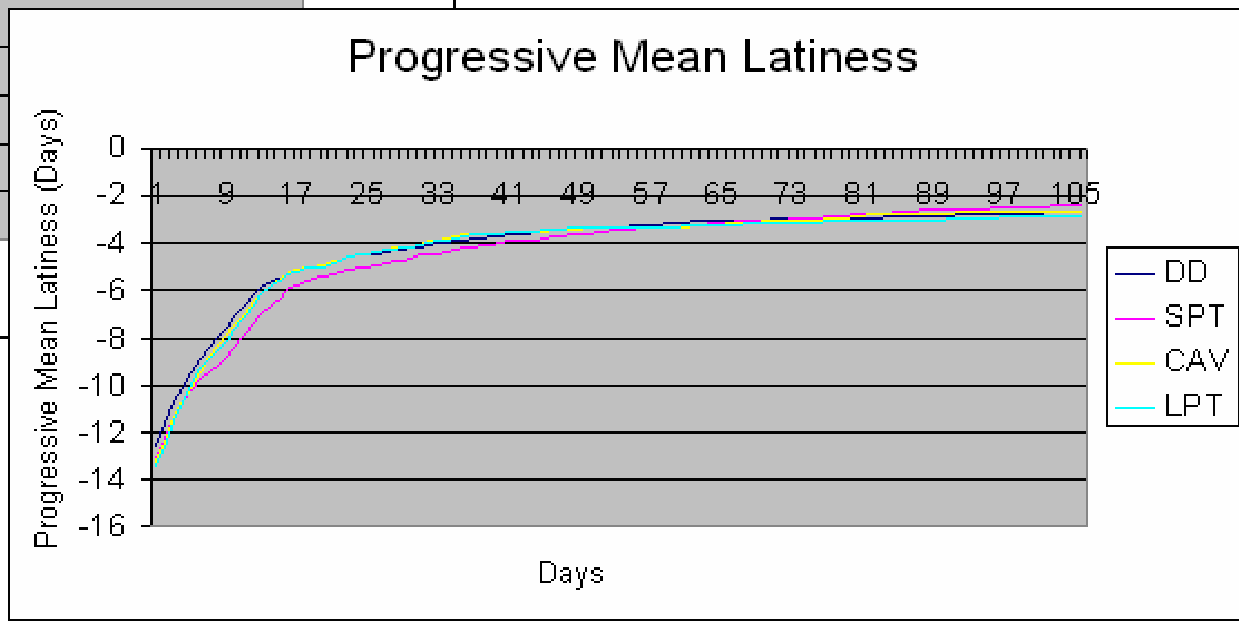
$$FM = \frac{\sum_{i=1}^{n_t} T_i}{n_t}$$ *Mean FlowTime*

CASE STUDY: MASTINO (**M**odeling, **A**nalysis & **S**imulation of **T**ube manufacturing process and **IN**dustrial **O**peration control)



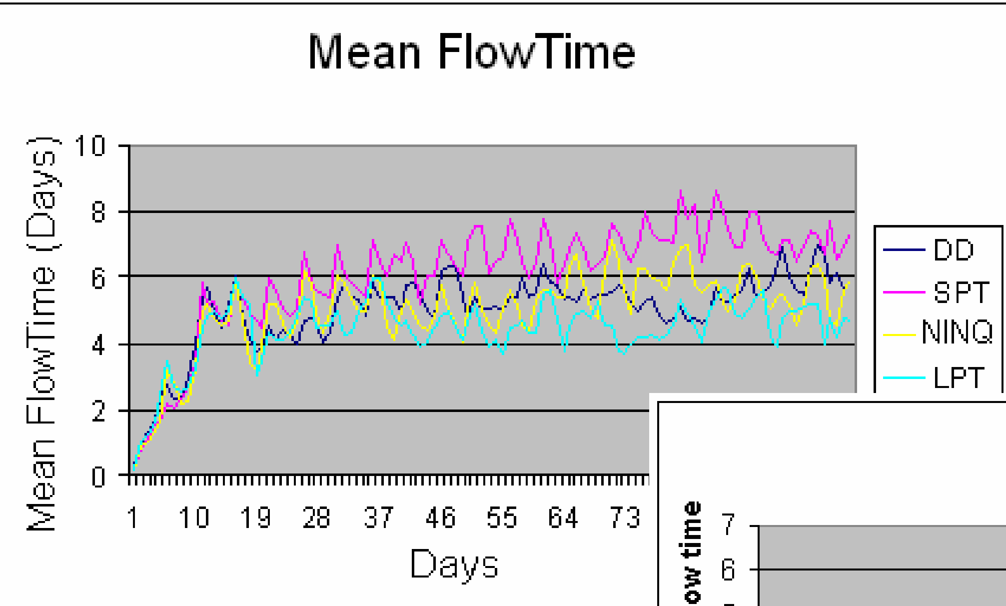
Mean Latiness in correspondence of the different scheduling rules

LM_{DD}= - 2.6 giorni
LM_{SPT}= - 2.4 giorni
LM_{NINQ}= - 2.6 giorni
LM_{LPT}= - 2.9 giorni



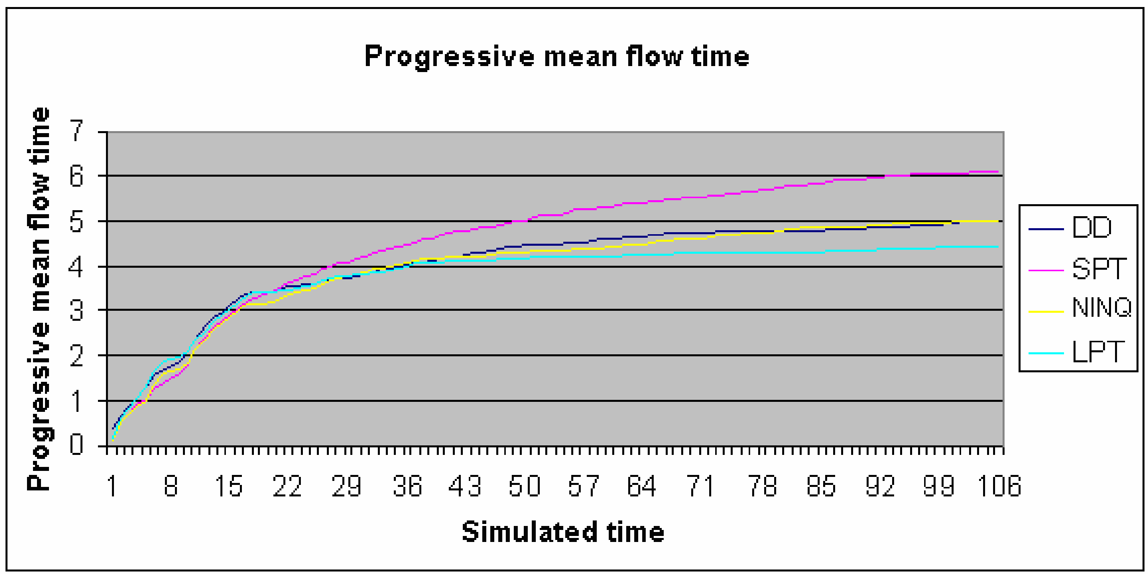
- $\Delta LM_{(LPT-DD)}$= 10%
- $\Delta LM_{(LPT-SPT)}$= 17%
- $\Delta LM_{(LPT-NINQ)}$= 10%

CASE STUDY: MASTINO (**M**odeling, **A**nalysis & **S**imulation of **T**ube manufacturing process and **IN**dustrial **O**peration control)



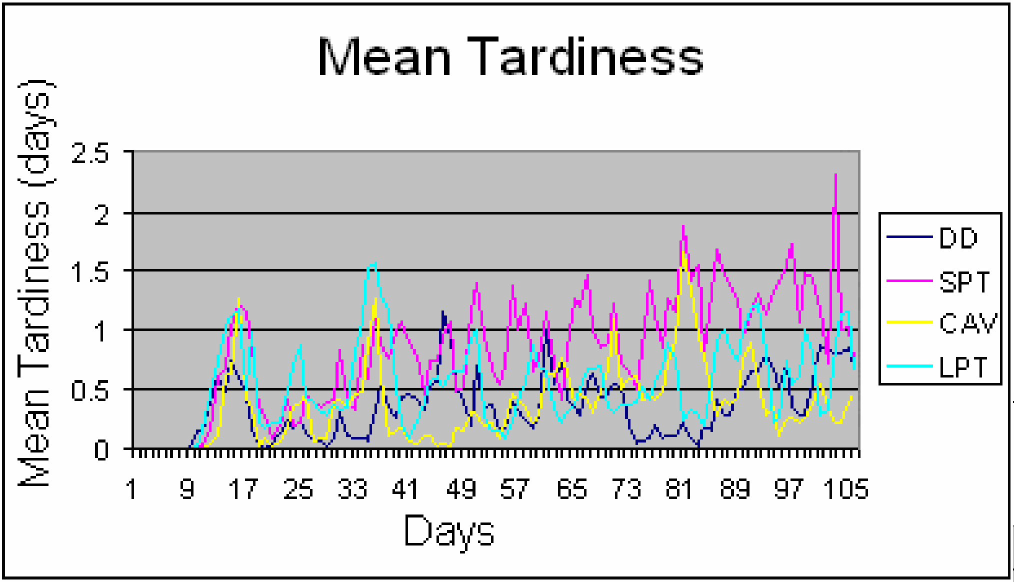
Mean FlowTime in correspondence of the different scheduling rules

- FM_{DD}=5 giorni
- FM_{SPT}= 6.1 giorni
- FM_{NINQ}=5 giorni
- FM_{LPT}=4.4 giorni



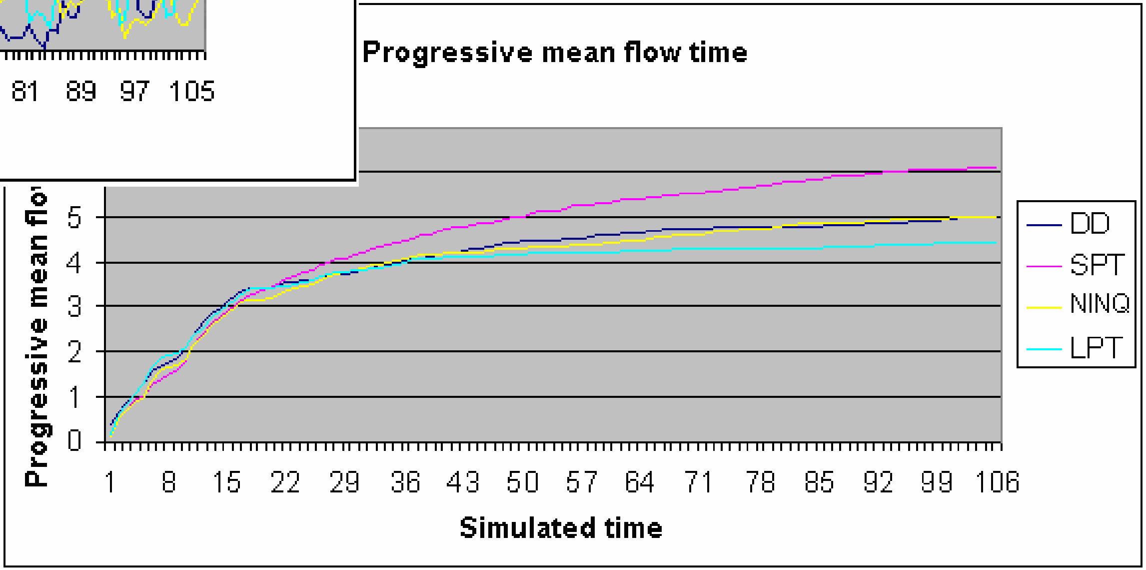
- $\Delta FM_{(LPT-DD)}$= 12%
- $\Delta FM_{(LPT-SPT)}$= 28%
- $\Delta FM_{(LPT-NINQ)}$= 12%

CASE STUDY: MASTINO (Modeling, Analysis & Simulation of Tube manufacturing process and INdustrial Operation control)



Mean Tardiness in correspondence of the different scheduling rules

- TM_{DD}=0.32 giorni
- TM_{SPT}= 0.83 giorni
- TM_{NINQ}= 0.39 giorni
- TM_{LPT}= 0.54 giorni



- $\Delta TM_{(DD\text{-}SPT)}$= 62%
- $\Delta TM_{(DD\text{-}LPT)}$= 42%
- $\Delta TM_{(DD\text{-}NINQ)}$= 18%

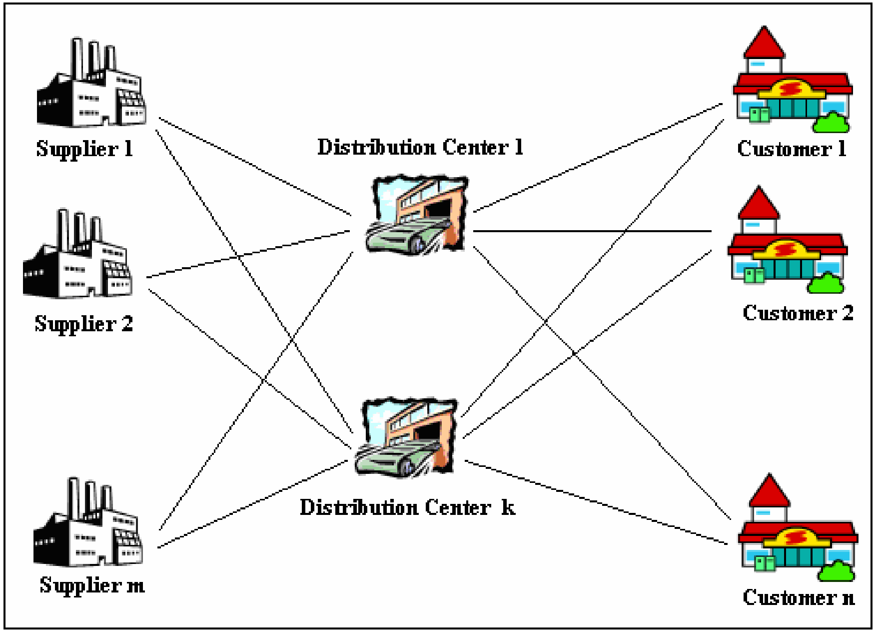
CASE STUDY: MASTINO (**M**odeling, **A**nalysis & **S**imulation of **T**ube manufacturing process and **IN**dustrial **O**peration control)

For mean flowtime minimization the best rules is Longest Production time (LPT)
For mean latiness minimization the best rules is Longest Production time (LPT)
For mean tardiness minimization the best rules is the Due Date (DD)

- The simulator recreates the high complexity of the real system. No restrictive assumptions have been made. Some results don't reflect the classic scheduling theory; this is due to systems characteristics. The results cannot be generalized but can be surely implemented in the production system analyzed.
- The analysis shows simulator potentialities as technological demonstrator.
- Simulator architecture (completely made by means of code and tables) allows short period of time for obtaining simulation results and can be linked to the company informative system (AS400) by means of .txt files.
- In addition simulator architecture easily accepts changes to implement new decision tools
- Further research are still on going trying to implement the simulator in the company informative system and adding a new decision tools based on genetic algorithms and neural network

EXTERNAL LOGISTIC (*Supply Chain Management*)

The research on supply chain management focalizes on transportation systems efficiency, inventory/store management.



The state of art overview: Several and different research works have been developed in this area regarding transportation systems analysis and inventory store management.

- Also in this case there is a huge difference between analytical results and real applications.
- Even though a lot of works have been already developed we propose new and innovative approach to use M&S to face these type of problems

CASE STUDY: VIRTUAL SHOP FOR RETAIL

- The case study proposes a powerful and innovative approach to analyze the store inventory management as well as to give an alternative and interesting solution to some critical problems related to store facility management.
- The bibliographic analysis in this specific area has revealed that the approach proposed in this case study is completely innovative.

The tools currently used (CAD software, specific managerial software) even though flexible, do not have, obviously, a virtual environment to specifically and precisely analyze the dynamic nature of the sales outlet.

CASE STUDY: VIRTUAL SHOP FOR RETAIL

Technologic demonstrator & application potential

- Virtual Prototyping and Store Design
- Store Remote Monitoring & Control by On-line Simulation
- Virtual Reality Totem
- Web Virtual Reality Store

The Synthetic Environment involes:

- People
- Personnel Operations
- Shelves
- Good & Inventory

An innovative integration of Virtual Environments and Modeling & Simulation has been developed to support dynamic simulation of a retail stores.

- Multigen Creator (*3D model*)
- Vega Prime (*Virtual Enviroment*)
- C++ (*Simulator*)

CASE STUDY: VIRTUAL SHOP FOR RETAIL

Inventory Management Model

The inventory management model combines different aspects such as the cost of mean storage level (considering financial cost, inventory cost and provision cost), the loss sales expressed in economic form, the cost for shelve refurbishment, the sales and the relative profit.

$$C_i^{ST} = V_i \cdot \left[k_i^{Fi} + k_i^{De} + k_i^{St}\right]$$

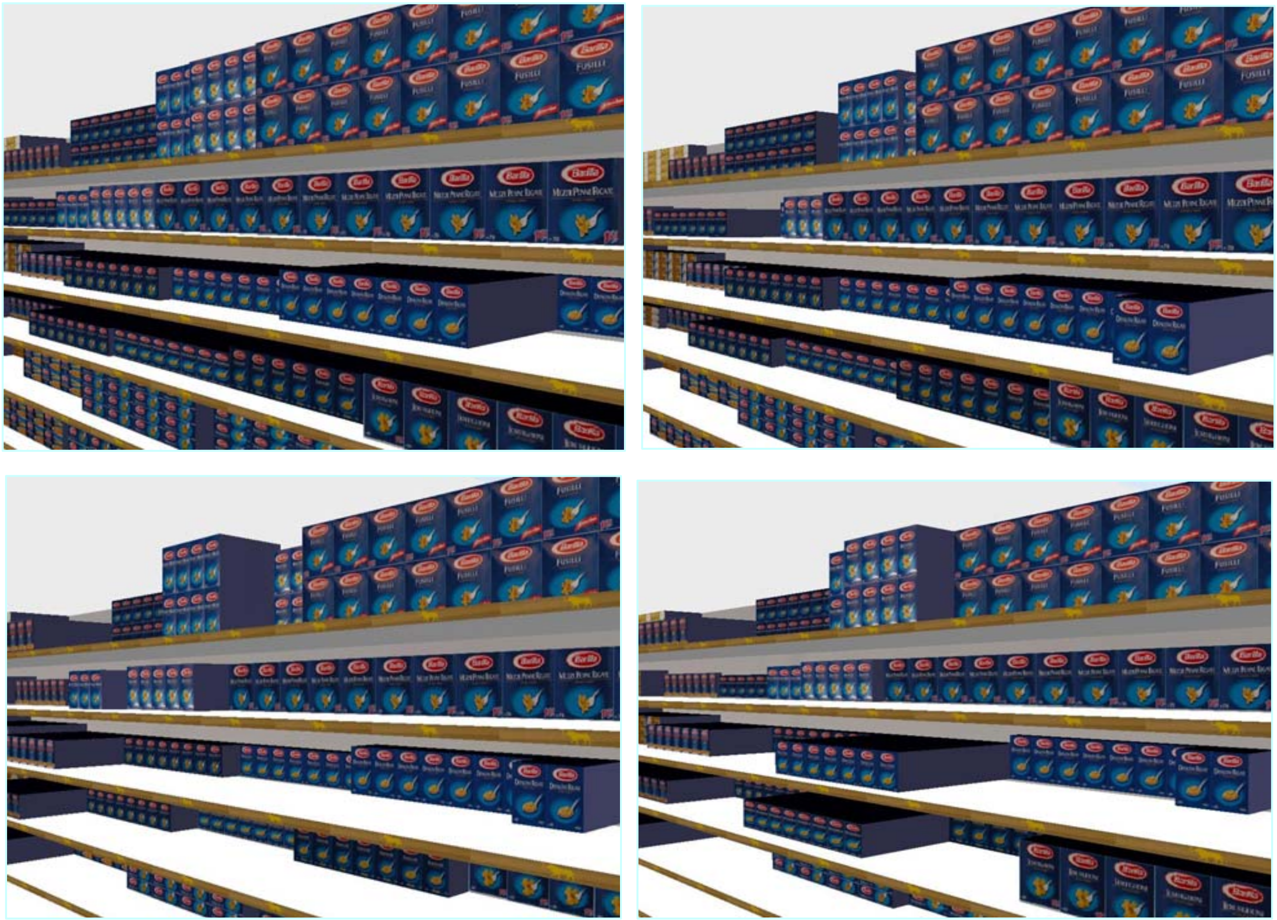
$$C_i^{SL} = F_i \cdot V_i \cdot k_i^{Pr} \cdot k_i^{Sb} \cdot \sum_{h=1}^{n_i} \Delta T_{i,h}^{SoctkOut}$$

$$C_i^{Rf} = k_i^{Rf} \sum_{k=1}^{m_i} \Delta T_{i,k}^{Rf}$$

$$P_i^{ES} = F_i \cdot V_i \cdot k_i^{Pr} \cdot \left(T - \sum_{h=1}^{n_i} \Delta T_{i,h}^{SoctkOut}\right)$$

C^{ST}_i	Storage Cost of i-th item
V_i	Store Value of the i-th item
k^{Fi}_i	Financial Cost Coefficient for i-th item
k^{De}_i	Deterioration Cost Coefficient for i-th item
k^{St}_i	Storage Infrastructure Cost Coeff. for i-th item
C^{SL}_i	Cost due to sale losses for i-th item
F_i	i-th item mean sales flow
k^{Pr}_i	Profit Coefficient of i-th item
k^{Sb}_i	Substitutive Sale Coefficient of i-th item
n_i	Number of Stockout of i-th item
$\Delta T^{Stockout}_{i,j}$	Duration of the j-th stockout of i-th item
C^{Rf}_i	Cost for shelves refurbishment for i-th item
k^{Rf}_i	Cost for refurbishment of i-th item
m_i	Number of shelves reloads of i-th item
$\Delta T^{Rf}_{i,j}$	Duration of the j-th reload of i-th item
P^{ES}_i	Profit from Effective sales of i-th item
T	Temporal Baseline

CASE STUDY: VIRTUAL SHOP FOR RETAIL



The Simulator allows to simulate the behavior of inventory in order to identify best facing considering:

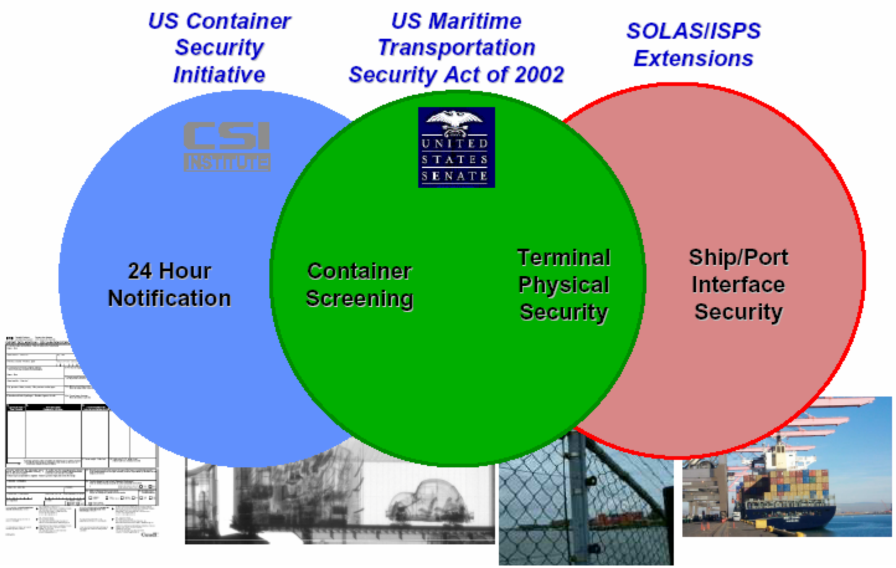
- Sale behavior
- Refurbishment policies
- Personnel
- Support & Logistics

CASE STUDY: VIRTUAL SHOP FOR RETAIL

- The approach proposed in this case study is completely innovative respect to the traditional tools used for similar objectives.
- An application example has been developed for what concern the store inventory management proposing a detailed analytical model using during the simulation for evaluating profits and costs per time unit for each item.
- The application potentials are extremely important: virtual prototyping and store design, store remote monitoring and control by on-line simulation, virtual reality totem, web virtual reality store.
- In all the cases the solutions proposed provide significant advantages and innovation respect to traditional tools and techniques
- At last we can conclude that on the basis of the bibliographic analysis made in this specific sector, the research work presented in this case study can be surely considered as an innovative and new contribution to large distribution supply chain management.

EXTERNAL LOGISTIC (*Supply Chain Security*)

The research on supply chain security analyzes and studies some critical issues related to security and technical efficiency, by means of Modeling and Simulation.



The state of art overview

- "Very young" research area (after September the 11th 2001)
- The bibliographic analysis shows that Normative and Standard correctly define supply chain security but several and different issues are still opened.

⬇

- Focus on container terminal terminals considered as the most important nodes in global supply chain.
- **Sensitivity analysis of the impact of security procedures on system performances**

CAE STUDY: SEAPORT (*SEcurity Advances PORT Simulator*)

Standard 20′

Inside Length	Inside Width	Inside Height	Door Width	Door Height	Capacity	Tare Weight	Maxi Cargo
19′ 4″	7′ 8″	7′ 10″	7′ 8″	7′ 6″	1 172 cft	4 916 lbs	47 900 lbs
5,900 m	2,350 m	2,393 m	2,342 m	2,280 m	33,2 cub.m	2 230 kg	21 770 kg

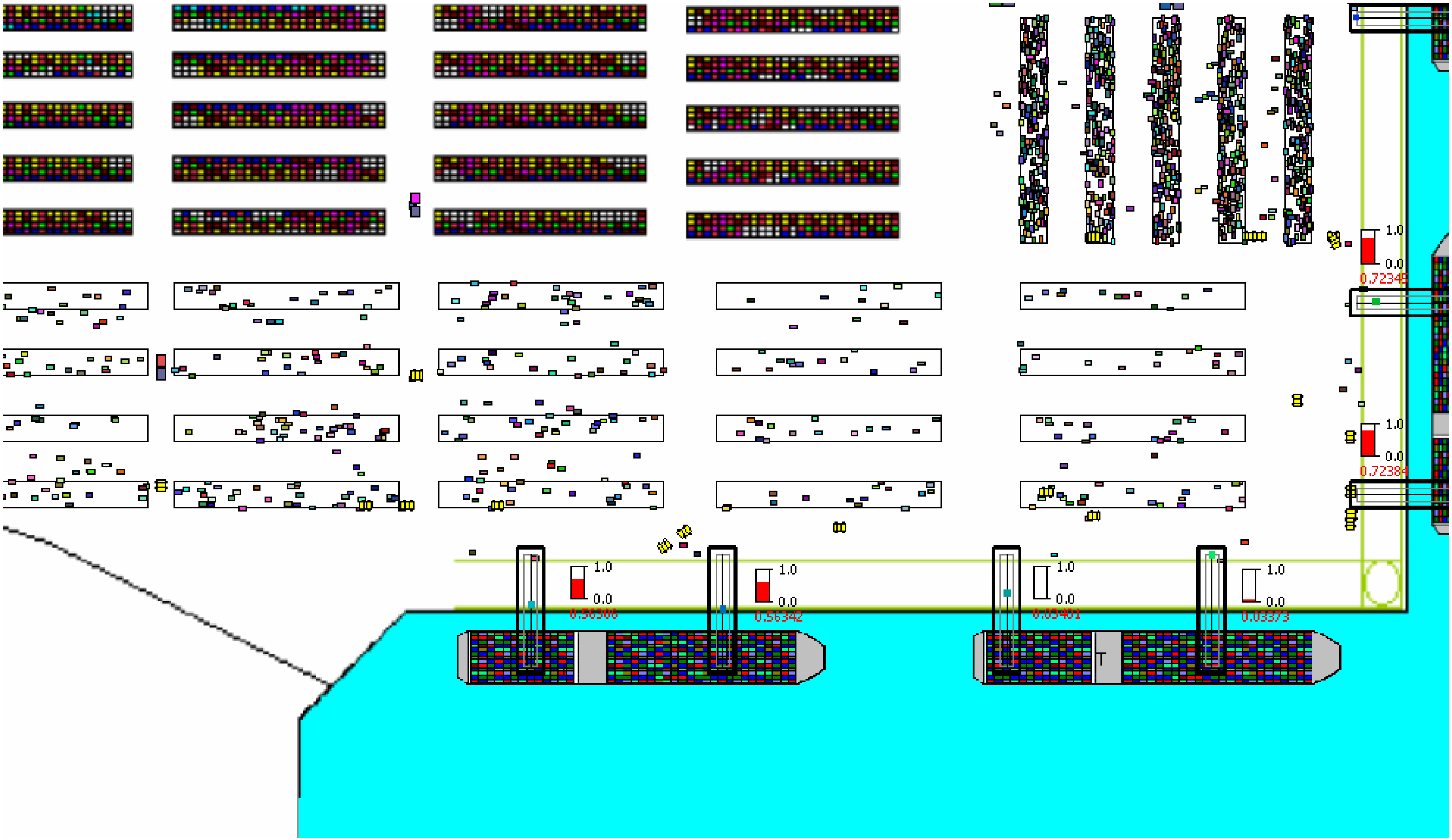
Standard 40′

Inside Length	Inside Width	Inside Height	Door Width	Door Height	Capacity	Tare Weight	Maxi Cargo
39′ 5″	7′ 8″	7′ 10″	7′ 8″	7′ 6″	2 390 cft	8 160 lbs	59 040 lbs
12,036 m	2,350 m	2,392 m	2,340 m	2,280 m	67,7 cub.m	3 700 kg	26 780 kg

- Among the security issues in container terminals, the container inspection phase plays a critical role because of threats that by means of containers can enter or exit a seaport.
- Our approach proposes to use M&S, Design of Experiments (DOE) and Analysis of Variance (ANOVA) to analyze security procedures for containers inspection and their impact on container terminal performances.

CAE STUDY: SEAPORT (*SEcurity Advances PORT Simulator*)

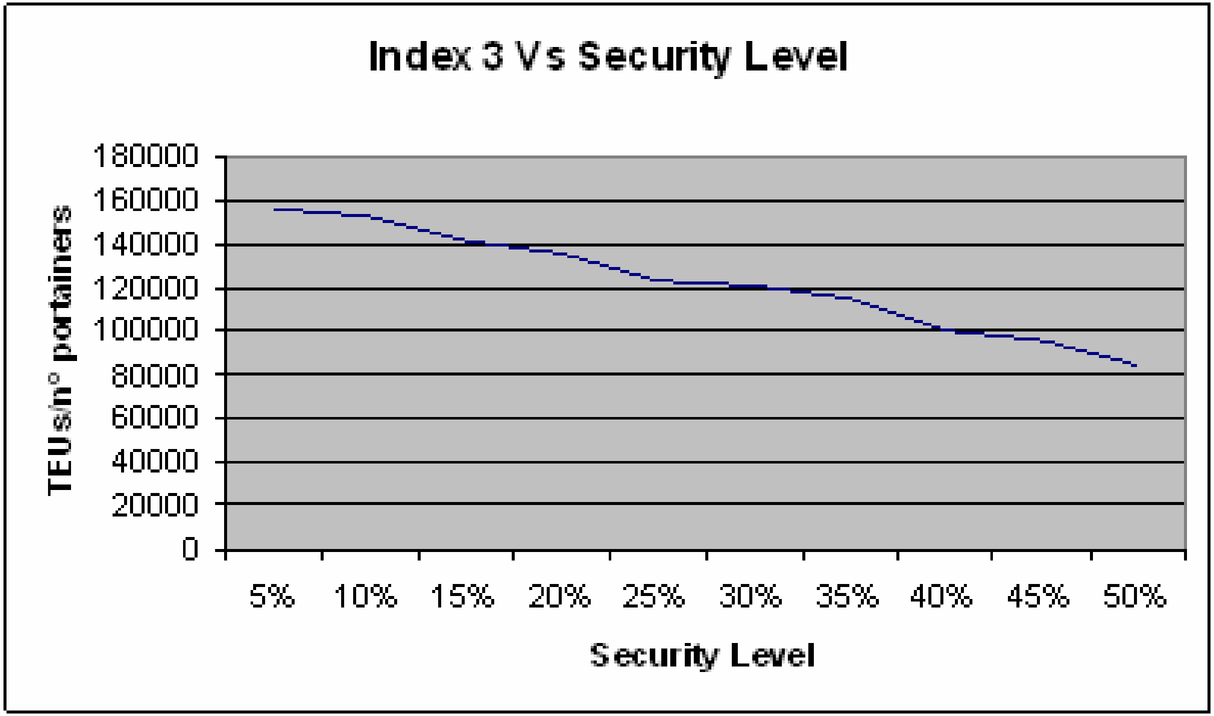
Container Terminal Simulation Model



CAE STUDY: SEAPORT (*SEcurity Advances PORT Simulator*)

Different security levels analysis

Security Level	Index1 (TEUs/mt)	Index2 (TEUs/hectares)	Index3 (TEUs/n°portainers)
5%	910	11548	155901
10%	881	[illegible]	[illegible]
15%	837	[illegible]	[illegible]
20%	794	[illegible]	[illegible]
25%	733	[illegible]	[illegible]
30%	698	[illegible]	[illegible]
35%	662	[illegible]	[illegible]
40%	614	[illegible]	[illegible]
45%	565	[illegible]	[illegible]
50%	520	[illegible]	[illegible]



Total block of the main activities

CAE STUDY: SEAPORT (*SEcurity Advances PORT Simulator*)

Factor	ID	Level 1	Level 2
Percentage to inspection	x_1	2% (-1)	10% (+1)
Trucks number	x_2	1 (-1)	3 (+1)
Buffer space	x_3	10 (-1)	50 (+1)
Manpower	x_4	2 (-1)	6 (+1)

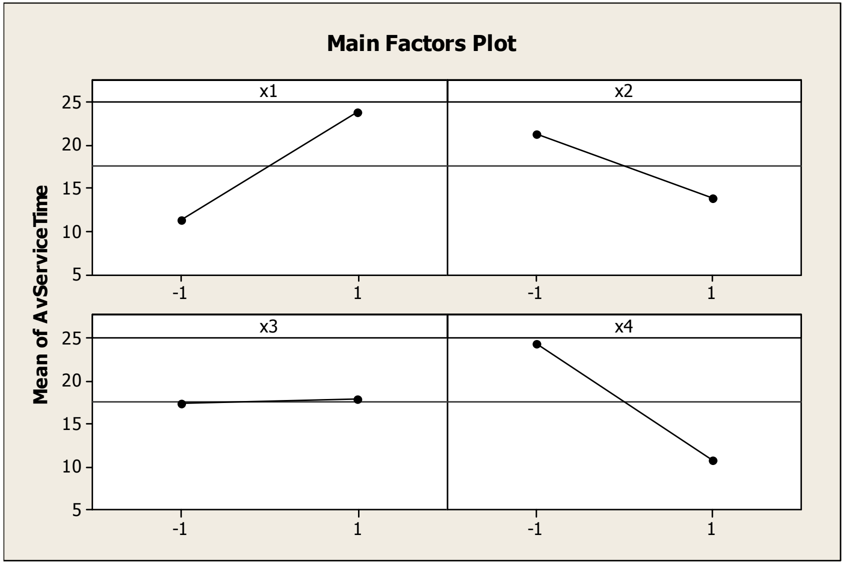
Inspected containers per day (Y), DOE & ANOVA

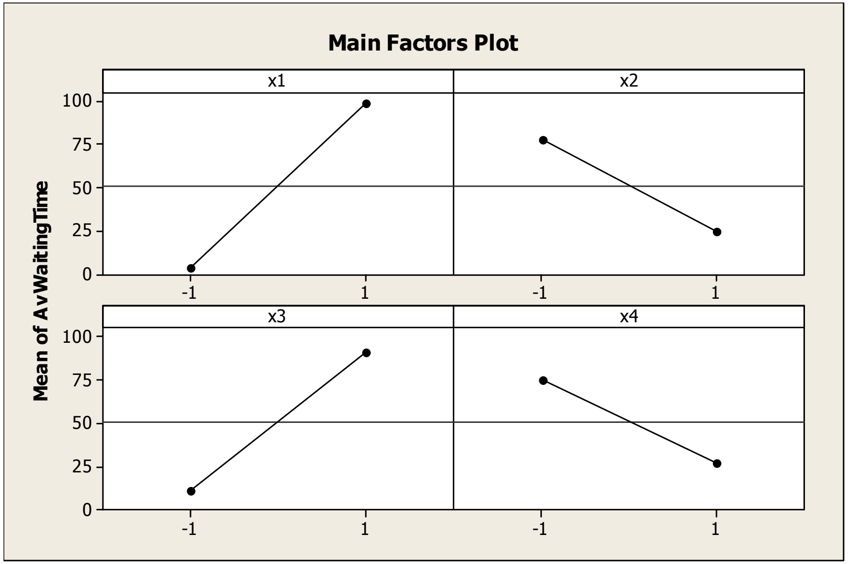
$$Y = \beta_0 + \sum_{j=1}^{j=k} \beta_j x_j + \sum \sum_{i<j} \beta_{ij} x_i x_j + \varepsilon$$

Simulation run	x_1	x_2	x_3	x_3	Containers per day (Y)		Simulation run	x_1	x_2	x_3	x_3	Containers per day (Y)
1	-1	-1	-1	-1	71		9	-1	-1	-1	+1	72
2	+1	-1	-1	-1	109		10	+1	-1	-1	+1	192
3	-1	+1	-1	-1	64		11	-1	+1	-1	+1	70
4	+1	+1	-1	-1	190		12	+1	+1	-1	+1	350
5	-1	-1	+1	-1	67		13	-1	-1	+1	+1	70
6	+1	-1	+1	-1	128		14	+1	-1	+1	+1	190
7	-1	+1	+1	-1	71		15	-1	+1	+1	+1	65
8	+1	+1	+1	-1	203		16	+1	+1	+1	+1	371

CAE STUDY: SEAPORT (*SEcurity Advances PORT Simulator*)

- Further analyses have been made concerning container inspection time (Y_1) and container waiting time before inspection (Y_2) finding out the input output relation by means of DOE and ANOVA.





CAE STUDY: SEAPORT (*SEcurity Advances PORT Simulator*)

- Supply chain security is a "young" research area.
- In general security procedures are well explained by standards and normative; nothing is said about the impact of security procedures and equipment on supply chain technical and economic efficiency.
- The bibliographic research in this specific area has highlighted the lack of research works and quantitative models.
- In particular one of the most critical issue analyzed, as before mentioned, is the impact of security procedures and equipment on container terminal efficiency by means of a Java based simulator, DOE and ANOVA.
- Thanks to these quantitative models we are able to correctly evaluate the impact of security procedures on terminal performances and to correctly set inspection resources taken into consideration the security levels and the flow of containers arriving in the port.

CONCLUSIONS

- Starting from the Industrial Engineering Sector definition two research area have been selected, *Production Systems Management* and *External Logistic*.
- For what concern the first research area the focus is the short period production planning and the plant lay-out analysis. The second area focalizes on supply chain management and security.
- For each research area 4 cases study have been developed proposing both new scientific results, innovative ways to use Modeling & Simulation as well as innovative approaches to classic problems using Modeling & Simulation.
- Most of the cases study start from real manufacturing/logistic systems and the results have been successively applied.
- The cases study development has required a huge training for learning all the software and above all for learning the programming language C++, Visual Basic, Java (more than 100 pages of codes have been written)
- Further research and collaboration with other universities/companies are still on going regarding all the case studies

PhD Publications

1. F. Longo, G. Mirabelli, E. Papoff, *Material Flow Analysis and Plant Lay-Out Optimization of a Manufacturing System,* International Journal of Computing, Vol. I, issue 5, pp. 107-116
2. F. Longo, G. Mirabelli., E. Papoff, *Techiche di analisi avanzate per la progettazione efficiente delle postazioni di assemblaggio manuale*, SdA – Soluzioni di Assemblaggio, VNU Business Publications Italia.
3. E. Briano, M. Brandolini, F. Longo, G. Mirabelli, *Container terminal scenarios analysis and awareness trough modeling & simulation* Proceedings of ECMS - May 2006, Bonn, Germany.
4. F. Longo, G. Mirabelli, E. Papoff, *Design of new maintenance procedures for supporting erp solutions implementation,* Proceedings of MM 2006, Sorrento Italy
5. F. Longo, G. Mirabelli, E. Papoff, *Modeling, analysis & simulation of tubes manufacturing process and industrial operations controls*, Proceedings of SCSC 2006, 30 July – 03 August, Calgary, Canada
6. A.G. Bruzzone, F. Longo, M. Massei, S. Saetta, *The vulnerability of supply chains as key factor in supply chain management*, Proceedings of SCSC 2006, 30 July – 03 August, Calgary, Canada
7. A.G. Bruzzone, M. Brandolini, F. Longo, *Enhancement process based on simulation supporting efficiency & Organization,* Proceedings of SCSC 2006, 30 July – 03 August, Calgary, Canada
8. E. Bocca, F. Longo, G. Mirabelli, S. Viazzo, *Develping Data Fusion systems devoted to security control in port facilities*, Proceedings of WSC 2005,, December 3rd – 8th, Orlando, Florida, USA (in progress)
9. A.G. Bruzzone, F. Longo, E. Papoff, *Metrics for global logistics and transportation facility information assurance, security, and overall protection*, Proceedings of ESS 2005, October 20th – 22nd, Marseille, France
10. F. Longo, G. Mirabelli, A.G. Bruzzone, *Container handling policy design by simulation framework*, Proceedings of International Conference HMS2005, October 20th – 22nd, Marseille, France
11. F. Longo, G. Mirabelli, S. Viazzo, *Simulation and Design of Experiment for analyzing security issues in container terminals*, Proceedings of International Conference MAS 2005, October 16th – 18th, Bergeggi (SV), Italy
12. F. Longo, G. Mirabelli, E. Papoff, *Material Flow Analysis and Plant Lay-Out Optimization of a Manufacturing System*, Proceedings of IDAACS 2005, September 5-7, Sofia (Bulgaria)
13. F. Longo, G. Mirabelli, E. Papoff, *Modeling Analysis and Simulation of a supply chain devoted to support pharmaceutical business retail*, Proceedings of ICPR 18, July 31 – August 4 2005, Salerno (SA) (Italy)

PhD Publications

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