MultiCraft

International Journal of Engineering, Science and Technology
Vol. 2, No. 9, 2010, pp. 107-124

INTERNATIONAL
JOURNAL OF
ENGINEERING,
SCIENCE AND
TECHNOLOGY
www.ijest-ng.com

A stochastic simulation approach for production scheduling and investment planning in the tile industry

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Abstract

The present paper aims to develop a simulation tool for tile manufacturing companies. The paper shows how simulation approach can be useful to support management decisions related to production scheduling and investment planning. Particularly the aim is to demonstrate the importance of an information system in tile firms. The Factory Data Model (FDM) parameter is used to describe the activities in ceramic tile industries operating in different European countries. A process- based analysis of tile manufacturers is undertaken and individual company performance is quantified by Key Performance Indicators (KPI). The overall model is composed of different processes, which are coded into Scilab environment and matched together to arrange a stochastic simulator. The simulations results are used to show how management decisions can significantly effect the KPIs. The simulations highlight the effects on KPIs of three specific parameters: the length of scheduling period, the quantity of stock needed and the reliability of the information system supporting orders. The results clearly show that the effect of allowing the presence of unattended orders within the outstanding orders list always has a remarkable negative influence on KPIs. Results also suggest that the presence of sub-groups of homogeneous tiles, based on colour variation, is one of the most important factors affecting a tile manufacturer's performance. The results of the simulations have two different practical implications. Firstly, they demonstrate the importance of information systems in tile companies, suggest to evaluate investment in information technology and indicate the value of promoting an information culture in the entire work forces. Secondly, they show the potential of simulation tools development to support decision making in a BPR (Business Processes Re-engineering) scenario.

Keywords: Simulation, tiles, information system, investments, management, BPR.

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1. Introduction

The economic scenario today is highly competitive in terms of number of competitors and costs. Globalization as the result of the rapid development of information and communication technologies (fast access to accurate and reliable data), transport system and consideration of common standards (which provide the world-wide comparability of the products) (Westkamper, 1997) allows the fusion of local and nation markets into a global one (Kalpic, 2002). Due to globalization, competition has intensified from a national scale to a global arena (Jin-Hai, 2003). To remain competitive, companies have to reach an high-level of performance by maintaining high quality, low cost, low manufacturing lead times, and high customer satisfaction (Al-Aomar, 2000). Unpredictable and fast changes in the internal and external environment, experienced by enterprises as *turbulence* (Warnecke, 1993), make very important to be able to analyze and test a manufacturing system before any large investment or any business process reengineering (BPR) activity. Moreover, shorter product life-cycles also constrains the time available for developing new manufacturing system, or for old manufacturing system reconfiguring (Klingstam, 1999). Because of its great versatility, flexibility, and power, simulation is one of the most widely used operations research techniques from the early eighties (Shannon, 1980). Simulation models are proved to be useful to support and drive company management in improving the performances of the production and logistic systems. As reported by O'Kane, many researchers argue that simulation is one of the major tools to assist in the re-engineering process and improve the businesses effectiveness and performance (O'Kane, 2007), in fact, according to Mansar, simulation could be properly used to test how appropriate it was to apply BPR best practices (Mansar, 2005). At the same time, O'Kane also reported that many authors argue about the high potential of simulation to make a significant contribution to the continuous improvement of the quality management systems themselves (O'Kane, 2007). However several studies show that there is a low usage of simulation by industries (Ryan, 2006), especially simulation has not been widely applied to SMEs (Small Medium Enterprises) (O'Kane, 2007). Usually, to achieve the expected results in term of performances improvement, a detailed model of the production and logistic system is needed. So the simulation modelling become an heavy programming task and carry on the development of such a simulation model is a very expensive activity, in term of resources and time used. Moreover the developed simulation model for a specific manufacture system is not easily adaptable for another one. This fact contributes to increase model development costs and prevent the use of simulation in tile manufacture.

1.1 Tile industries

The tile industries in Europe are concentrated in two countries: there is a Spanish cluster in the area of "Castellon" and an Italian one in the "Emilian" region (Harvas-Oliver, 2007). Originally the tile industries were characterized by large scale production of a limited range of products. Over the last few decades consumer demand for tiles has changed, becoming more sophisticated. Nowadays the Ceramic Tile sector is very competitive. This competition is ultimately reflected in an increase in the variety of products and services, together with a decrease in production costs (Giret, 2009). The fact that tile industries produce a considerable variety of products with shorter life cycles is pointed out by many authors (Harvàs-Oliver, 2007) (Andrès, 2005) (Regueiro, 2000) (Bonavia, 2006) (Vallada, 2005). These characteristics are much more significant for the Italian (Emilian) cluster of companies because they are focused on higher end more sophisticated markets and give more attention to product differentiation (Harvàs-Oliver, 2007). The increase of products number determines scheduling problems because shortening lead times and decreasing batch sizes are not very compatible with the current tile production systems. Efficient and flexible production will be needed in future successful ceramics companies (ECORYS, 2008). An exhaustive description of the production system in the tile industries was given by Andrés in 2005. These industries are dedicated to the production of ceramic products, which are used in the building sector to isolate floors and walls. The raw material used is clay, previously ground in a special mill. The layout for the production system can be schematized as a three stage hybrid flowshop with a certain number of facilities at the first stage (press and glazing line), an intermediate buffer, a different number of facilities at the second stage (kiln), another buffer and a certain number of facilities at the final stage (sorting and packing cells). The general description provided by Andres is confirmed even by the study of Ortiz on a specific tile enterprise (Ortiz, 1999). An exhaustive and detailed description of the best available technology for the tile industry is provided in the last report about the ceramic manufacturing industry by the European Commission (EC, 2007).

The tile industry production system suffers from problems of: finite products characteristics instability, information reliability along the supply-chain and high finite products inventory level. In fact, addressing the phenomenon of finite products characteristics instability, undesired colouring is one of the most important needs in the ceramic sector (Erginel, 2004). Each piece has to be inspected and classified in most companies and individual (product) models are usually stored in sub-groups based on the tone (colour degree) and the calibre (thickness) (Tortajada, 2006). The problems in information flows from/to the customers are related with the distribution channels structure that in many cases use agents and brokers. The data provided by the agents, into the information system, are often unreliable. The reasons of this unreliability are structural. Each agent has a specific market and addresses specific customers. The linkage between the agent and his customers is often stronger than his linkage with the manufacture. In order to fulfil customers needs in short time, agents usually put "fake" orders into the information system trying to anticipate customers requests and shortening lead time. When the agents are not able to change a "fake" order in a real one they simply delete it from the information system, just few days before the delivery date. Usually tile industries information systems are not developed to perform controls in order to measure and/or prevent this kind of behaviour. The importance of information systems in a tile manufacture was pointed out by Chalmeta in his work concerning the integration of IRIS Tile Group (Chalmeta, 2001). The high inventory level for finite products is underline as a persistent problem by Assopiastrelle analysis (Assopiastrelle, 2005). The problem is mainly related to finite products characteristics instability and information unreliability.

2. Aim and methodology

The present work presents a simulation approach for tile manufactures. Tile manufacture sector is composed mainly of SMEs and it therefore follows that they have only limited resources to devote to simulation (Bonavia, 2006). The proposed approach requires low resources for the development of a generic tile manufacture model by use of VirtES (Virtual Enterprise Simulator) methodology (Davoli, 2009) based on the open – source platform, Scilab. The VirtES methodology prevents from developing a very detailed model for the whole enterprise and allows to develop and/or integrate detailed models for specific sub – systems and/or processes. In this paper the generic tile enterprise model is presented, than the model is detailed to investigate the impact of information unreliability on industry performances.

3. Model assumptions

Generally there is a lack of scientific understanding of tile industrial processes, especially in the Italian cluster (Meyer-Stamer, 2001). The operational research applied on tile manufacture is poor, for example in a recent literature review about scheduling problems, Allahverdi reports only the works of Andres focused on tile manufacture (Allahverdi, 2008). Even the scientific knowledge of processes management are often neglected in tile industries. Only Ortiz reports about the re-engineering, based on CIMOSA architecture, of production planning processes in a tile industry (Ortiz, 1999). So the tile enterprise model is developed using multiple case-study analysis, based on Italian tile manufactures, and it is supported even by the study of Ortiz on a specific tile enterprise (Ortiz, 1999). The level of details in VirtES model is chosen in order to develop a generic tile enterprise model applicable in all case-study.

The model presented is developed mainly to evaluate the impact of information unreliability on a tile manufacture system. The main model assumptions consist of: orders and production capacity are balanced and production process without set-up times is assumed deterministic. Moreover the customers orders are simulated with a random function set, in according with the statistical data, and the production schedule is write up according with strategy adopted in the majority of the considered manufactures. The production process is deterministic but the presence of sub-groups, based on colour variation, is considered in end products.

There is a lack of references, in the recent literature, about the degree of tone variation. However, the range for tone variation can be extrapolated from the sorting machine lines as reported in a technical paper for the industry (SACMI, 2007). The impact of set-up times and scheduling strategy are not considered in the model.

To develop a VirtES simulation model at first stage a factory data (FDM) (Yu, 2000) of a tile industry is provided. The FDM model allows the flexibility of the model and its adoption even if only partially completed. The tile enterprise model herein developed, see Figure 1, according with FDM paradigm, is composed by resources, tokens and processes.

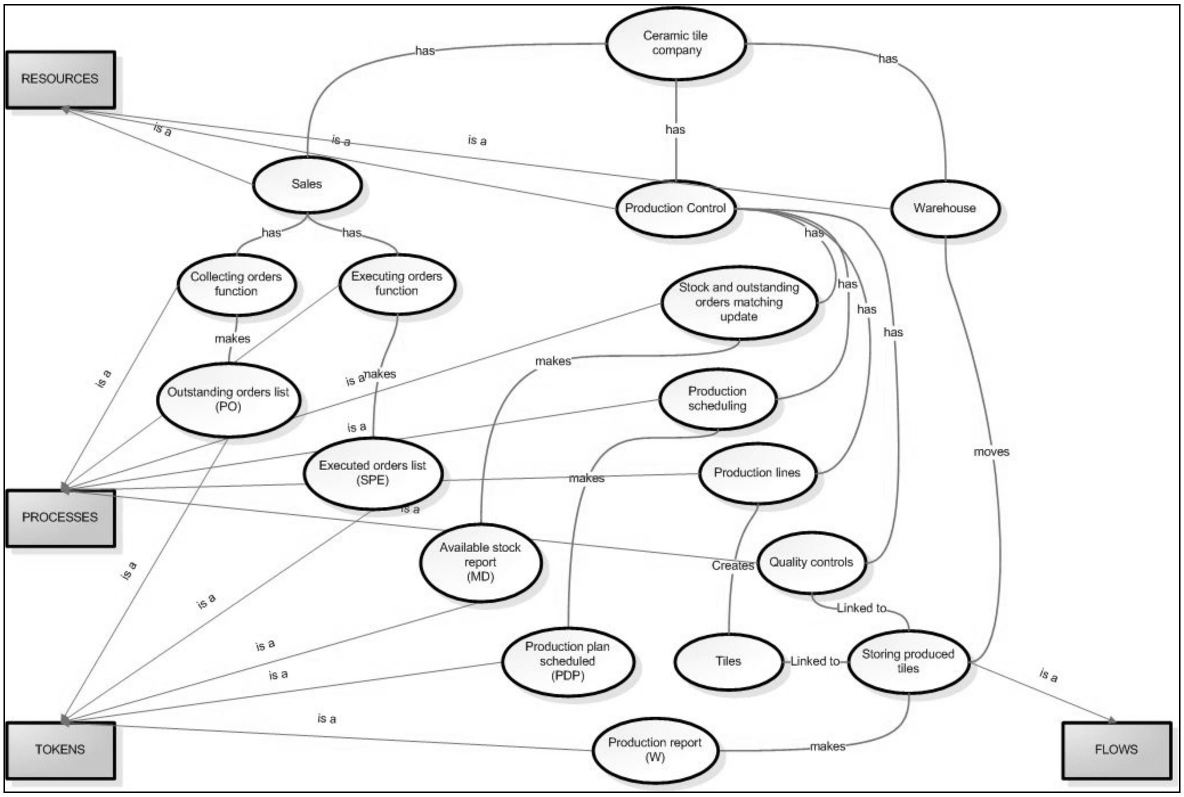


Figure 1. The tile enterprise FDM model.

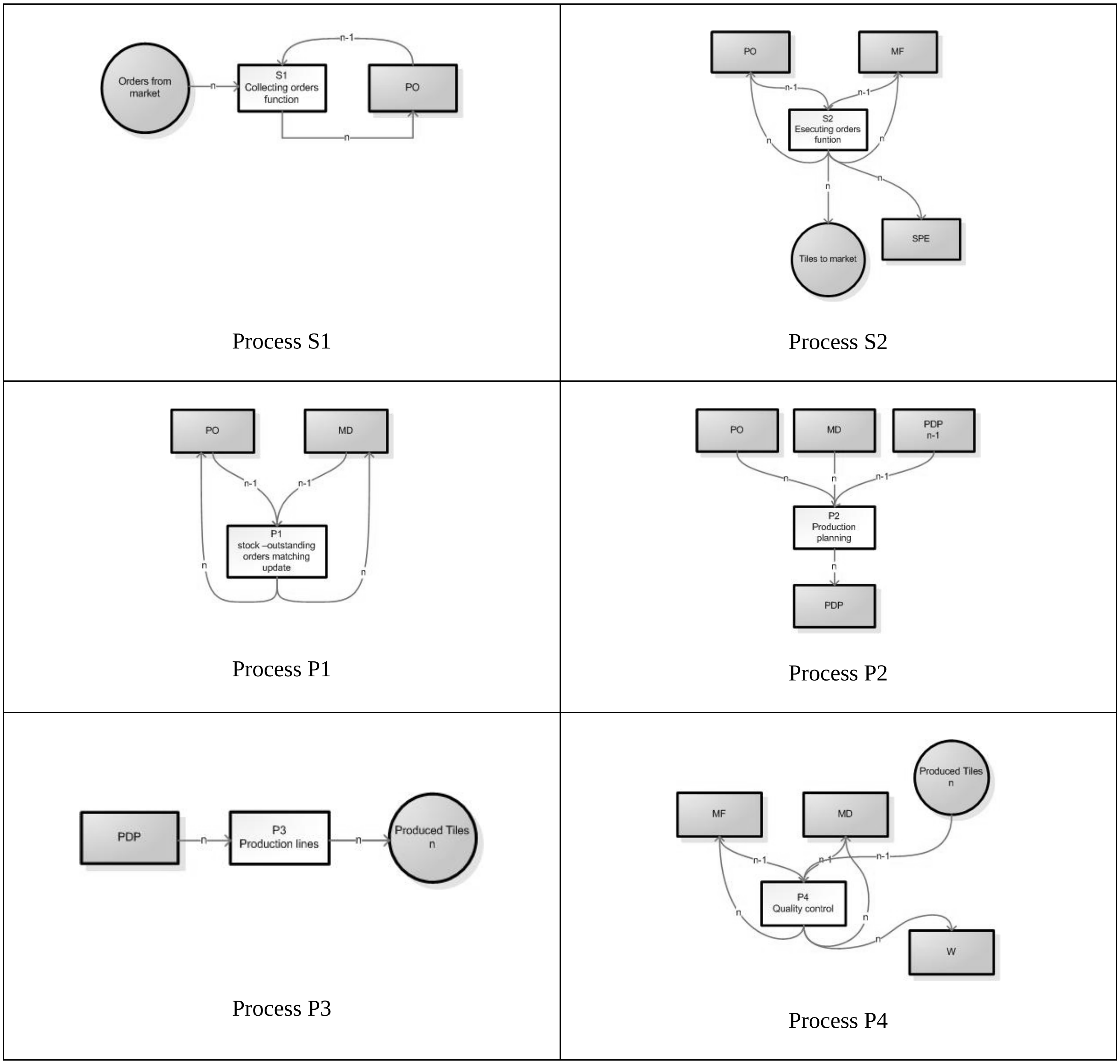
4. Virtual enterprise

In order to develop a virtual enterprise it is necessary to do an input – output chart for each process, see Figure 2, and to provide a complete processes interaction chart, see Figure 3.

4.1 List of acronyms

BPR: Business Processes Re-engineering
DAQ: average quantity of products sold in a day
DOE: Design Of Experiments
FDM: Factory Data Model
INI: initializing function
KPI: Key Performance Indicator
LDS: imposed stored tiles in days of production
LDSS: amount of goods needed to achieve the imposed LDS
M: spread between the average sale price and the average production cost for 1 m^2 of tiles
MAG: total amount of stored tile, only 1st quality goods
MD: available stock list
MF: physical warehouse
N: daily orders number
NPDP: master production scheduled length
P1: stock-outstanding orders matching process
P2: production planning process
P3: production process
P4: quality control process
PC: production capacity
PDP: master production scheduled
PO: outstanding orders list
REC: KPI recording function
S1: collecting orders function
S2: executing orders function
S3: canceling order function
SME: Small Medium Enterprise
SPE: executed orders report
TA: rate of unreliable orders generated each day
VirtES: Virtual Enterprise Simulator
W: production report

The “collecting orders process” creates orders using a random function. Orders can be created of two different types. Orders of both available products and unavailable products at generation time. Every order has been generated with a set of characteristics: product, quality, quantity, day of creation and day of delivery. The sum of the average quantities sold for each product should be equal to the production capacity, so balancing demand and production capacity. The “stock - outstanding orders matching process” matches orders with available goods. The matching is based on a set of characteristics: product, quality, tone, available quantity. The “executing order process” executes orders that were matched with available goods according with the day of delivery. The “production planning process” schedules products to produce The aim of the adopted scheduling strategy is to keep a certain quantity of goods in the warehouse for each product. The amount is determined by the formula: LDS x DAQ, where: LDS is a fixed number of days equal for all products and DAQ is the average quantity of products sold in a day, given within the product characteristics set. So for every product it is possible to have the amount of goods needed to achieve the imposed LDS, this quantity being termed (LDSS). The PDP is made for a certain number of days (NPDP) so an algorithm provide to allocate the production capacity proportionally to LDSS for each product. The “production process” executes the PDP. A deterministic process is implemented. This means that the process producing each product is included within the PDP according to the production characteristics of the products. For each product is given a set of production characteristics is given composed of: percentage of 1st, 2nd and 3rd quality, number of tones for each batch of production, quantity of product for each tone. No set up times are implemented. Minimum batch size is implemented. The “quality control process” checks the goods produced and updates the stock. It is assumed that all goods produced goods are stored in the warehouse.



Process S1

Process S2

Process P1

Process P2

Process P3

Process P4

Figure 2. Singles processes input – output charts

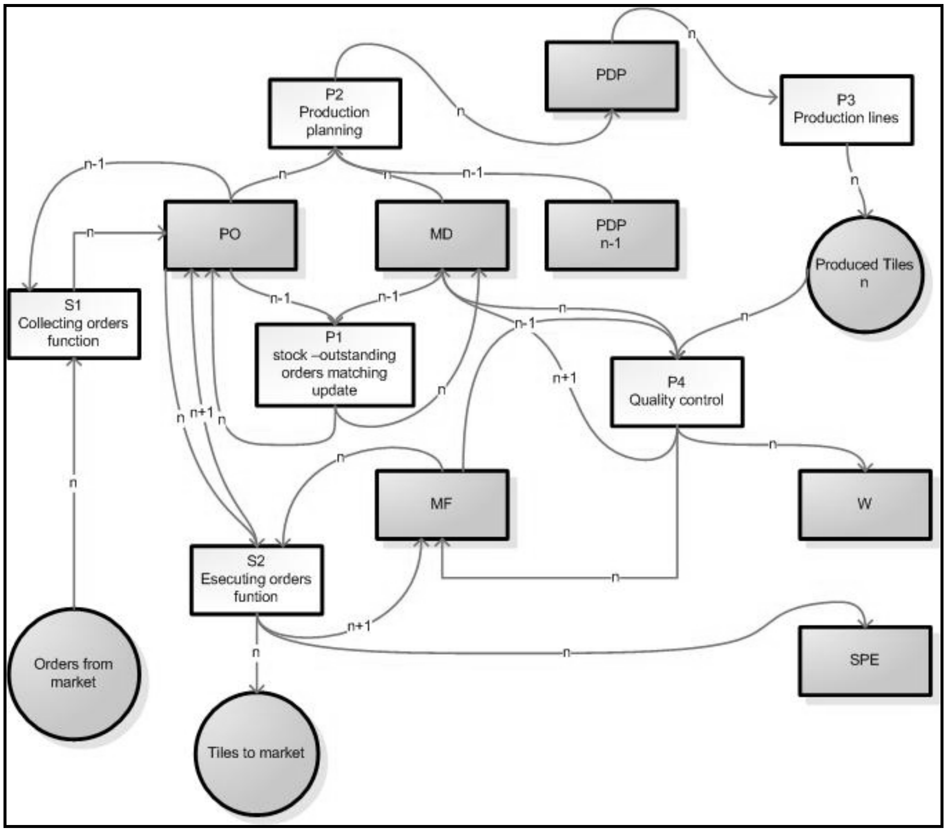


Figure 3. Processes interaction chart

The processes described are codified to allow implementation into a Scilab environment. A list of virtual products has been done in order to provide all the necessary information for processes. In view of the discussion above about colour variation and sub-groups of tiles, the products in the list are characterized by 3 or 4 tones for each production batch and the distribution of relative tones, see Table 1.

Table 1. Virtual products list

PRODUCTS ID	**QUALITY (1^{ST}, 2^{ND} ; 3^{RD})**			**N° TONES FOR BATCH**	**TONES DISTRIBUTION (ONLY FOR 1^{ST} QUALITY)**				**DAILY AVERAGE QUANTITY SOLD (m^2)**
1001	0.9	0.05	0.05	3	0.25	0.50	0.25	0.00	1000
1002	0.8	0.10	0.10	3	0.33	0.33	0.34	0.00	1000
1004	0.85	0.10	0.05	4	0.25	0.25	0.25	0.25	500
1005	0.9	0.05	0.05	4	0.25	0.25	0.25	0.25	500
…	…	…	..	…	…	…	…	…	…..
100(n-1)	0.9	0.05	0.05	3	0.34	0.33	0.33	0.00	250
100(n)	0.8	0.10	0.10	3	0.34	0.33	0.33	0.00	250

4.2 Main simulation sequence

The defined processes are listed in a sequence to simulate the daily enterprise work. To initialize a simulation a special process, called “INI” runs at the beginning of the first day and provides the initial amount of tiles in the warehouse and a random production plan for the first period. The special process “REC” records the KPIs at the end of each simulated day. The sequence, see Table 2, represents the general scheme followed by the simulator.

When order n arrives from market, function S1 generates it and places it in the outstanding orders list (PO). The process P1 checks if the requested tiles are in the warehouse (by checking MD report) and process P2 (production planning) verifies if are satisfied the conditions to place each product in the PDP. The products in the PDP are produced by the process P3 (production lines) that simulates the production of the tiles, the produced tiles go to the process P4 (quality control). The tiles pass the quality control tests and they are stored to the warehouse MF . The function S2 (executing orders function) searches for the satisfied orders and, according with the date of delivery, sends the orders to the market and store a report in SPE.

Table 2. Sequence of main simulation

PROCESS ID	PROCESS NAME	CONDITION
INI	**Initializing sequence**	Only the first day
S1	**Collecting orders process**	Each day
P1	**Stock – outstanding orders matching update**	Each day
P2	**Production planning**	Only the established days according with NPDP
P3	**Production lines**	Each day
P4	**Quality control**	Each day
S2	**Executing orders process**	Each day
REC	**KPI recording**	Each day

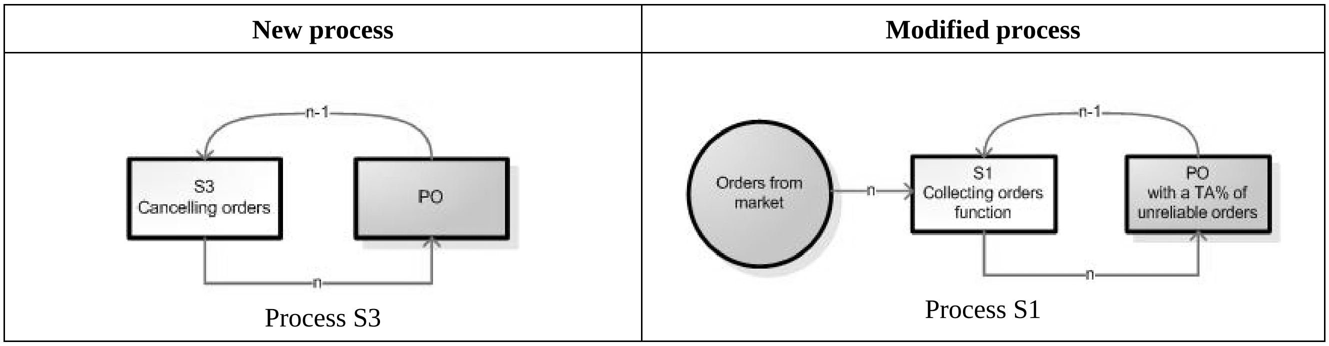


Figure 4. Modified and new-process for the add-on.

4.3 Add-on to perform simulation focusing on information unreliability

In order to simulate the effect of the unreliability of information, a specific add-on is implemented. The add-on is made of a modified S.1 process and a new process called S.3 (see Figure 4) and a new parameter termed "TA". The S.1 process is modified to create a certain number of unreliable orders. The TA parameter indicates the rate of unreliable orders generated each day. The S.1 process marks this excess of orders as "fake". The S.3 process inspects all the orders outstanding and deletes the "unreliable" ones which have a delivery date less than 3 days from the current day of simulation. In this way unreliable orders enter the system for a certain period and affect scheduling process before expiry.

5. KPI definition

In order to judge the effectiveness of different factors on the enterprise performances key performance indicators (KPIs) are needed. All the KPIs are expressed in square meters of tile and are referred only to 1^{st} quality products. The three KPIs chosen are referred to the amount of sold goods (SPE), the amount of stocked goods (MAG) and the amount of not fulfilled orders, back-orders (BO), as shown in Figure 5. The raw data provided from the simulation model are specific for the used features imposed in the model. The KPIs are normalized on production capacity (PC).

SPEi is the total amount of sold goods at day-*i* and it is the cumulative raw data provided by the model. incSPEi is the amount of sold good in day-*i* and incSPE is the daily average increment of sold goods in a defined period, from day-*i* to day-*j*, normalized on production capacity. MAG is the total amount of stocked goods at day-*i* and it is the raw data provided by the model. incMAGi is the variation in stocked good in day-*i* and incMAG is the daily average variation of stocked goods in a certain period, from day-*i* to day-*j*, normalized on production capacity. MAG_0 is the amount of socked goods at day-*i*, normalized on production capacity, i.e. the normalized amount of stocked tile at the first day of the period chosen to calculate incMAG. BOi is the total amount of back-orders at day-*i* and it is the cumulative raw data provided by the model. incBOi is the variation of back-orders in day-*i* and incBO is the daily average increment of back-orders in a certain period, from day-*i* to day-*j*, normalized on production capacity. Normalized KPIs have been used to develop the profit function model and the cumulative values have been used to show an example in the findings section. Raw data, day data and KPIs are shown in Table 3.

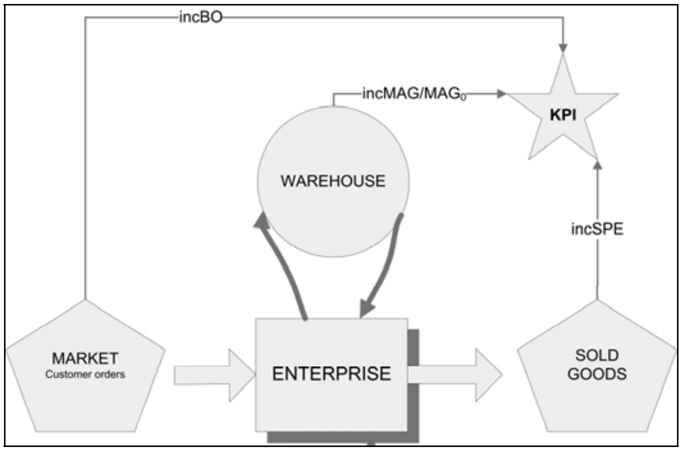


Figure 5. Enterprise environment interactions and KPIs

Table 3. Raw data, Day data and KPIs table

TYPE	NAME	FORMULA
Raw data	SPE	-
Raw data	MAG	-
Raw data	BO	-
Day data	incSPEi	$incSPE_i = \frac{SPE_i - SPE_{i-1}}{PC}$
Day data	incMAGi	$incMAG_i = \frac{MAG_i - MAG_{i-1}}{PC}$
Day data	incBOi	$incBO_i = \frac{BO_i - BO_{i-1}}{PC}$
KPI	incSPE	$incSPE = \frac{\sum_{t=i}^{j} incSPE_t}{(j-i)}$

Table 3. (cont'd). Raw data, Day data and KPIs table

TYPE	NAME	FORMULA
KPI	incMAG	$incMAG = \frac{\sum_{t=i}^{j} incMAG_t}{(j-i)}$
KPI	incBO	$incBO = \frac{\sum_{t=i}^{j} incBO_t}{(j-i)}$
KPI	MAG_0	$MAG_0 = \frac{MAG_i}{PC}$

6. Purpose of Experiment

The purpose of the experiment is to quantify the impact of unreliable orders included in the information system. Two main impacts are considered: enterprise earnings and capacity to fulfil customers orders. The degree of unreliability is represented by TA. A comparison between rate of TA and other parameters is needed to evaluate the relative importance of the TA rate itself. In our current study all simulation parameters are fixed to representative values for a typical, or 'average' company, in accordance with the experience of, and information supplied by, Assopiastrelle. Only TA and LDS are studied here, and within a predetermined range, for three different value of NPDP. LDS is the desired amount of stored tiles in days of production. This parameter is the one that operation managers address for first to improve the service level for final customers. The experimented LDS direct correlation with service level and stock costs imposed a difficult trade-of. It is impossible for managers to improve service level and to reduce costs at the same time, acting on LDS. The aim is to determinate the relative importance of TA and LDS for different value of NPDP. NPDP is the length of the master production schedule, it depends on many technical and commercial factors and, usually, it is decided by top managements. A variation of NPD can not be done at operational management level but, of course, it could be suggested. In fact a slight variation in LDS and NPDP can be achieved in practice without either financial investment or process redesign. The investigated range for TA is from 0 to 20% of "fake" orders acting in the information system, it is estimated from some analysis in specific enterprise. The investigated range for LDS is from 45 to 75 days of production equivalent represents the common range of the parameter approximately around the mean of 65.25 days for stocked tiles reported by Bonavia (2006). The considered NPDP lengths are taken in accordance with information supplied by Assopiastrelle. The full setting of parameters is provided in Table 4.

6.1 Computer DOE

To make a warm-up and an error analysis two groups of replication are used. Three runs, named group A, are performed using the main simulation sequence, for which TA = 0%. A second group of three runs, named group B, is performed using the add-on sequence with a TA of 20%. Within group B one order out of five was assumed to be unreliable, and the two group comparison is used to confirm the validity of the model itself.

Using the DOE application "Design-Expert 6 ©", the experiment is performed to investigate the effect of changes in LDS at different value of NPDP. The ranges selected for LDS and NPDP were 45 to 75 days and 10 to 30 days respectively. The DOE application indicates how the simulations should be set and Table 5 shows the entire sets of parameters for the series of runs. Every run is marked by a 3-record label: for instance 20.60.000 signifies a run for which LDS = 20 days NPDP = 60 days and TA = 0%.

Table 4. Setting of processes parameters

ID	PROCESS NAME	PARAMETERS	SET
P.S1	**Collecting orders process**	o Daily orders number (N) o Random function for Products generation o Random function for Quality generation o Random function for Quantity generation o Random function for Day of delivery generation o TA rate, unreliability of information system	o N = (PC)/(Average order amount) o Simple random function o Only 1 quality o Simple random function from 50 to 900 m^2 o Simple random function from 5 to 45 days o From 00% to 20%
P.P1	**Stock – outstanding orders matching update**	o Matching rules	o Matching for product, quality and a single tone is needed for each order
P.S2	**Execution of orders**	o Order characteristics to be executed	o Already matched and current day equal or superior to delivery day
P.P2	**Production planning**	Implemented scheduling strategy parameters are: o Production capacity o LDS o NPDP	 o 20.000 m^2 every day o from 45 to 75 days o from 10 to 30 days
P.P3	**Production lines**	o Minimum batch size	o 5.000 m^2

Table 5. Computer DOE

Group	Simulation label	NPDP (days)	LDS (days)	TA (%)
A	1x20.60.000	20	60	000
A	2x20.60.000	20	60	000
A	3x20.60.000	20	60	000
B	1x20.60.020	20	60	020
B	2x20.60.020	20	60	020
B	3x20.60.020	20	60	020
	10.45.000	10	45	000
	30.45.000	30	45	000
	10.75.000	10	75	000
	30.75.000	30	75	000
	10.45.010	10	45	010
	30.45.010	30	45	010
	10.75.010	10	75	010
	30.75.010	30	75	010
	10.45.020	10	45	020
	30.45.020	30	45	020
	10.75.020	10	75	020
	30.75.020	30	75	020

7. Findings

Graphical outputs related to raw data and day data are presented for run 1x20.60.00 of group A in Figures 6 and 7. The raw data are the output of the simulation experiment and the values are specific of the used parameters. The above mentioned data show that the model present a warm-up period necessary to reach the steady state. In the day data the simulation outputs are elaborated in order to provide the daily increment normalized to the production capacity, according with Table 3. As shown in Figure 7, the presence of a warm-up is still evident. Moreover the graphic outputs show a stochastic fluctuating motion of values among a central mean. The above mentioned result was expected because the single day observation period is not representative of the enterprise performances. The chosen KPIs are presented in Figure 8, where the fluctuating motion is smoothed and the presence of a warm-up period is still evident.

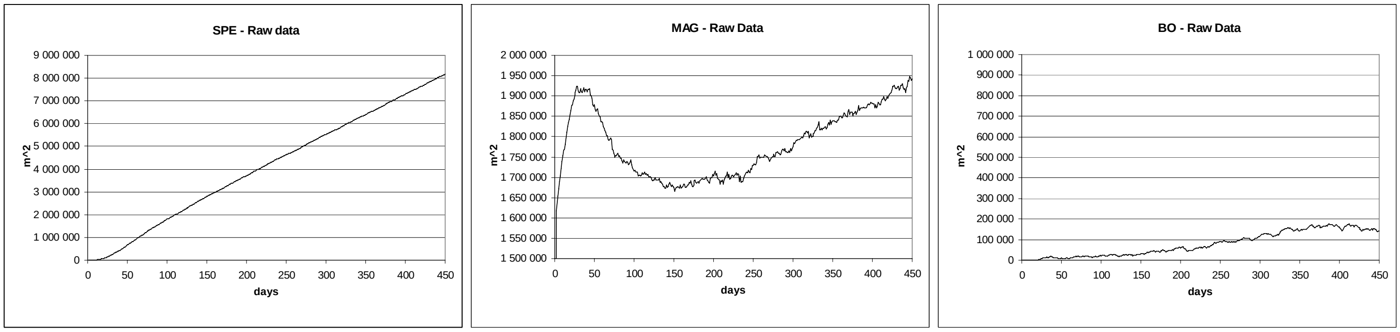


Figure 6. Raw data

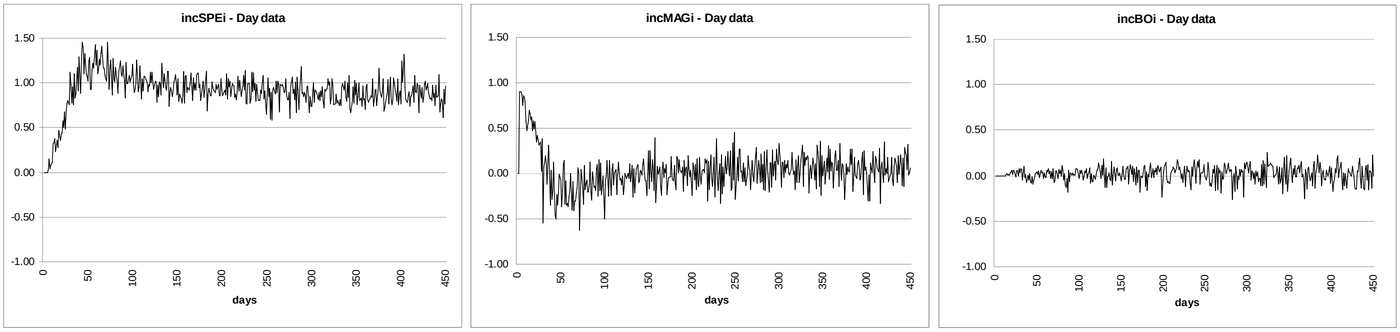


Figure 7. Day data

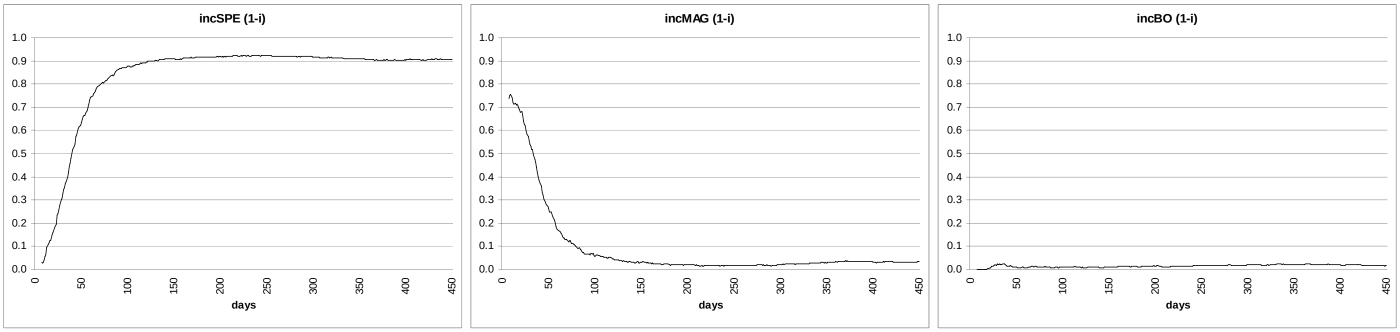


Figure 8. KPI

8. Warm-up analysis

Data collection and model validation have been done according to simulation modeling theory and practices as described by Chung (Chung, 2004). The simulation length has been defined according to the result of standard deviation (STD) analysis referring to all KPIs, except for MAG_0, as shown in Figure 9 for group A. Three replications have been used to perform the error analysis, over a number of four replications no significant differences were observed. A length of 250 working days has been taken for warm up phase in order to have error stability. The maximum related error, observed in KPIs, is below the standard deviation level of 0.01 (1%). A length of 200 working days has been taken for simulation run time, according with formulas in Table 3 for

KPIs calculation *i* is set to 250 and *j* to 450. As shown in Figure 10 for run 1x20.60.00 of group A, during the observation period the KPIs values are stable within the related errors. MAG_0 value depends on warm-up length, so the error analysis is done only for day-250. MAG_0 standard deviation for group A is about 0,7 and for group B it is about 1,2. All the simulation results, in term of KPIs, are shown in Table 6.

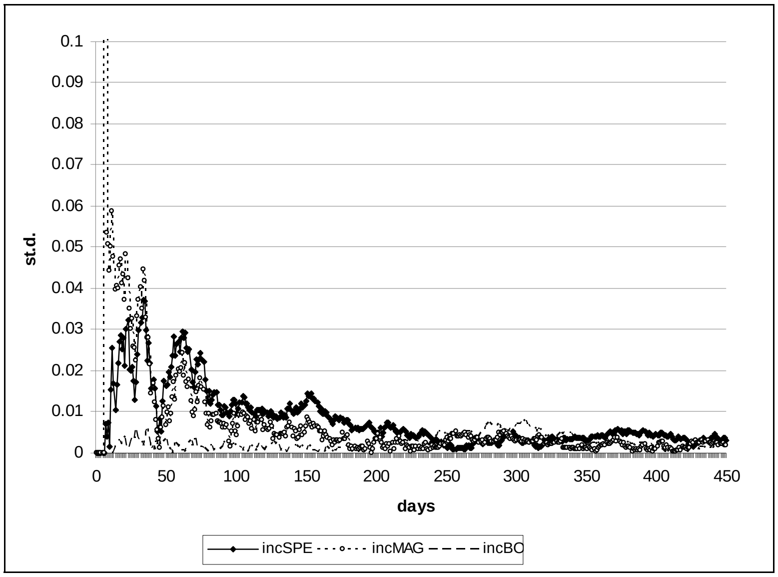


Figure 9. Error analysis upon testing area utilization rate.

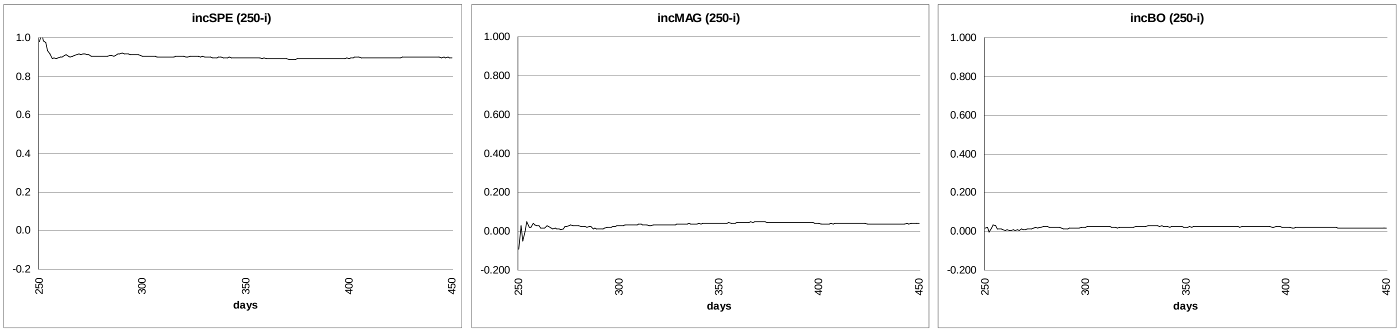


Figure 10. Observed KPIs after warm-up period.

Table 6. All simulation results

Group	Simulation label	NPDP (days)	LDS (days)	TA (%)	KPI1 incSPE	KPI2 incMAG	KPI3 incBO	KPI3 MAG_0
A	1x20.60.000	20	60	00	0.89	0.04	0.02	85,27
A	2x20.60.000	20	60	00	0.89	0.05	0.02	86,42
A	3x20.60.000	20	60	00	0.88	0.05	0.03	85,03
B	1x20.60.020	20	60	20	0.83	0.10	0.06	95,16
B	2x20.60.020	20	60	20	0.82	0.11	0.06	95,46
B	3x20.60.020	20	60	20	0.84	0.09	0.06	93,20
	10.45.000	10	45	00	0.82	0.11	0.08	79,69
	10.75.000	10	75	00	0.84	0.08	0.07	103,03
	30.45.000	30	45	00	0.91	0.04	0.00	74,14
	30.75.000	30	75	00	0.93	0.01	0.00	92,30
	10.45.000	10	45	10	0.80	0.13	0.09	87,58
	10.75.000	10	75	10	0.82	0.11	0.09	110,34
	30.45.000	30	45	10	0.88	0.06	0.02	78,83

Table 6. (cont'd). All simulation results

Group	Simulation label	NPDP (days)	LDS (days)	TA (%)	KPI1 incSPE	KPI2 incMAG	KPI3 incBO	KPI3 MAG_0
	30.75.000	30	75	10	0.89	0.05	0.03	95,32
	10.45.020	10	45	20	0.78	0.14	0.10	96,42
	10.75.020	10	75	20	0.80	0.13	0.10	116,30
	30.45.020	30	45	20	0.85	0.09	0.04	80,52
	30.75.020	30	75	20	0.85	0.08	0.04	100,74

9. Interpretation of results

A linear model function (1) is used to describe the correlation of KPIs with the studied parameters: LDS and TA at three different level of NPDP. The response analysis is performed with Design-Expert 6 © and the coefficients for different KPIs are shown in Table 7. The ANOVA test for KPIs shows that the model studied parameters are significant ($P<0.05$) at any level of NPDP, except for LDS parameter for incBO. The factorial ANOVA is completed at the 95% confidence level. The F-test is used to evaluate the significance of the experimental factor effects. ANOVA test results are shown in Tables from 8 to 11.

$$Y = \xi_0 + \xi_1 \times NPDP + \xi_2 \times LDS + \xi_3 \times TA + \varepsilon \qquad (1)$$

Table 7. Calculated coefficients for model function

Y	ζ_0	ζ_1	ζ_2	ζ_3	St.d.	Symbol
incSPE	0.786	0.00353	0.000417	-0.00300	0.01	β
incMAG	0.145	-0.00283	-0.000583	0.00271	0.01	α
incBO	0.0895	-0.00307	0.000056	0.00182	0.01	δ
MAG_0	59.6	-0.539	0.641	0,459	1.20	γ

Table 8. ANOVA results for incSPE

Source	DF	Seq SS	Adj SS	Adj MS	F	P
TA	1	0,010864	0,010864	0,010864	157,97	0,000
LDS	1	0,000675	0,000675	0,000675	9,81	0,008
NPDP	2	0,017344	0,017344	0,008672	126,10	0,000
Error	13	0,000894	0,000894	0,000069		
Total	17	0,029778				

Table 9. ANOVA results for incMAG

Source	DF	Seq SS	Adj SS	Adj MS	F	P
TA	1	0,009257	0,009257	0,009257	160,20	0,000
LDS	1	0,001008	0,001008	0,001008	17,45	0,001
NPDP	2	0,012033	0,012033	0,006017	104,12	0,000
Error	13	0,000751	0,000751	0,000058		
Total	17	0,023050				

Table 10. ANOVA results for incBO

Source	DF	Seq SS	Adj SS	Adj MS	F	P
TA	1	0,004114	0,004114	0,004114	159,32	0,000
LDS	1	0,000000	0,000000	0,000000	0,00	1,000
NPDP	2	0,014044	0,014044	0,007022	271,92	0,000
Error	13	0,000336	0,000336	0,000026		
Total	17	0,018494				

Table 11. ANOVA results for MAG_0

Source	DF	Seq SS	Adj SS	Adj MS	F	P
TA	1	369,46	369,46	369,46	88,59	0,000
LDS	1	1217,06	1217,06	1217,06	291,82	0,000
NPDP	2	458,50	458,50	229,25	54,97	0,000
Error	13	54,22	54,22	4,17		
Total	17	2099,24				

The ANOVA analysis shows that the influence of TA on KPIs is greater than the that one of the LDS at any level of NPDP, except for MAG_0. In the case of incSPE the most important factors are TA and NPDP. It can be argued that the importance to scheduling of a long period points to a larger batch size in tile production involving and this results in a small number of sub-groups based on a classification in terms of tone. It is more important to have less sub-groups than to have a more reactive production system. The same consideration holds about the influence of NPDP upon incMAG and MAG_0. Regarding incSPE, ANOVA analysis indicates that LDS is the less important parameter. This outcome results from the influence of the choices made in the very implementation of the model itself. This is due to the balance between production and the market request for tiles being a defined constituent of the model. A flat production capacity, which is a practical characteristic for a tile company, has in the model an implication of a matching flat market request. This may underestimate the importance of LDS upon incSPE. The same consideration can be done for LDS factor, that is indicated as non significant for incBO.

10. Cost/benefit analysis

In this section an example is developed where the results achieved with VirtES are implemented to analyze a specific manufacture. To enable a full cost/benefit analysis to be carried out, a simple function is proposed, termed the "Earning function" (2). In the proposed function incBO is not considered because it is not possible to propose any cost to this KPI. incBO can be considered apart as a measure of service level for customers. Of course the customers satisfaction affects industry earnings but it is not possible to propose a unique equation at this stage. Maximizing the proposed function means that the performance of the company, as defined in the model, is optimised in terms of enterprise profit.

$$E = f(incSPE, incMAG, MAG_0) = \left\{ M \times incSPE \times T - C_m \times \left[\frac{incMAG}{2} \times T + MAG_0 \right] \right\} \times PC \tag{2}$$

Where:

- *M* is the spread between the average sale price and the average production cost for 1 m^2 of tiles;
- C_m is the average warehousing cost for 1 m^2 of tiles;
- *T* is the considered time period in days;
- *PC* is the production capacity in square meters for day;

As presented above it is possible to have a linear function that correlated the KPIs with the parameters studied:

- $$incSPE = \beta_0 + \beta_1 \times NPDP + \beta_2 \times LDS + \beta_3 \times TA \tag{3}$$
- $$incMAG = \alpha_0 + \alpha_1 \times NPDP + \alpha_2 \times LDS + \alpha_3 \times TA \tag{4}$$
- $$MAG_0 = \gamma_0 + \gamma_1 \times NPDP + \gamma_2 \times LDS + \gamma_3 \times TA \tag{5}$$

After the substitution the "Earning function" can be written as shown in equation (6)

$$E=\left\{\left[\beta_0 MT-C_m\left(\frac{T}{2}\alpha_0+\gamma_0\right)\right]+NPDPD\left[\beta_1 MT-C_m\left(\frac{T}{2}\alpha_1+\gamma_1\right)\right]+LDS\left[\beta_2 MT-C_m\left(\frac{T}{2}\alpha_2+\gamma_2\right)\right]+TA\left[\beta_3 MT-C_m\left(\frac{T}{2}\alpha_3+\gamma_3\right)\right]\right\}PC \qquad (6)$$

By the way the equation allows some considerations to be made about the management of a tile firm. In equation (2) he first term including incSPE is the most important one, due to the weight of the coefficients. A more competitive market scenario reduces the spread *M* (Assopiastrelle, 2000) and contributes to an increase in warehousing cost due to increased storage of products and a more rapid obsolescence of the products themselves. This tendency highlights the importance of taking the other factors into account that in a previously strong growing market were neglected by management.

Some consideration ca be made from equation (6). A longer NPDP always has a positive impact on the function because of the production of a smaller number of larger homogeneous sub-groups of tiles. The LDS term suggests that the facility of a larger warehouse correlates directly with the ratio between *M* spread and C_m cost. The TA term indicates that an unreliable information system always negatively affects a firm's performance and the importance of this factor is comparable with those of the other parameters.

A numerical example of the "Earning Function" is given below with this set of parameters:

- $M = 0{,}222$ €/m^2, (Assopiastrelle, 2005)*;*
- $C_m = 0.01*C_p$, where C_p is the total production cost with $C_p = 8{,}163$ €/m^2 (Assopiastrelle, 2005). In absence of any literature or known studies about warehouse costs in tile industries, it is assumed that the warehouse variable cost is represented by 1% of the warehoused goods production cost. In this way the warehouse cost includes only the capital cost, this approximation underestimate the importance of warehouse cost;
- *T = 200 days*, the number of working days for 1 year;
- *PC = 20.000* m^2, the production capacity for an average tile manufacture.

See Figure 11 to compare the influence of TA and LDS at three different NPDP values, pay attention that for graphical, reason the plotted parameter is (100-TA) and not TA. In Figure 12 is given the numerical example for incBO that confirms the importance of TA terms to minimize incBO improving the service level for customers.

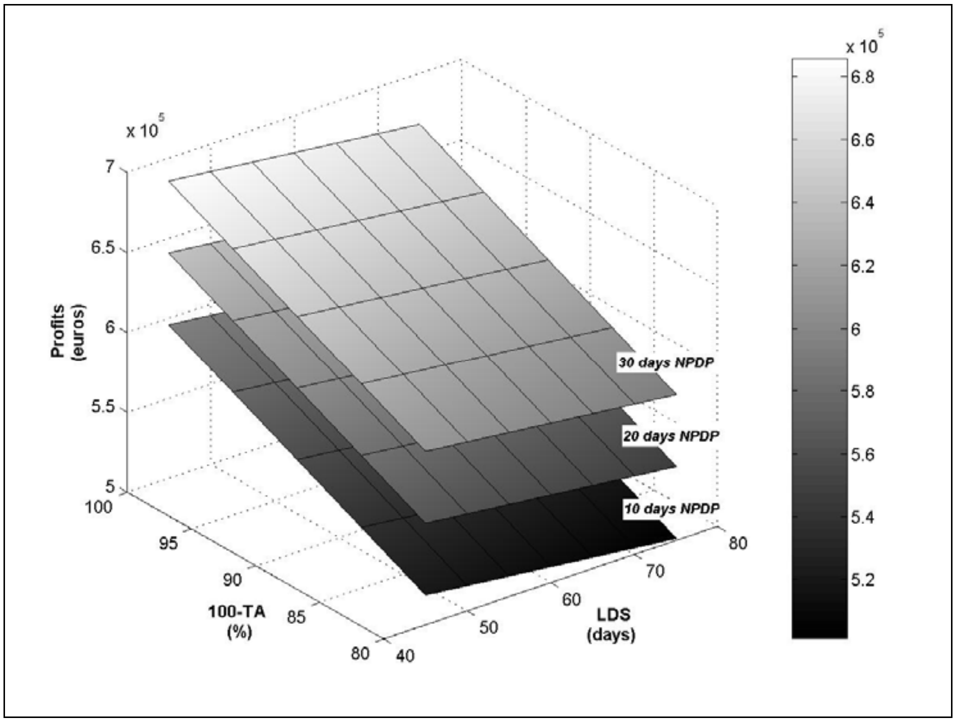


Figure 11. Example of response surfaces for the "Earning function"

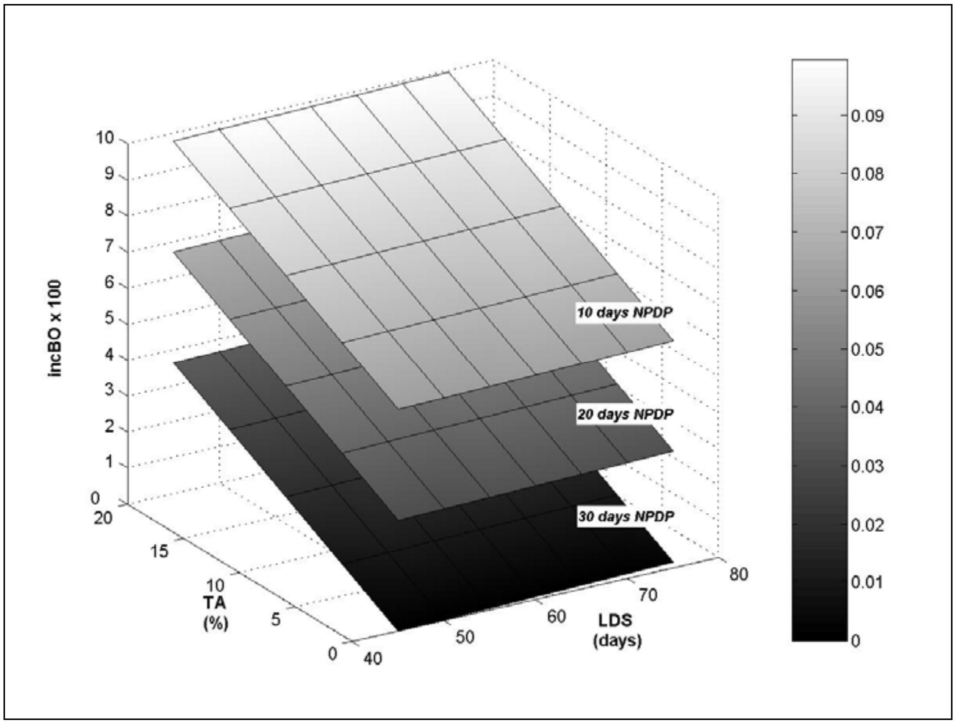


Figure 12. Example of response surfaces for incBO.

11. Conclusions

In this work we have described the development of a simulation model of a tile company which can be successfully used to investigate the influence of many parameters on its performances. The FDM model is implemented to create a virtual enterprise. The specific advantage of the FDM model is that it is possible to utilize it with only a partial modelling of the firm. This allows the creation of a model which focuses on a particular aspect without having to spend resources and time in creating a full, but demanding, enterprise model.

The paper presents the application of the proposed approach to a generic tile firm. In this case the model represents the whole manufacturing sector of the tile industry. The FDM-related model is based on the common features of tile firms obtained mainly from a literature review and collaboration with Assopiastrelle. The model is split into a series of functions, each of which is implemented in Scilab. The functions are arranged into a basic sequence and a set of KPI is identified to evaluate the firm's performance. The basic sequence of functions may be upgraded to investigate any particular aspect of company management, in this specific case the importance of the reliability of the information system. This add-on demonstrates how the final Scilab code maintains the characteristics of the FDM model while being easily extendable and upgradeable. When the set of parameters and the model specific to the application are fixed, the simulations, performed with the Scilab code, allows the empirical equation to be determined that connects the parameters studied with the KPI. This equation is useful in allowing the management to make a cost/benefit analysis. A simple "Earning function" is proposed to connect the parameters together. Finding the best set for the parameters for an individual case is possible by maximizing the "Earning function". A cost analysis is needed to explicitly relate the cost to the parameter setting and the minimization of investment needed.

In this paper the model focuses on the importance of the process, which collects and handles the information about the orders. This focus was identified because it was evident from the experience of Assopiastrelle that the information aspects of business constitute one of the areas of tile firms activities which needs improvement. The simulations performed here involve the construction of the equations which explicitly connect the dependence of KPI with 3 selected parameters. These are: NPDP (scheduling period in days), LDS (warehouse consistency in days of production capacity) and TA (rate of unreliable orders which penetrate the information system). The results indicate that the influence of TA rate is comparable with that of the LDS parameter at any NPDP studied values. For both, maximize the "Earning function" and minimize the back-orders quantity. Moreover the results suggest that one of the most important factors in tile industry performance is the presence of sub-groups of tiles due to variations in tile colouring.

The proposed approach is well suited to instances of tile enterprises because the Scilab model we have developed represents a starting point from which it is possible to create a model for a specific firm. The development of such a model can be carried out with modest financial and other resources. This is because the approach is deliberately planned to start from any specific aspect of activity, and to enlarge the model as needed. The implementation of this approach forms a useful tool for the enterprise in that it can support management decision-making and investment planning.

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Received June 2010
Accepted November 2010
Final acceptance in revised form December 2010