Action Research and the Theory of Constraints in practice at Melissa Kikizas S.A.

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Abstract

This dissertation provides a real case study for practising managers in the field of production management. The performance of a production operation was increased by using operations management methodology combined with production management principles. The work is conducted at Melissa Kikizas S.A. pasta factory in Larissa, Greece.

Action Research was chosen as the research methodology. The choice was appropriate because it gave insight into the processes, change was needed and people involvement was needed also. The Theory of constraints was selected among other production management theories. Finally simulation complemented the research process by providing an experiential understanding of the improvement procedure.

Several findings and conclusions are presented that contribute to the final increase of performance. New production schedule rules were implemented. Input problems from upstream processes were dealt. Communication problems between operations were dealt also. Rescheduling issues were discussed along with training and empowerment of operators. The total effect of the changes on the system is evaluated. Finally general findings and comments regarding the application of the Action Research are also presented.

Keywords:

Action Research, Theory of Constraints, Bottleneck, Pasta, Simulation, Production management.

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1 Introduction

1.1. System Description

The proposed research that is made in the context of a Master's dissertation deals with operational performance problems and ways to resolve them.

The system that is under study is in Melissa-Kikizas' Pasta Factory, a food industry located in Larissa in the area of Central Greece. The main parts of the food industry in Larissa are the Semolina mill, the pasta factory and the warehouse. The pasta factory is divided in two independent parts; the Long goods part that produces and packages long pasta goods like spaggeti and the Short goods that produces and packages short pasta goods like penne rigate.

The particular process is a "bottleneck" for the Short goods part of the factory. There seems to be a need for an organizational change at the operational level for the particular process. Action Research seems to be a valuable tool in attempting to combine this need for organizational change, along with the academic pursuit of building upon existing knowledge. Next, the real problem and its context is presented.

The Short goods part of the factory is organised as shown in Figure 1. The production lines produce 40 different shapes of pasta. The pasta is delivered in 4 arrays of silos and from there it is packaged in 10 different brands at the packaging department. There are 3 production lines of the following capacities: Line A: 1500 kg/hr, Line B: 1000-1500 kg/hr and Line C: 2000-3000 kg/hr. The packaging department operates 7 packaging lines. Each packaging line consists of the 1st packaging machine that packages the finished product in packs of 0.5 kg, the 2nd packaging machine that puts 6 packs in one carton and the palletizing which is done by two palletizing robots in 7 palletizing lines.

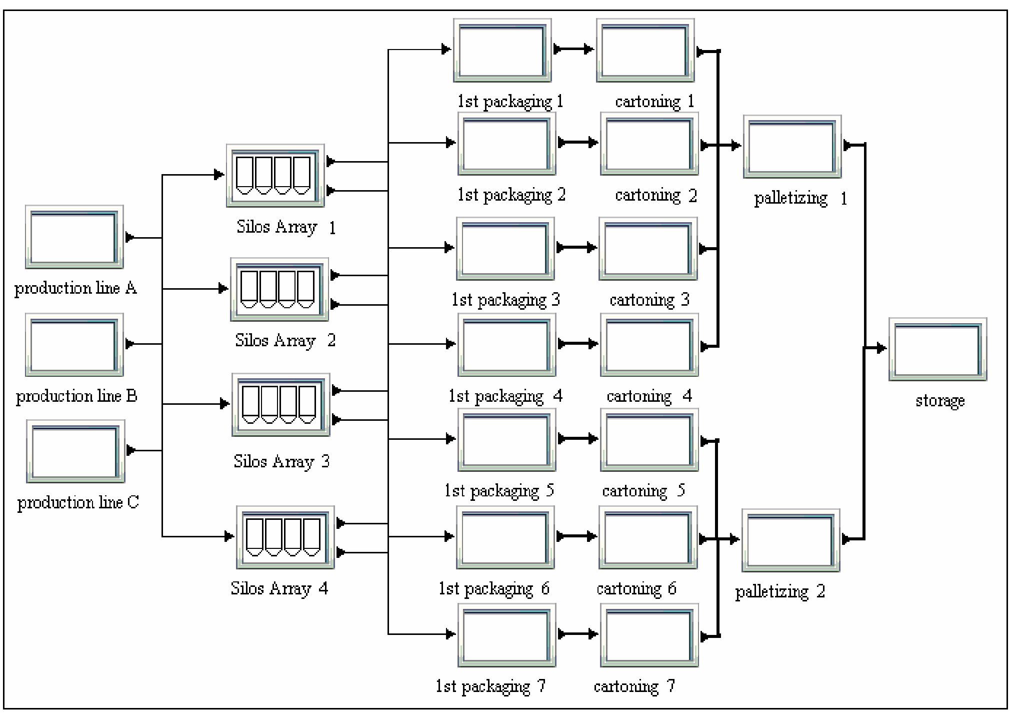


Figure 1: The diagram of processes in the industry

The maximum speed of each packaging line ranges from 65 to 120 packs per minute, which means the overall theoretical packaging capacity is above 14000 kg/hr.

1.2 Problem description

The capacity of packaging is more than 2 times the capacity of the production lines. Despite this the packaging process is the “bottleneck”.

Indeed it was the bottleneck for years and instead of using two shifts it is many times necessary to work also in the night shift to package the finished product. Otherwise the buffer of silos that is between production and packaging will be fully filled and then the production lines have to stop producing; a situation like that happened frequently in the past. The storage capacity is 80 tonnes of finished product at a density of 500 kg/m3.

In the past two years 2 brand new packaging lines were installed, along with two palletizing robots and the automatic conveyors of pallets that transfer the pallets to the front door of the warehouse. Also another two packaging machines were replaced in order to solve frequent technical problems and upgrade the packaging lines. This was a big investment. The results were slightly better in terms of packaging speeds but still packaging was the bottleneck.

From now and then, usually when production line C (the biggest) was operating and the products produced had a low bulk density (which ranges from 250 gr/lit, the most voluminous to 800 gr/lit) the buffers were filled with ready product and the production lines were forced to stop producing.

This was an awkward position for all being involved. The owners claimed that they had invested and they also recruited more personnel, 3 young guys technically educated at TEI. They arrange also to reinforce the technical assistance of packaging by one more technician who together with the experienced electrician had the responsibility to take care of the machines, along with the experienced manager of the packaging division. In addition, staff in the maintenance department (working in shifts all day round) is expected to give priority and assist the packaging department first, although they had the responsibility to take care of the entire factory operating 24 hours a day.

There were several reasons for this low performance of the packaging lines. Every stop in each station, (1^{st} packaging or cartooning or palletizing) resulted in a disruption in the whole line. So, for example, if the cartoning machine had a blockage, the packaging machine also stopped and needed extra time for start up resulting in time losses. Worst is the case when a blockage in the palletizing robot, although not frequent, results in a stoppage of three to four packaging lines, since one robot handles three or four palletizing lines.

Other reasons reside on the frequency of package change, which needs time for setup. When the batches are small the consumed time for setting up the machines is bigger, and bigger are also the delays to renew the packaging material and the different carton for different brands. Another factor affecting the performance is also the idle time; all the packaging machines cannot work at the same time, since there are some restrictions at their feeding or when the product is not enough.

The operators of the packaging machines have also their own reasonable justifications. The product volume was fluctuating and that caused problems to their machine regulations. Operators claimed that the same product from line A had a volume of 350gr/liter and when produced from line C had a volume of 300gr/liter resulting in a bigger volume of the package; causing blockages and delays in the put-in-the-carton station. This was an input problem coming from the production process and the production operators were told to measure, check and adjust the volume as accurately as possible. Horizontal communication between operators from different departments was an issue despite the efforts of the managers and their frequent meetings, since the production and packaging staff works mostly in the evening and night shift.

Other issues for the operators were poor communication between shifts and the technicians, as well as poor cooperation between old and young people. The delayed arrival of a technician that was busy somewhere else in the factory was another issue. Finally another point of argument for operators was the number of machines that they were operating. There was a debate on how many lines an operator should control. It seems that the limit was 3 and sometimes 4 lines while the other end was 2 lines minimum per operator. Another issue was the cleaning operations and their timing or scheduling.

Another issue was the interventions of the quality control that changed the schedule of packaging. Technical issues were always a matter of debate, and operators complained about the interventions of technicians and technicians complaining about the lack of expertise from the operators and the lack of discipline by younger people.

On the other side fluctuations of the demand reflected on the production schedule was another issue. Many times the machines were out of packaging material or cartons since the deliveries from suppliers weren't frequent enough. Of course the production schedule is always an issue and it fluctuates depending on season, marketing, pricing policy and others.

Nowadays the capacity utilisation of the machines is at a 40% to 50% of the total time, which is obviously very low. That means that, due to all reasons described previously, one packaging machine only works a 40-50% of its available time and at speeds lower than the theoretical average.

The resultant low performance leads to increased costs and therefore certain actions should be taken in order to increase productivity by enhancing operations performance in all directions and within an integrated approach (looking also into issues related to the precedent operations, such as the production operation which supplies the finished product). Other operations should also be examined, such as operations supplying packaging materials and the warehouse operations. For sure the problem affects a lot of people in the firm and all must be involved. Even a change of attitude of people working and cooperating in the same environment towards common goals and at the same direction needs to be finally accomplished.

Identifying the problem is the first step. Next, the approach to be followed is considered with the understanding that this needs to be systematic and integrated. The complexity of the situation described above makes it difficult for the researcher to employ a single methodology for solving the problem and eliminating its impacts. Mainly for this reason, which will be explained thoroughly below, a combination of theoretical tools and methods of research has been chosen.

The aims of this work are multiple; to offer a valuable case study to other practitioners, to provide a holistic perspective and systematic framework in improving process performance by exploiting appropriate Operations Management methods and tools, and to have a positive impact on the current business where it is applied. The objectives are stated thoroughly in the following chapter.

A literature review is presented in the next chapter. This chapter includes a brief review of the Action Research, a brief review of the Theory of Constraints and its tools along with a comparison with other theories of Operations Management, and finally a brief review of Simulation and its tools.

In Chapter 4 the methodology of this work is presented.

A thorough discussion of the findings and the main points that were discussed during the action research is presented in Chapter 5, which is divided into “two cycles of action research”.

Finally, the last chapter presents a synopsis of the conclusions.

2. The Research Objective

The primary objective is to address and examine the specific operational problems encountered in the food industry, and attempt to reveal the reasons and resolve the issues by using a systematic approach comprising certain methodologies in the operations management domain, such as the action research (AR) methodology in conjunction with production management theories such as the Theory of Constraints (TOC).

The industry is trying to increase productivity by resolving some issues regarding bottlenecks, allocation of resources, cooperation between people, attitudes and by optimizing processes. To achieve this it is apparent that it needs not only decisions or to allocate new resources but also to engage people in order to find solutions. So a systematic research is needed.

A secondary objective of this study is to provide a valuable case study for problem solving in similar operations in the industry in general.

It is expected to reach not only quantitative but also qualitative results.

Therefore, a research question that can cover both the objectives is “How can we improve performance of an operation process in a systematic way using principles and the appropriate methods from the OM area?” In addressing the aforementioned issues, this research question can be broken down to sub-questions that can be expressed as follows:

1. Can we systematically improve performance of certain operations that encounter process flow problems (such as the bottleneck problem) using the appropriate methodology in OM?
2. How would the performance be improved, if production management principles would be combined with OM approaches (e.g. the AR procedure)?

3. Literature Review

3.1 Action Research

Action Research is found within the literature in four common themes (Saunders 2007, pp 140-141):

The first theme emphasises the purpose of the research which is research in action rather than research about action. In other words the research is concerned with the resolution of organisational issues such as the implications of change together with those who experience the issues directly.

The second theme relates to the involvement of practitioners in the research and in particular, a collaborative democratic partnership between practitioners (or employees) and researchers/academics as either internal or external consultants (Saunders et al, 2007). One could add to them the operation managers themselves that want to change an operation.

The third theme emphasizes the iterative nature of the process of diagnosing, planning, taking action and evaluating as in the following figure.

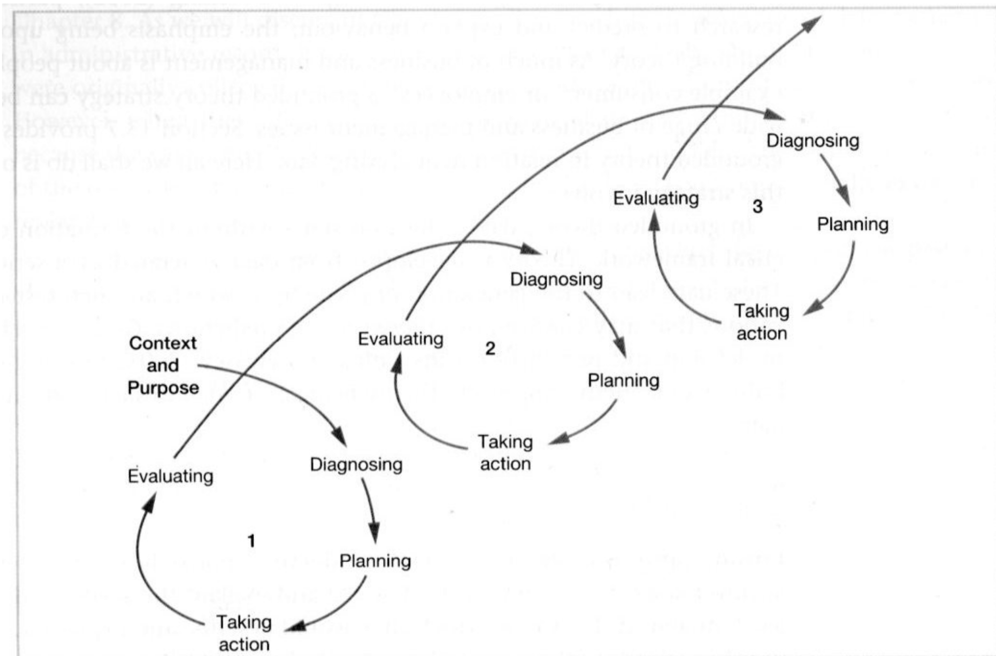


Figure 2: The action research spiral (Source: Saunders et al 2007, pp 141)

The fourth theme suggests that action research should have implications beyond the immediate projects. In other words, it must be clear that the results could inform other contexts. The same author concludes additionally that action research differs from other types of research in that it is promoting changes within the organisation and that makes this kind of research particularly useful for “how” questions.

As O’Brien (2001) puts it simply: action research is “learning by doing” - a group of people identify a problem, do something to resolve it, see how successful their efforts were, and if not satisfied, try again. A more concise definition according to the same author is:

"Action research...aims to contribute both to the practical concerns of people in an immediate problematic situation and to further the goals of social science simultaneously. Thus, there is a dual commitment in action research to study a system and concurrently to collaborate with members of the system in changing it in what is together regarded as a desirable direction. Accomplishing this twin goal requires the active collaboration of researcher and client, and thus it stresses the importance of co-learning as a primary aspect of the research process."

What separates this type of research from general professional practices, consulting, or daily problem-solving is the emphasis on scientific study, which is to say the researcher studies the problem systematically and ensures the intervention is informed by theoretical considerations. Much of the researcher's time is spent on refining the methodological tools to suit the exigencies of the situation, and on collecting, analyzing, and presenting data on an ongoing, cyclical basis. Several attributes separate action research from other types of research. Primary is its focus on turning the people involved into researchers, too - people learn best, and more willingly apply what they have learned, when they do it themselves. It also has a social dimension - the research takes place in real-world situations, and aims to solve real problems. Finally, the initiating researcher, unlike in other disciplines, makes no attempt to remain objective, but openly acknowledges their bias to the other participants (O'Brien, 2001).

Schein (cited in Saunders et al, 2007) emphasizes the importance of employee involvement throughout the research process, as employees are more likely to implement change they have helped to create. Once employees have identified a need for change and have widely shared this need, it becomes difficult to ignore, and the pressure for change comes from within the organisation. An action research strategy therefore combines both data gathering and facilitation of change. Moreover as Dick suggests participation can generate greater commitment and hence action. When change is a desired outcome, it is more easily achieved if people are committed to the change; some participative form of action research is often indicated.

The same author says that action research has two distinct foci. The first of these, aims to fulfil the agenda of those undertaking the research rather than that of the sponsor. The second focus starts with the needs of the sponsor and involves those undertaking the research in the sponsor's issues, rather than the sponsor in their issues. In the process operations under research these two aims coexist and are in agreement with all the previous observations. In particular in the present case on one hand the industry has complex operational problem-solving needs and on the other hand the researcher has the academic need for the research to be accomplished in order to receive his MBA degree. Additionally the researcher is involved into the operation processes and the industry is the sponsor of his MBA course.

Other reasons for contacting action research are that the operational problems, mainly low productivity in some machines, are due to a lot of reasons. There are parameters that can be measured but there are other issues that are not quite fully understood. The context of action research is almost always the organization: most action research studies are case studies. They are very often linked with a change agenda, via the creation of deeper knowledge and understanding about a particular social or organizational issue, in order to improve a particular situation (Unknown 2009, Emerald Insight article on internet "How to... carry out action research" available at: http://info.emeraldinsight.com/research/guides/action_research.htm).

As French (2009) suggests, Action Research is a methodology that is a member of the case-study family of methodologies. As such the findings cannot be generalised and the data are not representative for broader use. This is both an advantage and disadvantage of the method, depending on the ability to be generalized but also the effectiveness in performance improvement based on experiences, empirical findings and pertinent theory, as well. Thus, the same author suggests that action research, as any other small scale research, can use existing theories and suitable methods and offer evaluation of existing knowledge.

In the case of Melissa-Kikizas' pasta factory, Action Research is suitable for many reasons including the aforementioned. In addition, Action Research can provide results and bring about change, which the organization in concern values and acknowledges as an on-going process for improvement. Action Research can motivate and involve people to take action and this is mostly what is needed here. Also in the case of the particular process there isn't any methodology to address all particular issues and there are interrelated problems together with people involved, which makes the issues more complex. In order to provide practical and reliable suggestions one cannot isolate any problem and has to involve a lot of people. Thus, Action Research is considered suitable in this regard. Also it is expected to provide insights onto the system being studied and create knowledge through the synergies of the team that is in charge for exploring and taking actions to improve the process. The researcher's contribution is to gather, present and disseminate information in a way so as to catalyze and speed up the "processes" of studying, deciding, taking action and evaluating. Also the researcher is a practitioner himself and is involved in the actual processes. Finally the practitioner is backing up each step of the action research "spiral" with the appropriate justification supported by the management theories and principles.

Simulation is a secondary task that can assist and complement the research process by providing an experiential understanding of the improvement procedure and its characteristics within the system. Results obtained from simulations can be proven valuable for figuring out further steps needed to undertake in order to advance research. In addition this methodology can serve as a tool to present another perspective of the particular business. For example, concepts such as order cycle time, waiting time for resources, resource allocation and total time can be actively explored, along with their interdependencies and influences on the system. By experimenting with them, knowledge and insights are expected to be gained and rigorous process improvements are thus more likely to occur. Once reasons of the particular problems are revealed, appropriate responsive methods can then be applied explicitly for confronting the identified sources that cause the problems.

3.2 Theory of Constraints (TOC)

Initially, some related notions found in The Theory of Constraints are defined as follows:

Constraint definition

Anything that limits a system from achieving higher performance in attaining its goal is a constraint. There are two types of constraints: Bottleneck and Capacity constrained resource. A Bottleneck exists when the resource's capacity is less than or equal to the market demand and a Capacity constrained resource is a resource that has become a bottleneck as a result of inefficient utilization.

Capacity definition

Capacity is the upper limit or ceiling on the load that an operating unit can handle. Capacity also includes: Equipment, Space, Employee skills, etc. (Stevenson 2007).

According to Rahman (1998) the concept of TOC can be summarised as follows:

• Every system must have at least one constraint. If it were not true, then a real system such as a profit making organisation would make unlimited profit. A constraint therefore, "is anything that limits a system from achieving higher performance versus its goal".

• The existence of constraints represents opportunities for improvement. Contrary to conventional thinking, TOC views constraints as positive, not negative. Because constraints determine the performance of a system, a gradual elevation of the system's constraints will improve its performance.

The working principle of TOC provides a focus for a continuous improvement process. The principle consists of five focusing steps which are summarised in the following figure.

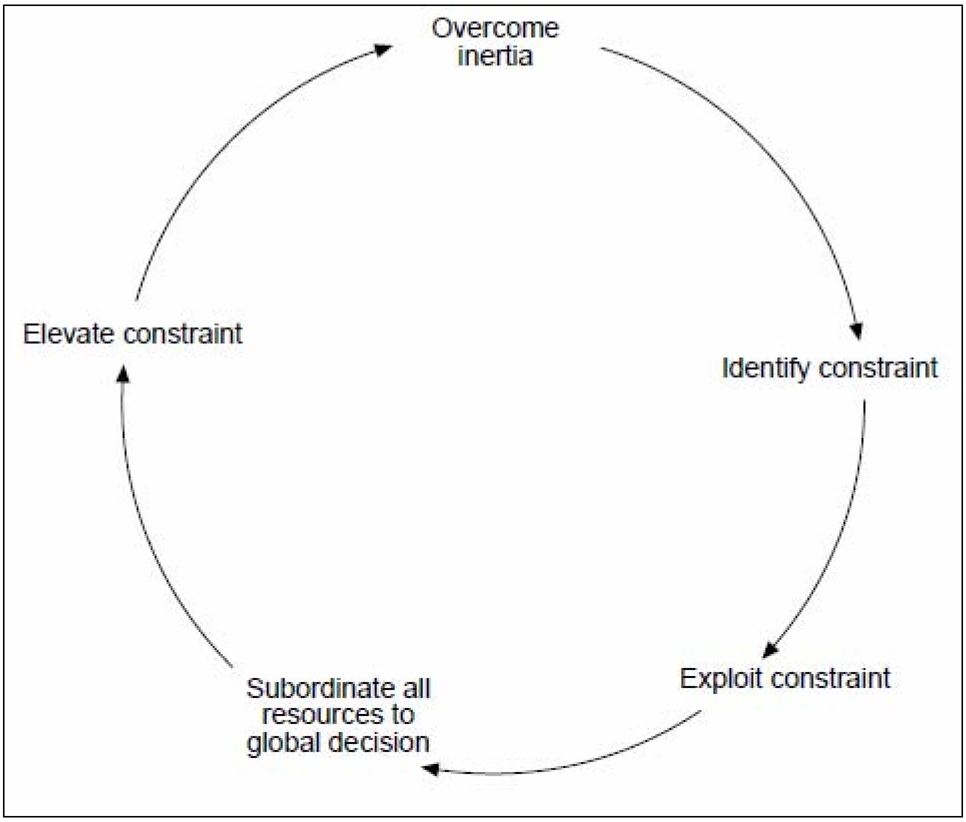


Figure 3: Process of on-going improvement (Source: Rahman 1998)

The steps are:

1) Identify the system's constraint(s). These may be physical (e.g. materials, machines, people, demand level) or managerial. Generally, organisations have very few physical constraints but many managerial constraints in the form of policies, procedures and rules and methods. It is important to identify these constraints and also necessary to prioritise them according to their impact on the goal(s) of the organisation.

As Gupta (2008) suggests there are not only physical constraints but also non-physical constraints such as poor relationships with suppliers, other policies, procedures or ways of thinking. Thus, it is possible according to the same author, that the operations function does not have enough of a specific resource or a specific resource is not utilized properly due to some policy constraints, thereby limiting the performance of the entire organization of interdependent resources, departments and processes.

For example bottlenecks are the work centres that have the biggest percentages of their capacity loaded (Dilworth 1993, pp 360).

2) Decide how to exploit the system's constraint(s). If the constraint is physical, the objective is to make the constraint as effective as possible. A managerial constraint should not be exploited but be eliminated and replaced with a policy which will support increased throughput.

3) Subordinate everything else to the above decision. This means that every other component of the system (nonconstraints) must be adjusted to support the maximum effectiveness of the constraint. Because constraints dictate a firm's throughput, resource synchronisation with the constraint provides the most effective manner of resource utilisation. Nonconstraint resources contain productive capacity (capacity to support the constraint throughput) and idle capacity (capacity to protect

against system disruptions and capacity not currently needed). If nonconstraint resources are used beyond their productive capacity to support the constraint, they do not improve throughput but increase unnecessary inventory.

4) Elevate the system's constraint(s). If existing constraints are still the most critical in the system, rigorous improvement efforts on these constraints will improve their performance. As the performance of the constraints improve, the potential of nonconstraint resources can be better realised, leading to improvements in overall system performance. Eventually the system will encounter a new constraint.

5) If in any of the previous steps a constraint is broken, go back to step 1. Do not let inertia become the next constraint. The first part of this step makes TOC a continuous process. The second part is a reminder that no policy (or solution) is appropriate (or correct) for all time or in every situation. It is critical for the organisation to recognise that as the business environment changes, business policy has to be refined to take account of those changes. Failure to implement step 5 may lead an organisation to disaster.

In the case of Melissa's pasta factory there is evidence that there are policies and procedures that are limiting the productivity along with physical constraints.

3.3 Drum Buffer Rope (DBR)

Drum-Buffer-Rope (DBR) is a production control technique and a scheduling technique that implements the TOC principles.

DBR is the TOC approach to production planning, scheduling and buffer management, (Gupta 2008).

The following definitions can be used:

Drum: Bottleneck, beating to set the pace of production for the rest of the system

Buffer: Inventory, placed in front of the bottleneck to ensure it is always kept busy. It determines output or throughput of the system

Rope: Communication signal, tells processes upstream when they should begin production.

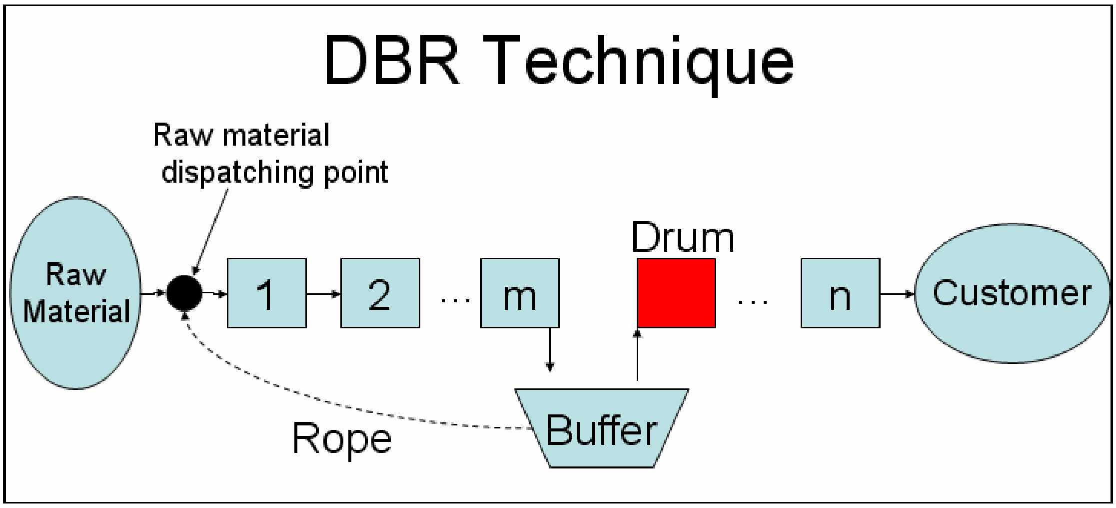


Figure 4: DBR (source:http://www.scribd.com/doc/7251905/Theory-of-Constraints)

Optimized Production Technology (OPT) is the predecessor of TOC. According to OPT developed by Goldratt, (cited in Watson et al 2007), there are the following rules for correct scheduling:

- Balance flow, not capacity. Plant capacity should not be balanced. It is more important to synchronize the flow of items than to make sure that the capacities of the equipment are equal.
- Constraints determine non-bottleneck utilization.
- Utilization and activation of a resource are not synonymous. Activation is the time spent running units on a machine or other resource whether they are needed or not. Making parts that cannot be used, just to keep the resource busy, is not utilising the resource. Utilization is running the resource in accordance with the rate at the bottleneck, (Dilworth 1993, pp 359).
- An hour lost at a bottleneck is an hour lost for the total system. An hour saved at a non-bottleneck is a mirage. Nonbottlenecks have extra capacity, so saving an hour there just adds to the extra capacity. So reducing set-ups at a bottleneck increases capacity and throughput, while additional set-ups at a non-bottleneck do not affect output but do minimize work in process (WIP) inventory, (Hill 2005, pp 369).
- Bottleneck governs both throughput and inventory in the system.

- The transfer batch may not, and many times should not, be equal to the process batch. Sometimes it is desirable to split a production lot and move some of it to the next machine, so it can begin processing before the entire run is completed on the earlier operation.

- The process batch should be variable, not fixed. The number of items run per batch at one operation may differ from other operations and may be different the next time the item is made. Batch size depends on such variables as demand and the time available for additional setups.

- Schedules should be established by looking at all of the constraints simultaneously. Lead time is the end result of a schedule and cannot be predetermined. Lead times are a function of the lot size, transfer batch, priority and other factors. They should not be assumed to be fixed, (Dilworth 1993, pp 359).

- Utilization of a non-bottleneck resource is determined not by its own capacity but by some other constraint in the system.

- Capacity and priority need to be considered simultaneously, not sequentially

-Damage from unforeseen problems can be isolated and minimized

- The sum of the local optimums is not equal to the global optimum

According to Gupta (2008) in DBR, the constraint resource is scheduled first and material release is back scheduled from the constraint by the setup and processing times of upstream resources and the time required for processing items in the constraint buffer at the constraint. The assumption is that non-constraint resources will have excess capacity so that queue time at non-constraints will be minimal.

Following there is a short description of the DBR scheduling method adapted from Wu et al (2010):

The three major components of DBR are the Drum, the Buffer, and the Rope. The Drum is a detailed schedule of the Capacity Constrained Resource (CCR). The Drum design performs the CCR exploiting decision process when scheduling the DBR. The design method of a Drum depends on the requirements and complexities of different shop. Therefore, a Drum, which is the final result or documents after this CCR exploiting decision, is the optimized processing sequence for all orders in CCR. The Buffer is a protection time to protect the CCR when raw materials are delayed by previous processing procedures. The Buffer size in a stable environment is generally defined as three times the average lead time to the constraint from the raw material release point (Schragenheim & Ronen cited in Wu et al, 2010). Finally, the Rope, which can be measured by offsetting the Buffer from the Drum, is a detailed schedule for releasing raw material into the shop floor to force all system parts to work only up to the pace dictated by the Drum. Under the DBR system, any employee or resource in a manufacturing plant can be guided to fulfil the CCR exploitation and subordination process, and thus attain the focus or goal of the plant. Therefore, two fold improvements can be found by the implementation of DBR system. The first is that it can squeeze and protect CCR potential throughput so as to improve the system throughput. The second is that it restricts unlimited release of material into the system so as to prevent the growth of inventory.

Buffer management serves two additional purposes (Schragenheim and Ronen, cited in Watson et al). First, it allows management to identify possible problems in the manufacturing system before they impact the schedule. Comparison of actual versus planned buffer size at set times during the manufacturing schedule allows managers to spot problems prior to the point at which they become critical, and, through quick feedback to the problem work centre, reduce unnecessary expediting. Second, buffer management can be used to focus improvement efforts on those processes that have the greatest negative impact on schedule performance, simplifying the management of continuous improvement activities.

An illustration of the Drum Buffer Rope technique is shown in the figure below.

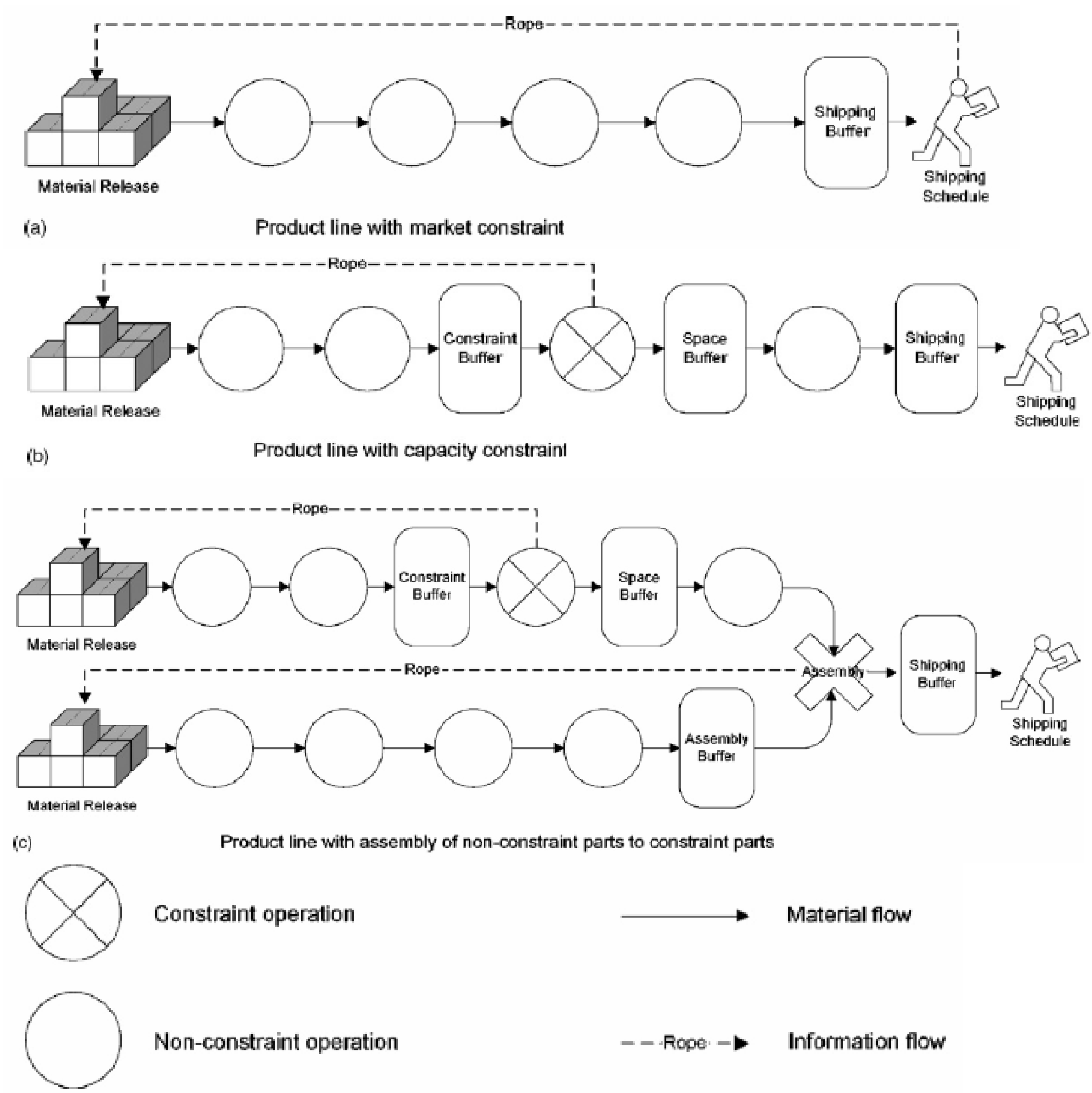


Figure 5: Typical drum buffer rope configurations (source: Watson et al 2007)

3.4 Manufacturing synchronisation, a comparison of approaches

Several approaches have been recommended for improving production management including manufacturing resources planning (MRP II), Just in time (JIT) and the theory of constraints (TOC). As Rodrigues (1998) suggests a common element of all the approaches is the need for greater synchronisation in the management of the flow of work through the factory. A perfectly synchronised manufacturing system is the process where components arrive at the work centres in time for their production, so that excessive in process stocks do not build up causing delays to orders, inventory costs are minimised and customer service is improved by delivering orders on time. According to the same author other advantages from the reduction of inventory are the exposure of quality problems that were unknown and even the elimination of problems such as deterioration and obsolescence of components held as inventory.

Thus Rodrigues concludes that manufacturing synchronisation is one source for gaining competitive advantage among others.

Below there is a description of the theoretical approaches for manufacturing synchronisation, as it is described by Rodrigues (1998).

3.4.1 The traditional way of managing production

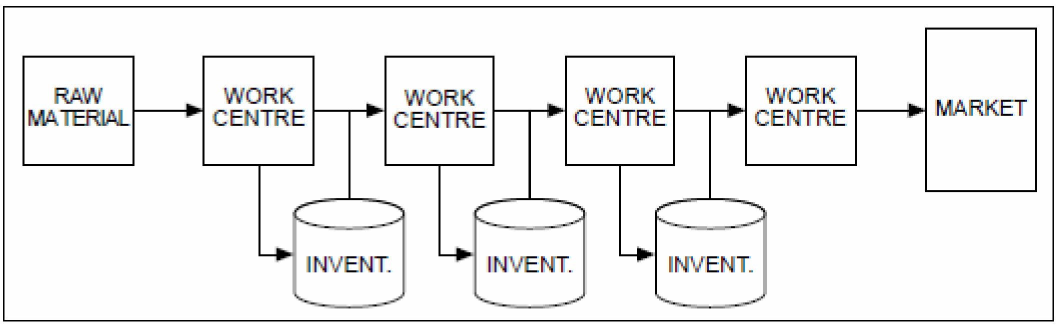


Figure 6: Production synchronization as in a JIC system (Rodrigues 1998)

The traditional way is known as just-in-case (JIC). The underlying assumption of this approach is that maximising the efficiencies of the individual parts leads to the optimal performance of the system as a whole. The maximisation of individual resources is achieved by defining economical lot sizes, local cost measurements, every resource being managed to work 100 per cent, etc. This approach also encourages the use of "just-in-case" stocks to cover contingencies, e.g. resource breakdown. Components are pushed in batches from one process to the next, not considering if they are required at that time at the next process. These assumptions have led to many Western companies experiencing the following problems:

- the end-of-month syndrome;
- high work in process;
- A lot of expediting;
- Late orders

In order to solve these problems, other approaches have emerged claiming to improve production activities and synchronise the production system. The main non-computerised approaches are Just In Time (JIT) and Theory of Constraints (TOC).

3.4.2 The JIT approach

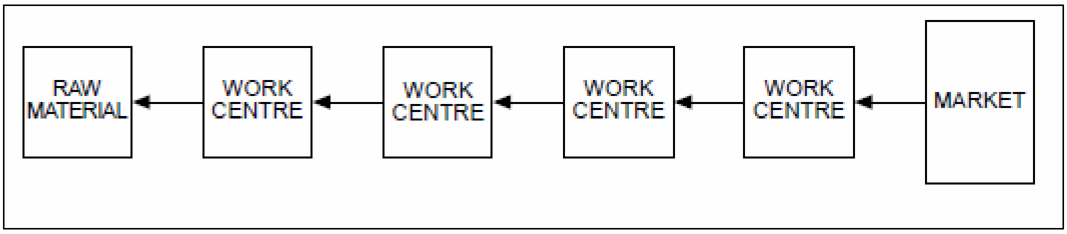


Figure 7: Production synchronization as in a JIT system (Rodrigues 1998)

The JIT approach for synchronising production theoretically tries to create a chain of balanced production cells, where products/components are manufactured just in time as needed, pulling them from the market backwards to raw materials, section by section. In practice, this approach allows small quantities of inventories, which are kept but tend to be minimised, for each cell, in order to keep them working in case of any disruption in the process. As a consequence, inventories and lead times are reduced, thus decreasing costs and improving customer service.

There are limitations with the JIT approach, in terms of manufacturing synchronisation. In some cases, it is not easy to create a balanced flow and even if you could, throughput would be at risk, whenever one of these cells breaks down. For this reason, JIT applies the idea that processes should be fail safe, using techniques such as total preventive maintenance. Moreover, Gupta and Heragu (1991) cited in Rodrigues (1998) say that JIT cannot accommodate more than a 10 per cent fluctuation in product demand, because it will create disruption in the material control system (Kanban).

3.4.3 The Theory of Constraints (TOC) approach

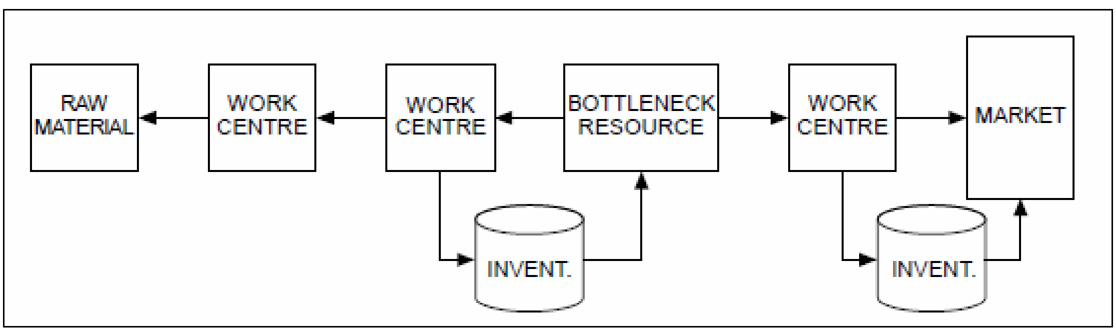


Figure 8: Production synchronization as in a drum-buffer-rope system (Rodrigues 1998)

The TOC approach for synchronising production is a mix of pull and push systems and it is called the drum-buffer-rope (DBR). It recognises that a bottleneck resource will exist in any process, therefore it tries firstly to identify it; secondly to define a maximum utilisation (drum) of this resource and then to subordinate all other resources to this decision (rope). In this way, components are pulled from the bottleneck resource backwards to the release point of raw-material and then pushed from this resource to final assemblies. In order to guarantee throughput, buffers are used in the system. They are located before the bottleneck resource to preserve its full utilisation and before the market in order to protect the order due dates.

TOC's limitations in terms of synchronising manufacturing are related to the implementation of this approach in practice. Although the method provides the guidelines for locating buffers, it has not got a specific procedure for defining their respective sizes. Moreover, in plants with wandering bottlenecks, this approach would be difficult to implement. Buffer management would require continuous monitoring, whenever there is a change in the bottleneck resource.

Rahman (1998) discussing the comparison between TOC, JIT, MRP and Linear Programming (LP) agrees that an organisation needs a combination of these production control methods to take advantage of each system's strength.

Inventory management plays a key role in JIT and TOC since by reducing inventory we can expose problems like in the following picture.

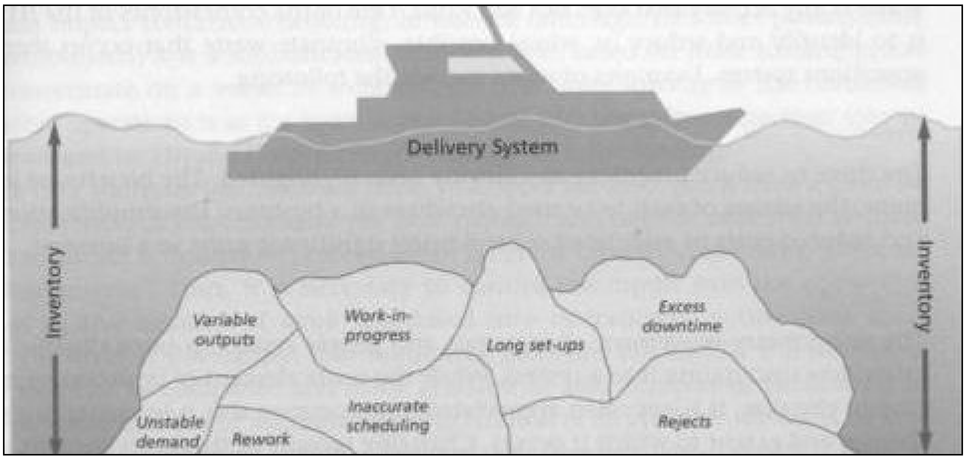


Figure 9: Excess inventory covers over problems that are consequently not exposed and dealt with (Hill pp. 367)

3.5 Process Simulation

By searching the pertinent literature it was found that it is hard to find a model that can explicitly apply to the particular problem. But what is proposed here as an alternative to analytical methods and mathematical models is the use of simulation models. The theory of queuing and use of resources and restrictions to resolve certain operational problems, such as bottlenecks has been integrated in simulation tools that can help someone analyze an operation process.

In this research simulation tools was used in order to assist Action Research.

Lewin's idea of Action Research (as cited in French 2009) was "studying things through changing them and seeing the effect". This is similar to what someone does with a simulation tool. With the simulation tool we can try changes and see the effects, then communicate and demonstrate this to the team of participants and then plan more precisely and execute the plan. This is the general idea behind the use of a simulation tool.

<u>Simulation and Systems</u>

Below there are some useful definitions given by Les Oakshott (1997).

System classification:

Systems are either static or dynamic. A static system is either where time doesn't play any significant role or where we are only interested in the system at one particular instant of time. A system that is changing over time is usually said to be a dynamic system.

Systems can also be discrete or continuous. A discrete system is where the state of the system changes at discrete time intervals, while a continuous system changes smoothly.

The modelled system is dynamic since it changes with time and by random events. It also changes at discrete time intervals.

Models of systems are either deterministic or stochastic. A deterministic model is where an exact solution can be obtained and this is often called an analytic solution. Unlike deterministic models, stochastic models do not necessarily give the same output for the same input. Within a stochastic model there will be at least one variable that is not known with certainty. The values of these variables are often expressed by a probability distribution (Oakshott 1997).

The model under discussion is a stochastic model; events happen randomly and can be described only by various probability distributions.

<u>Advantages and disadvantages of Simulation:</u>

According to Oakshott (1997) some advantages of simulation are:

Simulation can be used to study complex systems.

Simulation can be used to answer what if? type questions.

Simulation can be used in the modification of existing systems without disturbing the system.

Simulation often gives people a better understanding of a system.

Simulation can often help develop team work within an organisation.

Bottlenecks in a process can often be identified when simulation is used.

It is possible to study the transient nature of a process using simulation.

Simulation can help quantify the risk inherent in a system.

Simulation can sometimes be used as a real time scheduling model for certain systems.

According to the same author some disadvantages of simulation are:

Simulation does not guarantee optimal solutions.

Simulation cannot solve problems.

Simulation is a sampling device so "exact" solutions are not possible.

Statistical knowledge is required to analyse the output from a simulation model.

A simulation model can take longer to develop than an analytical model.

A simulation model can ignore important variables or relationships that exist in the real system.

A simulation project can be expensive to undertake as a major project may require a number of staff for several weeks or months to be assigned to the study.

Discrete-event simulation software packages are expensive (typically in the region of several thousands of pounds).

Collection of data for a simulation model can be difficult and time consuming.

Other benefits of simulation are, according to Robinson (1994):

Risk reduction

Greater Understanding

Operating cost reduction

Lead time reduction

Faster plant changes

Capital cost reduction

Improved customer service

According to Robinson (1994) although some of these benefits could be achieved by other methods such as mathematical modelling and real life experimentation; simulation is able to tackle a wide range of issues and there are a number of managerial reasons for simulation to be used in preference to these alternative techniques.

The same author presents the following benefits of simulation against real life experimentation. We could comment that practically managers and not only do a lot of real life experimentation, in other words we all have tried to learn by trial and error!

<u>Simulation versus real life experimentation</u>

Cost:

Real life experimentation can be very costly and we cannot fire staff at will or install additional equipment in order to measure the change in throughput.

Repeatability:

The exact conditions of a real life experiment are unlikely to be repeated, there is only one opportunity to collect the results.

Control of the time base:

The same simulation experiment can be made in a fraction of the time and other scenarios can be tried also. The effects of not planning an experiment well are not devastating like in the real life experimentation.

Legality and safety:

With simulation, ideas can be tested and once a solution has been found attention can be paid to the safety and legal requirements.

Simulation versus mathematical modelling:

The same author argues that there is an abundance of mathematical models that can be used to represent real world systems, and implementing these models will in most cases be quicker than simulation. Examples of mathematical models are linear programming, regression analysis and queuing theory. However, there are a number of good reasons why simulation should in some circumstances, be used in preference to mathematical modelling.

Non-standard distributions:

A simulation model can include both standard distributions and distributions based on collected data, while a mathematical model is restricted to a set of standard time distributions that need an approximation.

Interaction of random events:

When a machine breaks down on a production line the stoppage will have significant “knock-on” effects. Mathematical models cannot easily represent the complex interactions caused by such random events. Simulation is able to handle these complex interactions and predict their effect.

This argument of Robinson explains the reason for some personal experiences. For example a break down in one machine draws all the human technical resources, leaving other machines idle waiting for the same resources even in the case of start-up setup. How could one describe these multiple effects by mathematics?

The management perspective:

According to Robinson it is possible that a problem could be analysed without the use of simulation; however, among the most compelling reasons for its use are the benefits gained by managers. The ability to view the model running and to interact with it at any stage in the run has significantly added to these benefits.

Simulation fosters creative attitudes:

Often because of the risk of failure, ideas that would give considerable improvement are never tried. However, with simulation, ideas can be tried in a safe environment and at a low cost; this can only help to encourage innovation and improvement.

Simulation promotes total solutions:

There is a tendency for problems to be seen as local issues promoting local solutions. Typically, a build-up of work in progress in one area of a factory is shifted to another department and the problem is “solved”. A visual interactive simulation model showing an overview of the factory will demonstrate the weakness of local solutions and promote the implementation of total solutions.

Simulation makes people think:

A major benefit of simulation is that it creates a framework for people to think through specific issues.

Simulation enables good ideas to be communicated effectively:

Many good ideas have been trampled under foot because the benefits could not be demonstrated to a senior manager.

Axelrod (cited in Dooley K., 2002) says that there are seven different purposes of simulation in the social sciences: prediction, performance, training, entertainment, education, proof, and theory discovery. Moreover Dooley claims that Simulation is best used to answer the question “What if?” (Dooley K., 2002).

4. RESEARCH APPROACH METHODOLOGY

4.1 Performance measurement

In order to make valid observations and evaluations some metrics of performance should be used.

Based on the performance objectives identified by Slack et al. (2004, pp. 643) the following measures could be used:

For the quality of packaging measurement the mean time between failures and the scrap level could be chosen.

For the speed objective:

Regarding the packaging machines someone could measure the quantity packaged per hour or per work shift.

Regarding the speed of the technical intervention we could measure the cycle time of solving a blockage or a failure but that needs some discussion with the practitioners.

Other performance measurements among which we could select the most appropriate are:

Cost per operation hour or per tonne of product packaged.

The time an order is waiting for resources

Machine setup time

Average batch size

Average capacity/maximum capacity

Utilization of resources

Labour productivity

Proportion of product in buffer

Total work in progress from production till warehouse, which is related to the amount of ready product stored in the buffer between production and packaging.

From the above measurements a small set could be chosen in order to better evaluate the effect of each action research cycle and the corresponding actions.

As summarized by Rahman (1998) the TOC has two sets of measurements: global (financial) measurements and operational measurements. The operational measurements are:

1) Throughput (T): the rate at which the system generates money through sales (output which is not sold is not throughput but inventory).

2) Inventory (I): all the money invested in things the system intends to sell.

3) Operating expense (OE): all the money the system spends in turning inventory into throughput.

Throughput is represented as sales minus "totally variable" cost. Inventory includes any physical inventories such as raw material, work in process, unsold finished products, and includes tools, building, capital equipment and furnishings. Operating expense includes expenditures such as direct and indirect labour, supplies, outside contractors and interest payments.

In the case of Melissa's pasta factory throughput is measured by kg/day of ready product. Inventory is measured by the number of silos that are full of product and ready to be packaged, i.e. work in process. Operating expense that is relative could be the human working hours.

4.2 Research Methodology

Action research is the main proposed methodology for the aforementioned reasons.

According to Coughlan (2002) Action Research is increasingly common in the context of managers participating in academic programmes.

O'Brien (2001) suggests the Search conference as an Action research tool. The same author proposes also the following roles for the researcher: planner; leader; catalyser; facilitator; teacher; designer; listener; observer; synthesizer; reporter.

The research will be data driven more than theory driven since it is difficult to find a particular methodology in complex problems like this due to many reasons and factors. Data driven research fits more to action research according to Dick (2002). Moreover there is not a certain methodology or is not only one that can be followed and this is another characteristic of this kind of research, according to Dick (2002).

There are different parameters that make the situation complex and above all the human factor. The participants in the research may also need to change attitudes. That's another reason for choosing action research.

Action research, according to Dick (2002), implies that there is some trade – off between rigour and relevance. It is advantageous to choose action research and relevance to the local situation instead of rigour, which relates more with qualitative/quantitative research, but which is difficult to apply to the local situation.

The participants to the action research were the following:

- The Director
- The packaging Manager
- The production Manager
- The maintenance Manager
- The quality control Manager
- The maintenance staff
- The quality control staff
- The operators of the packaging machines
- Some operators and assistants of the production machines

According to preliminary research the low performance of the packaging process is due to various reasons. Compared to other industries of the same sector the performance of the firm seems poor in that part of the processes.

Several factors that affect the productivity of the packaging machines are primarily identified:

- The quality of packaging material
- The design of the packaging material
- The quality of the carton
- The volume of product to be packaged, that changes sometimes substantially causing this kind of problems.
- The availability of packaging material
- The number of setup changes per shift
- The machine faults at either one of the three stages of the packaging
- The number of operators per shift
- The availability of technician and electrician
- The training of operators and technician and their technical skills
- The interference of the quality control in the process

- The quality of product
- Cooperation between operators and technicians
- Horizontal cooperation between departments
- The production schedule
- Other factors regarding people attitudes that hinder productivity.

Other factors were found and evaluated during the action research procedures and by the use of appropriate tools such as cause and effect diagrams, Pareto diagrams and even why-why analysis. These tools are regarded as basic means in addressing problems for operations improvement (Slack et al, 2004).

The general route for action research is of iterative nature and can be illustrated as a series of the following steps: Plan, act, observe, reflect and further plan, act, observe, reflect…

The specific research task of this project was initially scheduled to last two months maximum. This is in accordance with observations made by Waser (2003), who suggested that a period of 4 months was too big and a time period between meetings of 1 month was quite extended, resulting thus in a loss of impetus. So the time between meetings should normally be less than 2 weeks and a total time of 2 months for the specific task were considered fair.

Action research according to Adams (2007) requires both research and managerial significance which in our case is granted since the researcher is employed in the particular industry.

The Theory of constraints was the basic theory and action research was the vehicle to apply the principles, in the case of Melissa-Kikizas pasta factory, bringing about improvement changes.

The specific procedures followed in this research can be described in stages as follows:

PLAN

1) Gather data. The researcher gathers data from the already existing sources.
2) The researcher feeds this data to the practitioners. This usually happens prior to a meeting.
3) The team meets and analyzes the data. This can be done on the first meeting time which may have a duration of maximum 2 hours. At this first meeting an introduction about the project and the need for change is carried out, along with the necessary rules and procedures and the required metrics that will be used to measure improvement, which need to be defined and agreed by all members. Some relevant suggestions/recommendations can be prepared at that time.
4) During this meeting the plan of action is made and the commitment of all members of the team is asked.

ACTION

5) The next phase refers to the action phase during which the agreed plan is applied.

OBSERVE-EVALUATE

6) During the action phase observations are made and measurements are taken as agreed in order to compare them later and discuss the outcomes. The researcher makes his own observations, along with the participants', but with the responsibility to make a report.

FURTHER PLAN

7) After a determined period (fixed, yet flexible) the evaluation has to be made. The researcher gathers the pertinent data.

8) The researcher feeds this data to the practitioners. This usually happens prior to the second meeting.
9) The team meets for the second time and analyzes the data
10) During the second meeting another plan of action is made.

ACTION
OBSERVE
FURTHER PLAN…

The procedure was repeated for 2 cycles according to the situations faced.

Data was gathered also through participants' observations, discussions and interviews. In fact, it was expected that some participants would be unavailable to attend these meetings, due to daily work; even some of them have to work in rotating shifts.

Validity of the findings as said before is an issue in action research and triangulation is needed for the data. The collected data and information was informally crosschecked by more than one independent source. The main crosscheck was exposure of the data to all the participants. When everyone agreed then the team was assured for the correctness. Also, all the information resources available in the factory were used, i.e archives and data sheets. Performance measurements didn't need a crosschecking.

4.3 Simulation methodology

Process simulation was used as a tool to describe the problem, plan, analyze and communicate it to the participants.

There are essentially four steps in performing business process simulation (CACI 2001):

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

The process simulation was done by the use of the "Simprocess" software. The evaluation version of the software package was used. This demo version is restricted but also the scope of this research is restricted and focused. A very appealing feature that "Simprocess" incorporates is the resource sharing feature that gave another view of the time required to wait for the resources.

1) Building the model

The model was built in the Simprocess graphical environment. The level of detail was such as to show the influence of the parameters in question. The parameters had to take certain values to resemble the reality as close as possible. A systematic search was necessary in order to find the appropriate range of values.

2) Running the model

The stochastic method prescribes some experimental runs of the model in order to extract some average numbers and statistics.

3) An analysis was made using as performance measure the time for each activity and for the total process. The variable that was simulated was the order. This was an interesting technique in order to look at the process through a different view, somehow like a service, disregarding for a while the technicalities of the production process.

4) A discussion was made based on the alternative scenarios.

5. Results

By incorporating the changes and the rules for scheduling, in other words by scheduling backwards (or upstream) from the packaging section to the production and the raw materials storage, the packaging section showed an increase in its performance. Also other measures on the packaging process itself and on other upstream and interdependent processes that were incorporated had helped to increase the productivity of the packaging process by eliminating some constraints.

To measure the performance, the metrics of tonnage per human shift was used. In the following table and figure it is shown that the performance of the packaging operation had increased. The new scheduling based on the bottleneck pace began at the end of 2009.

Table 1: Kilos per work shift versus time

	November	December	January	February	March	April	May	June	July	August
start of period	1/11/2008	1/12/2008	1/1/2009	1/2/2009	1/3/2009	1/4/2009	1/5/2009	1/6/2009	1/7/2009	1/8/2009
end of period	30/11/2008	31/12/2008	31/1/2009	28/2/2009	31/3/2009	30/4/2009	31/5/2009	30/6/2009	31/7/2009	31/8/2009
kg packaged	4392131	3259147	3936471	4092522	4208158	3499037	4630484	3438605	3751517	1878935
shifts used	224	230	245	212	218	198	233	175	200	109
total	1915009	1586960	1782514	1587862	1757502	1568110	1808231	1235155	1476195	831690
kg/shift	8549,1473	6899,82609	7275,567	7489,915	8061,936	7919,747	7760,648	7058,029	7380,975	7630,183
start of period	1/11/2009	1/12/2009	1/1/2010	1/2/2010	1/3/2010	1/4/2010	1/5/2010	1/6/2010	1/7/2010	1/8/2010
end of period	30/11/2009	31/12/2009	31/1/2010	28/2/2010	31/3/2010	30/4/2010	31/5/2010	30/6/2010	31/7/2010	31/8/2010
kg packaged		3396429	4095659	4307240	4325674	3588621	3965936	4350300	4177018	2008961
shifts used	192	149	207	180	202	181	192	185	192	102
total	1635166	1501621	1884549	1899516	1743163	1551936	1649747	1769139	1889572	923716
kg/shift	8516,4896	10077,9933	9104,101	10552,87	8629,52	8574,232	8592,432	9562,914	9841,521	9056,039

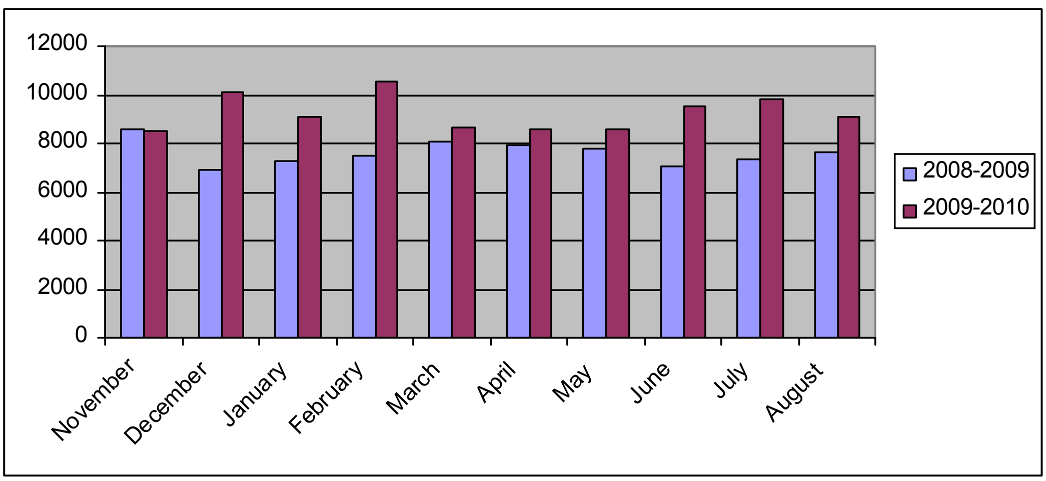


Figure 10: The increase in packaging productivity: kilos per work shift versus time

The effort to increase the performance of the packaging section led to good results and after August 2010 the results were even better. Beyond the indications of the numbers, there were also other signs that the packaging performance had increased. For instance the times that the silos were full of pasta were minimized and this was recognized by everyone involved. Still there is way ahead and there will be many improvements, but from that time the production lines seem to work properly avoiding stoppages from downstream.

The reasons for the improvement, the way the action research was conducted, and the conclusions and suggestions are presented in the next chapter thoroughly.

6. Discussion

6.1 First cycle of action research

In the first cycle, identification of the constraints involved in the system was an essential part of it. Also, changes in the scheduling procedure were proposed, tested and evaluated.

The principles of the Theory of Constraints were introduced.

The main idea was to schedule throughput to match the capacity of the bottleneck.

Some general rules were discussed and agreed to be followed in order to plan the production schedule. These are presented below.

An average production standard in kilos per hour was decided for each packaging machine after observation, discussions and taking into account previous studies done in Melissa's pasta factory. The standards were discussed and there was an agreement with everyone involved. So for example the first packaging machine could be scheduled to produce eight tonnes per work shift, on average.

Three categories of products were recognised according to the specific type of package used for each of them:

- The pillow packages that were made by four packaging machines,
- The square bottom packages that were made by two packaging machines,
- The bigger packages that were made by one packaging machine of small capacity.

So the production mix should be distributed on the packaging machines according to the packaging capacity for each type of package. For example when the capacity for square bottom packages is 24 tonnes per day and there are two machines available the product that can be packaged in square bottom bags is 48 tonnes per day maximum. The rest of the production, which is bigger than 48 tonnes per day, must be scheduled for the other packaging machines otherwise the silos will fill with product and the production upstream must stop.

There are also another three categories of products depending on the shape of pasta or the volume of the package:

- The small pastine like orzo, rizone, kritharaki, kouskouse
- The medium like kofto, conchigliette, elbows
- And the big ones like farfalle, penne rigate, or rigatoni.

This categorisation affects the number of setups in the packaging machines, since for each change between product categories there is some time consumed for setting up the machines.

A preferred sequence of the different product categories was proposed by the operators. Also combinations for the production mix were proposed according to the aforementioned categorisation. For example, when the production lines A and B are producing the voluminous products it was wise to produce the small pastine from the other production line C in order to reserve some space in the silos. Other combinations were also tried.

There were products made to stock and products made to order. The vast majority of products were made to stock. A certain level of stock was decided for each product measured in days of sales. The level of stock took into account also the capacity in the packaging section. For example, the target stock level for the square bottom packages was bigger than the target for product packages coming from the other packaging machines.

By incorporating all these rules, in other words by scheduling backwards (or upstream) from the packaging section to the production and the raw materials storage, the packaging section showed an increase in its performance.

During this first cycle of research, discussions and the observations made provided more recommendations and findings as presented next.

Finally, a discussion was made regarding the scheduling software tool. Currently, the scheduling plan is made by the use of excel. There is a sophisticated excel file, tested and used for years and thoroughly improved, that covers the short term needs for production scheduling. It is flexible and easy to use, to update and maintain. Apparently, it has some drawbacks, one of which is that it cannot show the big picture at once. For example, it is not possible to see in one single screen what the production schedule of the three production lines together is; it is needed to switch to another screen. Also, it is not possible to see in one single screen what the production schedule of a single packaging machine is. The planner has to switch between screens. Of course a big PC screen would be a somehow technical solution. The alternatives are to try and use the commercial scheduling software tools such as ASPROVA or the scheduling tools that accompany the ERP software packages. A preliminary research showed that these tools need a lot of configuration work and there was a general feeling that it needs a lot of work to maintain and update them, since the dynamic nature of production causes a lot of changes in the scheduling plan, due to the aforementioned reasons. It may only be fair to try out a commercial package. Thus, the trial period would provide at least insights and will offer some ideas on how one can deal with relative problems. A good discussion about the ERP scheduling modules is written by Metaxiotis et al (cited in the part of References for further reading).

6.1.1 A change in the scheduling process

At the end of August 2010, the scheduling in the packaging section included the detailed timing of machine setups. This was another scheduling plan; that can be called setups schedule. The setups scheduling plan prescribed the precise timing for machine setup. This was done using the usual norms for each machine and product. The researcher considered that this was a crucial thing that increased the performance. The operators tried to set up the machines at the exact time that was planned, thus having some implicit benchmarks to reach. Machine setups were being postponed by operators in the past, and that was justified by a certain reason; many setups decreased the working time of the machines, but this phenomenon had lead to unexpected delays.

The setups scheduling had resolved many issues. The operators had a schedule to follow and they could plan ahead their work to finish the machine setup at the scheduled time. Thus the setups schedule became a work schedule for each operator; and it seemed that by programming people's work schedule the performance of the system (people and machines) increased. So since then, two schedules were determined: the production schedule and the setups schedule.

However, one can argue that the production schedule isn't about people, it is about tones of pasta and orders that have to be fulfilled. So, in this regard, two programs had to be established. First the production schedule that deals with how many tones of pasta must be packaged from each machine and second the work schedule for each operator that has to determine when to start the machine setup for the next order. In other words the production schedule prescribes how many tones are needed for the order and the setups schedule prescribes the time that each order has to be finished.

On the other hand these schedules are dynamic and are changing frequently. The production schedule may change due to various reasons such as the lack of product, quality problems, lack of a material, etc. The setups schedule also may change due to machine breakdowns, blockages and other reasons. Any change in one schedule may cause changes to the other schedule and a rescheduling procedure may be needed.

The problem of rescheduling was known to the people involved. The general consensus was that many times a quick decision by someone that was on site and was aware of the current situation, was needed. Otherwise time would be lost till a proper decision is made. The discussions led to the agreement that some operators should be empowered to reschedule plans. Indeed this happened many times, the operators took initiatives and saved the day but there were also delays that could be avoided.

6.1.2 Management of silos

TOC emphasizes the Work In Process (WIP) management. The WIP in Melissa's case is the system of silos where the dry pasta is stored.

Another restriction for the packaging process is described next. There are 27 silos in total arranged in 4 rows. From each of the four rows there are two exits. That means from each row (of 7or 8 silos) only two silos can be emptied at the same time. So there are eight exits in total. In order to use all the exits and the maximum number of packaging lines the product has to be distributed to all four rows of silos and the minimum number of filled silos is eight. Even in this ideal case only two packaging lines can be fed by each row.

In the case where three different products for three packaging lines are filled in the same row, the one of these will be stored till one of the remaining is packaged. This was many times the case and it was due to bad management of the silos.

The silos were being filled by operators that worked in the production department, and were emptied by operators who normally work in the packaging department. There were times that their cooperation was good and they agreed with each other which product to put where in order to have the minimum delays. But also there were times that there wasn't any cooperation and the arrangement of the products in the silos weren't the best possible.

The management team proposed some rules and directions so that the silos are filled in the most appropriate way for the packaging process. But due to the dynamic nature of the system the general consensus was that the management can be best applied by trained and empowered operators from both departments, that are able to frequently (two to three times per work shift) decide on how to fill the silos.

6.1.3 Empowerment of operators

Case1:

In accordance to Synchronous Manufacturing or Drum-Buffer-Rope production control technique the following elements of the technique were identified:

The Drum, which sets the pace for the upstream operation, is the packaging process (bottleneck),

The Buffer (that ensures that there is enough inventory kept so that the bottleneck is never idle) is the system of silos with ready product waiting to be packaged and

The Rope is held by the packaging operation and corresponds to the information sent upstream from the bottleneck's side to prevent buildup and to synchronize activities such as production or silos filling.

The operator of the packaging machine could keep the "rope" and signal the release of the raw material in the upstream operation. That means that the operator should be empowered to do this provided that she/he is also trained and involved. That could be useful in Melissa's case in times where the managers are absent in the evening and night shifts or during the weekends, while the factory operations are running.

Wu et al (2010) report that the disaggregated daily production plan i.e., a shift production or hourly production plan, must depend on the experience of the shop manager. Although a daily production plan can guide a shop manager to produce a batch size per item, it is only a rough cut capacitated daily production plan for shop manager to implement in the shop. For example, the release timing and quantity of a raw material can not be determined based on this daily production plan. Wu et al agree that scheduling procedures to disaggregate the daily production plan into shift production schedule are needed. The scheduling objective has to be to minimize the mean flow time and maximize the production progressiveness.

In the case of Melissa's pasta factory the shop manager is the operator, since there are two shifts (evening and night shift) where there is no manager on site and also on weekends when the operators are there almost all by themselves to follow the production plan. So the operator has to make its shift production schedule. The updated shift production schedule can take into account also the latest changes in the upstream operations, that affect its operation and are not planned in the production plan neither in the daily production plan.

Case 2:

There was also another case where empowerment had an impact on keeping the silos empty. The production process produces a certain amount of product that needs to be reworked, by means of regrinding. This is produced normally during the changes of shapes, changes of dies, or changes of colour in tricolore batches. There were also cases where a product was out of specifications due to many reasons, among which may be a possible mistake of the production operators. The old procedure dictated that the product to be reworked was stored in the silos for a certain time, till it was checked by the quality control department. This procedure resulted in keeping some silos busy for some time. The number of silos that were kept busy ranged from 2 to 4 silos, in other words from 6 to 13 per cent of the total silos capacity. Although the quantities were small the speed of emptying these silos was half the speed of normal packaging. Also while emptying the reworked product one exit from the row of silos was occupied, leaving only one for the packaging machines.

The production operators were recommended to empty the silos by themselves when they have the chance, i.e. anytime there is a spare exit; without waiting. The management team agreed that when the silos are relatively full the operators can empty the silos without waiting. Also it was proposed that the best period to empty the product for rework was in the night shift since at that time less packaging lines operate, and so spare exits remained unused.

This was a case of trust and empowerment that had a positive impact in the management of silos.

6.1.4 The case of the tricolore products

The vast majority of pasta products can be packaged just after the end of production. That means that the transfer batch is minimum, almost zero, and different than the process batch. This is in accordance with the proposals of TOC.

Colour pasta, which are made by adding tomato and spinach, are produced sequentially in the same production machine. For a tricolore product three coloured products (normal pasta, green pasta and red pasta) are needed and they are mixed just before the packaging. Each one of the three coloured products is equal to the one third of the production batch. The packaging process can start only when the quantities for the two colours are ready and waiting in silos. So only when the third colour is exiting the production machine the three coloured products can be packaged and not before. Till then a buffer to contain the two thirds of the process batch is needed. In this case the transfer batch is equal to the two thirds of the process batch. This corresponds to a considerable amount of time, since for the minimum batch the packaging machine must be kept idle for at least 4 hours. Also a number of silos are needed to store this product.

For these special products additional rules were established.

It was proposed to schedule the tricolore products to be produced when the silos are empty or relatively empty or the products produced in other production machines were less voluminous and at lower capacities. Also the silos remain empty during production start-ups.

So it was decided to schedule preferentially the tricolore products in combination with other products that are produced at lower capacities, like small pastine (orzo, risone, kritharaki) where a reduction in the production capacity of 30% occurs. Also these products like pastine are less voluminous so the system isn't constrained by the size of the buffer silos. Finally tricolore batch is better to be scheduled at the start-ups of the factory operation or when the silos happen to be empty.

6.2 Second cycle of action research

In the second cycle a method to elevate the performance of the packaging operation is tried out through the use of simulation in order to avoid experimentations on the working environment.

Since the packaging process is a bottleneck it must be utilized in the most efficient way. This is the priority according to the Theory of Constraints.

Delays occur for many reasons. The focus for this time will be on the delays that are related to the interference of the quality control.

To study the effect of the quality control in the packaging process a simple simulation model is used.

In order to simulate the packaging process and the interference of the quality control some basic assumptions were made. The production process is continuous, but the effort was not to simulate the production or the packet of pasta production, since this may be too complex. A model describing the intervention of quality control on the packaging process is needed. For that reason it is proposed to study the cycle of the production order in the packaging operation process. In this way all other activities and procedures or processes are disregarded in purpose and the model is focused on the activities that are related to both packaging and quality control.

Another assumption is that the model describes one packaging line, while in reality there are 7 lines working in the same manner. The conclusions from the study of one packaging line can be applied and generalized for the others lines.

Also the model doesn't deal with other problems that increase the complexity such as maintenance needs, delays from malfunctions, availability of packaging materials, scheduling complexities and others mentioned earlier.

The simulation is done using CACI's Simprocess 4.6.1 Demo version. The developed model is shown in the figure below.

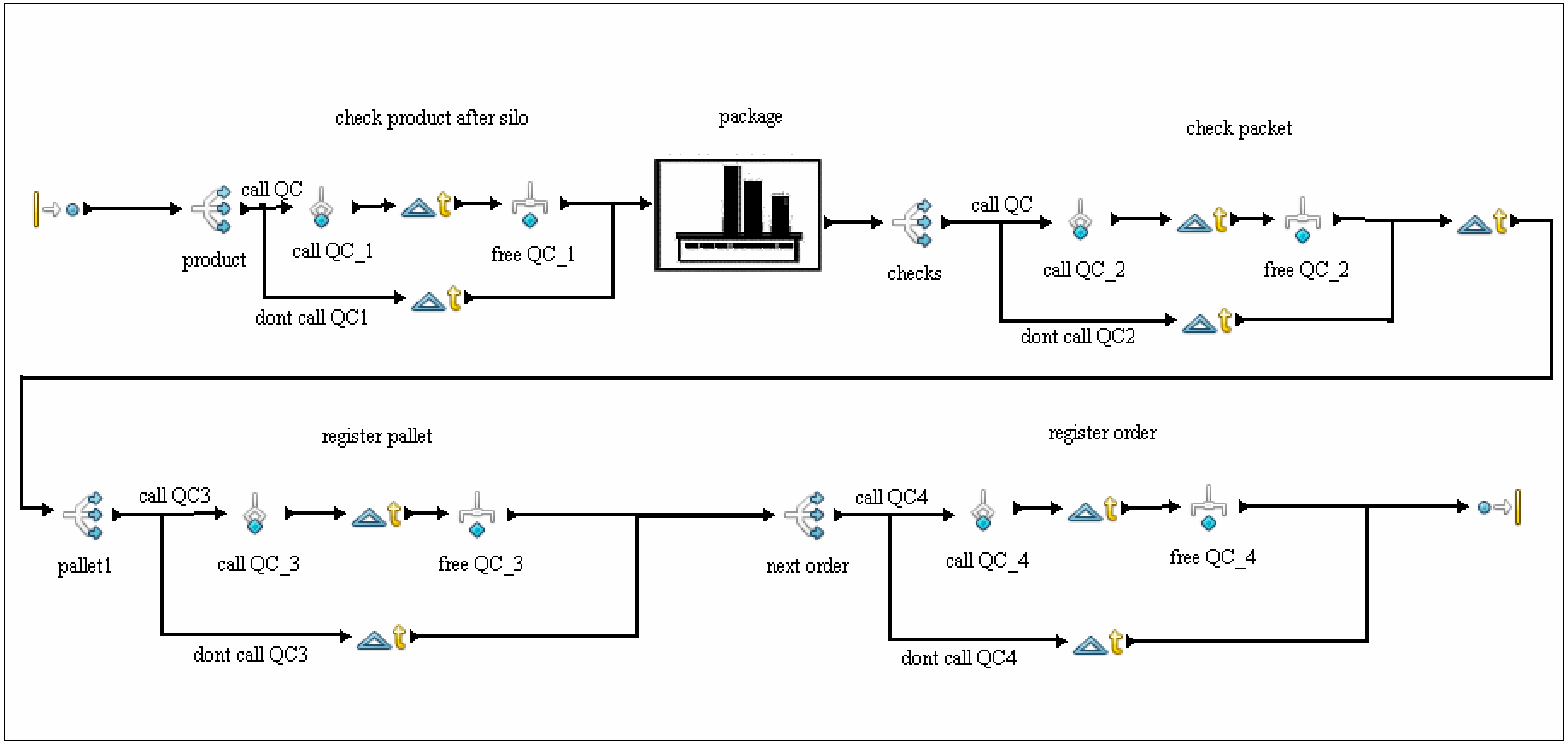
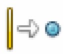
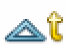
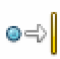
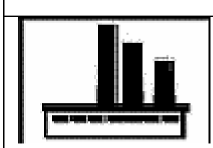


Figure 11: The simulation model used

The following table describes the main components that were used in the model.

Table 2: Main components of SIMPROCESS modeling

Component Symbol	Name	Function
	Generate	A Generate activity generates the arrival of entities into the model. Arrivals may be random, deterministic or conditional. A generate activity may have values for arrival time, quantity, frequency.
	Branch	A branch activity allows for defining alternative routings for flow objects. Branching may be based on a probability or a condition.
	Delay	Define distribution of duration for each single operation
	Get Resource	It captures resources that may be used for a number of downstream activities
	Free Resource	It releases resources that were captured by a get resource activity
	Dispose	A dispose activity disposes of the entities when they are finished with processing. A dispose activity can be used for collecting statistics for throughput or throughput time.
	Process	It can consist of a system of activities. In our model is just a delay activity that represents the time to package

So according to the model, a production order goes through the following cycle in the packaging process:

At first an order is generated. (All orders are assumed to be the same)

1. An order arrives at the site of the operator of the packaging machine.

2. At that point the order may follow two different routes:

- 2a) If the product doesn't need quality check, the operator starts packaging. In that case the order proceeds to the packaging process having spent a small amount of time that corresponds to the delay parameter "Don't call QC1"
- 2b) If the product needs to be checked by quality control, the order proceeds to the packaging process through a different way. Personnel from the Quality control is called and after some more time than in the previous case, which corresponds to the delay parameter "Call QC_1", the order proceeds to the packaging process.

From observations and data collected in a sample period of 3 months it is estimated that the quality control is intervening 20 times in every 350 orders. So there is a calculated chance of 6% for every order to be offered a quality control check at this point.

3. The order remains for a certain time in the packaging process.

4. At that point the order may follow one out of two alternative routes (process choices):

- 4a) If the ready packet doesn't need quality check, the order proceeds. In that case the order proceeds to the next activity having spent a small amount of time that corresponds to the delay parameter "Don't call QC2".
- 4b) If the ready packet needs to be checked by quality control, the order proceeds to the next activity through a different way. Personnel from the Quality control is called and after some more time than in the previous choice, which corresponds to the delay parameter "Call QC_2", the order proceeds to the next activity.

At that point there is an estimated chance of 3% for a quality control intervention to be needed.

5. The order may follow again one out of two alternative routes:

- 5a) If the ready pallet is registered by the operator, the order proceeds to the next activity having spent a small amount of time that corresponds to the delay parameter "Don't call QC3".
- 5b) If the ready pallet is registered by the quality control or another person, the order proceeds to the next activity through a different way. The appropriate personnel usually from the quality control is called and after some more time than the in previous case, which corresponds to the delay parameter "Call QC_3", the order proceeds to the next activity.

6. The order may follow again one out of two alternatives:

- 6a) If the order is registered by the operator, then the order proceeds to the last activity having spent a small amount of time that corresponds to the delay parameter "Don't call QC4".
- 6b) If the order is registered by the quality control or another person, the order proceeds to the last activity through a different way. The appropriate personnel usually from the quality control is called and after some more time than in the

previous case, which corresponds to the delay parameter "Call QC_4", the order proceeds to the next activity.

The registration of order process corresponds to the time someone spends in order to prepare or choose the next order to execute. This is a stage of decision where someone has to collect information, communicate with other coworkers, calculate and choose among certain options. For example, the operator, in order to choose the next order among a stack of orders, has to check if there is enough product in the silos. Another consideration for the operator, is which silo to select, since the silos are divided into four rows and from each row only two silos at a time can be used. So there is a short time packaging schedule decision to be made at that time and this decision is either made by the operator or another person usually from the quality control department or by both.

7. The order is finished.

It must be explicitly stated that in the model the variable in concern is the order. We also assume that each order is of the same size with the same degree of difficulty, imposing the same requirements in operators' expertise and the same needs in packaging time.

Analytical results from different run scenarios are presented in the Appendix.

The results don't reveal something unexpected or something not known. By common sense one can state that any disruption or interference or intervention will result in delays and will decrease the performance.

The value of the simulation lies in the ability to test "what if" scenarios. It also shows another perspective; the perspective of the order cycle. That helps in gaining a greater experiential understanding of the system in a different way. Also during the process of simulation some concepts can be quantified such as the intervention, which gave a better insight into the process. Another gain from the simulation was the ability to present the system and its dynamics, in a more visual, as well as convenient way.

The value of the simulation was that it could help us focus on a specific problem. By running a very simplified model many details can be disregarded in purpose, and the study can aim at the evaluation of third parties' interventions. The degree of intervention is applied in the model by a probability function. By changing the value of the chance it was possible to see what happens when the intervention is high or low. So high chance meant high intervention and low chance meant low intervention.

By changing the probability of the intervention, its effect on the performance of the system could be observed. It was possible to see not only the average conditions but also to test and see what happens when the degree of intervention is extremely high.

Next, the model and its results were presented at the regular meeting and comments were made. Some participants seemed interested in exploring the idea of the order and its cycle effects, but that was too general. The simulation helped in trying to see the process from a more distant view, isolated form the details and the technicalities that are normally present at all times.

Some conclusions were drawn by the discussions that followed the presentation of the model. These are presented next.

By the end of the action research and the incorporation of the proposed changes it was apparent that the packaging productivity had increased. For instance compared to the last month the production lines had worked simultaneously for three weeks without stoppages caused by the packaging process.

6.2.1 Interventions and operators empowerment

A conclusion acknowledged by most of the people was the fact that it could have been more effective for the process, if there were only one operator responsible for the whole packaging line. The operator should perform the required quality control checks. Indeed after the discussion session, the quality control department took precautions so as not to interrupt the packaging process and it succeeded in doing this. Quality control interruptions were decreased in number and the rate of interruption was measured at one time per four days in the period of April till June of the current year. The interruptions had a cause and were justified. The causes lied in the processes upstream and this is discussed below.

Again in this second cycle of action research the importance of training and empowerment of the personnel was emphasized.

It was also suggested that additional work such as registration of the ready palets can be made by the operators themselves, provided that they have the necessary equipment available.

6.2.2 Moving inspections and tests just before the constraint

The discussion regarding the quality of the product that affected the packaging performance initiated changes in the production process that preceded the packaging process. It was found that the variations in the specific volume of the dried product had a significant impact on the packaging productivity.

A parallel project was initiated also in the production department. The specific volume per kilo of each product was estimated and monitored. The volume of the product depended on some factors like: the shape of the product, humidity, weight of the product, thickness of the pasta, and the conditions in the press. There were actions that reduced the variation of the specific volume successfully and this diminished the problems due to the volume. Also certain packages were redesigned in order to better fit the product. The new specifications were applied in the production department and were followed by the production and the quality control personnel.

Some other measures were also taken in the production process to ensure that the dried product will need the least quality control checking. For example, by searching the quality control archives, it was concluded that certain products like small pastine present more frequently the problem of having other pieces of pasta in between. So after discussions it was proposed that some cleaning procedures in certain parts of the machines should be scheduled just before these production batches. This had also a positive effect and decreased the frequency of quality control intervention.

6.2.3 Increasing the capacity of the constraint

It is the most obvious indications supported by the theory of constraints. There are many ways in dealing with these issues and one of them is to add pure capacity.

During the last months another constraint appeared to be more and more important; the packaging lines are divided into two categories: the pillow bag machines and the square bottom bag machines. The square bottom bags is a new category and it is widely accepted more and more by the customers and the demand for this type of product is increasing very fast. In Melissa's pasta factory only two machines are of this type, although they are newly installed, modern and reliable it seems that they never stop in contrast to the other machines. Indeed marketing is moving products from the pillow bag to the square bottom bag and the latest news is that the management is considering adding another new machine of this type.

Another way to increase the throughput is obviously to decrease the time for each setup.

6.2.4 Additional recommendations

There were also the following recommendations for dealing with bottlenecks:

1. Ensure well-trained and cross-trained employees are available to operate and maintain the work center causing the constraint.
2. Assign the most quilified employees at the bottleneck sites, because these set the pace
3. Develop alternate routings, processing procedures, or subcontractors

According to Dilworth (1993) the bottleneck operations should be kept running to the greatest practicable extent and he proposes that they may be staffed to run during lunch and coffee breaks, because they limit the output of the entire plant. Also preventive maintenance is more important for those pieces of equipment that are proved to exhibit bottlenecks, and repair of any breakdown of them is given very high priority.

Some of these recommendations were already known but they were applied only occasionally. There was no systematic framework to analyse the pertinent systems and its characteristics, and no methodological tools have been examined and proven appropriate to effectively address this kind of issues.

6.3 General findings from the Action Research

There were also some other findings and observations that may be worth to mention.

6.3.1 Resistance to change

Resistance to change was easily overcome due to the strong and unambiguous commitment of the management. For instance the director of the factory was personally involved at all levels of the project, followed the project very closely and many times provided the leading force and gave genuine ideas. The director was also truly engaged in the project and motivated all people involved to take active part. The researcher's practising experience underscores the fact that it is indeed crucial to have the top managements' approval and commitment especially in organisations that are hierarchically governed. Also we can recall that one of the prerequisites in every audit for a quality assurance standards, as in the series of ISO quality standards is the written commitment of the senior management to apply these standards.

6.3.2 The effect on operating expenses

Gupta (2008) proposed that from the TOC perspective, the goal of an organization (i.e. to make money) is accomplished by increasing throughput while at the same time reducing inventory and operating expenses. While this is the ideal situation, the primary emphasis should be given on increasing the rate of throughput with secondary emphasis on reducing inventory, while efforts to reduce operating expenses should be clearly the third important objective. From the TOC's point of view, operating expenses are the cost of opening the doors and turning on the lights, and while such costs can be decreased in the short-term, doing so can have two negative effects:
(1) It will take management's attention away from increasing throughput; and
(2) It will almost inevitably harm the necessary conditions of employee and customer satisfaction.

The same author explains that the Management gets much more "bang for its buck" by focusing on increasing throughput, which has no theoretical limit, rather than focusing on reducing operating expenses, where a 10 or 20 percent decrease is considered significant but is difficult to maintain.

Lot sizing in TOC is governed by two opposite forces. The priority in TOC as explained by Gupta (2008) is to avoid having the constraint work on something that has not been ordered by a customer while there are parts in queue at the constraint that have been ordered by customers. At the same time, in order to exploit the constraint there may be some effort to minimize non-productive time on the constraint, including setups; lots in the constraint will therefore be maximised. On the other hand saving setups is not necessary at non-constraints.

Relatively large lot sizes often run through the bottlenecks to save setup time and provide more run time (Dilworth 1993, pp 360). On the other hand, additional setups may be scheduled on some noncritical operations to keep the lot sizes small so that work in process (WIP) and lead times are also small (Dilworth 1993, pp362).

Indeed in Melissa's case the effort increased the throughput but also increased the number of setups and start-ups/shutdowns in the upstream operations, which is the production process. The production runs were not evenly distributed throughout the day, creating instances were several set-ups were required in a very short period of time in the production process upstream.

6.3.3 A comment for the implementation of action research

A common truth in the field of qualitative research was hereby verified but it is worth commenting on that once again, because it is crucial to remember it, when conducting action research. The researcher should ask open-ended questions. Guided questions are misleading.

For example, questions such as “are we interested in looking for the reason for the increased productivity of packaging?” offers a lot of worthy and genuine information. The same question can be asked to all people involved. When the answer is the same, or almost the same, then we can conclude with more certainty that we have found a reason that increased the output of packaging. On the other hand, if we had asked a closed question such as “do you agree that the specified timing of set-ups increased the productivity of packaging?”, then most probably we would have obtained misleading answers. In this case, we could assume that most answers would be “yes”, since most of the respondents would prefer to agree with an already stated explanation.

Related to the aforementioned observation is the phenomenon of grapevine that should be taken into account. Hypothetically, if the results of the search were discussed openly, while the search were continuing, we could have reached different findings by promoting or favouring some opinions that were earlier spread out, and hiding thus others that had not been expressed by then. In other words the researcher thinks that opinions that circulate through the grapevine appear most often and are easily reproduced. The researcher, who is also a practitioner, was aware of the grapevine effect and the working environment and took precautions in order to avoid the implications mentioned previously. The key-factor was to gain the trust of the people involved. The proposition of the researcher was to make no critique on opinions expressed, since this could make people speak their thoughts out.

7 Conclusions

The present study was aimed at exploring the effects and improvement possibilities of the implementation of the Action Research approach aligned with the TOC management principles, in order to improve the productivity of the packaging process in the food industry in concern.

The first step was to identify the system's constraint; it was easily found that packaging was the bottleneck process. There were many reasons for this restrained part of the process. The Action Research (AR) methodology was used to find the reasons one by one and the interrelated problems. The Theory of Constraints (TOC) fundamentals were applied to complement the AR methodology.

Eventually a number of changes were employed. At first the production schedule planning procedure changed, taking into account the bottleneck. Certain rules were agreed for the best utilization of the bottleneck. The focus moved to the bottleneck process that from now on sets the pace of production.

It was also recognised the need to schedule the setup of the machines precisely based on a specific time plan.

The imperative need for rescheduling operations due to certain unplanned reasons was recognised. In analogy with the Drum Buffer Rope (DBR) technique, the Drum, Buffer and Rope characteristics for the present system were identified, for which the appropriate efficient recommendation was obtained: an operator at the packaging department should be responsible to decide the rescheduling plan provided that he/she is properly trained and empowered.

Empowerment and training was recognised as the key to resolve and manage issues like:

- Rework management,
- Silos management, and
- Quality control issues

Regarding the quality issues, improvement findings led to certain actions, e.g. moving some inspections and tests just before the bottleneck. Also, tighter specifications were imposed onto the upstream processes. In that part of the research, simulation work was performed to complement the AR methodology and illustrate the basic elements of the system, while providing certain valuable insights, such as the effects of the resources' waiting queues to the order cycle time in the packaging process.

Other minor modification procedures were also discussed and addressed, such as the one considering the management of special products (i.e. tricolore products).

Although there was an increase in the output of the system there is still way for improvements and changes; some of them were pointed out for future actions.

The total effect of the present research on the production system in Melissa-Kikizas pasta factory was positive. The productivity had significantly increased. There were much less frequent stops of the production lines due to fully filled silos. In average the silos were now less occupied than in the last year.

Regarding the academic objective, it can be stated that this study may have ultimately led to a small contribution to the applications area of the action research approach for operations management, as it can provide a systematic and holistic framework for addressing similar problems in the process industry.

It must be noted once again that Action Research offers valuable and sound advantages for managing process system improvements, as it provides a generic framework for systematically addressing this type of problems. It can methodically bring about changes through the active involvement of all people that comprise part of the system in concern and through their binding agreement to serve the iterative nature of the procedures that AR dictates.

In conclusion, the research questions have been answered in the context of the current case study. The productivity of operations has been improved by using Action Research backed up with production management principles such as the Theory of Constraints. In general, the results cannot be generalized, but the value of this research work is that it presents a real case to the practitioner with valuable insights on how to systematically improve a process that exhibits certain problems and how to further monitor its improvement procedures to ultimately reach unhindered business objectives.

8 Reflection on Learning

The author had multiple gains and multiple experiences from this dissertation.

First of all he gained a better insight of his working environment. He had the chance to work, discuss and cooperate with people. He had the chance to value the teamwork. He had tried the Action Research approach that is a powerful methodology. He got a better view of some of the production management theories and especially of the Theory of Constraints and its evolution in time. He had the chance to tryout and use modern software tools of discrete simulation like “Simprocess”. Also he had the chance to compare commercial scheduling software programs and see how professionals deal with the complexities of the scheduling problem in general.

He saw once again that by searching systematically and deeply one can find many and different things than it was expected initially.

The author gained confidence on applying the management theories. The search of bibliography and literature was also a valuable experience by itself.

The author believes that the time spent working on the dissertation has been invested well and is justified by reason.

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Appendix

In this part of the Appendix some data from the simulation runs are presented.
The following scenarios were considered:
Scenario/simulation run 1(as in figure 12): The packaging operator handles all operation activities by himself. There is no time waiting for resources.
Scenario/simulation run 2 (as in figure 13): There is a 10% chance for quality control intervention in all activities. The time waiting for resources is 0.67 hours in average.
Scenario/simulation run 3 (as in figure 14): There is a 50% chance for quality control intervention in all activities. The time waiting for resources is 1.259 hours in average.
Scenario/simulation run 4 (as in figure 15): There is a 10% chance for quality control intervention in the first three activities and the last activity is operated only by the quality control. The time waiting for resources is 1.097 hours in average.
Scenario/simulation run 5 (as in figure 16): There is a 50% chance for quality control intervention in the first three activities and the last activity is operated only by the quality control. The time waiting for resources is 1.485 hours in average.

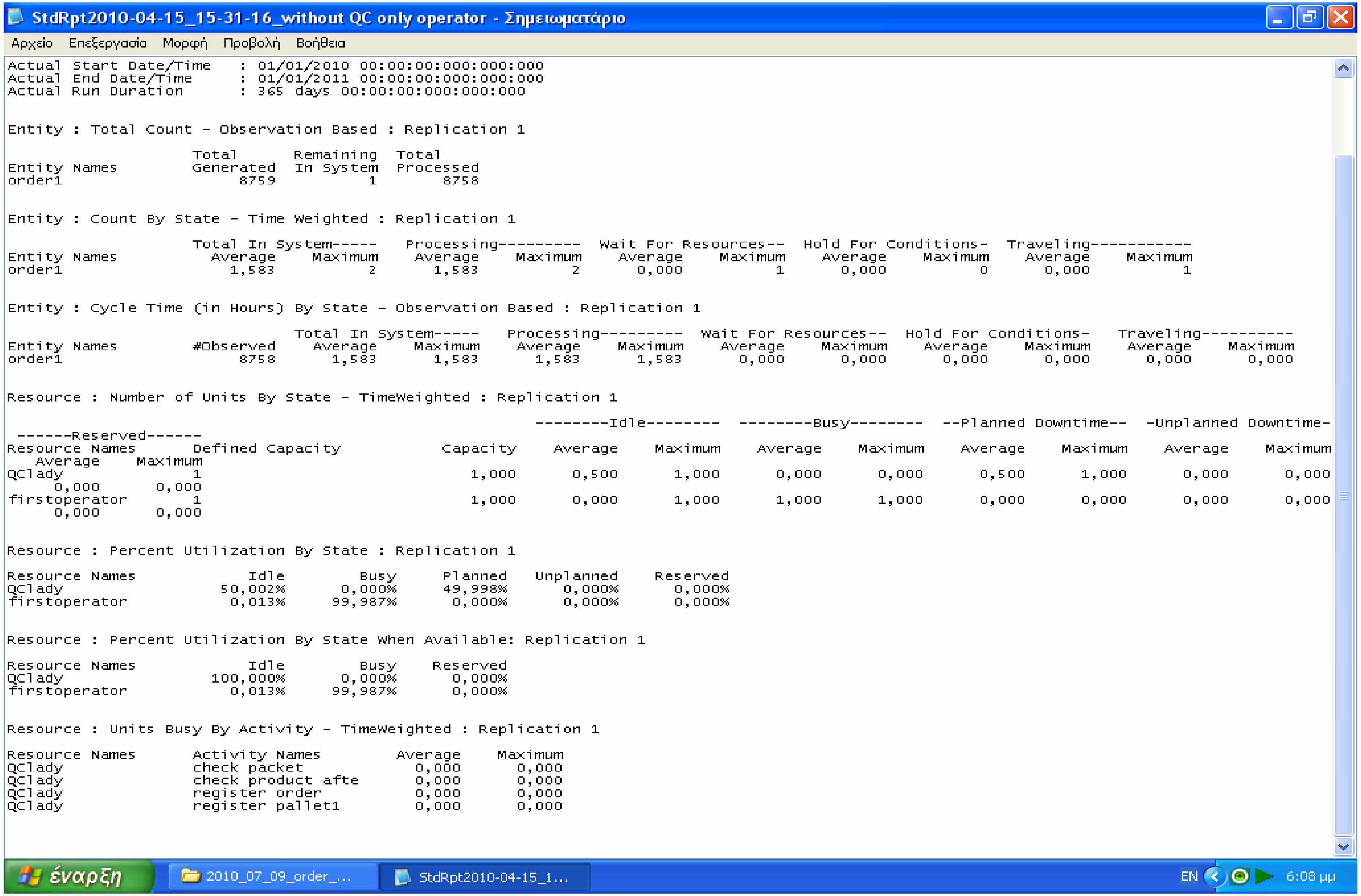
Also another set of scenarios is presented where the incoming order rate is less frequent. The rate in this scenario is one order per four hours.
Scenario/simulation run 6(as in figure 17): The packaging operator handles all operation activities by himself. There is no time waiting for resources.
Scenario/simulation run 7 (as in figure 18): There is a 10% chance for quality control intervention in all activities. The time waiting for resources is 0.203 hours in average.
Scenario/simulation run 8 (as in figure 19): There is a 50% chance for quality control intervention in all activities. The time waiting for resources is 1.027 hours in average.
Scenario/simulation run 9 (as in figure 20): There is a 10% chance for quality control intervention in the first three activities and the last activity is operated only by the quality control. The time waiting for resources is 0,708 hours in average.
Scenario/simulation run 10 (as in figure 21): There is a 50% chance for quality control intervention in the first three activities and the last activity is operated only by the quality control. The time waiting for resources is 1.281 hours in average.

The results are summarized in table 3 and table 4 below.
The rates and the times are not representing the real situation but are indicative in order to show the effect of waiting for resources to the cycle time of an order.
The conclusion is that when the operator runs operations only by himself, the cycle time of the order is less, or the less chances of intervention the less is the cycle time of each order.

Table 3: Frequency of orders: 1/hour. Total minimum duration time is 60+10+5+10+10=95 minutes, that is: 1,583 hours.

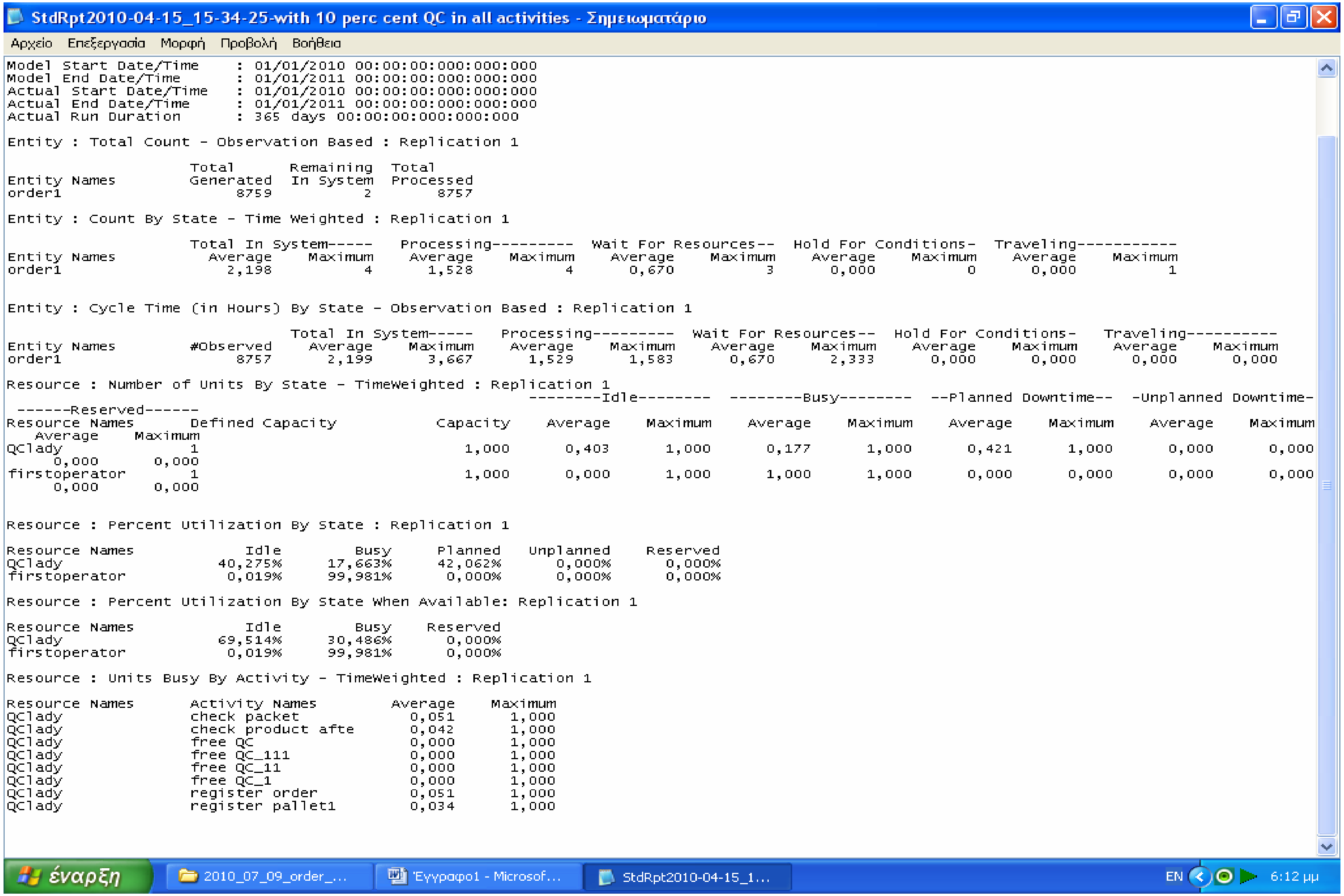
	365 days. One order per 1 hour					closer today	
name	unit	description	only operator	10% chance for QC intervention in all activities	50% chance for QC intervention in all activities	10% chance for QC intervention in 3 activities and 100% in last activity	50% chance for QC intervention in 3 activities and 100% in last activity
order1	cycle time in hours	Total in system average	1,583	2,199	2,678	2,5	2,869
order1	cycle time in hours	Total in system maximum	1,583	3,667	3,667	3,667	3,667
order1	cycle time in hours	processing average	1,583	1,529	1,419	1,403	1,384
order1	cycle time in hours	processing maximum	1,583	1,583	1,583	1,583	1,583
order1	cycle time in hours	wait for resources average	0	0,67	1,259	1,097	1,485
order1	cycle time in hours	wait for resources maximum	0	2,333	2,5	2,5	2,5
Qclady	% utilization by state	idle	50,002	40,275	14,357	18,515	3,779
Qclady	% utilization by state	busy	0	17,663	85,643	57,319	73,251
Qclady	% utilization by state	planned	49,998	42,062	25,638	24,166	22,971
firstoperator	% utilization by state	idle	0,013	0,019	0,019	0,09	0,019
firstoperator	% utilization by state	busy	99,987	99,981	99,981	99,981	99,981
firstoperator	% utilization by state	planned	0	0	0	0	0
Qclady	% utilization by state when available	idle	100	69,514	14,357	24,415	4,905
Qclady	% utilization by state when available	busy	0	30,486	85,643	75,585	95,095
firstoperator	% utilization by state when available	idle	0,013	0,019	0,019	0,019	0,019
firstoperator	% utilization by state when available	busy	99,987	99,981	99,981	99,981	99,981

Below there are the simulation run statistics as they are produced by the model.




```
Actual Start Date/Time     : 01/01/2010 00:00:00:000:000:000
Actual End Date/Time       : 01/01/2011 00:00:00:000:000:000
Actual Run Duration        : 365 days 00:00:00:000:000:000


Entity : Total Count - Observation Based : Replication 1

                    Total      Remaining  Total
Entity Names        Generated  In System  Processed
order1                   8759          1       8758


Entity : Count By State - Time Weighted : Replication 1

                    Total In System-----   Processing---------  Wait For Resources--  Hold For Conditions-  Traveling----------
Entity Names          Average    Maximum     Average    Maximum    Average    Maximum    Average    Maximum    Average    Maximum
order1                  1,583          2       1,583          2      0,000          1      0,000          0      0,000          1


Entity : Cycle Time (in Hours) By State - Observation Based : Replication 1

                               Total In System-----   Processing---------  Wait For Resources--  Hold For Conditions-   Traveling----------
Entity Names        #Observed    Average    Maximum     Average    Maximum    Average    Maximum    Average    Maximum    Average    Maximum
order1                   8758      1,583      1,583       1,583      1,583      0,000      0,000      0,000      0,000      0,000      0,000


Resource : Number of Units By State - TimeWeighted : Replication 1

                                                         --------Idle--------  --------Busy--------  --Planned Downtime--  -Unplanned Downtime-
 ------Reserved------
Resource Names      Defined Capacity             Capacity     Average    Maximum    Average    Maximum    Average    Maximum    Average    Maximum
    Average     Maximum
QClady                 1                            1,000      0,500      1,000      0,000      0,000      0,500      1,000      0,000      0,000
     0,000       0,000
firstoperator          1                            1,000      0,000      1,000      1,000      1,000      0,000      0,000      0,000      0,000
     0,000       0,000


Resource : Percent Utilization By State : Replication 1

Resource Names            Idle        Busy     Planned   Unplanned    Reserved
QClady                 50,002%      0,000%     49,998%      0,000%      0,000%
firstoperator           0,013%     99,987%      0,000%      0,000%      0,000%


Resource : Percent Utilization By State When Available: Replication 1

Resource Names            Idle        Busy    Reserved
QClady                100,000%      0,000%      0,000%
firstoperator           0,013%     99,987%      0,000%


Resource : Units Busy By Activity - TimeWeighted : Replication 1

Resource Names      Activity Names          Average    Maximum
QClady              check packet              0,000      0,000
QClady              check product afte        0,000      0,000
QClady              register order            0,000      0,000
QClady              register pallet1          0,000      0,000
```

Figure 12: Simulation run 1 (without quality control intervention)



StdRpt2010-04-15_15-34-25-with 10 perc cent QC in all activities - Σημειωματάριο

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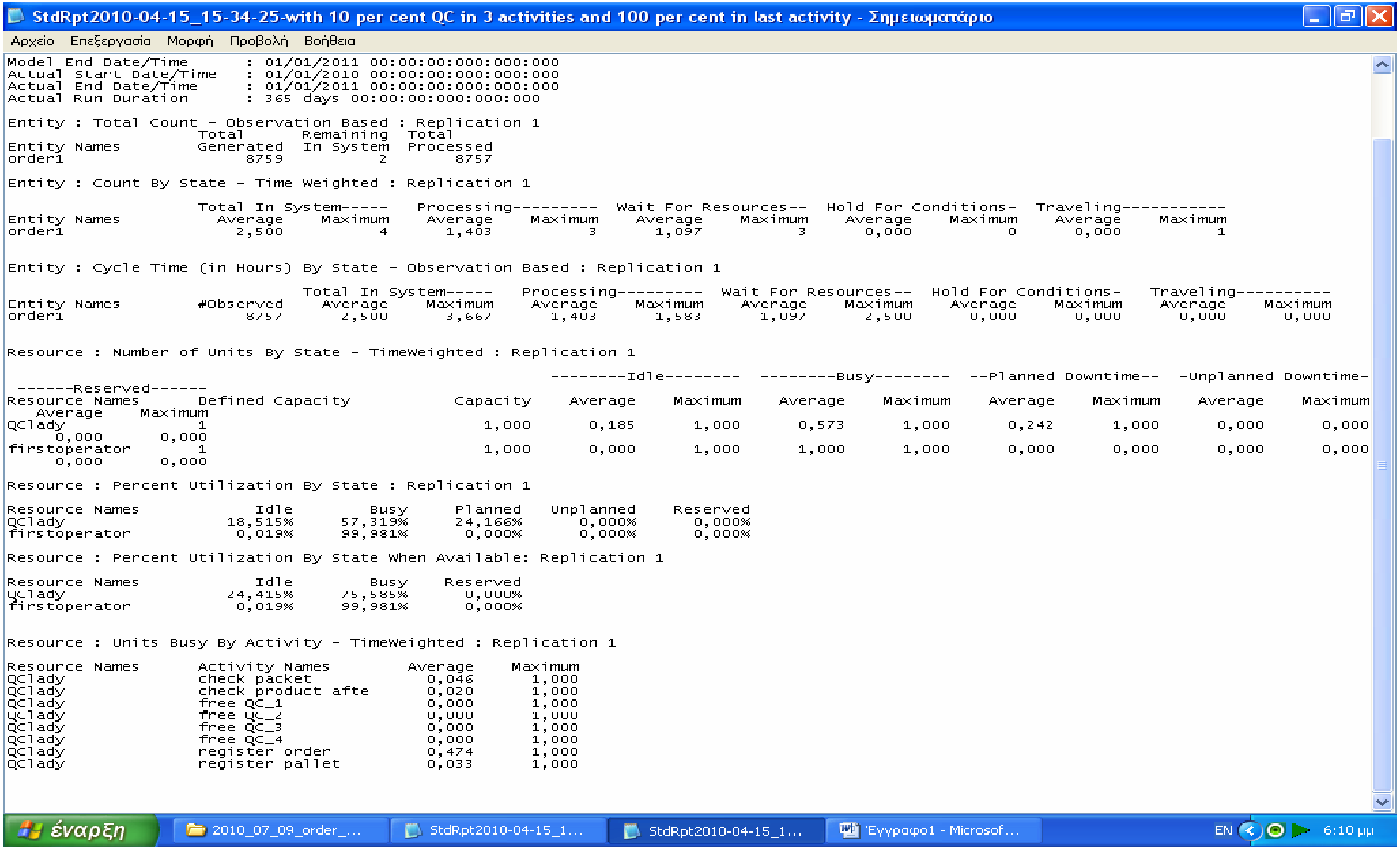
```
Model Start Date/Time      : 01/01/2010 00:00:00:000:000:000
Model End Date/Time        : 01/01/2011 00:00:00:000:000:000
Actual Start Date/Time     : 01/01/2010 00:00:00:000:000:000
Actual End Date/Time       : 01/01/2011 00:00:00:000:000:000
Actual Run Duration        : 365 days 00:00:00:000:000:000

Entity : Total Count - Observation Based : Replication 1

                    Total      Remaining  Total
Entity Names        Generated  In System  Processed
order1                   8759          2       8757

Entity : Count By State - Time Weighted : Replication 1

                    Total In System-----  Processing---------  Wait For Resources--  Hold For Conditions-  Traveling-----------
Entity Names          Average    Maximum    Average    Maximum    Average    Maximum    Average    Maximum    Average    Maximum
order1                  2,198          4      1,528          4      0,670          3      0,000          0      0,000          1


Entity : Cycle Time (in Hours) By State - Observation Based : Replication 1

                               Total In System-----  Processing---------  Wait For Resources--  Hold For Conditions-  Traveling----------
Entity Names        #Observed    Average    Maximum    Average    Maximum    Average    Maximum    Average    Maximum    Average    Maximum
order1                   8757      2,199      3,667      1,529      1,583      0,670      2,333      0,000      0,000      0,000      0,000

Resource : Number of Units By State - TimeWeighted : Replication 1
                                                        --------Idle--------  --------Busy--------  --Planned Downtime--  -Unplanned Downtime-
 ------Reserved------
Resource Names      Defined Capacity          Capacity     Average     Maximum     Average     Maximum     Average     Maximum     Average     Maximum
   Average    Maximum
QClady                     1                     1,000       0,403       1,000       0,177       1,000       0,421       1,000       0,000       0,000
     0,000      0,000
firstoperator              1                     1,000       0,000       1,000       1,000       1,000       0,000       0,000       0,000       0,000
     0,000      0,000


Resource : Percent Utilization By State : Replication 1

Resource Names              Idle        Busy     Planned   Unplanned    Reserved
QClady                   40,275%     17,663%     42,062%      0,000%      0,000%
firstoperator             0,019%     99,981%      0,000%      0,000%      0,000%

Resource : Percent Utilization By State When Available: Replication 1

Resource Names              Idle        Busy    Reserved
QClady                   69,514%     30,486%      0,000%
firstoperator             0,019%     99,981%      0,000%

Resource : Units Busy By Activity - TimeWeighted : Replication 1

Resource Names      Activity Names         Average    Maximum
QClady              check packet             0,051      1,000
QClady              check product afte       0,042      1,000
QClady              free QC                  0,000      1,000
QClady              free QC_111              0,000      1,000
QClady              free QC_11               0,000      1,000
QClady              free QC_1                0,000      1,000
QClady              register order           0,051      1,000
QClady              register pallet1         0,034      1,000
```


Figure 13: Simulation run 2 (10% chance of quality control intervention)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Αρχείο Επεξεργασία Μορφή Προβολή Βοήθεια

Model End Date/Time : 01/01/2011 00:00:00:000:000:000
Actual Start Date/Time : 01/01/2010 00:00:00:000:000:000
Actual End Date/Time : 01/01/2011 00:00:00:000:000:000
Actual Run Duration : 365 days 00:00:00:000:000:000

Entity : Total Count - Observation Based : Replication 1

Entity Names	Total Generated	Remaining In System	Total Processed
order1	8759	2	8757

Entity : Count By State - Time Weighted : Replication 1

Entity Names	Total In System----- Average	Maximum	Processing--------- Average	Maximum	Wait For Resources-- Average	Maximum	Hold For Conditions- Average	Maximum	Traveling----------- Average	Maximum
order1	2,500	4	1,403	3	1,097	3	0,000	0	0,000	1

Entity : Cycle Time (in Hours) By State - Observation Based : Replication 1

Entity Names	#Observed	Total In System----- Average	Maximum	Processing--------- Average	Maximum	Wait For Resources-- Average	Maximum	Hold For Conditions- Average	Maximum	Traveling---------- Average	Maximum
order1	8757	2,500	3,667	1,403	1,583	1,097	2,500	0,000	0,000	0,000	0,000

Resource : Number of Units By State - TimeWeighted : Replication 1

Resource Names	Defined Capacity	Capacity	--------Idle-------- Average	Maximum	--------Busy-------- Average	Maximum	--Planned Downtime-- Average	Maximum	-Unplanned Downtime- Average	Maximum	------Reserved------ Average	Maximum
QClady	1	1,000	0,185	1,000	0,573	1,000	0,242	1,000	0,000	0,000	0,000	0,000
firstoperator	1	1,000	0,000	1,000	1,000	1,000	0,000	0,000	0,000	0,000	0,000	0,000

Resource : Percent Utilization By State : Replication 1

Resource Names	Idle	Busy	Planned	Unplanned	Reserved
QClady	18,515%	57,319%	24,166%	0,000%	0,000%
firstoperator	0,019%	99,981%	0,000%	0,000%	0,000%

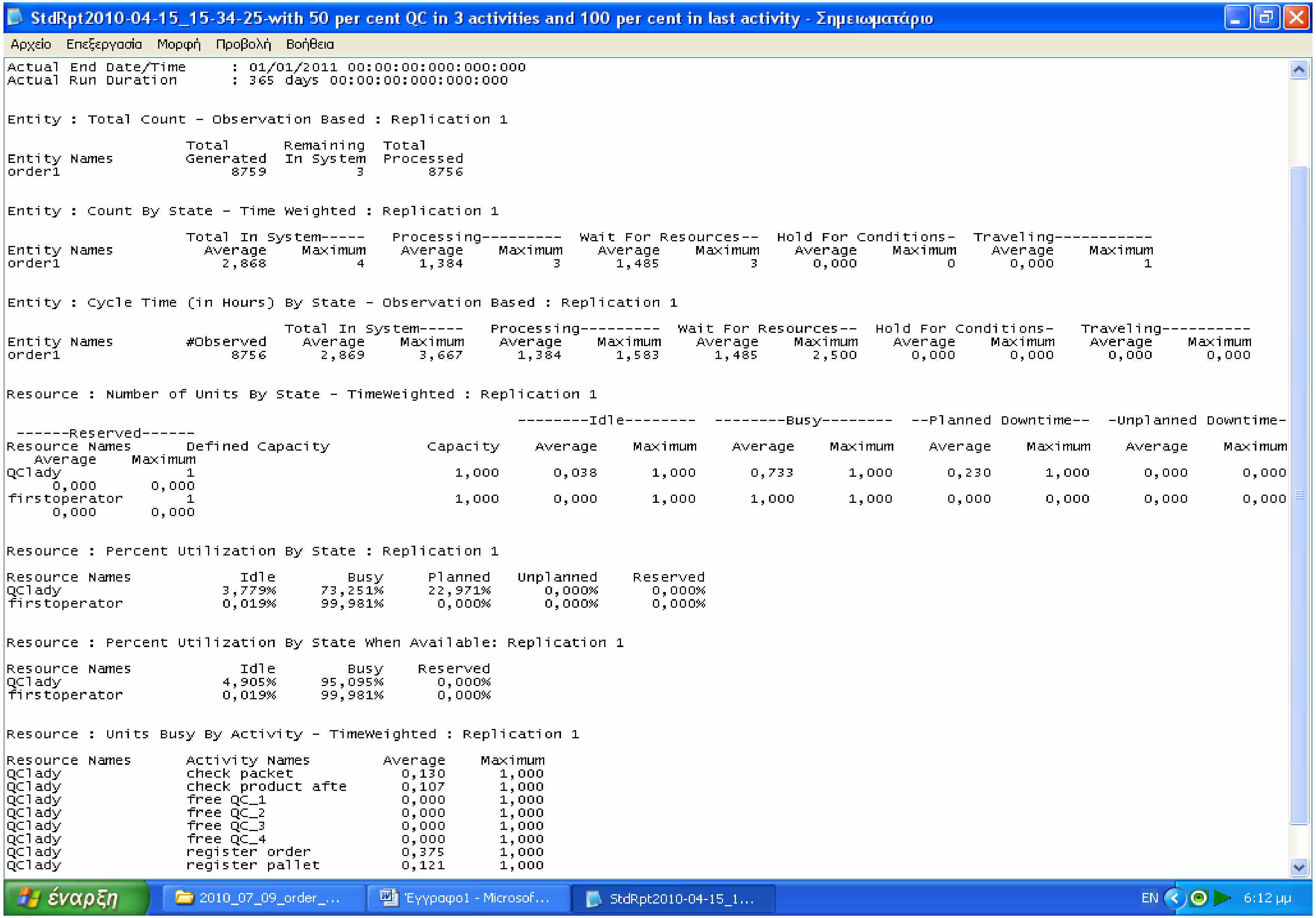
Resource : Percent Utilization By State When Available: Replication 1

Resource Names	Idle	Busy	Reserved
QClady	24,415%	75,585%	0,000%
firstoperator	0,019%	99,981%	0,000%

Resource : Units Busy By Activity - TimeWeighted : Replication 1

Resource Names	Activity Names	Average	Maximum
QClady	check packet	0,046	1,000
QClady	check product afte	0,020	1,000
QClady	free QC_1	0,000	1,000
QClady	free QC_2	0,000	1,000
QClady	free QC_3	0,000	1,000
QClady	free QC_4	0,000	1,000
QClady	register order	0,474	1,000
QClady	register pallet	0,033	1,000

Figure 14: Simulation run 3 (10% chance of quality control intervention in the three activities and 100% in last activity)



Actual End Date/Time : 01/01/2011 00:00:00:000:000:000
Actual Run Duration : 365 days 00:00:00:000:000:000

Entity : Total Count - Observation Based : Replication 1

Entity Names	Total Generated	Remaining In System	Total Processed
order1	8759	3	8756

Entity : Count By State - Time Weighted : Replication 1

Entity Names	Total In System----- Average	Maximum	Processing--------- Average	Maximum	Wait For Resources-- Average	Maximum	Hold For Conditions- Average	Maximum	Traveling----------- Average	Maximum
order1	2,868	4	1,384	3	1,485	3	0,000	0	0,000	1

Entity : Cycle Time (in Hours) By State - Observation Based : Replication 1

Entity Names	#Observed	Total In System----- Average	Maximum	Processing--------- Average	Maximum	Wait For Resources-- Average	Maximum	Hold For Conditions- Average	Maximum	Traveling---------- Average	Maximum
order1	8756	2,869	3,667	1,384	1,583	1,485	2,500	0,000	0,000	0,000	0,000

Resource : Number of Units By State - TimeWeighted : Replication 1

Resource Names	Defined Capacity	Capacity	--------Idle-------- Average	Maximum	--------Busy-------- Average	Maximum	--Planned Downtime-- Average	Maximum	-Unplanned Downtime- Average	Maximum	------Reserved------ Average	Maximum
QClady	1	1,000	0,038	1,000	0,733	1,000	0,230	1,000	0,000	0,000	0,000	0,000
firstoperator	1	1,000	0,000	1,000	1,000	1,000	0,000	0,000	0,000	0,000	0,000	0,000

Resource : Percent Utilization By State : Replication 1

Resource Names	Idle	Busy	Planned	Unplanned	Reserved
QClady	3,779%	73,251%	22,971%	0,000%	0,000%
firstoperator	0,019%	99,981%	0,000%	0,000%	0,000%

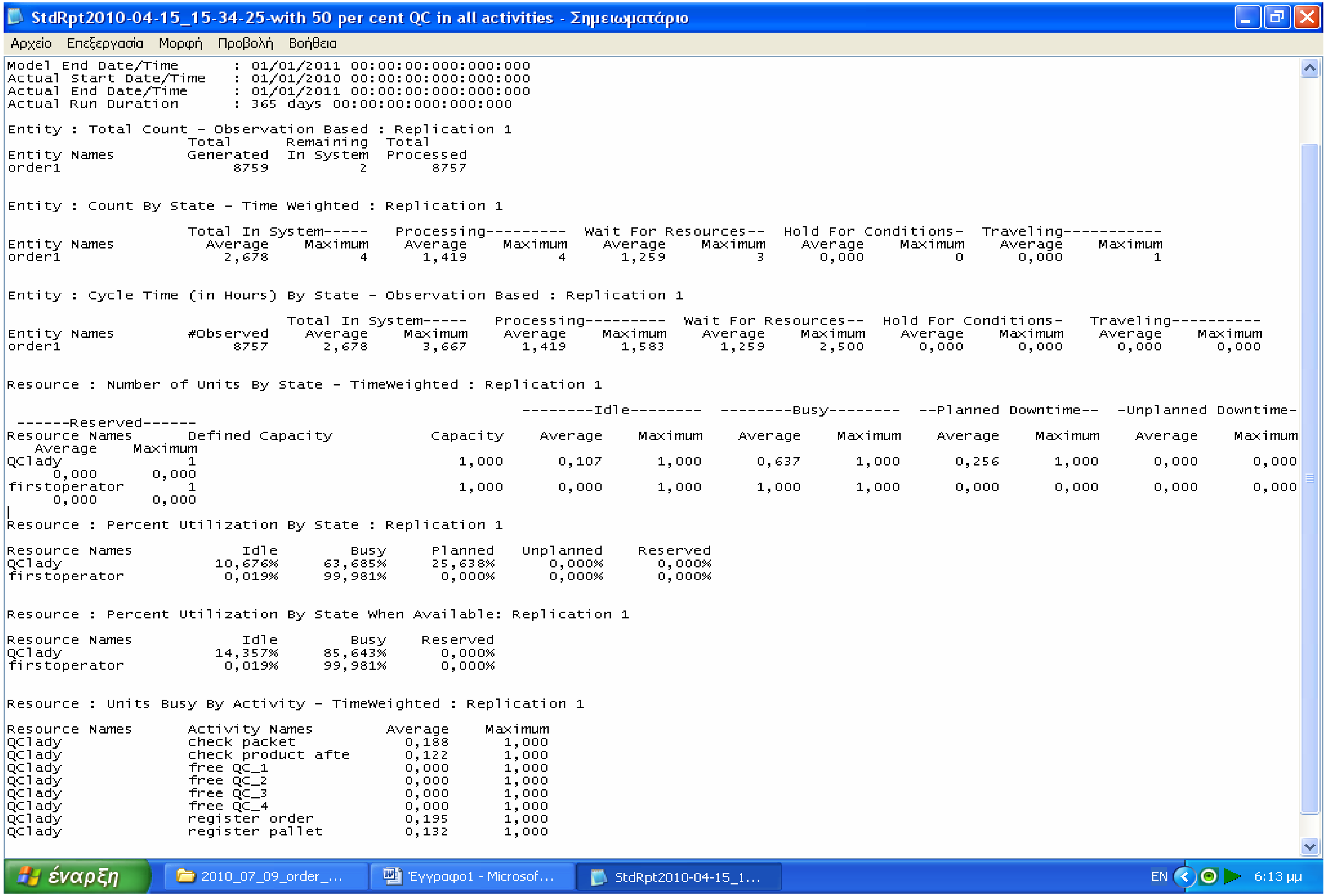
Resource : Percent Utilization By State When Available: Replication 1

Resource Names	Idle	Busy	Reserved
QClady	4,905%	95,095%	0,000%
firstoperator	0,019%	99,981%	0,000%

Resource : Units Busy By Activity - TimeWeighted : Replication 1

Resource Names	Activity Names	Average	Maximum
QClady	check packet	0,130	1,000
QClady	check product afte	0,107	1,000
QClady	free QC_1	0,000	1,000
QClady	free QC_2	0,000	1,000
QClady	free QC_3	0,000	1,000
QClady	free QC_4	0,000	1,000
QClady	register order	0,375	1,000
QClady	register pallet	0,121	1,000

Figure 15: Simulation run 4 (50% chance of quality control intervention in the three activities and 100% in last activity)



StdRpt2010-04-15_15-34-25-with 50 per cent QC in all activities - Σημειωματάριο

Αρχείο Επεξεργασία Μορφή Προβολή Βοήθεια

Model End Date/Time : 01/01/2011 00:00:00:000:000:000
Actual Start Date/Time : 01/01/2010 00:00:00:000:000:000
Actual End Date/Time : 01/01/2011 00:00:00:000:000:000
Actual Run Duration : 365 days 00:00:00:000:000:000

Entity : Total Count - Observation Based : Replication 1

Entity Names	Total Generated	Remaining In System	Total Processed
order1	8759	2	8757

Entity : Count By State - Time Weighted : Replication 1

Entity Names	Total In System----- Average	Maximum	Processing--------- Average	Maximum	Wait For Resources-- Average	Maximum	Hold For Conditions- Average	Maximum	Traveling---------- Average	Maximum
order1	2,678	4	1,419	4	1,259	3	0,000	0	0,000	1

Entity : Cycle Time (in Hours) By State - Observation Based : Replication 1

Entity Names	#Observed	Total In System----- Average	Maximum	Processing--------- Average	Maximum	Wait For Resources-- Average	Maximum	Hold For Conditions- Average	Maximum	Traveling---------- Average	Maximum
order1	8757	2,678	3,667	1,419	1,583	1,259	2,500	0,000	0,000	0,000	0,000

Resource : Number of Units By State - TimeWeighted : Replication 1

Resource Names	Defined Capacity	Capacity	--------Idle-------- Average	Maximum	--------Busy-------- Average	Maximum	--Planned Downtime-- Average	Maximum	-Unplanned Downtime- Average	Maximum	------Reserved------ Average	Maximum
QClady	1	1,000	0,107	1,000	0,637	1,000	0,256	1,000	0,000	0,000	0,000	0,000
firstoperator	1	1,000	0,000	1,000	1,000	1,000	0,000	0,000	0,000	0,000	0,000	0,000

Resource : Percent Utilization By State : Replication 1

Resource Names	Idle	Busy	Planned	Unplanned	Reserved
QClady	10,676%	63,685%	25,638%	0,000%	0,000%
firstoperator	0,019%	99,981%	0,000%	0,000%	0,000%

Resource : Percent Utilization By State When Available: Replication 1

Resource Names	Idle	Busy	Reserved
QClady	14,357%	85,643%	0,000%
firstoperator	0,019%	99,981%	0,000%

Resource : Units Busy By Activity - TimeWeighted : Replication 1

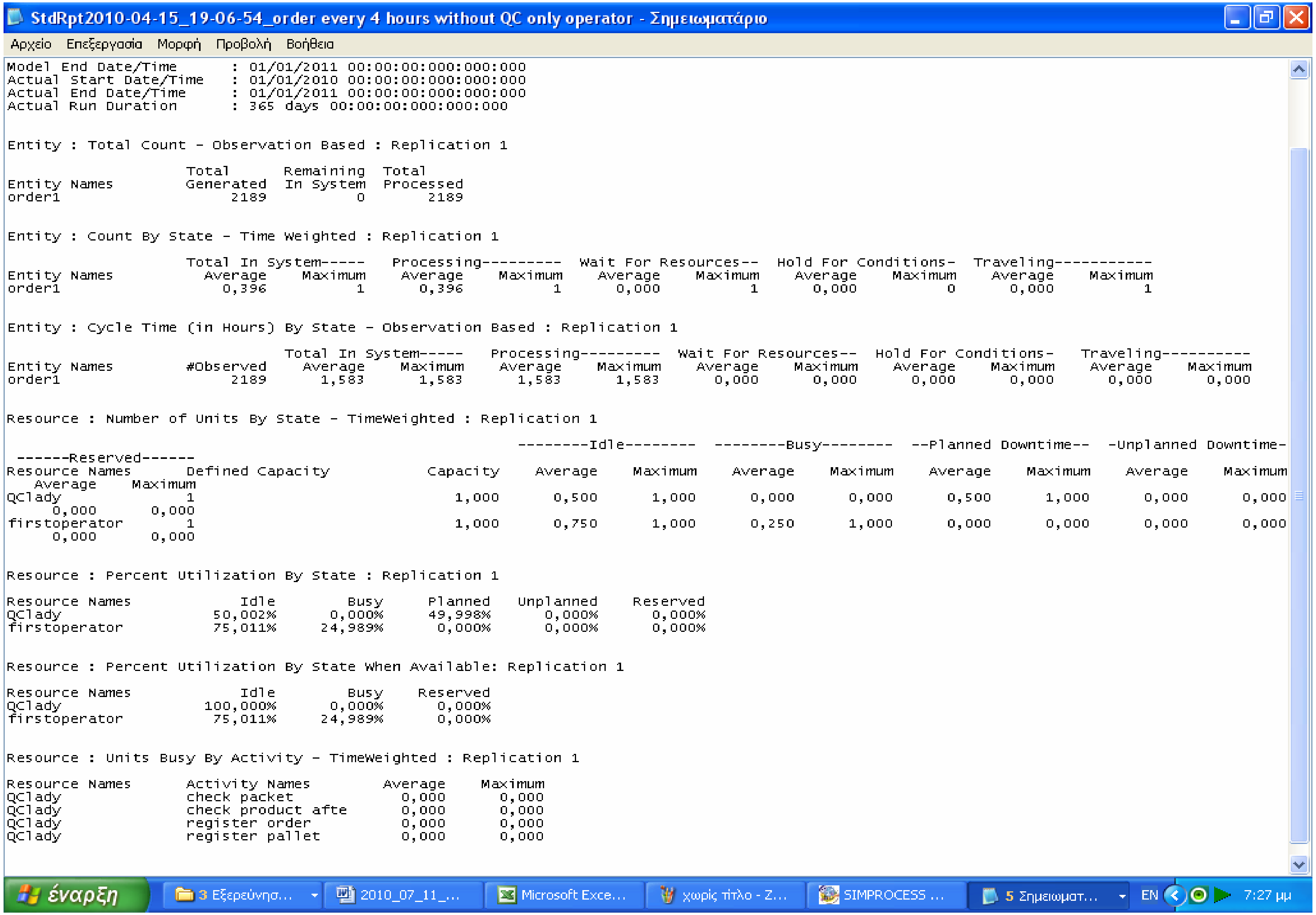
Resource Names	Activity Names	Average	Maximum
QClady	check packet	0,188	1,000
QClady	check product afte	0,122	1,000
QClady	free QC_1	0,000	1,000
QClady	free QC_2	0,000	1,000
QClady	free QC_3	0,000	1,000
QClady	free QC_4	0,000	1,000
QClady	register order	0,195	1,000
QClady	register pallet	0,132	1,000

Figure 16: Simulation run 5 (50% chance of quality control intervention)

Table 4: Order every 4 hours (previously it was every 1 hour): Total minimum duration time is 60+10+5+10+10=95 minutes, that is: 1,583 hours.

	365 days. One order per 4 hours: less work for the operator					closer today	
name	unit	description	only operator	10% chance for QC intervention in all activities	50% chance for QC intervention in all activities	10% chance for QC intervention in 3 activities and 100% in last activity	50% chance for QC intervention in 3 activities and 100% in last activity
order1	cycle time in hours	Total in system average	1,583	1,729	2,321	2,085	2,493
order1	cycle time in hours	Total in system maximum	1,583	3	3,333	3,333	3,333
order1	cycle time in hours	processing average	1,583	1,526	1,295	1,377	1,212
order1	cycle time in hours	processing maximum	1,583	1,583	1,583	1,417	1,417
order1	cycle time in hours	wait for resources average	0	0,203	1,027	0,708	1,281
order1	cycle time in hours	wait for resources maximum	0	2	2,333	2,333	2,333
Qclady	% utilization by state	idle	50,002	47,278	36,778	40,067	33,05
Qclady	% utilization by state	busy	0	4,583	22,827	15,771	29,02
Qclady	% utilization by state	planned	49,998	48,138	40,395	44,163	37,929
firstoperator	% utilization by state	idle	75,011	75,011	75,011	75,011	75,011
firstoperator	% utilization by state	busy	24,989	24,989	24,989	24,989	24,989
firstoperator	% utilization by state	planned	0	0	0	0	0
Qclady	% utilization by state when available	idle	100	91,262	61,703	71,756	53,247
Qclady	% utilization by state when available	busy	0	8,838	38,297	28,244	46,753
firstoperator	% utilization by state when available	idle	75,011	75,011	75,011	75,011	75,011
firstoperator	% utilization by state when available	busy	24,989	24,989	24,989	24,989	24,989

Below there are the simulation run statistics as they are produced by the model.




```
Model End Date/Time      : 01/01/2011 00:00:00:000:000:000
Actual Start Date/Time   : 01/01/2010 00:00:00:000:000:000
Actual End Date/Time     : 01/01/2011 00:00:00:000:000:000
Actual Run Duration      : 365 days 00:00:00:000:000:000

Entity : Total Count - Observation Based : Replication 1

                    Total      Remaining  Total
Entity Names        Generated  In System  Processed
order1                   2189          0       2189

Entity : Count By State - Time Weighted : Replication 1

                    Total In System-----  Processing---------  Wait For Resources--  Hold For Conditions-  Traveling-----------
Entity Names          Average    Maximum    Average    Maximum    Average    Maximum    Average    Maximum    Average    Maximum
order1                  0,396          1      0,396          1      0,000          1      0,000          0      0,000          1

Entity : Cycle Time (in Hours) By State - Observation Based : Replication 1

                               Total In System-----  Processing---------  Wait For Resources--  Hold For Conditions-  Traveling----------
Entity Names        #Observed    Average    Maximum    Average    Maximum    Average    Maximum    Average    Maximum    Average    Maximum
order1                   2189      1,583      1,583      1,583      1,583      0,000      0,000      0,000      0,000      0,000      0,000

Resource : Number of Units By State - TimeWeighted : Replication 1

                                                       --------Idle--------  --------Busy--------  --Planned Downtime--  -Unplanned Downtime-
 ------Reserved------
Resource Names      Defined Capacity          Capacity    Average    Maximum    Average    Maximum    Average    Maximum    Average    Maximum
   Average    Maximum
QClady                 1                         1,000      0,500      1,000      0,000      0,000      0,500      1,000      0,000      0,000
     0,000      0,000
firstoperator          1                         1,000      0,750      1,000      0,250      1,000      0,000      0,000      0,000      0,000
     0,000      0,000

Resource : Percent Utilization By State : Replication 1

Resource Names              Idle         Busy      Planned    Unplanned     Reserved
QClady                   50,002%       0,000%      49,998%       0,000%       0,000%
firstoperator            75,011%      24,989%       0,000%       0,000%       0,000%

Resource : Percent Utilization By State When Available: Replication 1

Resource Names              Idle         Busy     Reserved
QClady                  100,000%       0,000%       0,000%
firstoperator            75,011%      24,989%       0,000%

Resource : Units Busy By Activity - TimeWeighted : Replication 1

Resource Names      Activity Names        Average    Maximum
QClady              check packet            0,000      0,000
QClady              check product afte      0,000      0,000
QClady              register order          0,000      0,000
QClady              register pallet         0,000      0,000
```


Figure 17: simulation run 6. The packaging operator operates all activities by himself. There is no time waiting for resources.

StdRpt2010-04-15_19-06-54_order every 4 hours with 10 per cent QC in all activities - Σημειωματάριο

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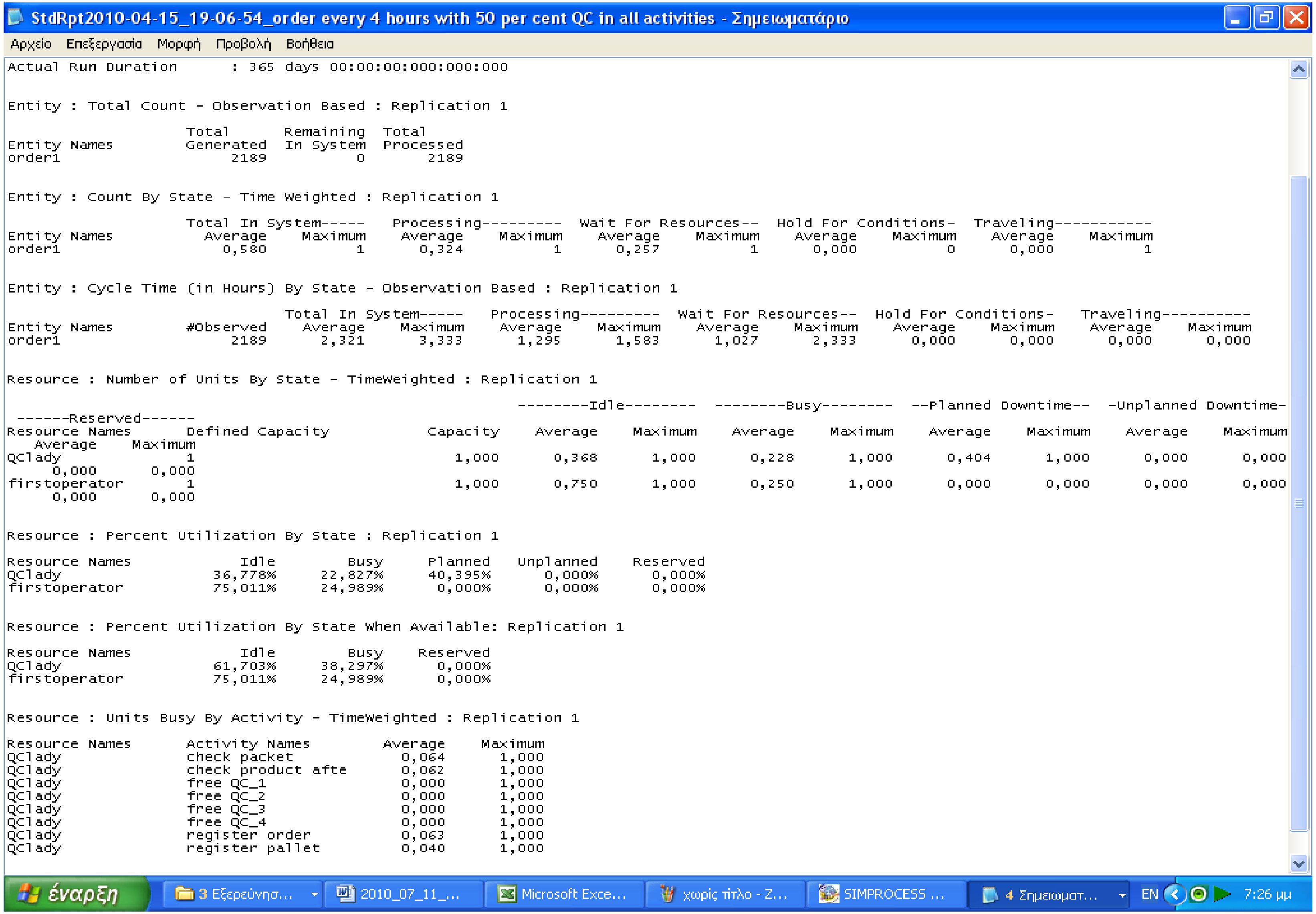
```
Actual Run Duration      : 365 days 00:00:00:000:000:000

Entity : Total Count - Observation Based : Replication 1

                     Total      Remaining  Total
Entity Names         Generated  In System  Processed
order1                    2189          0       2189

Entity : Count By State - Time Weighted : Replication 1

                     Total In System-----  Processing---------  Wait For Resources--  Hold For Conditions-  Traveling-----------
Entity Names           Average    Maximum    Average    Maximum    Average    Maximum    Average    Maximum    Average    Maximum
order1                   0,432          1      0,381          1      0,051          1      0,000          0      0,000          1

Entity : Cycle Time (in Hours) By State - Observation Based : Replication 1

                                Total In System-----  Processing---------  Wait For Resources--  Hold For Conditions-  Traveling----------
Entity Names         #Observed    Average    Maximum    Average    Maximum    Average    Maximum    Average    Maximum    Average    Maximum
order1                    2189      1,729      3,000      1,526      1,583      0,203      2,000      0,000      0,000      0,000      0,000

Resource : Number of Units By State - TimeWeighted : Replication 1

                                                        --------Idle--------  --------Busy--------  --Planned Downtime--  -Unplanned Downtime-
 ------Reserved------
Resource Names       Defined Capacity         Capacity    Average    Maximum    Average    Maximum    Average    Maximum    Average    Maximum
   Average    Maximum
QClady                              1            1,000      0,473      1,000      0,046      1,000      0,481      1,000      0,000      0,000
     0,000      0,000
firstoperator                       1            1,000      0,750      1,000      0,250      1,000      0,000      0,000      0,000      0,000
     0,000      0,000

Resource : Percent Utilization By State : Replication 1

Resource Names             Idle        Busy     Planned   Unplanned    Reserved
QClady                  47,278%      4,583%     48,138%      0,000%      0,000%
firstoperator           75,011%     24,989%      0,000%      0,000%      0,000%

Resource : Percent Utilization By State When Available: Replication 1

Resource Names             Idle        Busy    Reserved
QClady                  91,162%      8,838%      0,000%
firstoperator           75,011%     24,989%      0,000%

Resource : Units Busy By Activity - TimeWeighted : Replication 1

Resource Names       Activity Names         Average    Maximum
QClady               check packet             0,012      1,000
QClady               check product afte       0,013      1,000
QClady               free QC_1                0,000      1,000
QClady               free QC_2                0,000      1,000
QClady               free QC_3                0,000      1,000
QClady               free QC_4                0,000      1,000
QClady               register order           0,013      1,000
QClady               register pallet          0,007      1,000
```

έναρξη | 3 Εξερεύνηση... | 2010_07_11_... | Microsoft Exce... | χωρίς τίτλο - Z... | SIMPROCESS ... | 3 Σημειωματ... | EN | 7:26 μμ

Figure 18: simulation run 7: There is a 10% chance for quality control intervention in all activities.



StdRpt2010-04-15_19-06-54_order every 4 hours with 50 per cent QC in all activities - Σημειωματάριο

Αρχείο Επεξεργασία Μορφή Προβολή Βοήθεια

Actual Run Duration : 365 days 00:00:00:000:000:000

Entity : Total Count - Observation Based : Replication 1

Entity Names	Total Generated	Remaining In System	Total Processed
order1	2189	0	2189

Entity : Count By State - Time Weighted : Replication 1

Entity Names	Total In System----- Average	Maximum	Processing--------- Average	Maximum	Wait For Resources-- Average	Maximum	Hold For Conditions- Average	Maximum	Traveling----------- Average	Maximum
order1	0,580	1	0,324	1	0,257	1	0,000	0	0,000	1

Entity : Cycle Time (in Hours) By State - Observation Based : Replication 1

Entity Names	#Observed	Total In System----- Average	Maximum	Processing--------- Average	Maximum	Wait For Resources-- Average	Maximum	Hold For Conditions- Average	Maximum	Traveling---------- Average	Maximum
order1	2189	2,321	3,333	1,295	1,583	1,027	2,333	0,000	0,000	0,000	0,000

Resource : Number of Units By State - TimeWeighted : Replication 1

Resource Names	Defined Capacity	Capacity	--------Idle-------- Average	Maximum	--------Busy-------- Average	Maximum	--Planned Downtime-- Average	Maximum	-Unplanned Downtime- Average	Maximum	------Reserved------ Average	Maximum
QClady	1	1,000	0,368	1,000	0,228	1,000	0,404	1,000	0,000	0,000	0,000	0,000
firstoperator	1	1,000	0,750	1,000	0,250	1,000	0,000	0,000	0,000	0,000	0,000	0,000

Resource : Percent Utilization By State : Replication 1

Resource Names	Idle	Busy	Planned	Unplanned	Reserved
QClady	36,778%	22,827%	40,395%	0,000%	0,000%
firstoperator	75,011%	24,989%	0,000%	0,000%	0,000%

Resource : Percent Utilization By State When Available: Replication 1

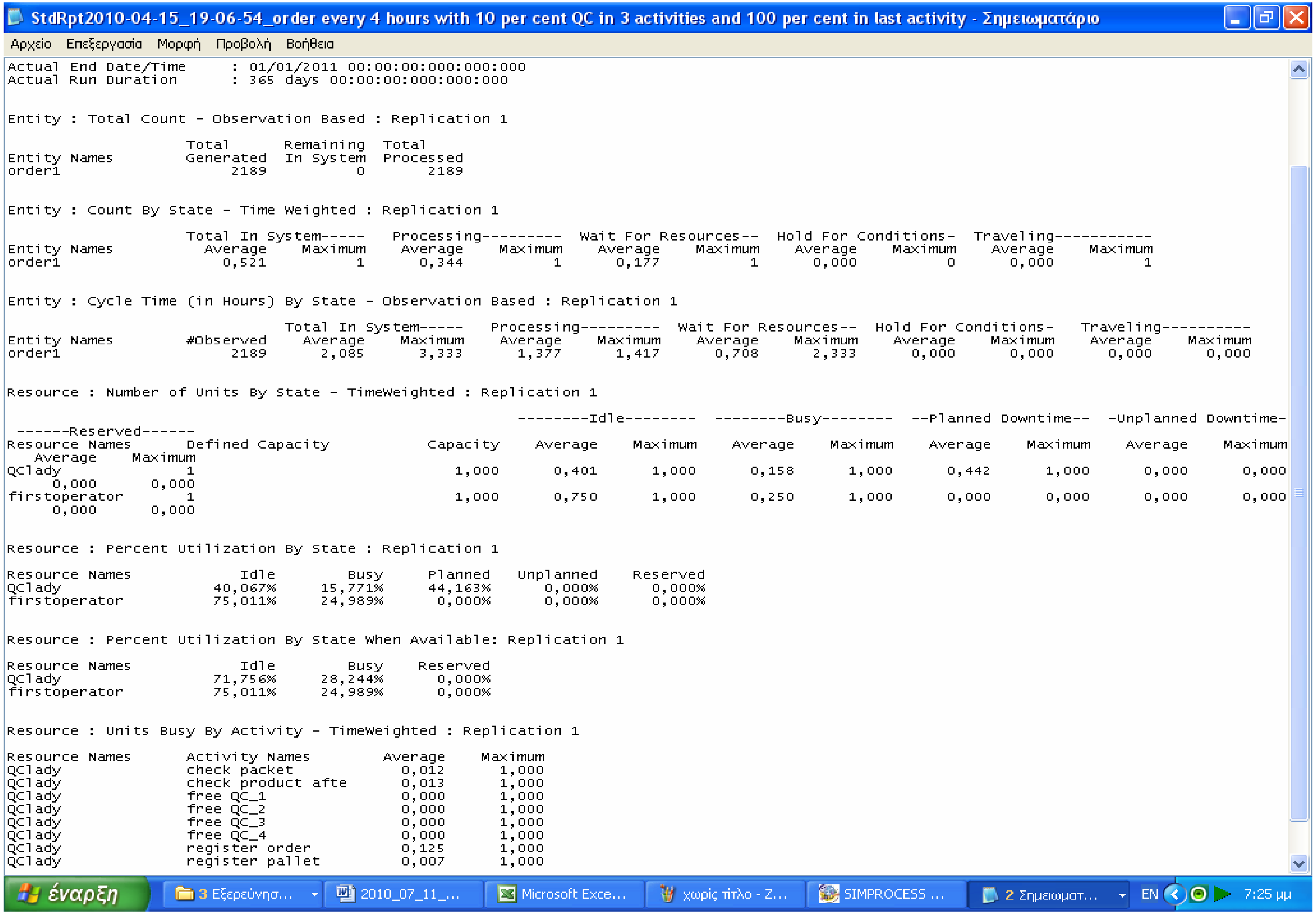
Resource Names	Idle	Busy	Reserved
QClady	61,703%	38,297%	0,000%
firstoperator	75,011%	24,989%	0,000%

Resource : Units Busy By Activity - TimeWeighted : Replication 1

Resource Names	Activity Names	Average	Maximum
QClady	check packet	0,064	1,000
QClady	check product afte	0,062	1,000
QClady	free QC_1	0,000	1,000
QClady	free QC_2	0,000	1,000
QClady	free QC_3	0,000	1,000
QClady	free QC_4	0,000	1,000
QClady	register order	0,063	1,000
QClady	register pallet	0,040	1,000

έναρξη | 3 Εξερεύνηση... | 2010_07_11_... | Microsoft Exce... | χωρίς τίτλο - Ζ... | SIMPROCESS ... | 4 Σημειωματ... | EN | 7:26 μμ

Figure 19: simulation run 8: There is a 50% chance for quality control intervention in all activities.



StdRpt2010-04-15_19-06-54_order every 4 hours with 10 per cent QC in 3 activities and 100 per cent in last activity - Σημειωματάριο

Αρχείο Επεξεργασία Μορφή Προβολή Βοήθεια

Actual End Date/Time : 01/01/2011 00:00:00:000:000:000
Actual Run Duration : 365 days 00:00:00:000:000:000

Entity : Total Count - Observation Based : Replication 1

Entity Names	Total Generated	Remaining In System	Total Processed
order1	2189	0	2189

Entity : Count By State - Time Weighted : Replication 1

Entity Names	Total In System Average	Total In System Maximum	Processing Average	Processing Maximum	Wait For Resources Average	Wait For Resources Maximum	Hold For Conditions Average	Hold For Conditions Maximum	Traveling Average	Traveling Maximum
order1	0,521	1	0,344	1	0,177	1	0,000	0	0,000	1

Entity : Cycle Time (in Hours) By State - Observation Based : Replication 1

Entity Names	#Observed	Total In System Average	Total In System Maximum	Processing Average	Processing Maximum	Wait For Resources Average	Wait For Resources Maximum	Hold For Conditions Average	Hold For Conditions Maximum	Traveling Average	Traveling Maximum
order1	2189	2,085	3,333	1,377	1,417	0,708	2,333	0,000	0,000	0,000	0,000

Resource : Number of Units By State - TimeWeighted : Replication 1

Resource Names	Defined Capacity	Capacity	Idle Average	Idle Maximum	Busy Average	Busy Maximum	Planned Downtime Average	Planned Downtime Maximum	Unplanned Downtime Average	Unplanned Downtime Maximum	Reserved Average	Reserved Maximum
QClady	1	1,000	0,401	1,000	0,158	1,000	0,442	1,000	0,000	0,000	0,000	0,000
firstoperator	1	1,000	0,750	1,000	0,250	1,000	0,000	0,000	0,000	0,000	0,000	0,000

Resource : Percent Utilization By State : Replication 1

Resource Names	Idle	Busy	Planned	Unplanned	Reserved
QClady	40,067%	15,771%	44,163%	0,000%	0,000%
firstoperator	75,011%	24,989%	0,000%	0,000%	0,000%

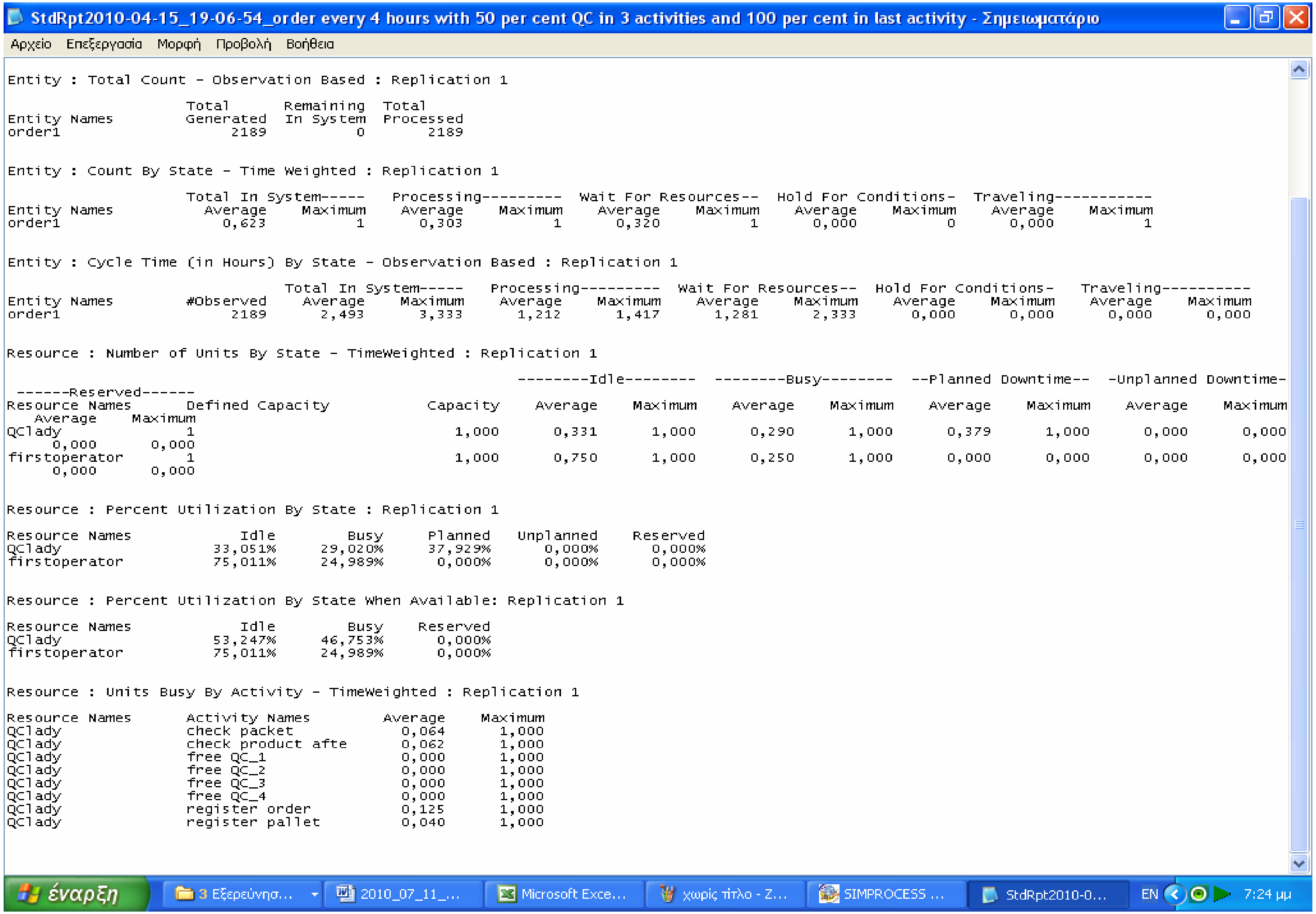
Resource : Percent Utilization By State When Available: Replication 1

Resource Names	Idle	Busy	Reserved
QClady	71,756%	28,244%	0,000%
firstoperator	75,011%	24,989%	0,000%

Resource : Units Busy By Activity - TimeWeighted : Replication 1

Resource Names	Activity Names	Average	Maximum
QClady	check packet	0,012	1,000
QClady	check product afte	0,013	1,000
QClady	free QC_1	0,000	1,000
QClady	free QC_2	0,000	1,000
QClady	free QC_3	0,000	1,000
QClady	free QC_4	0,000	1,000
QClady	register order	0,125	1,000
QClady	register pallet	0,007	1,000

Figure 20: simulation run 9: There is a 10% chance for quality control intervention in the first three activities and the last activity is operated by the quality control



StdRpt2010-04-15_19-06-54_order every 4 hours with 50 per cent QC in 3 activities and 100 per cent in last activity - Σημειωματάριο

Αρχείο Επεξεργασία Μορφή Προβολή Βοήθεια

Entity : Total Count - Observation Based : Replication 1

Entity Names	Total Generated	Remaining In System	Total Processed
order1	2189	0	2189

Entity : Count By State - Time Weighted : Replication 1

Entity Names	Total In System----- Average	Maximum	Processing--------- Average	Maximum	Wait For Resources-- Average	Maximum	Hold For Conditions- Average	Maximum	Traveling----------- Average	Maximum
order1	0,623	1	0,303	1	0,320	1	0,000	0	0,000	1

Entity : Cycle Time (in Hours) By State - Observation Based : Replication 1

Entity Names	#Observed	Total In System----- Average	Maximum	Processing--------- Average	Maximum	Wait For Resources-- Average	Maximum	Hold For Conditions- Average	Maximum	Traveling---------- Average	Maximum
order1	2189	2,493	3,333	1,212	1,417	1,281	2,333	0,000	0,000	0,000	0,000

Resource : Number of Units By State - TimeWeighted : Replication 1

Resource Names	------Reserved------ Average	Maximum	Defined Capacity	Capacity	--------Idle-------- Average	Maximum	--------Busy-------- Average	Maximum	--Planned Downtime-- Average	Maximum	-Unplanned Downtime- Average	Maximum
QClady	0,000	0,000	1	1,000	0,331	1,000	0,290	1,000	0,379	1,000	0,000	0,000
firstoperator	0,000	0,000	1	1,000	0,750	1,000	0,250	1,000	0,000	0,000	0,000	0,000

Resource : Percent Utilization By State : Replication 1

Resource Names	Idle	Busy	Planned	Unplanned	Reserved
QClady	33,051%	29,020%	37,929%	0,000%	0,000%
firstoperator	75,011%	24,989%	0,000%	0,000%	0,000%

Resource : Percent Utilization By State When Available: Replication 1

Resource Names	Idle	Busy	Reserved
QClady	53,247%	46,753%	0,000%
firstoperator	75,011%	24,989%	0,000%

Resource : Units Busy By Activity - TimeWeighted : Replication 1

Resource Names	Activity Names	Average	Maximum
QClady	check packet	0,064	1,000
QClady	check product afte	0,062	1,000
QClady	free QC_1	0,000	1,000
QClady	free QC_2	0,000	1,000
QClady	free QC_3	0,000	1,000
QClady	free QC_4	0,000	1,000
QClady	register order	0,125	1,000
QClady	register pallet	0,040	1,000

έναρξη 3 Εξερεύνηση... 2010_07_11_... Microsoft Exce... χωρίς τίτλο - Ζ... SIMPROCESS ... StdRpt2010-0... EN 7:24 μμ

Figure 21: simulation run 10: There is a 50% chance for quality control intervention in the first three activities and the last activity is operated by the quality control