# SIMULATION OF A MILK RUN MATERIAL TRANSPORTATION SYSTEM IN THE SEMICONDUCTORS INDUSTRY

Ricardo Raposo

University of Porto
School of Engineering
MITPortugal program EDAM Area
Rua Dr. Roberto Frias
4200-465 Porto
Portugal
ricardo.raposo@itarion.com

Guilherme Pereira
Luís Dias
University of Minho
School of Engineering
Production and Systems Dpt
Campus de Gualtar
4710 057 Braga
Portugal
gui/lsd @dps.uminho.pt

## KEYWORDS

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## ABSTRACT

This paper deals with a project that consisted in the implementation of a Milk Run Lot Transportation System in Qimonda Porto Test Area, done by a multidisciplinary team formed by Qimonda Porto's workers, and the development of the corresponding simulation model. The first part of the study concerns an industrial engineering assessment of the test area, which identified sources of waste and improvement possibilities, and the implementation process of a Milk Run system in this area. Secondly, the results of the system implementation are discussed, and the construction of a simulation model in Arena® is presented. The purpose of the simulation exercise is to test different system configurations that may allow the improvement of the real-world system. Finally, some information about the simulation results and further steps to be taken regarding the improvement of the system is presented. The target of the project, framed in a Lean approach, was to reduce waste, namely transportation waste, thus optimizing the utilization of the test area human resources.

## INTRODUCTION

This paper reports the implementation of a Milk Run Lot Transportation System in Qimonda Porto (onwards referred to as QPT) Test Area, done by a multidisciplinary team formed by QPT's workers, and the development of the corresponding simulation model (Raposo 2009). Qimonda is a global memory supplier with a diversified DRAM product portfolio. At the time of the project, Qimonda had approximately 13,500 employees worldwide, accessed five 300mm manufacturing sites on three continents and operated six major R&D facilities. In Portugal, Qimonda has its major European backend production site, founded in 1996, counting with a workforce of approximately 2,000 employees at the time of the project. QPT assembles, tests and packs semiconductor products, namely DRAM memories for computers, servers and other digital applications (MP3, mobiles, digital cameras, game consoles and others), in a plant that has a clean room area of 15,500 m2. Qimonda is a company working in an industry which is commonly designated as capital intensive (opposite to labor intensive industries), the one of semiconductors. A business process or an industry is considered capital intensive when there is a high ratio of the necessary capital to the amount of labor that is required. The process flow in a semiconductor backend factory, like QPT, can roughly be described by the following steps, having wafers as the major input, and marked chips as its output.

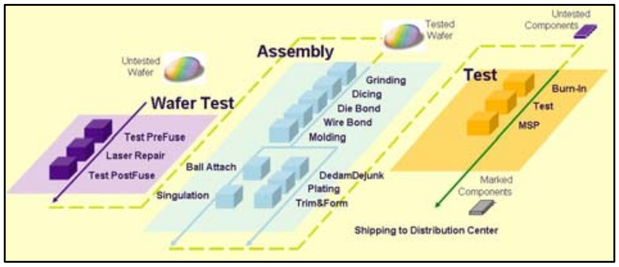


Figure 1: Qimonda Porto Backend Process Flow

Figure 2: Qimonda Porto Major Input and Output

The process area named as Test in Figure 1 actually encompasses 3 different processes:

- Burn-in: consists in an accelerated aging of the components, through thermal and electrical stress, to eliminate the components that would fail in the first years of life;
- Test: extensive electrical tests to ensure the components electrical and functional specifications;
- MSP (Mark, Scan & Pack): scanning (to ensure physical dimensions compliance), marking and packing (for expedition) the components;

This project concerns the test area of QPT. At QPT, mainly in the Test Area, the highest capital investment is associated with the equipment and the optimization of its utilization is a very important factor, essential to keep the cost per piece below the desired limits. Facing the fact that the test area is the one that represents the largest investment at QPT, QPT's line is balanced in order that the test area may be the bottleneck of the factory.

## PROBLEM DEFINITION

Within the Lean Manufacturing approach (Womack and Jones 1996), a "waste focused" assessment of the test area was performed in 2006. The purpose of this assessment, focused on the OEE (Overall Equipment Efficiency) metric developed by SEMI (Semiconductor Equipment and Materials International), was to identify waste sources and trigger the implementation of actions to minimize these. The assessment followed a Multi Observation Study (MOS) methodology. One of the most significant inefficiencies detected in the study concerned the time spent in transportation activities by the operators, which was at the time of the study done in an ad-hoc way by all the operators. The identified action to address this waste was the implementation of an organized lot distribution system. This paper concerns the implementation of this project, whose primary purpose was to reduce the time spent in transportation activities by the operators. However, by dedicating operators to transportation activities, it was also expected that operators working with the equipment would be more focused on their specific tasks, as they would have to leave the line less frequently. From a value stream mapping perspective, the value stream consisting of all the actions (both value added and non-value added) required to transform the raw materials into final products (Rother and Shook 1999), an important metric is the time that the materials spend in non-value added activities, of which transportation is an example. This project is not expected to impact significantly the time where the "material is effectively transported", but the time that "people spend transporting materials". The project objectives are then stated in the following table.

| | |
|---|---|
| **Objective Statement** | Reduce the time spent in transportation activities by 30% |
| **Primary Metric** | Time spent in transportation activities by the operators |
| **Secondary Metric** | Equipment Downtime states related with the operator absence, cycle time |

Table 1: Project Objectives

For this purpose, the following section will focus on the description of the implemented system and the results of its implementation. Afterwards, a section concerning the development of the Arena® Simulation Model is presented. This work will then discuss some results and state some conclusions, including some ideas for future work on this applied industrial field.

## SYSTEM IMPLEMENTATION AND RESULTS

As the lean approach birth is commonly associated with Toyota Production System (Ohno 1988), one of the approaches to minimize the waste in transportation is framed on this approach, and consists in the creation of a new role, the *mizusumashi*, or water spider (Nomura and Takakuwa 2005). The key role of the worker with this function is to support the production activities, by performing mostly non-value added activities, so that other operators can be entirely focused on value added activities.

Optimization of the water spider transportation activities may be achieved through the definition of a programmed route for material transportation, commonly known as a milk run (Hugos 2003), in an analogy to the milk delivery systems, which would follow a well-defined route, delivering full bottles and picking up empty bottles. This is an alternative to systems based on an on-demand activity in which the transporters individually transport material for each workstation, always returning to the "purchased-parts market" (Smalley 2004; Harris and Harris 2007).

A milk run system framed in a lean manufacturing environment usually relies on *Kanban* (Smalley 2004). Among other functions, these information systems are a means of controlling the quantities of materials being transported, and the frequency with which these are transported. Kanban cards are usually physical cards, typically used to signal when a downstream process requires more material to process, working as a replenishment order to the upstream process.

Opposite to traditional "push" scheduling systems, kanban methods link and synchronize the production processes, starting as far as desired in the value chain. Although a fundamental characteristic of the concept is its simplicity, the concept has evolved over time, and although the word itself means card, today other formats exist for the same function, as "electronic" Kanban systems (Smalley 2004).

### Description of the test area organization and specificities

Test area characteristics, relevant in the definition of the system, are (Figures 3 and 4):

- For lot tracking purposes, and to ensure the correct sequence of process steps, a MES (Manufacturing Execution System) is used;
- The area does not work in FIFO (First In First Out) mode, mostly due to the high product mix, allowing to minimize the number of toolkit conversions, and to maximize the equipment productive time;
- More adequate lots to process at each moment are individually selected by the senior line operators, which imposes the need of a short period between the lot request and the lot delivery;
- Lots may undergo a different number of process steps, according to the product, as described in Figure 3;
- Between processing steps, lots can be either stored in the logistical center, at the market, or transported to another test cell directly;
- Due to the dimension of the corridors between test cells, it is not possible to circulate with large trolleys between the test cells, just in the transportation corridors;

- Different test cells and production lines may have very different throughputs;
- Lots flow from the logistical center of the area to the test cells, and vice-versa, between test cells and from the test cells to the Test Gate;
- The Test Area "purchased parts market", is based on a vertical rotating-shelf storage solution;

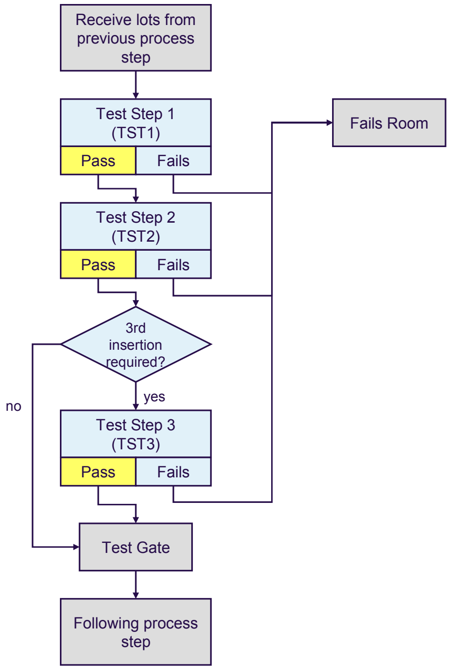


Figure 3: Test Area Simplified Process Flow

- Lots are formed by a group of packs, as presented in Figure 4, with each pack being formed by a group of trays, each tray having a capacity of 90 to 140 chips;

Figure 4: Packs of Trays with Straps

## Implemented system and results

To dimension the milk run system, information was collected about the type and volume of materials that had to be transported (Figure 5 Figure 5), the limitations to the transportation of materials, the standard work elements duration and the possible configurations for the milk run route, among others.

Considering the characteristics described in the previous section, and the information collected along the project, the system was dimensioned in the following way:

- A decoupled route format was selected, in which the transportation and market management tasks are performed by different resources (Harris et al. 2003);
- Dedicated human resources: one market attendant and 2 delivery route operators (onwards referred as DRO);
- Route frequency: each DRO should start a new route every 12 minutes, and DROs should be offset by 6 minutes, for a DRO to pass in each Point of Drop (onwards referred as PoD) rack every 6 minutes;
- Transport trolley capacity: the selected transportation mode were carts with a capacity for 10 packs, which the operators will transport on foot;
- Point of Drop rack capacity: a strategy based on Point of Drop (instead of Point of Delivery) racks was defined due to space limitations, with each PoD rack serving a group of test cells (the dimension of the PoD rack was not considered a critical factor and the selected PoD racks have a capacity for 15 packs);
- Lot selection method: operators request the lots via an application developed by the project team, being a physical kanban used to signal the lot destination;

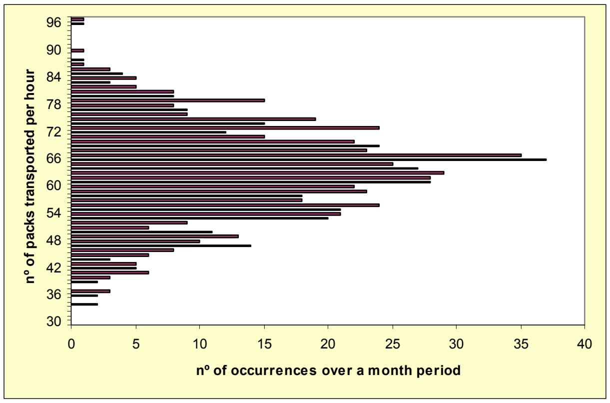


Figure 5: Distribution of Number of Packs to Transport per Hour

After the system was implemented and running a new MOS was performed, allowing to determine the results of the system implementation. Against the expectations, the overall time spent in transportation activities did not diminish, and remained approximately the same. This may indicate that the system is not optimized or is under-loaded. These hypotheses will be addressed in the simulation section.

Although not optimized, the system has brought advantages to the operators working in the equipments, focusing equipment operators on specific tasks on their work cells. The machine states that express the absence of an operator to assist the equipment improved and are presented in the following table.

| Equipment State | Before | After |
|---|---|---|
| Machine Stocker is empty and WIP is available to load (test cell is idle) | 1.8% | 0.3% |
| Lot is finished, waiting for unloading, new lot available | 0.9% | 0.4% |
| Down, waiting for operator to assist the test cell | 1.7% | 0.2% |

Table 2: Comparison of Equipment States Affected by Absence of Operator

## ARENA® SIMULATION MODEL

At this point it is relevant to present the objectives of this simulation exercise (Shannon 1975). When dimensioning the milk run system, the team had to take several decisions, using their experience and the best available information. However, the implemented system did not bring all of the expected gains. The purpose of this simulation is to evaluate different scenarios understanding how the system responds, and find answers to remaining questions. Among these are:

- In terms of human resources, the system was dimensioned as requiring 2 DROs and one Market Attendant. Is this dimensioning correct? May different combinations of the key factors that have an impact on this decision (e.g. route frequency, route length or travelling speed) enable a system which requires 1 DRO instead of 2?
- May an electrical car solution, which affords the advantage to transport more packs (and consequently lots) simultaneously and have shorter transportation times, allow having 1 DRO instead of 2?

Simulation is a very useful tool in the analysis of manufacturing systems. Simulation can be used both during the design phase (Smith 2003), to assess the way in which the system will behave and evaluate alternatives, after the system being implemented, to measure its performance, or to evaluate the impact of system modifications and optimizations. Simulation techniques have been used to address manufacturing system topics related to lean production policies, as the utilization of kanbans (Treadwell and Herrmann 2005) or the formulation of a decision support system based on the automatic creation of Arena® simulation models representing different control strategies of materials flow in a production line (Ferreira et al. 2005). Current concerns in the development of simulation models include flexibility and user friendliness for users without specific simulation knowledge. The need of an adaptable simulation framework to compare different production control policies has already been discussed (Gahagan and Herrmann 2001). Arena® was the selected simulation tool to this exercise, due to its popularity (Dias et al. 2007), flexibility provided by its hierarchical structure and user-friendliness. "Simulation with Arena" (Kelton et al. 2007) provides not only an introduction to the concepts of the software and of the simulation process, but also a hands-on approach to model development, and, consequently, of great use in the development of this work.

The factors that characterize a specific configuration of QPT's milk run system are the following:

- The number of DROs;
- The location of the PoD racks and the associated test cells to each PoD rack, which has an impact on the route design, the travelled distances and the number of packs/lots to deliver and retrieve at each PoD rack;
- The traveling speed, or equivalently, the time that is spent in each path of the route;
- The time spent in lot loading and unloading activities;
- The transportation capacity of each DRO;
- The holding capacity of each PoD rack.

The feasibility of a certain configuration will be determined by the ability of the DROs to handle the associated workload. If the simulation run, for a specific configuration, shows frequent overflow situations at the PoD racks or at the transportation carts, with the lots accumulating at the PoD racks due to lack of transportation capacity, we can state that such configuration is not feasible. In summary, the simulation exercise will consist in testing different combinations of the previously mentioned parameters to assess the existence of overflow situations.

Meanwhile, a sensitivity analysis (Barton and Lee 2002) of some parameters will also be performed. When developing a simulation model, an important aspect is to understand how variations of the model data inputs affect the final result. Besides the need of directing data collecting efforts to the inputs the system is sensitive to, in order to have a good level of confidence on the results and an effective utilization of the data-collecting resources, a sensitivity analysis is also important for other reasons. Even if we are confident about the data, if we realize that the system is very sensitive to an input, final results should be presented with some caution, as small unforeseen differences or variations of the real system may lead to large differences between the model results and the real system results. Still, even if there are not very accurate input data, the model development and simulation may provide important insight about the interaction between the element models, and about the way the system will perform.

The diagram presented in Figure 6 exemplifies lot flow in the area. Among PoD racks the lots are transported by the DROs, and between the PoD racks and the Test Cells, the line operators transport the lots. A full-blown model of this system would consider all of these transportation steps. To develop this model, the number of packs/lots being transported would have to be estimated individually for each test cell, and the PoD racks would be modeled as transit points for the packs/lots on their way to the test cells.

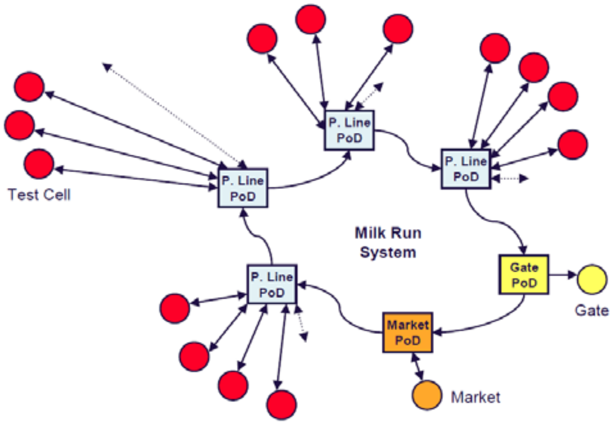


Figure 6: Diagram of Lot Flow in the Test Area

However, the purpose of this simulation exercise is to evaluate the lot transportation system, which interfaces with the production lines at the PoD racks in which the lots are dropped and picked. From the lot transportation system perspective, after the lot is dropped in the rack, what occurs is a delay process and an attribute modification, as the lot changes from being a lot to process, to a processed lot. To fulfill the goals of this study, such a detailed model is not required, as the study focuses on the route followed by the DROs. It will be sufficient to model each PoD rack as a block that receives, processes and outputs a number of packs that corresponds to the sum of the packs assigned to each individual test cell served by the relevant PoD rack. This will greatly simplify the model, without affecting the level of detail that is required for this exercise.

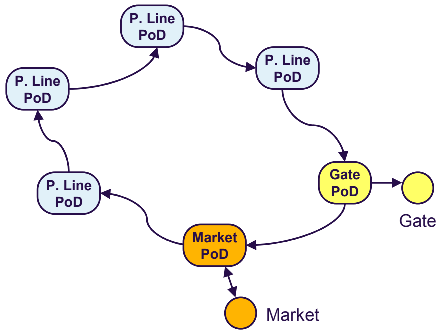


Figure 7: Simplified Diagram of Lot Flow in the Area Used in the Model

The first step in the construction of the model is to map the process in a flowchart (Figure 8). As the purpose of the simulation is to analyze the way the lots flow on the production floor under different circumstances, the flowchart will describe the way they are handled on the production floor, from the lot "perspective". In Arena® terminology (Kelton 2007), lots are then the *entities* in this simulation model and move along the different process steps of the model.

The following aspects of the real world system are reflected in the model:

- the model addresses the transportation of packs, and not of lots, because the transportation capacity is defined in terms of the former;
- the route of each of the DROs starts with a fixed frequency, with the trigger points for each of the DROs separated by half of the period;
- if a DRO is not available when the route should start, the route will start as soon as the DRO is available;
- each DRO has a transportation capacity of 10 packs;
- after being processed or staging at the market, packs are assigned to the next destination (another test cell, the market or the test gate) following a probabilistic distribution that reflects the real-system one;
- lots that are processed in successive steps in test cells associated to the same PoD rack do not need to be transported by the DRO between the two steps.

Building the model in the more intuitive way would consist in generating packs as entities, and allocating these to transporters. However, this approach revealed some practical difficulties, namely regarding the allocation of several entities to the same transporter in the same run. This led to the development of a new approach. The underlying concept is that "DRO entities" will be created, will never be disposed and will permanently circulate the model, representing the DROs. These entities will have an associated array attribute, which will represent the number of packs that the operator is carrying to each PoD rack and operation in each moment.

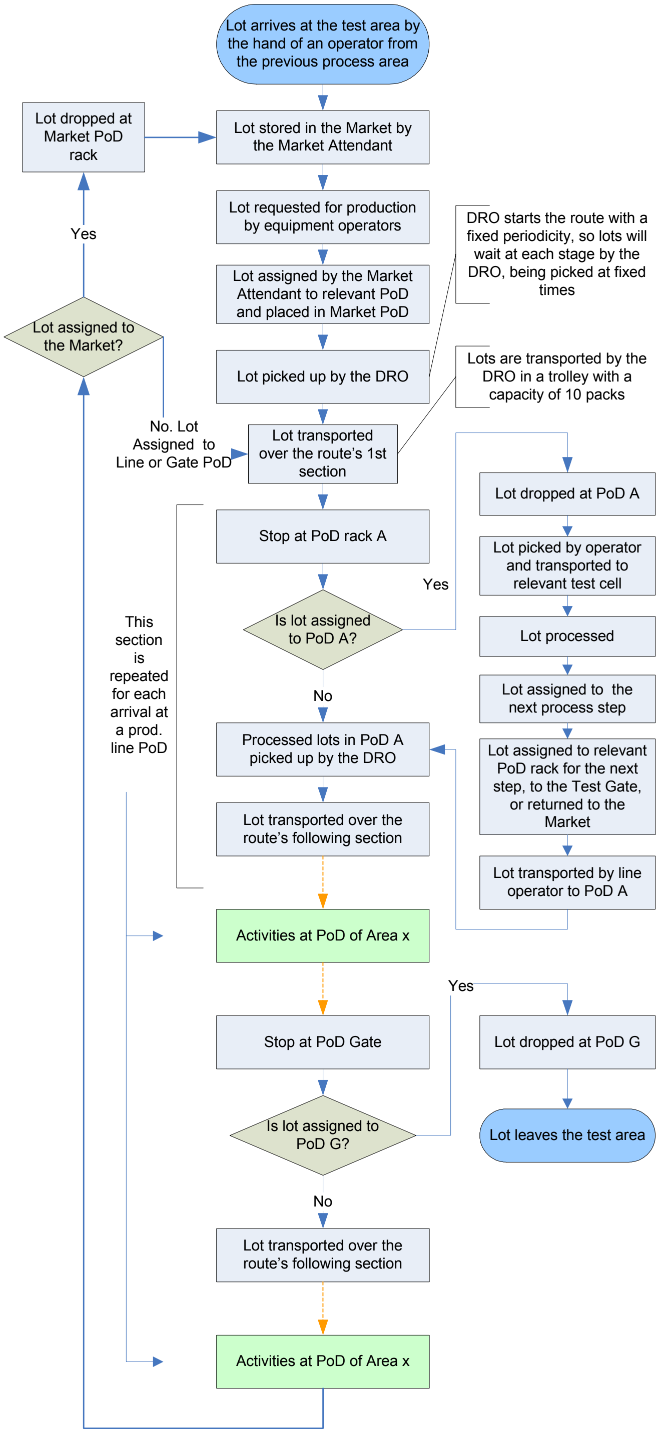


Figure 8: System Flowchart

The relatively small dimension of the Arena simulation model results from a systematic reduction, achieved by building generic "code" that can be shared by several instances of the model. However, the model shows great complexity, using several multidimensional global variables, and using specific attributes to enable the correct identification of entities, even if placed in different stations of the model, simply running the same code (Ferreira et al. 2005). The overall model picture is presented in Figure 9.

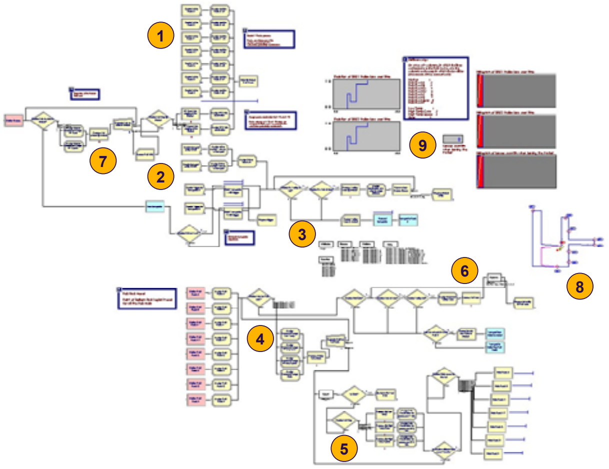


Figure 9 – Arena® Model

The purpose of each of the sections is the following:

1. Create the packs in the first process step (TST1) to be distributed to the lines;
2. Create "DRO entities" and triggers for the route start;
3. Activities at the Market PoD rack;
4. Arrival of DRO at a production line PoD rack (pack delivery);
5. Pack processing and assignment to the following step and PoD rack;
6. Pack pick-up from the PoD rack and DRO departure;
8. Model Animation;
9. Model Data visualization

The animation was kept as simple as possible, mostly for model verification and validation purposes, and was performed using Arena® guided transporters over networks – Figure 10.

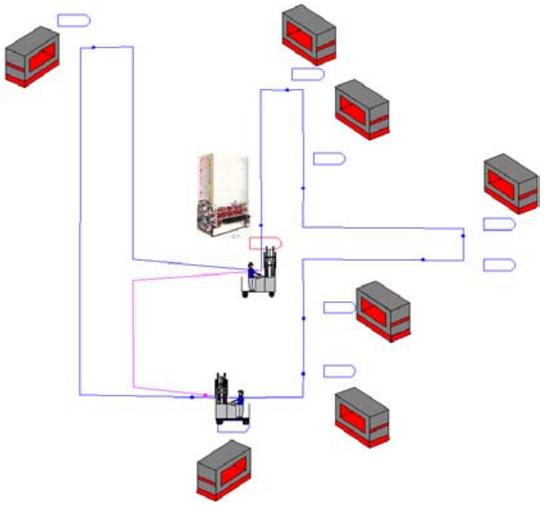


Figure 10: Animation Area Sample Screenshot

## SIMULATION RESULTS

With the purpose of answering the questions mentioned in the previous section, the following scenarios were tested.

| Reference | DRO number | Traveling speed (m/s) | Route frequency by DRO (min) |
|---|---|---|---|
| Scenario A | 2 | 0.71 | 12 |
| Scenario B | 1 | 0.71 | 12 |
| Scenario C | 1 | 0.71 | 10 |
| Scenario D | 1 | 0.71 | 8 |
| Scenario E | 1 | 1.94 | 8 |
| Scenario F | 1 | 1.94 | 6 |

Table 3: Experimental Scenarios

In these scenarios the route design and length was not modified. Scenario A corresponds to the existing system, with the travelling speed resulting from a standard work study. Scenarios E and F correspond to the utilization of an electrical tow tractor. For each of the scenarios, its feasibility was analyzed. A scenario is considered feasible if the packs do not have to wait for a long time to be picked up by the DROs from the PoD racks (reference value is less than 6 minutes) and if the number of packs in the PoD racks does not exceed the current PoD rack capacity of 15 packs. The model was built so that these values are returned by Arena® after the simulation run finishes. Equally interesting to analyse is the transporter workload, which is expected to be low for the current setup, facing the results from the MOS. Several authors addressed the analysis and validity of simulation results, and also the design of experiments applied to simulation exercises (Kelton 1995; Kleijnen 1995). Arena® itself contains features aimed at reducing uncertainty regarding simulation results, such as the Replications and Warm-up period options of the Run setup, but also the half-width parameter presented in the results. Adequate values were considered for these. The results, summarized in Tables 4 and 5, allow us to draw the following conclusions:

- The current scenario (scenario A) allows low queuing times of the lots in the PoD racks, but implies an inefficient utilization of the resources;
- Keeping the actual setup in terms of route frequency and travelling speed, but reducing the number of DROs to 1 (scenario B), is not an option, as the DRO is over-loaded, departing from the Market with the cart full most of the times, and with long waiting times (Figure 11);
- A solution with 1 DRO is feasible when the route frequency is reduced (Scenarios D, E and F); if the traveling speed is increased (Scenario E) the DROs are still under-loaded and if the travelling speed is 0.71 m/s (Scenario D) the DRO is slightly over-loaded;
- Facing the fact that even only one transportation resource is still greatly under-loaded when an electrical tow tractor solution is used (speed of 1.94 m/s), the following options should be considered: using the same resource for transportation activities in the neighbor area (Burn-in); implement a coupled

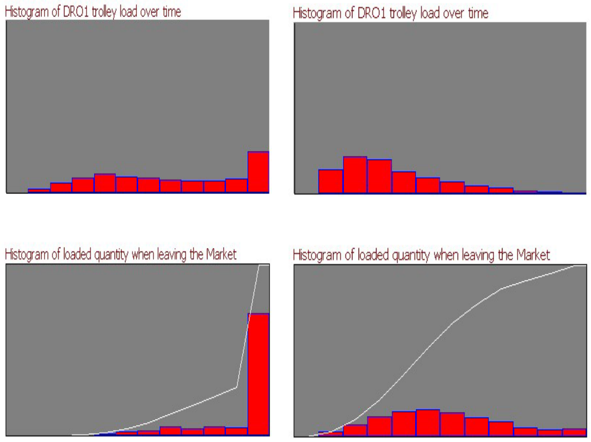
route, in which the DRO performs also the market attendant functions.

| Scenario | Pack waiting time (min) | | Packs in PoD rack | | DRO load |
|---|---|---|---|---|---|
| | avg | max | avg | max | |
| A | 3 | 17 | 1 | 8 | 57% |
| B | 22 | 197 | 4 | 22 | 65% |
| C | 9 | 103 | 2 | 15 | 74% |
| D | 5 | 50 | 1 | 13 | 87% |
| E | 5 | 39 | 1 | 9 | 38% |
| F | 3 | 17 | 1 | 7 | 44% |

Table 4: Experiment Results

| Scenario | DROs | Trolley capacity | Waiting times |
|---|---|---|---|
| A | under-loaded | adequate | very low |
| B | under-loaded | over-loaded | very high |
| C | loaded | over-loaded | high |
| D | slight overload | slight overload | low |
| E | under-loaded | adequate | low |
| F | under-loaded | adequate | very low |

Table 5: Interpretation of Experiment Results



**Scenario B** **Scenario F**

(first column on the left – 0; first column on the right – 10)

Figure 11: Arena® Model Histograms

It was also the purpose of this project to verify the sensitivity of the model to some of its inputs, namely:

- Pack load and unload times at the Point of Drop racks;
- Pack processing times in the 3 test process steps;

To perform this analysis, the following situations were simulated:

- Scenario G: identical to Scenario F, but with pack load and unload delays of 10 seconds instead of 5;
- Scenario H: identical to Scenario D, but with pack load and unload delays of 10 seconds instead of 5;
- Scenario I: identical to Scenario D, but with pack processing times following a triangular distribution (min:0.5; most likely: 3.0; max: 5.5), very different from the current one;

The system was found to be sensitive to variations in the pack loading and unloading time periods. For a situation in which the transporter was underloaded (scenario F), the increase in this parameter from 5s to 10s led to an increase of the transporter occupation from 44% to 66%, while the queue waiting times were similar (in the range of 3.1 to 3.5). For a situation in which the transporter was already significantly loaded (scenario D), the transporter occupation rose slightly from 87% to 91%, but the queue average waiting times increased sharply, from a range of 4.2 to 5.5 minutes, to a range of 25 to 30 minutes, with maximum values ranging from 120 to 210 minutes. Regarding variations in the pack processing times, the system was found to be insensitive. A strong variation of this parameter, considering scenario D as a reference, led to similar transporter occupation (87%) and queue waiting times.

## CONCLUSIONS, FINDINGS AND FURTHER STEPS

This paper addresses a project that consisted of the implementation of a Milk Run Lot Transportation System in Qimonda Portugal Test Area. The target of the project, framed in a Lean approach, was to reduce waste, namely the transportation waste, optimizing the utilization of the test area human resources. The project was triggered by a Multi Observation Study performed in the Test Area which identified that approximately 4.8% of the operators' time was spent in transportation activities, performed in a "taxi" mode. After characterizing the test area and its transportation needs, a milk run system based on a fixed route, with 2 Delivery Route Operators and a Market Attendant, was implemented. Each DRO initiates a new route every 12 minutes, with a DRO starting a new route 6 minutes after the previous DRO started his route. To support this system, and avoid long periods of time between the lot request by the equipment operator and the lot delivery by the DRO, an IT application was developed to support the lot request process. Another MOS, performed after the milk run system was implemented, revealed that the average time spent in transportation by each manufacturing team remained approximately the same, contrarily to the expectations. Nevertheless, the system allowed equipment operators to focus on their activities, as the same MOS reveals, because the indicators related with the availability of operators to assist the equipment improved. Still, the MOS revealed that the system is not optimized and this triggered the development of a simulation study to understand which may be the best setup.

The simulation study, performed in Arena®, confirmed that the current setup allows having fast deliveries of the lots to the lines, with the lots staying for a short time in the PoD racks, but also that the transportation resources are under-utilized. The simulation of other scenarios revealed that it is possible to have a system with just one DRO, under certain conditions. One option is to use an electrical tow tractor, which allows reduction of the travelling time, and increase the number of routes per hour. Simulation revealed that in this situation the transportation resource would be under-loaded as well, what opens the possibility of the same resource carrying out transportation activities in the neighbour area (Burn-in) or of implementing a coupled route. Another option would be to increase the number of routes per hour of the current setup, reducing the interval between route starts from 12 minutes to 8 minutes. It must be taken into account that the latter option would represent a high workload to the DRO, just feasible if there is some rotation of the operators occupying the DRO function along the shift.

The results of this simulation experiment will now be shared with the decision-makers, in order to determine the steps to achieve a more optimized setup, and focus even further the operators on value added activities.

## REFERENCES

Barton, P.I., and Lee, C.K. (2002). “Modeling, simulation, sensitivity analysis, and optimization of hybrid systems”. *ACM Transactions on Modeling and Computer Simulation (TOMACS)* 12(4) (October 2002), 256-289 (ISSN:1049-3301).

Dias, L.S., Pereira, G.B. and Rodrigues, A .G. (2007). “A Shortlist of the Most Popular Discrete Simulation Tools”. *Simulation News Europe*, April 2007, 17(1), 33-36. (ISSN 0929-2268)

Ferreira, L., Pereira, G. and Machado, R. (2005). “Geração Automática de Modelos de Simulação de uma Linha de Montagem de Auto-Rádios”. *Investigação Operacional*, Junho, 25(1), 37-62. (ISSN 0874-5161).

Gahagan, S. M., and Herrmann, J. W., (2001). “Improving simulation model adaptability with a production control framework”. *Proceedings of the 2001 Winter Simulation Conference.* Arlington: ed. B.A. Peters, J.S. Smith, D.J. Medeiros, and M.W. Rohrer.

Harris, C., and Harris, R. (2007). *Developing a Lean Workforce*. Portland: Productivity Press. (ISBN 9781563273483)

Harris, R., Harris, C., Wilson, E., (2003). *Making Materials Flow*. Brookline: Lean Enterprise Institute. (ISBN 0-9741824-9-4)

Hugos, M., (2003). *Essentials of Supply Chain Management*. Chichester: John Wiley & Sons. (ISBN 9780471434290)

Kelton, W.D., (1995). “A Tutorial on Design and Analysis of Simulation Experiments”. *Winter Simulation Conference 1995*: 24-31

Kelton, W., Sadowski, R., and Sturrock, D. (2007). *Simulation with Arena*. New York: McGraw-Hill.(ISBN 9780073259895)

Kleijnen, J.P.C., (1995). “Statistical validation of simulation models”. *European Journal of Operational Research*, Elsevier, 87(1), 21-34.

Nomura, J., and Takakuwa, S., (2006). “Optimization of a number of containers for assembly lines: the fixed course pick-up system”. *International Journal of Simulation Modelling 5* (2006) 4, 155-166 (ISSN 1726-4529).

Ohno, T. (1988). *Toyota Production System: Beyond Large-Scale Production*. Productivity Press; 1st edition. (ISBN 0684810352)

Raposo, R., (2009). “Implementation of a Milk Run Material Transportation System in the Test Area of Qimonda Porto Backend”. Unpublished Thesis, framed in MITPortugal’s EDAM TME Advanced Studies Course, supervised by professors Guilherme Pereira and Luís Dias from Universidade do Minho, Portugal.

Rother, M., and Shook, J., (1999). *Learning to See: Value Stream Mapping to Add Value and Eliminate MUDA*. Brookline, Mass.: Lean Enterprise Institute,. (ISBN 0-9667843-0-8)

Shannon, R., (1975). *Systems Simulation: The Art and Science*. Englewood Cliffs: Prentice-Hall. (ISBN 9780138818395)

Smalley, A., (2004). *Creating Level Pull: a Lean Production-System Improvement Guide for Production-Control, Operations, and Engineering Professionals*. Lean Enterprises Inst Inc. (ISBN 0-9743225-0-4)

Smith, J.S., (2003). “Survey on the use of simulation for manufacturing system design and operation”. *Journal of Manufacturing Systems.* 22(2): 157-171.

Swain, J. J. (2001). “Power tools for visualization and decision making: 2001 Simulation Software Survey”. *OR/MS Today* Baltimore, Maryland: INFORMS. 28(1): 52-63.

Treadwell, M. and Herrmann, J., (2005). “A Kanban Module for Simulating Pull Production in Arena”. *Proceedings of the Winter Simulation Conference. Orlando, Fla. Dec. 4-7, 2005.*

Womack, J., & Jones, D. (1996). *Lean Thinking*. New York: Simon & Schuster. (ISBN 0684810352)

## BIOGRAPHY

**RICARDO RAPOSO** was born in 1975 in Coimbra, Portugal. He graduated in Electrical Engineering in the University of Coimbra, Portugal. Since then he has worked in telecommunications and semiconductor areas, holding positions related to network design and process engineering. He is currently finalizing the TME Advanced Studies Course framed in MITPortugal’s program *Engineering Design and Advanced Manufacturing* area.

**GUILHERME PEREIRA** was born in 1961 in Porto, Portugal. He graduated in Industrial Engineering and Management in the University of Minho, Portugal. He holds an MSc degree in Operational Research and a PhD degree in Manufacturing and Mechanical Engineering from the University of Birmingham, UK. His main research interests are Operational Research and Simulation.

**LUÍS DIAS** was born in Vila Nova de Foz Coa, Portugal He graduated in Computer Science and Systems Engineering in the University of Minho, Portugal. He holds a PhD degree in Production and Systems Engineering from the University of Minho, Portugal. His main research interests are Operational Research and Simulation.