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LESSONS LEARNED ON SIMULATION MODELING FOR MATERIAL FLOW IN OVERSEAS FACTORIES

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ABSTRACT

Simulation modeling of material flow in electronic factories faces additional and specific challenges when the location of the modelers is distant from the plant under study, such as in a foreign country. The main challenges relate mostly with: (i) communication between stakeholders; (ii) commitment to the project versus daily production work; (iii) restrictions on the factory floor; and (iv) financial matters. In this perspective, this paper presents a set of study cases resulted from a few years of experience of a simulation team in modeling material flow on electronic factories. The study compares the insights of simulation between plants located abroad and locally, and also reinforces the importance of involving experts plant operators to produce reliable simulation models in this perspective.

1 INTRODUCTION

This paper presents the experience of a R&D team in simulation modeling. The group specializes in material flow (Wagner & Enzler, 2005) applied to electronic factories around the world for a specific customer. The team started with one person eagerness about simulation to whom such technology could bring benefits to the process and layout of the local factory in Brazil, the main customer of the R&D organization. The initiative, thought, trigged a few years of work on simulation projects (Table 1) object of this paper and presented as study cases.

Table 1: Simulation Projects.

Phase	Projects
1. Initial	• RFID x Barcode distribution center analysis
2. Europe	• Finland – RFID x Barcode distribution center analysis • Hungary o ENO supermarket stock replenishment o ENO supermarket layout o Kanban engine buffer o RFID x Barcode distribution center analysis
3. Brazil	• ATO Supermarket process and layout • Daily employee registration system • Manufacturing CNC line • Assembly to order cell elevator
4. Asia	• South Korea – Number of elevators for new factory • China – Normalized material flow process justification

	• India – Layout adaptation to new normalized material flow process

Those projects are mostly instances of "material handling system" application area (others fall either under "manufacturing system" or "warehousing and distribution system") and can be further classified into "conceptual design", "detailed design" or "fully operational" phases of the modeled system in each case, according to (Ülgen & Williams, 2001) classification.

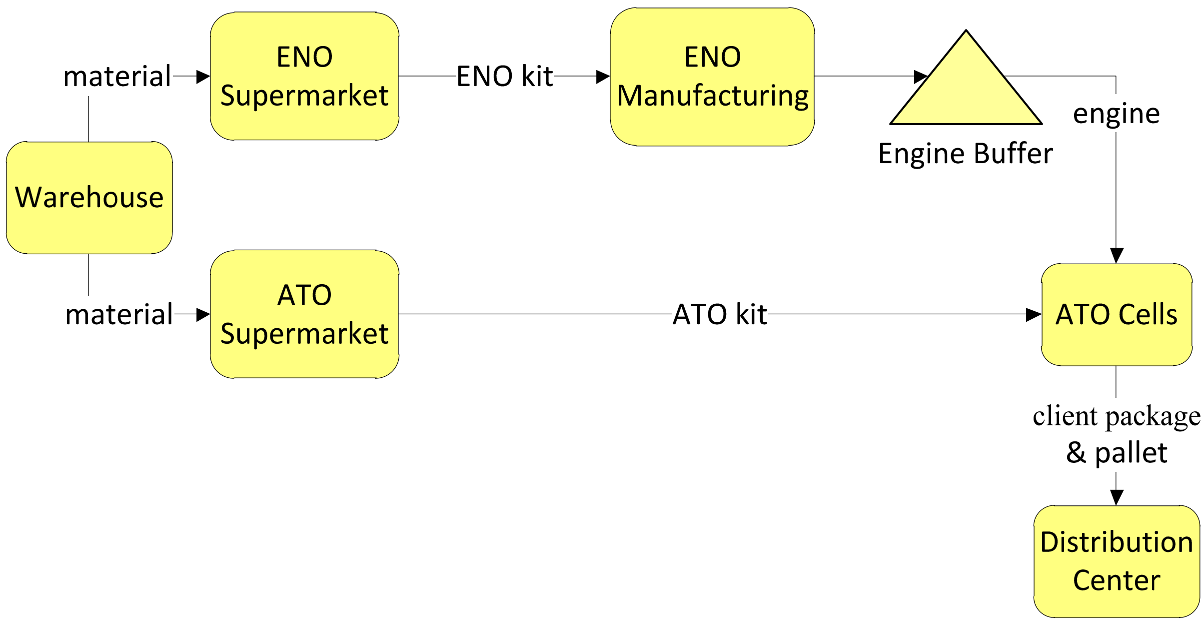

Figure 1: Simplified high level material flow process.

All projects are related to a set of factories located in different countries but owned by the same organization. In a macro sense, these factories follow the same process model, as can be seen on Figure 1, where the built electronic device is called "engine". After production, the engines have to be customized according to customer needs and packed, becoming "client packages", in order to be shipped.

Figure 1 shows that a Warehouse provides material to (i) engine production lines, called ENO – Engine Operation, and (ii) customization & packing lines, called ATO – Assembly to Order. The Warehouse uses separated supermarket areas for ENO and ATO for preparation of material kits (called "kitting") by type of product to facilitate and optimize the material supply. Figure 2 exemplifies the kitting of electronic elements in the necessary quantities to build 50 engines and Figure 3, on the other hand, exemplifies the kitting of packing parts to mount 50 client packages.

The ENO Supermarket delivers to the ENO Manufacturing which produces engines and feeds them to the Engine Buffer. The ATO Cells get the engines from Engine Buffer and the customization/packing material kits from ATO Supermarket to mount the final "client package" and assembly the pallets which go to Distribution Center to be shipped to the client.

Based on the high level process presented on Figure 1, the following sections presents: (i) the main assumptions and challenges for running the projects, like financing, customer commitment and project communication; (ii) a summary of the projects with focus on objectives, challenges and results; and (iii) the study conclusions.

To ease the understanding, the studied projects were divided in four groups or phases (Initial, Europe, Brazil and Asia at Table 1), not always presented in chronological order. During the projects execution, the team went through great experiences and learned important lessons regarding simulation technics and simulation projects management, which are highlighted in the document.

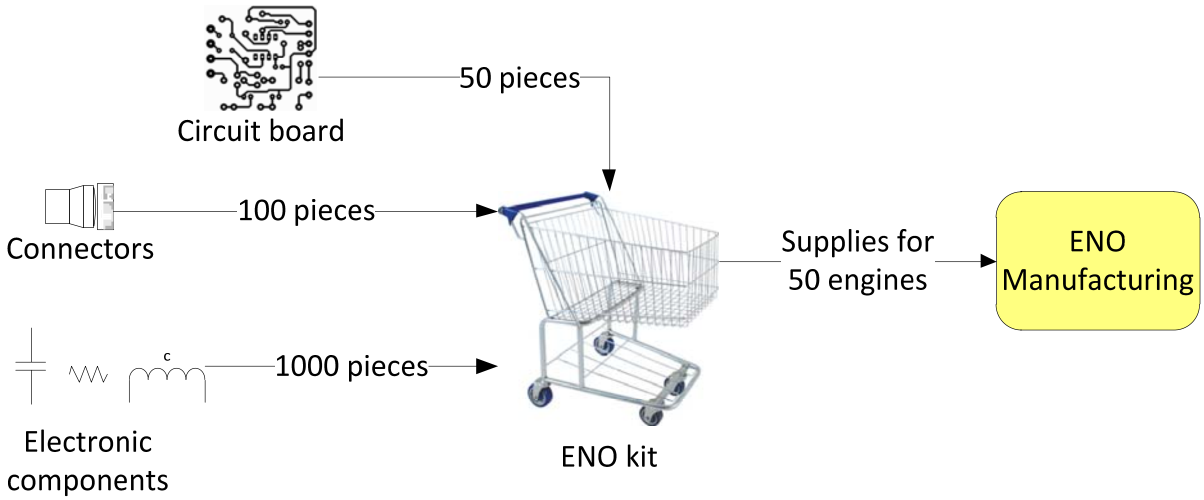

Figure 2: ENO kitting.

Figure 3: ATO kitting.

2 ASSUMPTIONS AND CHALLENGES

This section discuss the main assumptions and challenges of the studied cases in the perspective of international simulation projects. Other assumptions, not related to the international aspects, shall be analyzed in another opportunity.

2.1 Government financing

The projects on phases 1 to 3 on Table 1 were financed through a Brazilian tax exemption program, budget granted to the local manufacture in Brazil by a federal incentive law. Initially the project funding could be used for projects on any site, but, by a customer strategic decision at the end of phase 2, these funds would rather be used only in the Brazilian factory, motivating phase 3.

Phase 4 comprehended more robust simulation studies than the ones performed before. The team, by that time, had gotten enough experience and detailed knowledge about the customer processes and, since the governmental benefit was halted, the customer funded the simulation services directly.

2.2 Customer commitment

Assuming "business process" and "statistics distributions" as the minimum information to develop a simulation model for material flow (Kühn, 2006), the quality of project results always depended of customer commitment in the provision of a) objectives definition, b) general explanations, c) process details and d) data used for statistical distributions determination.

Soon, the team realized how important was to travel to the customer site to perform the necessary investigation for building the simulation model. In most cases, the project management role could be done remotely, but the technical team had to have face-to-face gatherings with the involved personnel, especially with the operational ones (the experts).

Certainly for this particular customer, but probably for any customer as well, on factory floor process investigation, you have to go to the factory´s floor and talk to the experts (Li & Meerkov, 2009). Other option to consider would be the usage of technical documentation, but you can´t depend on process documentation from factory floor, The experience shows that such documentation are usually outdated or prepared without the required care or manipulated by the author for some reason. Neither you can count on managers as the only source information when they are not directly involved with the operation since, in general, they miss key details for simulation production.

Therefore, to perform simulation modeling of material flow on factory´s floor, you have to interview the experts. However, these people are always engaged with the production itself, being hard for them to stop and provide enough information for model development. To achieve stakeholders commitment with the task in hand and collect the needful information, it takes a clear order from direct management and regular follow ups about the importance of supporting the modeling project.

In our study cases, the commitment history typically happened as follows:

- At the beginning, the project manager and the customer agreed to the project scope and objectives. However, the customer is represented by a factory manager not directly involved in the operational task. Then, at the first team meeting which includes the actual experts, the project objectives had been substantially modified, caused by key points raised by these experts.
- To acquire the current business process from operational people is not a difficult task. The interviewed expert knows very well what he/she is saying because it is his/her day by day job and he/she is glad to talk about that. At this time he/she believes the simulation results are going to bring considerable benefits to his/her work, as stated by Roberto Lu in (Ülgen, Bury, Lu, Edward, & Wood, 2010).
- To acquire data for statistical distribution is different. Usually the expert doesn't have the information on hand and he/she relies on extracting a report from a system, consequently depending on IT and infrastructure. On other words, it involves another sector with other priorities, operators and manager. When that happens, the interviewed frequently "promises the information for soon", but he/she is busy (even more busy than usual, since he is supporting the simulation project) and the data promised goes to the bottom of his/her stack of daily priorities. It takes time to get an answer because it has low priority until a manager intervention happens. At that time, the operational people involved usually change their mind and start to have doubts about the importance of simulation, a common reaction as indicated by Scott Bury in (Ülgen, Bury, Lu, Edward, & Wood, 2010).
- In some cases the required data doesn't exist, demanding manual intervention for measurement. During the first projects, the simulation modelers made the measurements by themselves, but soon they figured out that it takes too much time, especially when they are abroad and each added project hour increases overall travel costs. Since measurement tasks don't require skilled knowledge (a high school student well trained and with a chronometer could do), the customer could easily be put in charge of that task. Experience showed that asking the customer to provide the measurements only worked when the simulation team supervised it. Also based on the studied cases, leaving the customer alone on this task, usually results on collecting of quickly average

numbers with poor information for statistical distribution preparation. So, it´s beneficial to plan that the measurement task happens during the simulation team´s visit of the factory.

2.3 Project communication

Communication is an important matter in any project (PMI, 2008). In projects managed and executed remotely, communication is vital (Mills, 2012), especially considering issues like language barriers, culture differences, need of conference calls on different time zones, reporting, written registers, etc. Particularly for the projects from our study cases, communication issues identified beyond the usual ones were:

- Project management issues:
  - The project manager shall identify as soon as possible the main customer and key stakeholders and work close enough with them to mitigate any communication issues, looking for the best communication tools tailored for that particular project. Not an easy task to achieve on remote projects.
  - Delay of customer to provide information for project planning at the beginning, resulting on a shorter time window for execution. Frequently those two elements result on an overload of work for the modeling team at a certain point.
  - Difficulty to define what to simulate. It is usually hard for the customer to understand how simulation modeling works (Harrison, Lin, Carroll, & Carley, 2011) and it takes time to have reasonable agreement about what to simulate. In some cases, the scope of the required simulation was too extensive, generating complex model and bringing less results than expected.
  - Difficulty to agree within the simulation team on the size (effort and time need for execution) of project tasks when these tasks are related to new elements. It usually happens when the team elaborates tools (spreadsheets) for static simulation/optimization studies.
- Difficulty to show the simulation running – usually the simulation results are shown by tables, charts and conclusions from that. In most cases one report with the related explanation would be enough, but the animation model has also to be provided. Under material flow (Wagner & Enzler, 2005) usually the animation runs over the CAD (Dieter & Schmidt, 2012) factory floor layout. The first visualization of animation by the customer usually brings nice comments ("wow", "look my sector running…", etc.) even if it doesn't contributes much to the result reporting itself. Since the animation is an important marketing tool for the simulation model, it is worth showing the animation to the customer at least once. However:
  - Running the animation in a conference call usually doesn't work well, unless everybody on the meeting have a very fast internet connection which is seldom the case.
  - Providing a pre-recorded video of the animation may result on a file too large, which may not have proper resolution and limiting the explanation flow/interaction.
  - Providing the original model and instructions to run it could be an option, but in general the customer doesn´t have the required software license. In the case of Arena (Kelton, Sadowski, & Sadowski, 2000), a discrete event simulation software used on the study cases, it requires boring installation tasks[1], which results on the stakeholders giving up after the first attempt and looking only the table/reported results.
  - Best option would be to present the project results and animation face to face, which would require additional travel costs when related to factories overseas.

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[1] Installation of the Arena, installation of another application to inform the license number used to build the model, run the license application, set the license, run the Arena, learn how to use the Arena in the model, etc.

2.4 Factory floor restrictions

In the case of factory floor, some restrictions and issues to be considered on international simulation projects are:

- As mentioned on 2.2, material floor analysis requires support from operation experts, concurrent with his/her daily work.
- The modeling team may face security barriers to enter in the factory with equipment (cameras, chronometers, laptops, etc.) to make measurements or register information, possibly delaying their stay on site.
- It is required to find the factory fully operational on the period of measurement in order to produce a good mass of data.
- In general data requests to the operation support takes more time to be answered than what was originally expected.

3 THE STUDY CASES

This section presents the objectives, key results and lessons learned on the Table 1 projects in the context of being executed remotely abroad.

3.1 PHASE 1: Initial learning

The team started a simulation laboratory by acquiring a license of Arena (Kelton, Sadowski, & Sadowski, 2000) and training of a limited number of personnel on this tool. It was, then, agreed that a pilot project would model the distribution center of its local factory in Brazil to analyze the costs and benefits of implementing an RFID system (Glover & Bhatt, 2006) to replace the bar code technology (Palmer, 1995) on the identification of client packages in the distribution center of the plant in Brazil.

Challenges:

- It was the very first simulation project executed by the team. There were a lot to learn, including how to design the model, how to extract the process from experts, which data to get or measure, how to get data, how to perform measurements, how to implement the model using the Arena tool, how to deal with the customer.
- It was hard for the team to understand the organization of the distribution center, consequently hard to draw the process and define the data to be used. The complexity of the organization, lacking detailed documented processes, made it harder. Lack of experience of the simulation team on the involved business terms and elements increased the challenge.

Results:

- The simulation presented benefits regarding "time saving on process" in the replacement of barcode by RFID.
- Costs were not considered in the simulation.
- System was not implemented since it required deeper investigation on costs and global directions instead of setting a local initiative.

3.2 PHASE 2: Europe

On phase 2, a trained team performed simulation modeling for factories in Finland and Hungary.

3.2.1 Finland

On the second project, the team was allocated to develop the same study of barcode being replaced by RFID in product identification, but for the distribution center of a factory in Finland.

Challenges:

- Even working in the same theme, the environment was quite different, which impacted the development of the model, when considering the factory floor space, process particularities, operators training, support equipment, access to data system like SAP (Muir & Kimbell, 2009).
- To acquire the required measurements, the team decided to measure directly and ended not using the support from the involved experts.

Results:

- Given the lessons learned during the previous project, and considering that the process at this site was very clear, lean (Dennis, 2002), and the data were easier to obtain, the project had achieved good results in a reasonable time.
- The transition from barcodes to RFID tags was not recommended because of high costs on equipment at that time and not enough savings in process time.

3.2.2 Hungary

With more confidence after the first projects, the team developed some simulation models in Hungary, performing layout adequacy and use of resource analysis to investigate the fact that the factory was doubling its capacity of ATO cells which would affect some related sectors as:

- ENO supermarket (Figure 1) stock replenishment which needed analysis of stock replenishment to estimate capacity of operators. The demand was simulate and compare two scenarios of stock replenishment in the engine operation area, presenting the average occupancy of operator; replenishment cycle time by cluster; and number of replenishments by factory shift. The stock replenishment is responsible for replenishment of ENO cell, return material handling, and tray handling.
- ENO supermarket layout which needed to calculate the kitting (Figure 2) lead time in a new ENO supermarket layout. The demand was simulate the future new layout for the ENO supermarket area, comparing the average kitting lead time for two different kitting patterns.
- Kanban engine buffer which would need to understand a kanban (Ohno, 1988) behavior on ATO supermarket (Figure 1). The demand was to simulate a kanban model for ATO supermarket material replenishment, identifying average lead time and average operators occupancy for high, middle and low demand.
- Distribution center which "client package" barcode identification model would be compared with a RFID identification one. The demand was to present the comparison between RFID and Barcode identification in the different areas of the distribution center. The study was similar to Finnish and Brazilian distribution center's previous studies.

Challenges:

- The first challenge was the planning phase. The project manager tried to get detailed requirements and some data so the simulation team would arrive well prepared at the factory and with part of the work previously done, but that was not possible. That resulted on overloaded team on the site, since they had to prepare the plan with less involvement of the project manager who was working remotely. That caused several hours of after hours and weekend work in order to meet the schedule. The information requested to the customer before the trip was:
  - Draft of the process design,
  - Pre definition of which data would come from a system or manually measured,
  - List of stakeholders and communication planning,
  - Factory schedule checked to avoid lower production weeks.
- During one of the trips to the factory, it was under low production, impacting the measure sampling and consequently generating poor statistics distributions.

Results:

- The results of simulations and comparisons for Hungary plant were informed to the customer and it seems that they were satisfied with the outcome, but the simulation team didn´t get access to their final decisions neither got the information of what was effectively implemented due to business confidentiality.

3.3 PHASE 3: Brazil

On this phase, the team worked on reengineering the Brazilian factory process to become cleaner and less expensive, through process improvement, material flow improvement and optimization in the use of plant resources. It required a series of punctual simulations.

Projects in Brazil, which were local, had the same difficulties that the projects abroad, such as difficulty to define the scope, difficulty on obtaining timely data and validation of results, caused by low commitment of experts with the simulation project due to the operation overload of the plant. Nevertheless, communication was easier. The customer proximity facilitated communication, but on the other hand, there was no urgency to force the projects to generate solutions quickly. To improve the results the team used Scrum (Quaglia & Tocantins, 2011), an agile methodology (Cobb, 2011) based on software production, to run most of projects.

3.3.1 ATO Supermarket process and layout

Development of new process and layout for Brazilian ATO supermarket based on lean principles (Dennis, 2002). Also, prove the new supermarket efficiency by simulating to analyze the workload of

- Supermarket operators, responsible for kitting (Figure 3) and taking the kits to ATO cells,
- Supplier operators, responsible to take material from warehouse to supermarket.

Challenges:

- The regular difficulties mentioned on 3.3.

Results:

- The simulation proved the efficiency of the process.
- Process was implemented as suggested.

3.3.2 Daily employee registration system

Impact analysis of a new employee registration system implementation in the factory required by new federal governmental regulations.

Challenges:

- It was not a process or technical issue, but it would affect most of the thousands of factory employees and interfere in the factory layout as a whole.

Results:

- Developed a simulation model of factory floor with about 20 registration machines strategically distributed in the plant for register of entry and exit of the operational employees considering the 3 factory shifts.
- Since the factory operates in shifts and the employees enter and leave the factory at the same time, the location of the machines were calculated to avoid bottlenecks in the movement of employees and to minimize the stay of them inside the factory.
- The registration system was implemented as simulated.

3.3.3 Manufacturing CNC line

Identification of the operators workload in a case of an CNC machine (Overby, 2011) that operates on both sides of the engine circuit board (the same circuit board enters twice in the CNC) instead of only one side by machine.

Challenges:

- The expert from the customer assigned to support the project was quite busy at the time causing long delays to validate the model.

Results:

- The simulation presented reasonable options to use the operator in the CNC system,
- Even though the solution was positive for the two-sides operation, it was not implemented immediately due to operational restriction at that time, and the results saved for future implementation.

3.3.4 Assembly to order cell elevator

Determining the number of elevators required to attend a set of ATO cells located in a different floor from the ATO supermarket and from the distribution center. Material and products, following a regular demand, should use an elevator to reach the ATO cells or the distribution center.

Challenges:

- The regular difficulties mentioned on 3.3.

Results:

- Developed a simulation model to identify the number of ATO cells that only one elevator could support in case of average demand.
- Before the simulation, the customer thought it was necessary to have two elevators for the expected demand, but simulation showed that one elevator was enough.
- The implementation followed the simulation results with one elevator and the number of operators specified.

3.4 PHASE 4: Asia

As said on 2.1, the Asia projects were paid by customer as service, not using governmental incentives. On this situation, it was clear that the customer was expecting results more emphatically than in the previous projects.

3.4.1 South Korea

Simulation of a future plant in South Korea which would substitute an older factory. The model should include the entire plant, from the warehouse to the distribution center (Figure 1), with a special situation of being a 4-storey building. The source material, engine boxes, pallets of products, leftovers and the staff should travel between the levels using elevators to perform the factory material flow. The goal was to elaborate a few layout scenarios for each floor and identify the appropriate number of elevators to support the entire operation.

Challenges:

- At first, the strategy was to work remotely to acquire information and conduct the study, thereby reducing travel costs. That was a nightmare to the simulation team until a high ranked manager from the customer cleverly concluded that it was too risk. He demanded a workshop in the plant site with their managers and the project team. It was a fortunately decision, but it happened late on the schedule and the team had lost precious time before the workshop, since it was not possible to move the project deadline.
- Everyone on the client side, from managers to operators were highly committed to the project, giving the necessary support. Even so, the execution time of the project was too short causing overload of activities affecting the simulation team.
- It was then noticed that the used software tool, Arena (Kelton, Sadowski, & Sadowski, 2000), brought challenges to the work sharing, since the model as a whole has to go to a single file, making it difficult to have more than one person working on the same model.

Results:

- At the end the team provided valuable results, including:
  - The required layout scenarios,
  - Results from static simulations, mostly regarding elevators workload and bottleneck studies on trolley movement,
  - List of factory floor insights regarding material flow.
- Some dynamic simulation models (discrete event simulation) were also developed which ended being too extensive, demanding too much information and providing little valuable results.
- A list of potential simulation initiatives emerged from this study, which may encourage new projects in a near future.

3.4.2 China

The customer was normalizing the material flow process in its factories around the world. Unlike the others, the Chinese factory had particularities regarding its warehouse and manufacturing facilities being in separate buildings which could doubt the value of implementing the new standardized process in this factory. Thus, the simulation model developed compared the current process with the normalized to justify or not the process change.

Challenges:

- Very short time for project execution, and lack of communication about requirements caused results not as completed as desired.
- The customer was well-advised about the high risks of the project before it started and opted for the project execution. It might not have been the best decision for the simulation team to accept the project.
- The team changed its simulation tool for discrete events, from Arena (Kelton, Sadowski, & Sadowski, 2000) to Simio (Kelton, Sturrock, & Smith, 2010) to allow the distribution of the modeling work.
- The team was again overloaded, suffered delays for lack of data, had to deal personally with stakeholders having restricted support from project manager who was working remotely.

Results:

- It was concluded that the new normalized process would bring more costs to this factory, so it was advised not to change the process. The customer was not fully convinced of the results, accepting it with restrictions.

3.4.3 India

The goal was to adapt the factory layout to better suit the new normalized process for material flow mentioned on the previous section. The team should formulate different scenarios, simulate and compare the best ones, attending the production demand and minimizing the costs.

Challenges:

- At first, it was a motivating project. A sightly case with enough time for planning and execution and an experienced team, therefore, a motivated group. Everything was indicating that there would be no problem to manage the project remotely. But, when the team was working on the site, things didn't happen as expected/planned: the required information came with serious delays, incomplete or with low quality. This led to the interruption of the project before conclusion. Possibly, the project could have had a different conclusion if the project manager was present to handle the project issues at the factory, but it was not possible to send him to the site on time due to entry visa issues.

Results:

- Project was interrupted before any conclusion.

4 CONCLUSIONS

This paper describes briefly the experience of a simulation modeling team which started from a researcher initiative and developed into a team´s successful portfolio of simulation projects with international scope. Although the overall findings on that experience reinforces most of the critical success factors discussed in (Ülgen & Williams, 2001), the case studies presented focused on the communication and remote project management aspects, from which some observations were extracted as the key lessons learned, as follows.

On simulation of material flow on factories of electronics, the involvement of operational people in the model production is essential. However, on today's industrial competitiveness, the experts in the factory operation are always busy with the production becoming hard to get their support. This situation becomes more critical on simulation cases being developed on factories abroad.

Project management being done remotely is a suitable option for material flow simulations abroad, but there are potential situations that can happen and they are hard to forecast. They include cultural and technical situations which can have bigger effects than usual since the manager are not able to have face to face interaction with the main stakeholders who possibly he/she hardly knows.

In some cases, it might become expensive to present simulation results to customer because the regular strategy is to spend the first period with customer collecting information, then developing the model with little communication with customer, presenting the results at the end, a waterfall approach. On this approach, either the team spends the whole project time on the customer site or the development is done remotely with one team member returning later (another trip) to present results. A cheaper option would be present the results remotely, but this would have to handle presentation limitations, especially regarding the display of the animation part of the simulation.

Material flow requires a large amount of information mostly referring to process and measurement data, which usually involves more than one sector (business and TI at least) in the factory. This situation brings more key persons involved in the project and consequently more risks to the project. The risks are even bigger at the case of projects abroad. Usually, the risks are reflected in delays in the project.

It´s recommended that the simulation team supervises the data measurement done by the customer in order to get more useful/reliable data. Other option would be to require the simulation team to perform the measurements and get exactly what they need, but it is usually an expensive solution particularly on simulation involving plants abroad, since the measurement takes considerable time.

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