OPTIMIZING A HIGHLY FLEXIBLE SHOE PRODUCTION PLANT USING SIMULATION

F.A. Voorhorst [(a)], A. Avai [(b)], C. R. Boër[(c)]

[(a)]HUGO BOSS Ticino SA, Coldrerio, Switzerland
[(b)]Technology Transfer System, Milano, Italy
[(c)] CIM Institute for Sustainable Innovation, Lugano, Switzerland

[(a)]Fred_Voorhorst@hugoboss.com, [(b)]Antonio.Avai@ttsnetwork.com, [(c)]Claudio.Boër@icimsi.ch

ABSTRACT
This paper explores the use of simulation for the optimization of highly flexible production plants. Basis for this work is a model of a real shoe production plant that produces up to 13 different styles concurrently, resulting in maximum 11 different production sequences. The flexibility of the plant is ensured by organizing the process in a sequence of so-called work islands, using trolleys to move shoes between them. Depending on production needs one third of the operators are reallocated. The model considers the full complexity of allocation rules, assembly flows and production mix. Analyses were performed by running use cases, from very simple (providing an insight in basic dynamics) up to complex (supporting the identification of interaction effects and validation against reality). Analysis gave insight in bottlenecks and dependencies between parameters. Experiences gained distilled in guidelines on how simulation can support the improvement of highly flexibly organized production plants.

Keywords: shoe plant simulation, production mix, labour allocation

1. INTRODUCTION
Discrete event simulation has been widely used to model production line (Roser et al. 2003) and to analyse its overall performances as well as its behaviour (Boër et all. 1993). For the most part, past models have concentrated on the mechanical aspects of assembly line design and largely ignored the human or operator component. (Baines et all. 2003). The simulation model, presented in this paper, was developed in Arena (Kelton et all. 2003) and it augments the standard production system model to include labour movements and its dynamic allocation many times per shift.

This paper describes the experiences and findings in using discrete event simulation as tool to better understand a plants dynamic behaviour prior to optimization and further improvements

The remainder of this paper is organized as follows: in section 2 a short description of the problem is presented and section 3 gives an overview about the actual system to produce men shoes. Section 4 provides a description of all the modelling and implementation issues to be faced in order to get a simulation model with a correct detail level. In section 5 the results are presented and conclusions follow.

2. PROBLEM DESCRIPTION
The challenge we face is to better understand the dynamic behaviour of the shoe production plant in order to be able to predict the daily volume and as basis for improvements to obtain a more fluent production. Actually there are many factors influencing these aspects, such as labour availability and allocation of operators, availability of lasts and, clearly, the composition of the daily production plan, the so-called production mix. The production process has almost 40 different operations, grouped in work islands, to which approximately 70 operators are allocated. The production plant can work on more then 100 shoe variants, each one different in production routing and/or cycle times for operations.

The main goal of this project is to identify the scenarios under which the system breaks down (production target is not achieved) in order to evaluate the impact of key factors such as production mix and labour allocation on the overall performances. The theoretical target productivity is about 1.700 pairs of shoes per day. However in the real system, daily through-put is not constant and shows large variations, sometimes 25% below target value.

3. SYSTEM DESCRIPTION
The actual production plant assembles high quality man shoes in various colours, mainly of 3 different families:

1. Shoes with glued leather sole
2. Shoes with stitched leather sole
3. Shoes with rubber sole

From the 3 families the production processes of 50 shoe styles were modelled, amounting in 11 different process sequences (differences due to colour are not included).

The organization in work islands makes the production a very flexible system, both in terms of product types and capacity allowing the possibility to maximize through-put while minimizing investment such as the total number of lasts per style needed. At any point in time there are up to 13 different styles in production, each needing a specific last model with a significantly different (between families) or a slightly different (within one family) production sequence. In addition, shoes of the same style can have different colours, such as black, ebony, brown, grey, white, etc. which have an additional impact on the production sequence.

The production plant, organized in a circular fashion, is split in 2 main departments:

- The assembly department where shoes are assembled by means of last starting from upper, sole and insole, as it is displayed in Figure 1.

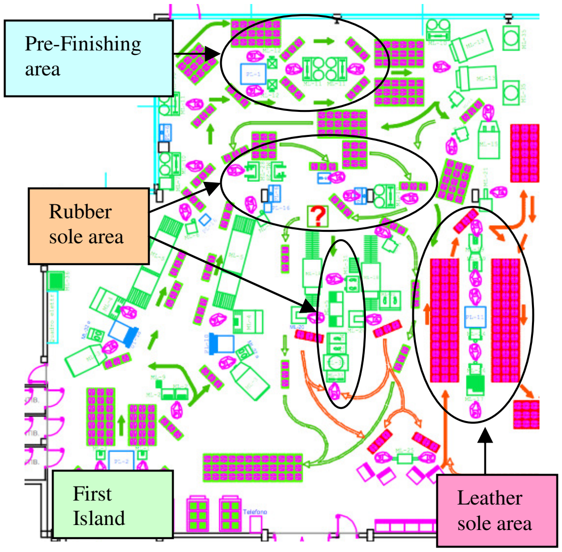

Figure 1: Layout of assembly department

- The finishing department, see Figure 2, where shoes are creamed, brushed, finished and packaged.

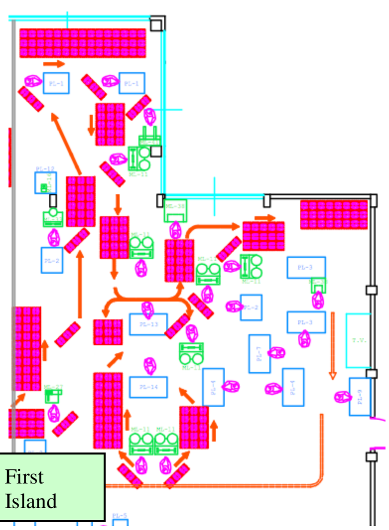

Figure 2: Layout of finishing department

Each department is organized in different working islands, by grouping one or more machines and working positions. Furthermore, as shown in Figure 1, in the assembly department, 3 macro areas, to which a single team is assigned, can be identified:

1. The pre-finishing area, composed by 3 islands, where the leather upper can be aged, daubed of cream and brushed.
2. The rubber sole area, formed by 7 islands where rubber soles are glued and coupled with shoes.
3. The leather sole area, composed by 4 islands where shoes, with leather soles, are stitched.

The rubber and leather sole areas are crossed only by some shoe articles, so workers are allocated only when some trolleys are waiting to be worked.

Shoes move from one island to the other by means of trolleys, moved by workers. In general an operator takes a waiting trolley, performs an operation to each shoe on the trolley and pushes the processed trolley to the waiting area for the next island. There are 2 trolley types:

- Assembly trolley: each one holds uppers, with the respective lasts, soles and insoles. They are used only in the assembly department.
- Finishing trolley: it transports shoes trough the finishing department.

The number of assembly and finishing trolleys is limited in order to keep constant the flow of shoes but, on the other hand, it can have a negative impact on the through-put. If many trolleys are stacked up in different positions, there are none available to be loaded with new shoes. Better production fluency is achieved when the length of trolley queues are minimal.

4. MODELLING ISSUE

This paragraph describes the simulation architecture as well as all the relevant aspects analyzed during the modelling and simulation model deployment phases.

The applied methodology follows a top down approach: first, the flow of shoes in the production plant has been simulated, and it has been refined adding details and rules by means of several meetings and interviews with foreman and production responsible. Then, the rules dealing with the production batches composition and dispatching have been modelled and tested. Last, the dynamic behaviour of labour allocation between different islands and inside the 3 macro areas has been simulated. It was assumed that operators have equal skills and are interchangeable. Furthermore, an extensive campaign to measure cycle times by direct observations was carried on.

4.1. Simulation architecture and input data analysis

The simulation model is driven by 3 Excel files with the following input data:

1. The production mix, in terms of shoe articles, quantity and colour to be produced
2. The assembly sequence per style along with stochastic cycle times for each operation
3. Several parameters related to the process together with the distances between islands

All these data are automatically imported in the simulation model at the beginning of each run.

For the stochastic cycle times a triangular distribution was used. (Chung C. A. 2004)

4.2. Simulation of shoes flow

A particular attention was kept to simulate the following issues that are described in the next 2 paragraphs:

- The input buffer policy in each island
- The trolley selection and dispatching rules at the roughing island

4.2.1. Input buffer policy

Every island has an input buffer where trolleys are stacked up if they cannot be processed immediately. These buffers are simulated as queues following the same policy except for the last removing island.

The defined policy for a queue is as following: each coming trolley is ranked based on its order number and, then, it is released following the FIFO rule (first in – first out) when the machine is free. In this way, each island tries working together all trolleys with the same order number.

At the last removing island, lasts are taken out from the shoe and put back into baskets. To minimize the number of baskets being filled in parallel, the last removing island does not follow the FIFO rule. Instead, trolleys are worked on last codes. This ensures a minimal change in baskets as large numbers of the same last are processed in one batch.

4.2.2. Trolley selection at roughing island

All worked shoes have to be roughed in the roughing island then they pass trough a reactivation oven where the cement is reactivated and, eventually, sole is applied to shoe bottom and pressed. There are 2 reactivation ovens for shoes with leather soles and one for rubber soles. In order to reach the productivity target and to keep the number of workers involved in the mentioned processes as small as possible, the worker at roughing island follows some rules of thumb to decide which trolley to take out from his/her queue, work it and move to the right reactivation oven.

The main issue in the modelling phase was just to understand the basic lines followed in this decision process and then to clearly define the several rules of thumb.

By means of direct observations and interviews with foreman and workers staffing the roughing island as well as reactivation ovens, it was found out the second reactivation oven for leather sole is switched on when

- The amount of stacked up trolleys at first oven for reactivating leather sole is greater then a certain threshold
- The oven for activating rubber sole is switched off.

Once it's switched on, it should work for about an hour and then it is switched off again.

Generally, more then 10 trolleys with different shoe articles are staked up at roughing island. Many times during a shift, the worker in this island has to decide when the second oven for leather sole has to be switched on, which and how many trolleys sent to it, or, vice versa, when the oven for rubber sole has to be activated.

The selection process is triggered by 2 events:

1. If some trolleys, holding shoes with rubber sole, are waiting at the roughing machine, they will be worked if the queue at oven for rubber sole is very short. This kind of process goes on until the queue at first oven for leather sole is long enough to avoid its stopping.
2. If no trolleys, holding rubber sole, are waiting and the queue at first oven for leather sole is too long then the selection process is a little bit complex. The basic idea is to try to work at roughing machine a certain amount of trolleys holding the same last in order to reduce the number of set up at roughing machine and to keep on the second oven for leather sole for an hour, at least. This area could become a candidate to be investigated by means of simulation to improve system performances.

Furthermore, when too many trolleys are staked up at this island, another manual roughing machine is activated for about an hour staffed by an operator to reduce the length queue of waiting trolleys.

4.3. Production batches composition

A *production batch* represents a single lot put in production at the same time in order to use the available lasts efficiently. It can be composed by one or several orders of different shoes but using the same last code to be produced. The *batch size* represents the amount of lasts used for each production batch.

At the very beginning of the simulation, the whole production plan is examined to aggregate sequential items with the same last code and to disaggregate items with ordered quantities greater than the number of available lasts. In the first case, the aggregation mechanism is mainly based on *homogeneous batch concept*: the basic idea is to create batches, using the same last code, with a similar size. In the latter case, orders with big quantity are split based on

- Available last
- Homogeneous batch as mentioned before.

A split order is put in production again when, at least, there is a certain percentage of available last in the stock again compared to the batch size.

4.4. Simulation of dynamic labour reallocation

Workers are re-allocated many times during a shift mainly because:

- The amount of available labour is less than the actual working positions
- Some shoe articles have long cycle times for some operations/islands and the number of workers allocated to these islands have to be increased to avoid queues

The decision on how to allocate labour takes into account many factors such as:

- Batch size
- Assembly sequence and cycle times
- Work already in process
- Last availability
- Labour availability
- Skill of each worker

By changing the schedule it is possible to influence the labour need. In the real system, the production responsible can modify the schedule based on the actual situation in production. This is done in order to increase flexibility in labour management, and to avoid trolleys being stacked up in front of some islands. This supervisory behaviour is discarded as it is beyond the scope of this project and the simulation strictly follows the schedule.

The first step to simulate the dynamic labour reallocation was to understand the general principles and rules applied by the production responsible and model them in a formal way. In particular, the following items were defined:

- The decision events: when decisions on labour reallocation have to be taken
- The worker allocation or de-allocation rules for each decision moment

In general, labour allocation rules can be applied during these four specific decision moments:

1. When a new item arrives to an island with no worker available
2. When a queue of an island is getting too long
3. When an island has no item to be worked
4. When a worker has completed a certain number of trolleys

In the first two moments, an available worker has to be moved to the needed island, in the third case, an operator becomes available to be moved and in the last case a worker is eligible for transferring.

4.5. Labour allocation modelling

About 65% of available workers have a fixed position. In both assembly and finishing some work islands are continuously staffed whereas others are not. The remaining flexible workers are assigned depending on the production needs. In the simulation this is modelled by grouping the flexible workers in a single pool, and allocating them according to rules reacting to the first or second event, as mentioned before.

An operator, if available, is taken from the pool immediately when an island ‘requests’ an operator, for example when the number of waiting trolleys exceeds a specific amount. When there are no workers available in the pool, 2 different situations have been simulated:

1. If the requiring island belongs to a macro area, as mentioned in the paragraph 3, an operator, working in the same area of the empty island, can be shared: he/she can work in 2 different positions alternatively.
2. If the requiring island does not belong to a macro area, it has to make a “*reservation*”. This mechanism will be described in the next paragraph.

4.5.1. Reservation mechanism

The reservation mechanism simulates the request of labour dynamic reallocation when all available workers are busy and some trolleys are waiting for being worked in, at least, one island. In the actual system this mechanism represents the moment when some trolleys reach an empty island and the foreman has to wait until, at least, a worker can be moved.

A reservation is triggered when some trolleys are staked up in an empty island and when no workers can be moved to this position. This situation can become critical because many trolleys could pile up. In order to avoid this scenario, a worker has to start working in this empty island as soon as possible.

When a reservation is made, the first worker becoming available (either free or candidate for transferring) is reallocated. The simulation model calculates the travelling time based on the starting and arrival positions.

5. SIMULATION RESULTS AND PERFORMANCES EVALUATION

After having concluded the validation, the simulation model was ready to make several runs and analyse of production performance and through-put under different conditions, aiming to identify bottlenecks and main important process drivers. To help the validation and analysis an animation was provided as shown in Figure 3.

The simulation was tested against different production mixes. Production mixes defines the combination of shoe families produced and for each family the quantities (batch sizes) produced. Both the combinations of families as well as the batch sizes were systematically changed.

The following variables were measured:

- The overall performances, mainly daily through-put
- The labour utilization
- The production fluency indicated by the staking trolley in some key islands.

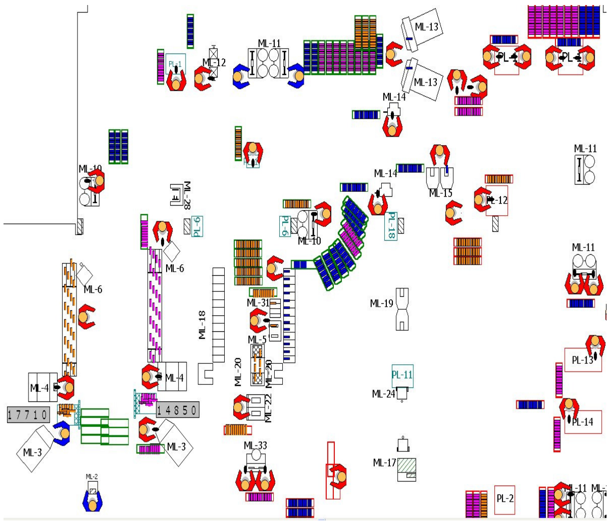

Figure 3 Screenshot of simulation model animation

To obtain a good understanding of the production dynamics the analysis was based on use-cases of different complexity, first simulating simple production plan composed by only one shoe family and then adding the other two families changing the mix and the batch size, and finally using production mixes composed of three types of shoes. Furthermore, first the performances of the two departments were assessed separately and then the whole production system was analyzed. In addition, a specific analysis was carried out to investigate some input parameters dealing with labour management.

5.1. Use-case one for assembly area: producing only one family of shoes

In this first use-case the production mix is composed only by a single shoe family to identify the family specific bottlenecks. Figure 4 shows an example of the trough-put for the different shoe families in the assembly area. Such a results such demonstrate the large difference in produced quantities depends on the shoe family. Similar differences were found for resource allocation and production fluency. As expected, through-put is determined by the produced shoe family and not influenced by the batch size.

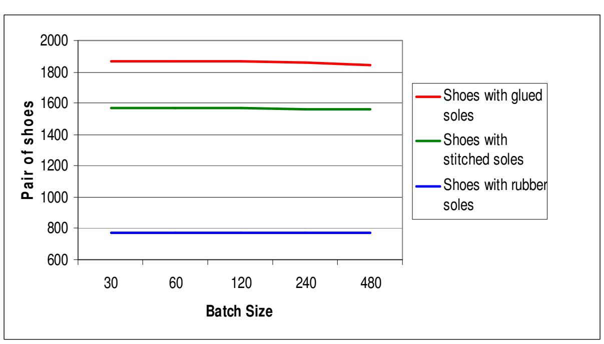

Figure 4 Daily through-put vs batch size for each shoe family in the assembly area

5.2. Use-case two: producing two shoes families

In the second use-case the production mix is composed of two shoe types to identify main interaction effects between shoe families. Figure 5 and 6 show an example of through-put when combining two shoe families in the assembly area. Results show how produced quantities are impacted by the production mix i.e. the combination of families/styles produced, and not influenced by the batch sizes. As expected, through-put is determined by the production-mix.

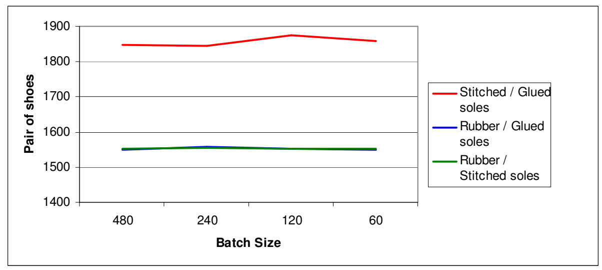

Figure 5: Through-put vs batch sizes when combining two shoe families

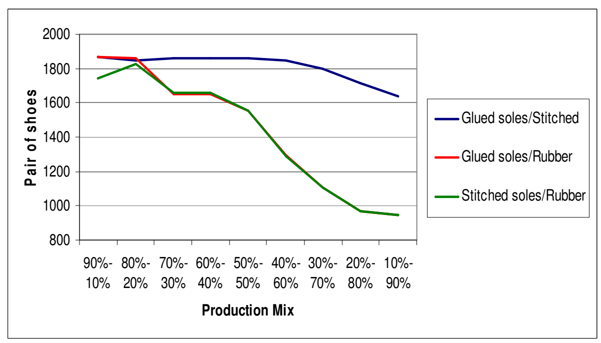

Figure 6 Through-put vs production mix when combining two shoe families

Similar differences were found for resource saturation (see Figure 7) and production fluency.

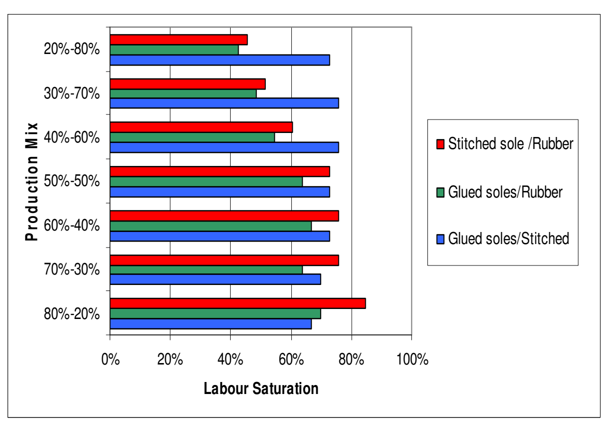

Figure 7 Labour saturation VS production mix

5.3. Use-case three for assembly area: producing three shoes families

In the third use-case the production mix is composed of three shoe types. To limit the number of simulation runs the production mixes followed the strategy used in production. Typically, half of the production capacity is assigned to one shoe family while the second half is shared by the remaining families.

Looking at Figure 8, the productivity is influenced minimally by the batch size if between 120 and 240 and if the ratio of stitched/rubber shoe families is between 1 and 2. Rubber shoes have a significant impact on productivity that is lower about 5% then the target if the daily percentage of produced shoes with rubber soles is bigger then 30%. Currently, the annual demand for rubber sole is close to 20-25%, although demand changes with every year and/or season.

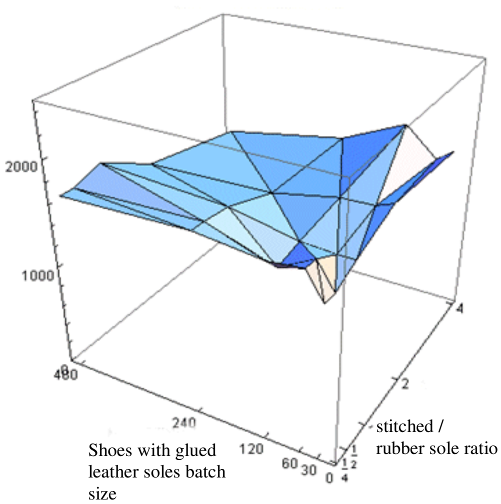

Figure 8 Through-put vs batch size when combining three shoe families, for the assembly area

As far as concerning the labour utilization under not critical production mixes, its overall saturation ranges from 64% up to 76% for the assembly area and most variations were found at the following areas:

- The cream island, its utilization increases by about 30% rising the quantity of shoes with stitched leather sole in the production plan
- The reactivation oven for rubber sole and the last removing island, their utilization is largely influenced by the batch size of shoes with rubber sole

Although these more complex production-mixes allowed for a validation of the simulation against the real production, we did not find a clear relationship between the production mix and through-put.

5.4. Finishing area overall performances

The finishing area performances are not directly related with shoe families/styles, but with finishing sequence as well as cycle time of each shoe article. Based on this consideration, all the shoe articles were grouped in three macro categories i.e. easy, normal and difficult to finishing, and specific production mixes were defined with different compositions.

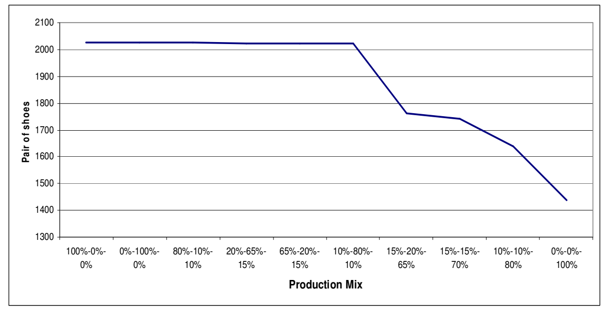

Figure 9 Through-put vs production mix

The daily through-put considering only finishing department, see Figure 9, ranges from about 1400 up to 2050 pairs of shoes and it is not influenced by batch size. Brushing and cream islands are the main bottlenecks and most of the finishing trolleys are staked up in these key position.

As far as concerning labour utilization, its saturation ranges from 72% to 95%, as shown in Figure 10, simulating only the finishing area.

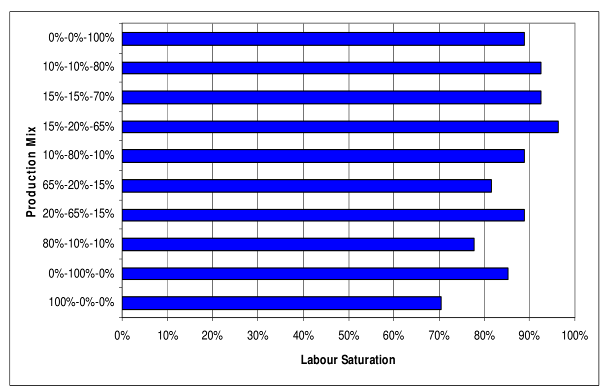

Figure 10 Labour saturation in the finishing area vs production mix

5.5. Production plant overall performances

Based on the previous results, the target productivity for the plant can be reached under scenarios with the following constraints:

- The rubber sole percentage in the daily production mix is lower then 30%
- The percentage of shoe articles with long cycle times in the finishing area is lower then 65%

In the first case, the assembly area is the bottleneck for the production plant, while in the second case the finishing department cut down the productivity.

Finally, a real production mix of two weeks was tested simulating the whole production plant as well as only the finishing area. In the first case the through-put is about 1863 pair of shoes per day, while in the latter, it is 2020 pair of shoes, indicating room for optimization.

A similar result was found analysing labour utilization through sensitivity analysis. Hourly productivity of the all production system is decreased by 10% when the number of available operators for the assembly area is reduced from 33 to 27. As expected for this production mix, decreasing the labor availability in the finishing area has no impact on the overall performances.

Some what if analysis were carried on some input parameters managing labour allocation, showing that a some potentials to increase through-put by a fine tuning activity.

6. CONCLUSION

This paper explored the use of simulation to better understand production dynamics as basis for determining an optimization strategy. The real shoe production plant provided a challenging example of a highly flexible production process operating on diverse production mixes.

Through a combination of analysing simple and complex scenarios, full picture of the production's dynamic was obtained. Simple use-cases were instrumental in identifying basic dynamics and understand the system response of more complex use-cases. The more complex use-cases, although difficult to interpret, had the advantage that they supported the validation of simulation results against real production.

Further research will concentrate on combining detailed modelling such as described in this paper with 'modelling the model' technologies, for overall optimization (testing against realistic use-cases) (Merkureyeva et all, 2008). We expect a combined approach of a time consuming detailed model and a less detailed but faster model enables to find concrete solutions for optimal sets of process parameters while reducing analysis time.

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AUTHORS BIOGRAPHIES

Fred Voorhorst is managing innovation at HUGO BOSS Ticino SA, a department for Product Development and Operation Management for five product groups, one of which is Shoes. He has more than ten years of experience in managing (business) innovation projects, both in industrial as well as academic context.

Antonio Avai is a partner and technical director of Technology Transfer System, an IT company located in Milan. He has managed research programs with focus on methodologies and leading information technologies to support all the life cycle of manufacturing processes. He has more than 15 years of experience in discrete event simulation and its integration with other software tools and technologies, and has authored several papers on these topics.

Claudio Roberto Boër is Director of the ICIMSI Institute CIM for Sustainable Innovation of the University of Applied Science of Southern Switzerland. He has more than 16 years of industrial experience and research in implementation of computer aided design and manufacturing as well as design and setting up manufacturing and assembly flexible systems. He is author of the book on Mass Customization in the Footwear based on the European funded project EUROShoE that dealt, among several issues, with the complexity and optimization of footwear assembly systems.