MODELLING AND SIMULATION OF A FISH PROCESSING FACTORY SHIP

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ABSTRACT

A fish processing factory ship is a large vessel with on-board facilities for inmediatly processing and freezing caught fish. This paper presents a case study in a Spanish company with special attention to the variability sources. The role of human operators is crucial to respond to this changing environment. However, the uncertainty due to the quantity and quality of the catch, the natural human uncertainty and the different operation conditions makes it difficult to make the optimal decision regarding either resource allocation or the mix of products. An exploratory simulation model of the plant and the human tasks is developed as a way to gain insight into the process. The analysis approach uses a Discrete Event Simulation and a Digital Human Model to go from generals to specifics. As a result, we could characterize the process efficiency in different production scenarios, the organizational effects in the packing workstation and the ergonomic and operational assessment of the wrapping operations.

Keywords: Modelling and Simulation, Discrete Event Simulation, Digital Human Modelling, Fish processing, Factory ship

1. INTRODUCTION

A factory ship is a large vessel with on-board facilities for processing and freezing caught fish. There are about 24,000 vessels greater than 100 tons in the world's factory fishing fleet (FAO Archives 2004). According to Eurostat, in terms of tonnage the Spanish fishing fleet is by far the largest (415,000 gross tonnes) of Europe. This fleet produces around a 1,000,000 t of fish per year (FAO Archives 2007). The Spanish fleet is composed of 11,000 ships, but only 400 trawlers, seiners and liners account for 50% of the global tonnage. These are the ships that fish out of the UE territorial waters (Ministerio de Medio Ambiente, Medio Rural y Marino 2011).

The Spanish company involved in this study has fifteen trawlers that operate in the Southwest and Southeast Atlantic Ocean fishing grounds. Some of these trawlers are multispecies and other are rather specialized in one species. The most complex type of trawler –the multispecies- has two or three parallel lines capable of produce between 25t and 40t of frozen fish per day.

The fish processing industry involves several production workstations with both manual and automatic operations. The analysis of such a system implies to consider the process flow through several parallel lines with different inputs and outputs. In fact, there is a great variety of final products. The uncertainty due to the quantity and quality of the raw material makes it difficult to take the optimal decision regarding either resource allocation or the mix of products. The mathematical analysis is then quite complex to conduct. Even more, unless a dynamic approach is adopted, some key factors are very difficult to estimate, such as the time-in-process of the final product. There is a direct relationship between this parameter and the quality of the frozen fish (Trucco et al.1982). As a consequence, a simulation based analysis in order to assess different production alternatives has been considered. .

The fish processing has been seldom analysed under an engineering production perspective. It is remarkable the network-based simulation of a processing facility in land made by Jonatansson and Randhawa (1986). Among the results from their model are statistics on utilization of machines and workers in the process, size of in-process inventory at different locations in the process, and throughput times.

On the other hand, the working conditions of the operator have been widely discussed. Several ergonomic and clinical studies have been carried out. One of them took place in eight different factories in the Kaohsiung port (Taiwan) reporting a clear prevalence of shoulder and upper-limb disorders among the workers (Chiang et al. 1993). A L.E.S.T. analysis (Ergonomic Evaluation Method developed by the Institute of Labour Economics and Industrial Sociology of France) was conducted to characterize the risk in a fish processing plant in Ecuador (Torres and Rodríguez 2007). Regarding the assessment of on board workers, a study of Swedish fishers showed that they experience frequent musculoskeletal disorders (MSDs), according to the type of task, but also a special type of stress due to the natural ship instability (Törner et al. 1988). Another critical factor of these operators is the level of noise, which has been also studied for workers of a fishing trawler (Szczepański and Weclawic 1991).

The process on board is highly dependent on human operators (between 45 and 65 people spend several weeks working on board). Due to hard working conditions, another aim of the study was to study the ergonomic conditions of the human tasks by means of the use of digital human modelling (DHM). Some studies already applied this tool to the fishing sector (Zhang 2010). DHM has been used as a means to jointly consider productivity and ergonomic measures for the workstation design in a very wide range of sectors, i.e., food industry in Ben-Gal I and Bukchin (2002), mining in Rego et al. (2010) or automobile industry in Fritzsche (2010). We have not found a reference of DHM use in the fish processing sector, neither in land nor on board.

A combined simulation approach has been adopted for the characterization and improvement of the process: (i) a global analysis of the production system by means of discrete event simulation and (ii) an ergonomic study of the individual tasks. The aim of this paper is to describe the case study and the proposed methodology for its analysis. Although this is an on-going project, some relevant preliminary results are also described.

2. PROCESS DESCRIPTION

In spite the processing process starts and depends on the previous fishing process, only the indoor activities will be explained for the sake of simplicity. The flow diagram of the fish processing is depicted in Figure 1. Initially, the captured fish on deck is introduced into the processing plant by means of a ramp connected to a hopper which feeds a distribution conveyor belt. A manual classification (Figure 2) sends the fish to the filleting line –Product “Fillet”-. If it is too big or too small to go to this filleting line, it goes to the whole fish line –Product “HG product”-. If it is not able to be processed in time or it does not fit the requirements, it is returned to the sea -Discards-.

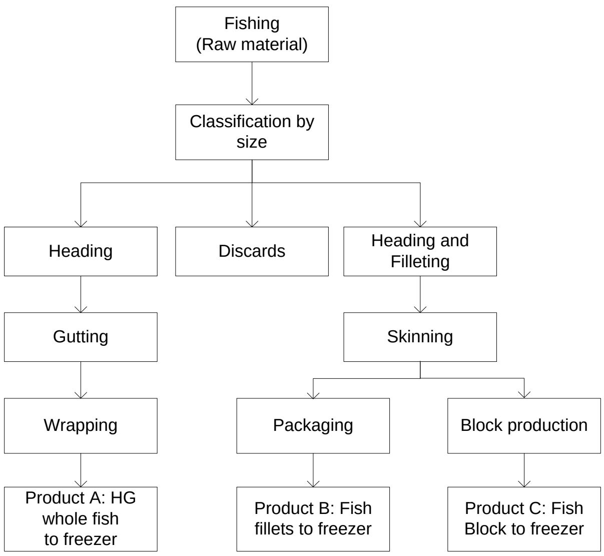

Figure 1. Flow diagram of the factory ship process

On the whole fish line, the fish undergo three sequential operations, named heading, gutting and wrapping. Heading and gutting operations are performed by two machines assisted each one by an operator. The fish without the head and the guts -around a 70 % of the weight of the fish- is washed in the second machine. It waits into an intermediate buffer to be wrapped by an operator. Finally, as showed in Figure 3, it is placed into a box with similar sized HG products (headed and gutted). The full box is ready to go to the freezing stage.

Figure 2. Manual Classification of the Fish.

Figure 3. Wrapped HG fish in a box.

If the fish has an adequate size, it is sent to the fillet lines. Three parallel workstations accomplish the heading, gutting, filleting and skinning of the fish. Each fish yields two fillets that directly go to the skinning, an operation that removes the skin from each fillet. The overall yield is estimated in 40% of the initial weight of the fish. The fillets are the directed to a common belt to be manually put into trays. This operation, the packing, consists on selecting similar sized fillets, trimming them if they still have rests on skin or bones, and place them forming several layers into a tray. A plastic sheet is placed between layers to avoid the adherence of fillets. The full box of fillets goes then to the freezing stage.

Figure 4. Packed fillets in a tray

The fillets can be rejected from the packing operations. This can be because they don't reach the quality requirements or because the packing operators have not enough capacity to process them. In that case, they go to the block conformation. This third product is a block of fillets weighing 7.5 kg and measuring 485 mm x 255 mm x 63 mm, intended for further processing (breaded sticks, skewered fish, cooked dishes, etc.)

The variability of the process can be explained by several causes:

1. Variability due to the product. An important difference between any processing plant and a factory ship is the greater uncertainty about what and when the raw material enters the process. This is due to the heterogeneous distribution of the fish along the sea and the irregular distribution of species and sizes. The different species morphology and size influence the availability to automatic filleting. This forces the process to be flexible.
2. Variability due to the process. Apart from the above mentioned influence of the species and sizes into the mix HG, fillets proportion there are other factors that link the product characteristics and the process parameters. First, when the fish waits too long before it is processed the Rigor Mortis makes too rigid to go through certain operations. In that case, a break down in filleting machines can occur. The second factor is the packaging capacity in the filleting line. When the volume of fillets coming from the skinning operation exceeds the manual packaging capacity, the fillets enter to the block production, a less-valued product.
3. Variability due to the resources. The human operations have a natural variability even if they are repetitive, due to factors like mood, tiredness, hour of the day or experience.
4. Variability due to the environment. The ship rocking has a double consequence on the work development. On the one hand, the scales that can be used on board (able to compensate the movement of the ship) are unaffordable. This makes that they can not be a part in the process as it is in land. As a consequence, weights on trays are estimated by operators and errors are made. On the other hand, it is a recognized stressing effect in the operators. Space restrictions often lead to the operator to adapt to suboptimal workstation design. Besides, noise, vibration and humidity are factors that increase the risk of accidents.

3. SYSTEM MODELLING AND SIMULATION

Uncertainty in the model was modelled using probability distributions for the sizes on the caught fish (table 1) and the cycle time for activities (operators and machines cycles). The parameters of the size of fish were obtained from the analysis of the production reports, that provide data of final product categories packed and freezed during a set of working periods (usually three days). The general operation system was defined from the videos, layout information and interviews. Operators cycle time was obtained from videos observation and machine cycle times were determined with the engineering department help.

Table 1. Fish weight categories

Number of group	Range of weight	Description
1	(0, 200]	Fit for whole line
2	(200, 500]	Fit for whole line or fillet line (second category)
3	(500, 800]	Fit for whole line or fillet line (second category)
4	(800,1500]	Fit for whole line
5	(1500, 4500]	Fit for whole line

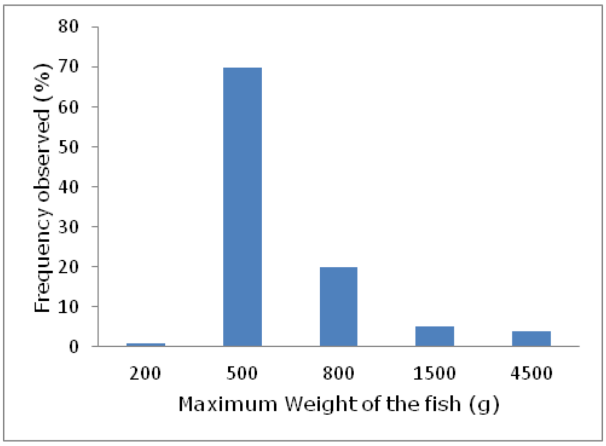

Figure 5. Expected frequency of each fish weight category

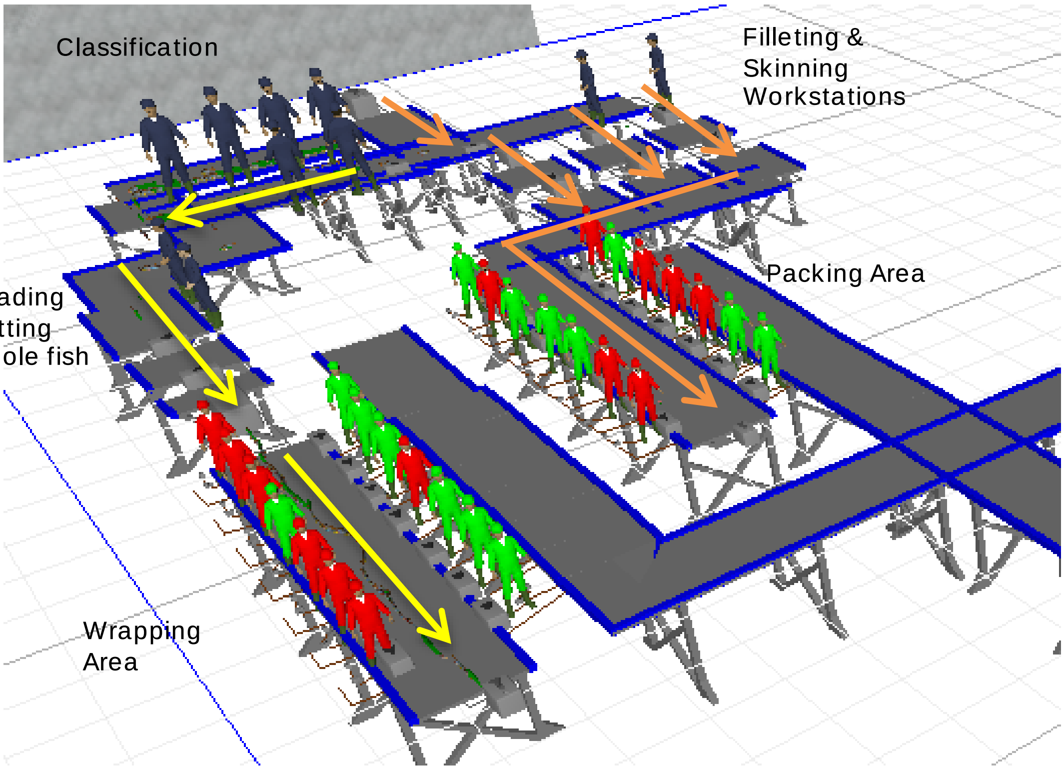

Figure 6. Simulation model of the processing plant in the factory ship

In the simulation model the fish are modelled as entities. However, the parameter unit varies depending on the specific operation (fish, lot or fillet).

- Fish. Standard unit from the initial source.
- Lot. During the classification the operator picks up several elements of fish at once –a lot-. The number of fish that compose a lot goes from one to four, according to two empirical distribution functions (to HG process, to fillet process). After the classification, the units are considered individually again.
- Fillet. In the filleting machines, entities modelled as fishes are destroyed after the process time, and two new entities are created as fish fillets.

Wrapping and packing operations imply an individual processing of the product (select, wrap or place) and a common processing as a box or tray (transport). The number of elements that form a box (for HG product) or a tray (for fillets) depends on their size. This has been considered an important factor, because the number of units per container influences the time-in-process of the products, the utilization of the operators and the global time spent in transport to the freezer.

The model was developed using SIMIO, an object-based 3D modelling environment. In the simulation model the fish are modelled as entities. The machines and operators are modelled as resources.

Although it has been defined a fish size distribution (Figure 5) this does not mean that all the group 2 and 3 sized fish are sent to the fillets line and the rest of the fish are sent to the whole fish line. A preliminary study of the maximum capacity of the lines regarding the fish supply and the mix of products has been done in order to estimate this key parameter of the global efficiency of the plant (Figure 7).

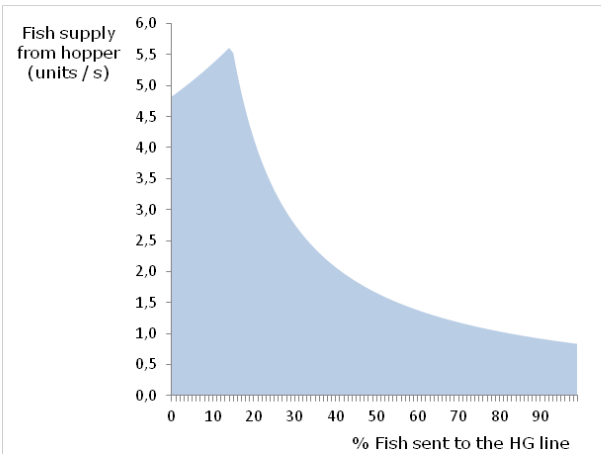

Figure 7. Maximum supply rate that can be processed by the filleting machines depending on the percentage of product to whole fish (HG) line.

As a result, it is clear that the maximum capacity of the plant occurs when the fish supply is 5.5 units per second and 15% of the supply is sent to the HG line. The normal operation of the factory ship should be next to this optimum working point. Three scenarios will be tested for three different mix of products (10, 15 and 25% of fish supply sent to the HG line).

In order to define the state of the plant in each operation scenario, a set of performance indicators has to be defined. In this case, we will be accounting for variations in:

- Resource Utilization. Occupation of Operators and Machine compared with the total working time.
- Product Yield. All the fish supply that undergoes the process has four possible outputs: discards, freezed whole fish, freezed fillets or fish block. The production rates of discards and fish block are the variables related to the inefficiency of the system. As a consequence, a better product yield implies reducing them to the minimum.
- Time in process. The time in hours between its exit from the fish hopper and its freezing.
- Production rate. The rates in units per second of the main products of the plant.

Table 2. Summary statistics of the three scenarios

State var.	Element	Scen. 1 (10% to HG)	Scen. 2 (15 % to HG)	Scen. 3 (25% to HG)
Resource utilization	Wrapping operators	48.1 %	58.2 %	78.6 %
	Packing operators	96.3 %	95.3 %	94.3 %
	Average HG machines	39.5 %	52.5 %	90.6 %
	Average fillet machines	48.9 %	47.9 %	44.2 %
Product yield	Fish supply to block	54.3 %	54.2 %	49.9 %
	Fish supply discarded	11.0 %	9.0 %	5.2 %
Time-in-process (h)	Average Time HG	0.12	0.11	0.11
	Average Time of fillets	0.13	0.13	0.13
Production rate	HG product (units/s)	0.22	0.27	0.37
	Fillets (units/s)	2.12	2.09	2.09

For a fish supply of 3 units/ sec, scenario 3 has showed better resource utilization for the HG line, a better yield of the products (less discards and less fish supply sent to the lowest valued product) and similar time in process. With a mix of 25% of fish supply sent to the HG lines and 75% to the filleting lines, the HG machines are closed to the saturation.

There is not a great difference between the resource utilization in the filleting lines. This can be explained because of the packing bottleneck that reduces the potential capacity of the line. This has been one of the reasons that leaded to the aim of improving the ergonomics and productivity of the workstation.

4. WORKSTATION MODELLING AND SIMULATION

A supplementary analysis of the wrapping/packing organization task has been done. At present all the operators are placed around a common conveyor belt where the products coming from the automatic machines are (Figure 8). It has to be remembered that every box/tray has to be fulfilled with similar sized HG fish/fillets (there are until five categories). We have considered that the first product taken by the operator determines the size of the rest. As a result, in all the scenarios an effect of decrease on the utilization rate of the operators is produced as his distance from the source increases (Figure 9). This can be explained because the amount of products at the end of the line (after all the precedent worker have chosen their products) is lower and the operator may be blocked, waiting for a specific size to end a cycle.

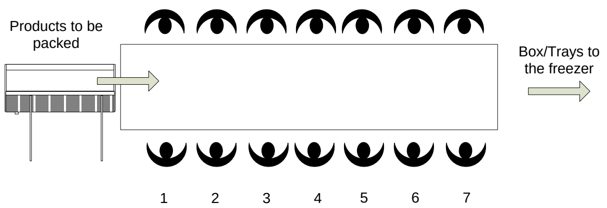

Figure 8. Present organization of the wrapping operators

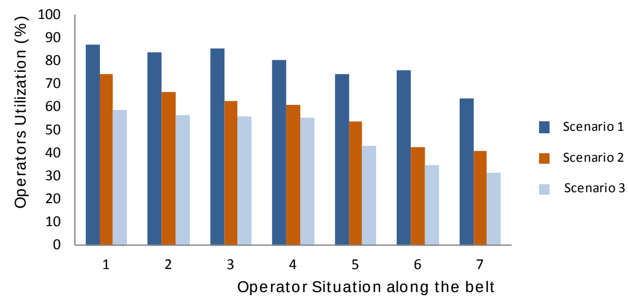

Figure 9. Utilization of the wrapping operators related to their position along the conveyor belt

Accordingly, an alternative organization of the workers has been modelled. The idea was to divide the operators in two teams. This idea supposes that there is a mechanic device suitable to divide the product flow depending on their size. Each group of workers should then process more similar products into the final containers. As it was expected, the new distribution showed a more homogeneous distribution of the utilization rate. However, the improvement did not compensate the loss of product yield. More details of this analysis will be provided in the final version of the paper.

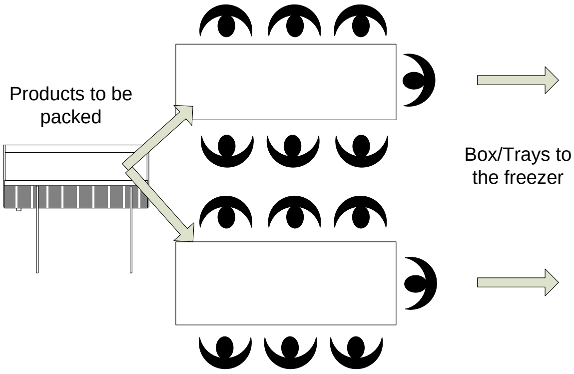

Figure 10. Alternative distribution of the wrapping workstation

For its ergonomic evaluation, the wrapping activity will be considered composed of several components or subtasks. Each subtask will be now described.

1. Pick up. The operator bends his back to reach a fillet from the belt. See Figure 11.a.
   A set of three reach areas have been modelled to cover the entire possible pick up movements.
2. Trimming. If needed, fillets are scissor cut to make them look better and to remove leftover bones. See Figure 11.b.
3. Place on the tray. The fillet is placed on the tray. See Figure 11.c.
4. Plastic sheet between layers. The layer is usually complete after 4, 5 or 6 fillets. A plastic roll is then unwind over the fillets layer. This roll can be seen in Figure 11.c.
5. Tray placed on freezer belt. The tray full of fillets weights around 8 kg. At that point the plastic sheet is cut and the tray is placed over the belt at should level. See Figure 11.d.

Figure 11. Samples of postures during the wrapping operation –(a) pick up; (b) trimming; (c) place fillet; (d) place tray-.

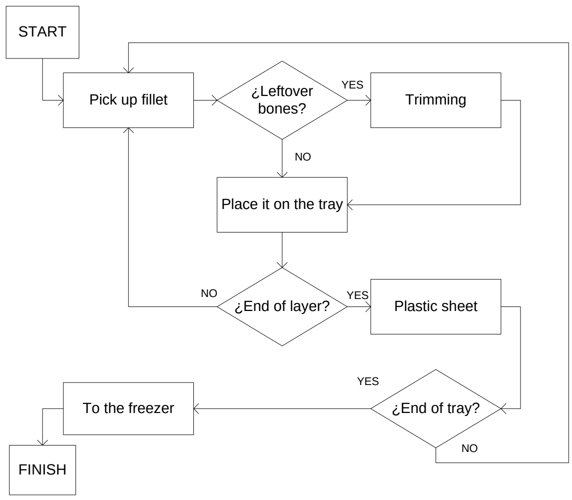

Figure 12. Flow diagram of the wrapping operation

The above mentioned subtasks have been modelled in Delmia V5R20. Their analysis has been done according to the methodology presented in previous work of the research group (Rego et al. 2011). The first stage implies modelling the operators, assuming they fit to the 50^{th} percentile of the French population. The workstation and the used tools have been modelled by using the geometrical information that the company provided.

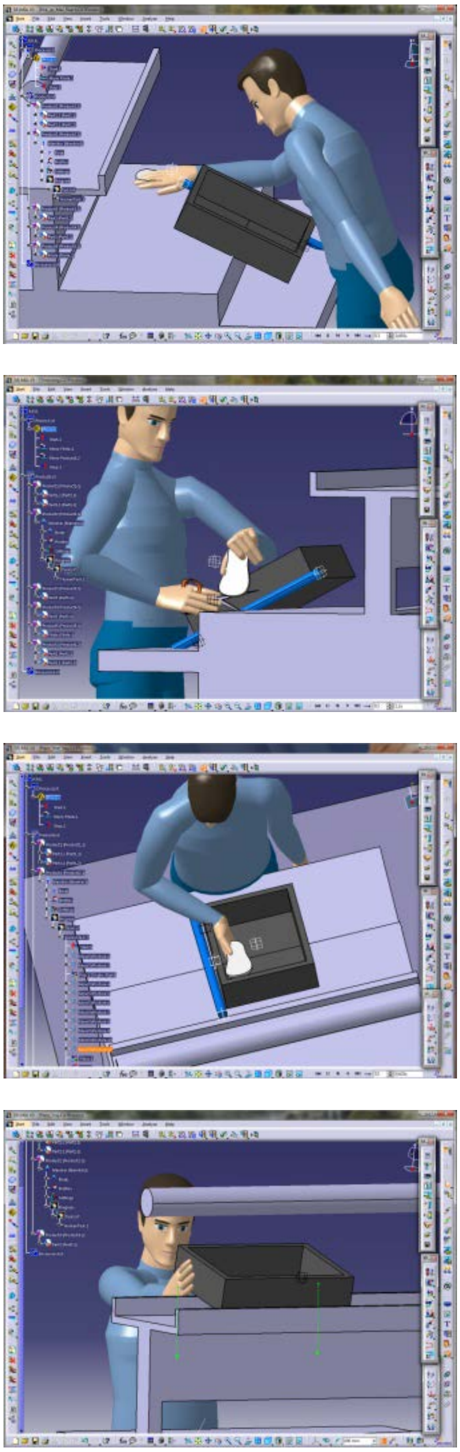

Figure 13. Modelled postures of the subtasks -(a) Pick up Max Reach; (b) Trimming; (c) Place fillet; (d) Place tray

The RULA score index has been chosen to report the ergonomic evaluation of each subtask. RULA is a well-known and widely used ergonomic assessment method (Cimino et al. 2008) and it is especially thought for the assessment of tasks that mainly imply the upper limbs. The final score is related to the risk of the posture, and goes from 1 (no risk at all) to 7 (urgent need of change to avoid injury). The L4/L5 compression limit has been also considered as an important indicator of the biomechanical risk associated to the adopted postures. The Spine Compression value is a complementary measure of risk of MSDs. According to NIOSH guidelines, compression force on the intervertebral disk over 3.4 kN may eventually lead to injuries. Delmia V5R20 provides with both indicators to evaluate each posture of which an activity is made of.

The following charts represent the previous indicators for the different subtasks. As it can be noticed, in Figure 13, the RULA Score reaches high levels of risk during the maximum reach pick up task and the place tray task. The L4/L5 compression limits (Figure 14) supports this report with a similar evolution. However, the 3.4 kN limit is never achieved. The rest of the subtasks –place fillet, plastic sheet and trimming operation- remain in relatively “safe” levels.

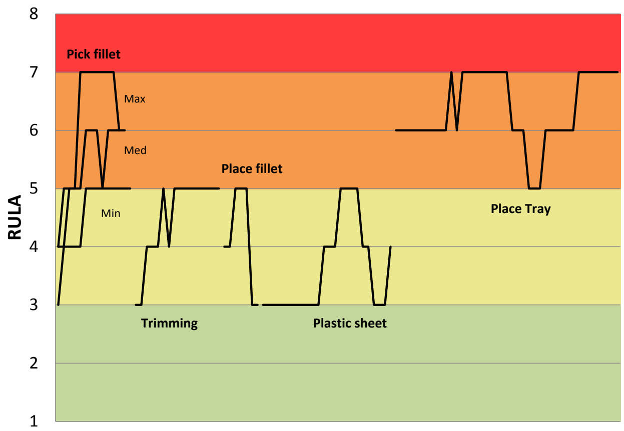

Figure 14. Postural risk of the modelled subtasks

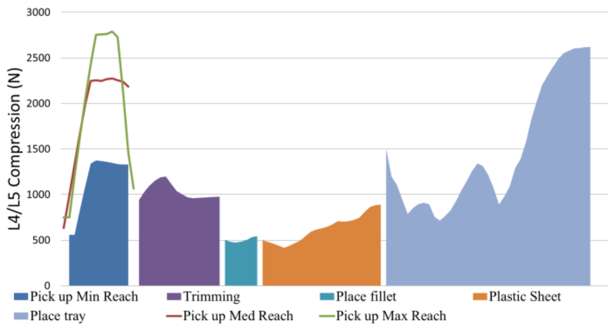

Figure 15. Compression Force on the intervertebral disc between L4 and L5 for the modelled subtasks

Table 3. Summary of results for the wrapping operation

	RULA Score		L4/L5 Comp.	
	Avg	Max	Avg (N)	Max (N)
Pick up Min	4,75	6	1206,18	1375
Pick up Med	5,07	6	1912,71	2275
Pick up Max	6,15	7	2041,38	2789
Trimming	4,50	5	1034,94	1198
Place Fillet	4,14	5	502,43	544
Plastic Sheet	3,58	5	627,65	891
Place Tray	6,37	7	1473,87	2619

A different analysis can be done for the different parts of the body are analysed separately. The RULA method correlates each limb range of movement with the risk of injury. In Figure 15 we present a rate of the average RULA limb score of each subtask related to the maximum score. In agreement with the literature (Chiang 1993, Törner 1988), there is a clear prevalence of upper limb risks. The forearm and wrists are the most likely parts of developing MSDs. Another remarkable result is that even if the trimming and the place fillet operation were not dangerous in terms of the global analysis, in this analysis it has the highest rates of risk in forearm and wrist.

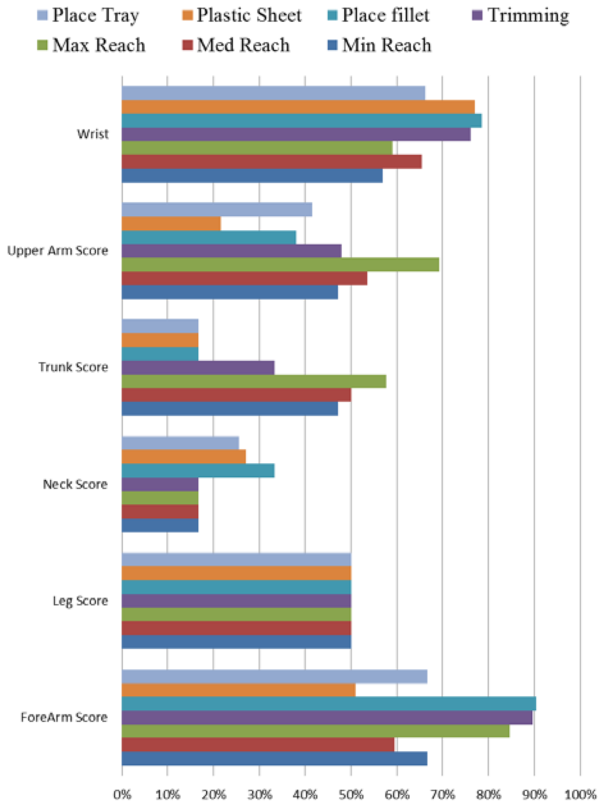

Figure 16. Risk of the different limbs in each subtask

5. VALIDATION AND RESULTS

Validation and verification are necessary steps before accepting any result from the model. During the modeling stage a continuous verification effort has been performed by comparing the model with the videos, production reports and the analysis of the real operation times. Whenever a deviation was found the modelling stage was stopped to find the cause of it. After that, a group of experienced workers from the company found that the results seemed reasonable according to their experience. For the ergonomic model validation, we also took into account that the literature was in agreement with the main results.

The following results can be highlighted:

1. The product mix is a key parameter that has a strong influence in the production rate and the resource utilization. Due to the filleting machines restriction, the point of maximum efficiency of the plant is set at a process input rate of 5.5 units per second and a product mix of 15% to HG lines and 85% fillets.
2. Although the process is oriented to the production of fillets, a more balanced mix between HG product and fillets benefits the product yield and the occupation rates when the input rate is set at 3 units per second.
3. The bottleneck operations are the wrapping operation in the fillet lines and the packing operations in the HG lines.
4. The organization of this workers (wrapping and packing) around a common belt have an effect of decrease of their utilization rate as they are place further from the source. A higher specialization (two different belts with fewer operators per belt) was tried as an alternative, but its effects were negative.
5. A redesign of the wrapping operation seems convenient due to their central role in the whole process.
6. The ergonomic analysis of this task showed that placing the tray full of fillets on the belt and reaching the fillet from the maximum reach are the hardest tasks in terms of RULA score and L4/L5 compression. The use of smaller trays and an alternative location of the to-freezer-belt should be studied in order to reduce the impact of the "placing full tray task". A redesign of the workplace to reduce the reach distance would reduce the need of back bending.
7. The analysis of the different body limbs showed prevalence on wrist and forearm risk. The trimming operation is one of the most demanding in terms of wrist and forearm postures. A better scissor design could be proposed in order to reduce the probability of injury.

6. CONCLUSIONS

A fish processing facilities simulation model of a common factory ship has been presented. The used methodology included a discrete event simulation of the global process and a digital human model of the bottleneck operation. As a result, the key parameters affecting the process efficiency and the bottleneck operations have been characterized. A set of key performance indicators has been defined to characterize the process efficiency and how it was affected in three different scenarios. Secondly, some organizational effects have been found in the last stages of the process. Finally, an ergonomic and operational analysis of the wrapping operations is presented as a means of improving both the working conditions and productivity.

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