A SIMULATION-BASED ERGONOMIC EVALUATION FOR THE OPERATIONAL IMPROVEMENT OF THE SLATE SPLITTERS WORK

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ABSTRACT
The natural roofing slates manufacturing process relies on highly labour-intensive activities and more specifically on the mastery of a specialized group of workers known as splitters. The splitting of slate blocks is a complex manual and demanding work that involves both important physical exertions and quick and accurate decision making processes. Since a lot of repetitive and potentially hazardous movements have to be made there is a substantial risk of developing musculoskeletal disorders (MSDs). Besides, plant's costs and productivity depend largely on their individual performance. In this paper we present a quantitative approach to a combined ergonomic and operational assessment of the slates splitters tasks. A RULA analysis is carried out by means of a Digital Human Model (DHM) aiming at quantifying the level of ergonomic risk in several scenarios and leading to a set of simple improving workplace proposals in terms of ergonomics and productivity.

Keywords: ergonomics, DHM, slate splitters, workplace design.

1. INTRODUCTION

Spain is the first slate producing country in the world, with an export volume that exceeds 80% of slate mined and produced. On its part, Galician slate production accounts for around 70% of the national production.

Europizarras is a Galician medium company mainly devoted to the production of the highest value added roofing slates, that is to say, the thinnest commercial tiles. The thinner a tile is the harder and more wasteful the manufacturing process becomes. Europizarras exports more than 90% of its production to the French market which presents a quite constant demand (AGP 2010).

Despite this constant demand, the slates price evolution shows a downward trend when expressed in terms of constant Euros, i.e., discounting the effect of inflation, as depicted in Figure 1.

Figure 1: Exportations to France (up) and Spanish Slate Aggregated Prices Evolution between 1970 and 2006 (down). In red, Prices in Constant Euros.

Attending to the production costs set up, whilst the quarry costs present the typical even distribution in mining activities, the costs distribution regarding the slates manufacturing plant is very characteristic, mainly depending on personnel expenses (Table 1). This is due to the artisanal nature of the processes involved. As a matter of fact, an average slate manufacturing plant employs six workers for every dedicated worker in the quarry. (BIC-Galicia 1997).

Table 1: Costs Distribution in Slate Production Centres

Concept	Personnel	Maint.	Supplies	Amort.
Quarry	27%	26%	25%	22%
Plant	78%	13%	5%	1%

It is also known that 55% on average of the total production costs are incurred in the manufacturing plant. Therefore, the weight of personnel costs involved in manufacturing operations in the plant accounts for almost 43% of the total company costs. Splitters salaries play a fundamental role in this matter, especially in the case of our company. Because of their relative geographic isolation from the main production areas they have to offer a surplus income to attract specialized splitters.

The splitting of slate blocks is a manual work involving a lot of repetitive movements, lifting, pushing and pulling, twisting, and hitting actions so that there is a substantial risk of developing Musculoskeletal Disorders (MSDs). From an ergonomic point of view many factors can contribute, either individually or in combination, to the development of MSDs at work (OSHA EU 2005):

1. Physical: including using force, repetition of movements, awkward and static posture, vibration and cold working environments.
2. Organizational: including high work demand, lack of control over work, low job satisfaction, repetitive work, high pace of work, time pressure.
3. Individual: including prior medical history, physical capacity and age.

All of these factors are present in the everyday working activities of the slate splitters. Besides, as slate needs to be wet to allow a proper exfoliation, it is carried out in a cold and wet environment. The inhalation of silica dust is also a well acknowledged problem (Fundacion 2008)

Whereas there are many other previous studies that have focused on other different ergonomic risks assessment (Walsh 2000, Guiver 2002) the approaches to the study of MSDs in slate splitters are scarce and traditionally conducted (Weber 1996). But above all, all these studies are conducted under an epidemiologic prism so they do not pretend to link ergonomics and productivity.

On the other hand, there are numerous and important references of simulation-based conducted experimentation for the operational assessment of different workplaces (Cimino 2010). Digital Human Models (DHM) applications in the automotive sector (Shao 2007) as well as in the aeronautical sector (Boeing 2010) are common, but its role as an usual workplace design tool in Small and Medium Enterprises is still rare (Santos 2006).

The splitting operation is at the core of the whole manufacturing process. It is the task where product, resources and process circumstances converge in a less controllable way from a variability point of view (del Rio 2009). So far, attempts on the splitting process automation have not succeeded, especially when the nominal thickness is 3.5 millimetres as is our case.

For all the above described reasons, we propose a quantitative approach to the slates splitting process risk assessment regarding MSDs for the operational improvement of the slate splitters work. To do so, we first determine the set of tasks and postures a splitter normally performs. Then, a virtual model of the splitter and its workplace is built so that the RULA analysis can be conducted by means of the DHM software DELMIA Human. Finally, attending to the obtained results, a set of simple improving workplace proposals in terms of ergonomics and productivity is presented.

2. THE SPLITTING PROCESS

After the extraction of slate blocks from the quarry and its transportation to the manufacturing plant, the slate is cut in slabs by means of circular saws. Later on, they are taken by the splitters one by one and cut in several pieces by means of a special type of chisel so they can handle them better and also determine the presence of flaws. Then, they change to a smaller chisel for cutting these parts into plates. The chisel, placed in position against the edge of the block, is lightly tapped with a mallet. The natural structure of slate allows its exfoliation; a crack appears in the direction of cleavage, and slight leverage with the chisel serves to split the block into two pieces with smooth and even surfaces. This is repeated until the original block is converted into a variable number of pieces. The resulting number of plates depends mostly on the quality of the slate rock from quarry as well as the splitters experience and skill. Splitters classify slates into two groups. One is the target format of tiles of 32x22x3.5 mm –the 80% of the total, that we named L32 (Slates Lots of 32) – and the other one gathers all other formats in a category named LN32 (Lots of Not 32).The splitting working cycle is divided in four main subtasks:

1. Previous Operations (grey blocks in Figure 2)
2. Rough Splitting (blue blocks): it happens a non constant number of times depending on the size of the slate block.
3. Splitting (orange blocks): it happens as many times as final plates are obtained.
4. Sorting (green blocks).

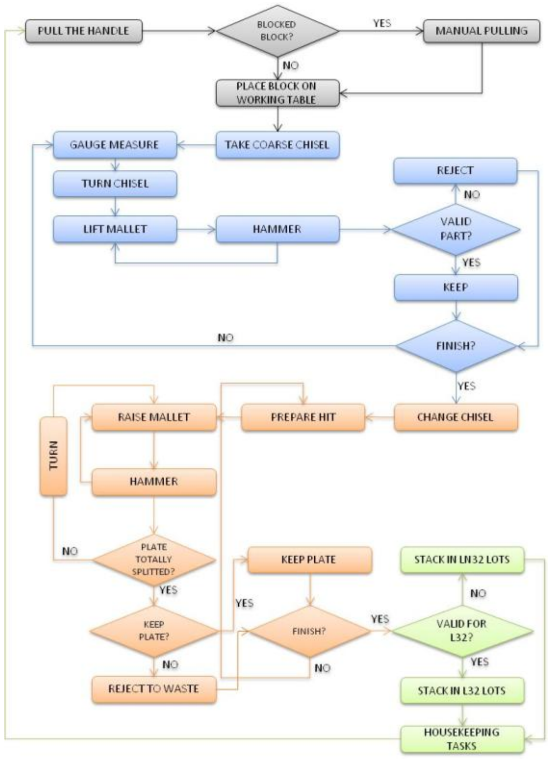

Figure 2: Splitting Process Diagram.

These tasks have been statistically characterized for the simulation model. Data have been collected from digital video recordings taken in situ. Data collection based on commercial video-recorder technology is portable, familiar to many people, does not encumber the worker and is relatively inexpensive (Neumann 2001). Once a workplace recording is made, it must then be processed to extract the desired information. In Table 2 we present the standard times for the set of activities of which a normal working cycle is made up.

Table 2: Standard Times

Activity			Standard Time (s)
Previous Operations			8.00
Rough Splitting			2.94
Splitting	To waste	Turning	9.45
		No turning	6.60
	To keep	Turning	7.02
		No turning	4.17
Sorting			27.90

THE ERGONOMIC METHOD: RULA

RULA (Rapid Upper Limb Assessment) is a classic ergonomic risk assessment method proposed in 1993 (McAtamney 1993). Originally it is thought to be applied on those postures which seem to be critic along the task. It separately analyzes left and right sides of the body by dividing the human body into two groups. Group A comprises arms, forearms and wrists, and group B is composed by legs, trunk and neck. After a series of evaluations it scores the potential risks associated to the postures under analysis according to a grand score from which derive a risk level and a resultant set of recommendations (Table 3).

RULA is a well known and widely used ergonomic assessment method (Cimino 2008) and it is commonly employed among the commercial DHM simulators. It is especially thought for the assessment of tasks that mainly imply the upper limbs as is the splitters case. Besides, as it is implemented into DELMIA, it allows its continuous application to every single modelled posture of which a task is made up. On the contrary, were the same method applied in a traditional manner it would be limited only to those tasks a priori considered as the most dangerous.

Table 3: RULA Action Levels

Level	Action levels from RULA
1	When grand score is 1 or 2, posture is acceptable.
2	When grand score is 3 or 4, further investigation is required; changes may be necessary
3	When grand score is 5 or 6, investigation and changes are required soon.
4	When grand score is 7, investigation and changes are required immediately.

3. THE SIMULATION TOOL: DELMIA

Human modelling systems are considered a basic element for a more efficient design process. In this sense, virtual ergonomic simulation can be used for taking decisions concerning worker postures or sequence of movements, workplace layout and other features which have consequences both in cost and risk of injures. Thus, DHM's not only need to be realistic but their results must be reproducible and verifiable in order to be useful tools for design and evaluation purposes. Some studies regarding this issue have been made. One of them was conducted jointly by the U.S. Air Force and TNO Human Factors and showed that a DELMIA virtual manikin provides 94% fidelity compared to a real subject, in contrast to 64% to 80% fidelity for other competitors in this field (Oudenhuijzen 2008).

The simulator allows the generation of human postures using either direct or inverse kinematics. DELMIA proposes a predetermined set of angular joint speeds corresponding to the average performance of the considered segment of population. Although these times do not directly imply an ergonomically safe movement, they are a reasonable basis to this end. Accordingly, comparative analyses of deviations between actual and simulated times have been conducted as a means of identifying plausible sources of ergonomic exposures.

A typical splitter has centred the tasks analysis although data were also collected and analyzed from other two different splitters for validating purposes. This worker is a well trained and experienced middle-aged man. A right-handed virtual manikin corresponding to the 50th percentile (P50) of the French male population anthropometric distribution was adopted for the simulation model as it fits the splitter's profile. Also, all data related to the geometric and operational workplace characterization were obtained and the corresponding elements were built.

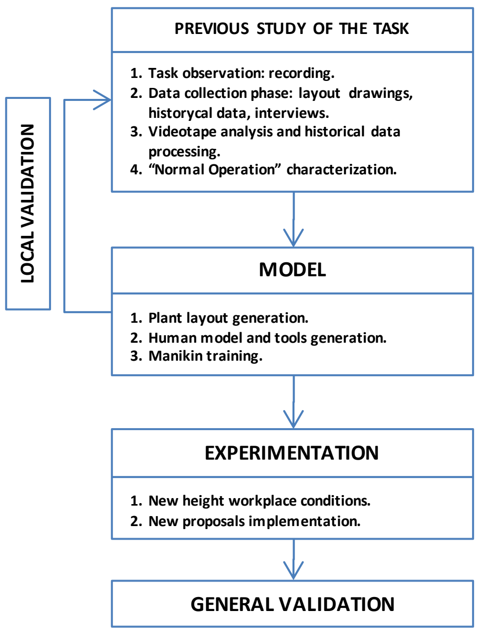

Figure 3: The General M&S Sequence

The overall M&S development process is depicted in Figure 3. The tasks have been characterized and analyzed by means of video recordings, technical layout drawings, historical data and interviews. Then the modelling process may start by reproducing a virtual environment assuring the geometric similarity (Figure 4). Defining the precise and complete set of tasks and MTPs –Moves to Posture- is a delicate and exact process. Once the model is verified and validated, the experimentation phase may begin. After this phase, a general validation is considered. It will imply to fit the new proposal in a simulation model of the whole plant in order to ensure their feasibility and productivity.

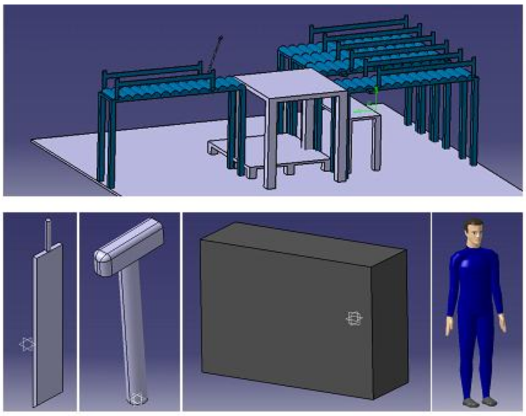

Figure 4: The elements of the Virtual Model.

4. SIMULATION MODEL VERIFICATION AND VALIDATION

The valid recreation of a real system in a simulation environment demands the accomplishment of both verification and validation phases. To do so, we based on a combination of visual and operational assessment of the simulation model.

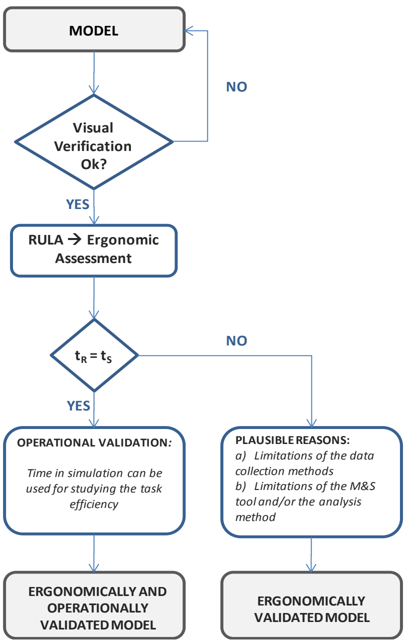

Figure 5: The Validation Model Scheme.

The exhaustive visualization of the model as it is simulated allows the identification of discrepancies and inaccuracies between the virtual and the real process. At this point the experience and opinions of the actual workers and company engineers have been necessarily considered. At the same time, we compared real and virtual tasks times and then we analyzed their fitness. Deviations between simulation times (tS) and their equivalent real times (tR) were then studied until finding out their origin. The followed procedure is shown in Figure 5.

This process leads to an ergonomic and operational validation in most cases. However, in some tasks only the ergonomic validation has been reached as the operational accuracy has not been good enough. We took this decision whenever the gap between simulation and real times was more than 20%. We have identified two main reasons that explain these differences.

The first one is that despite the easiness and quickness of our video tape approach, its limitations as a data acquisition method are important when compared with other motion capture systems. As a consequence, it was difficult to model some complex, quick and simultaneous body movements. The second cause of these deviations is that DELMIA does not consider accelerations as such but to assimilate percussions to sweeping movements. However, it is important to point out that our model has provided valuable, quick and fit for purpose results, according to the company expectations and also to our budget, time and scope restrictions.

5. EXPERIMENTATION

The National Institute for Occupational and Safety Health (NIOSH) proposes general ranges of optimal workbench heights depending on the required effort level of the task. Working activities are generally classified in three categories, namely, precision work, light work and heavy work. In addition, as workers heights are evidently different, it is also generally accepted to take not the workbench height as a reference but the elbow height. As a result, workbench height should be above elbow height for precision work, just below elbow height for light work, and between 10 and 16 centimetres below elbow height for heavy work (NIOSH 1997).

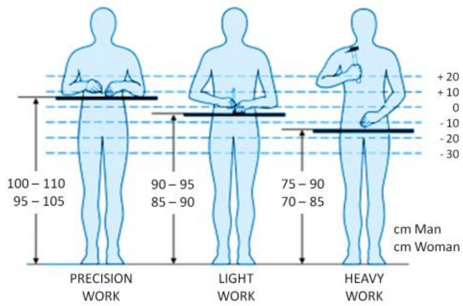

Figure 6: Recommended Workbench Heights depending on the Task Effort Level.

While performing their tasks, splitters combine heavy, light and precision work in a continuous series of quick and repetitive movements so that it is very difficult to identify their corresponding shares and so determining a kind of ergonomically workbench height. Besides, as most of them use a pallet to separate from the wet floor, the effect of height on the ergonomic characterization of the actual operation is far from immediate.

Our manikin is 1.74 metres height but considering the extra pallet height, the effective worker height is ten centimetres higher. Another consideration is that the workbench surface is not actually where the splitter is engaging his tasks, but the upper surface of the slate block.

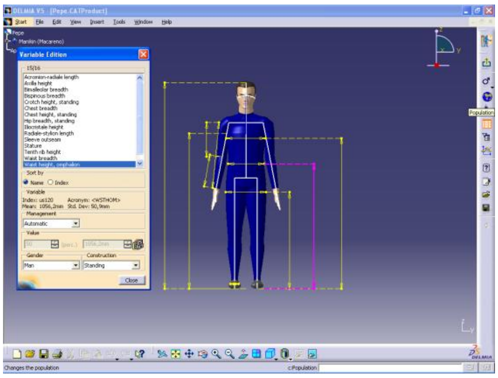

Figure 7: Virtual Manikin Anthropometric Characteristics

To assess the influence of working height on the task performance, two simulation scenarios have been proposed. The first one is analyzed in the so called H1 simulation. It implies that the splitter's elbow is 16 centimetres above the upper surface of the slate block, so this arrangement is in line with a heavy work approach. In the H2 simulation, we do not consider the presence of the pallet so the worker's elbows are 6 centimetres above the working surface. This scenario fits with a light work level. In both cases, the whole range of tasks a splitter has to accomplish has been simulated.

5.1. H1 Previous Operations

Previous Operations include receiving and placing the block on the working table. Not seldom it requires the worker to laterally push it until is properly placed. The worker holds the hammer with his right hand and is forced to bend his back to grasp the rough splitting chisel which is on the working table.

Previous Operations modelling has involved the definition of more than 80 postures that happen in a sequence of 8 seconds. Every posture is assessed using RULA. There is little difference between the actual total operation time and the simulated, which means that it represents quite enough the operation.

As shown in Figure 9, the risk level reaches 4 at the beginning, corresponding with the initial block positioning that requires waist twisting and pushing. It maintains level 3 until the final back bending when it rises to level 4.

Figure 8: Previous Operations.

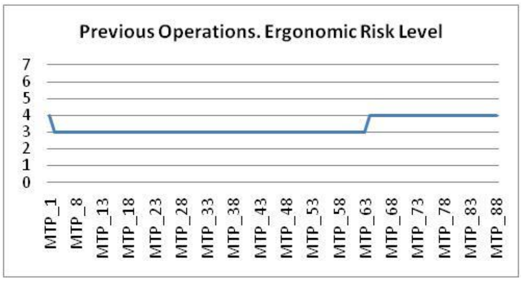

Figure 9: Previous Operations Ergonomic Assessment.

5.2. H1 Rough Splitting

This is the task where physical strength requirements are higher. The block is initially divided into several slabs depending on its length and on the presence of flaws so it may present different durations. If the worker notices the existence of flaws that affect either to the whole block or a part of it, he will throw it to the waste conveyor belt next to him. In this sense, splitting has also a deal of responsibility regarding inspection tasks. The early flaws detection saves time and costs as it reduces reprocessing tasks.

The Rough Splitting simulation shows a significant deviation of -65% between the simulated and the actual hamming time. The cause of this deviation is that the simulator does not consider accelerations as such but to assimilate percussions to sweeping movements, so is underestimating the level of effort. Moreover, two factors have to be accounted. On the one hand, percussions imply noise and vibrations that are transmitted to the body through the hand and arm. On the other hand, inspection time is not being considered in this simple model. As a result, the time of the simulation is not realistic. However, ergonomic results are still acceptable.

Figure 10: Rough Splitting

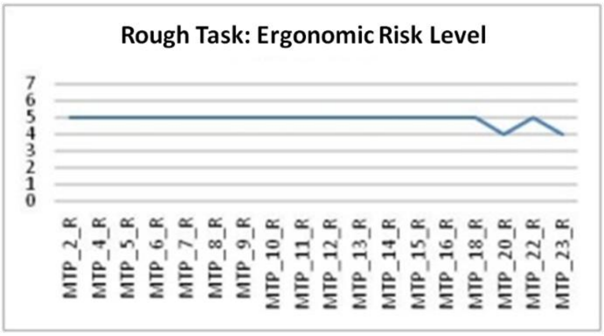

Figure 11: Rough Splitting Grand Score

Figure 11 depicts the associated risk for every posture. Risk levels range between 4 and 5. These levels indicate the convenience of changes to preventing from injuries in the mid and long term.

5.3. H1 Splitting

Splitting is a very skilful activity that determines the final commercial thickness of the slate tiles. Splitting with turning refers to the fact that the worker eventually needs to totally turn the part and hit it from the opposite side in order to effectively split it up.

In the splitting with turning case, the difference between real and virtual times is one of 54%. We probably commit this deviation due to the complexity of the positions being modelled. A set of complex positions -hand grasping, wrist turning, forearm approaching and the assistance of the left arm, among others- has to be built in a very quick sequence. A better biomechanical data input system should be preferable rather than an estimation of trajectories from recorded video frames.

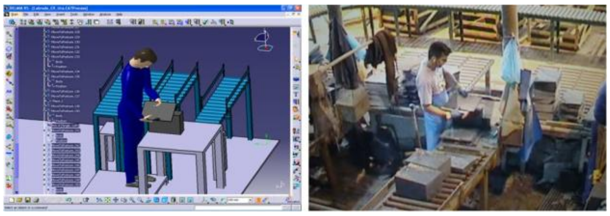

Figure 12: Splitting with Turning. The part is lifted and turned to be split again.

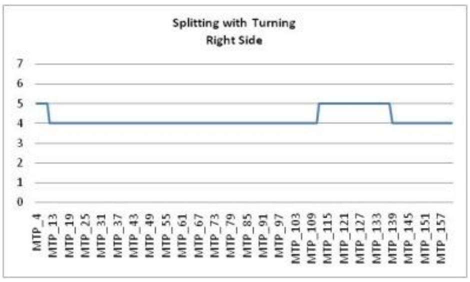

Figure 13: Right Side Analysis.

When the splitting task is simulated without turning, virtual times are similar to the real ones, but ergonomic risk level does not change compared with the turning case.

5.4. H1 Sorting

Sorting may result in many different situations. For the sake of simplicity, we model the two main sub-operations which happen more often. The first one is to reject the slate plate which implies that the worker needs to throw the slate over the waste conveyor belt which is located on his left side. The second one is to put a lot of slates on its corresponding rolling table, usually between 12 and 15 plates that involve a lifting load – about 10 kilograms– and a consequent exertion.

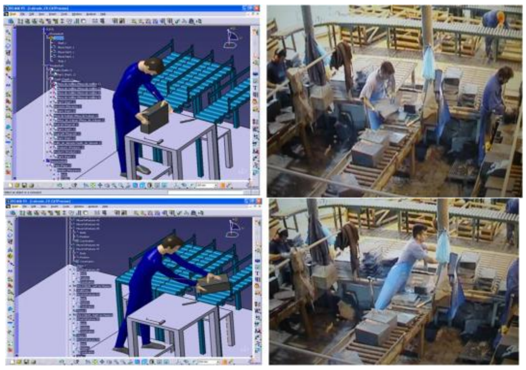

Figure 14: Sorting Task. Grasping and Placing a Lot of Target Size Plates.

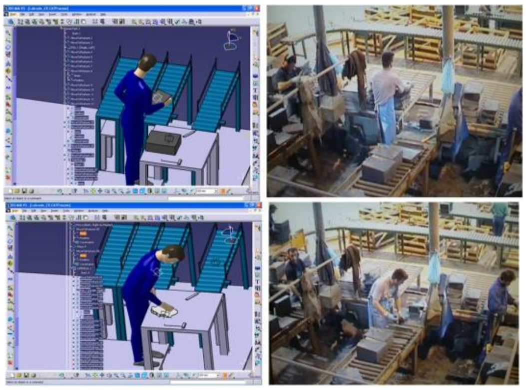

Figure 15: Sorting Task. Placing a Lot of Secondary Size Plates and Housekeeping.

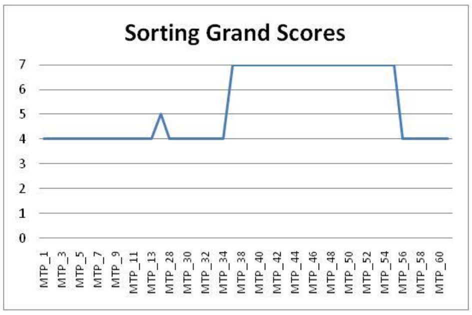

Figure 16: Sorting Task. Grand Scores according to the set of Moves To Posture (MTPs).

We have also modelled the workplace housekeeping tasks. The manikin bends, take a cloth, and cleans his workbench. Although this is not a truly productive task it plays an essential role in maintaining a safe and right production rate.

5.5. H1 Tasks Ergonomic Characterization

In Figure 17, a summary of the H1 case results is given. As it was expected, the overall ergonomic valuation of the splitter tasks is negative. The level of intervention is urgent in the sorting set of tasks and necessary or suggested for the rest.

TASK	PREVIOUS OPERATIONS	ROUGH SPLITTING	SPLITTING				SORTING
			NO TURNING		TURNING		
			KEEP	REJECT	KEEP	REJECT	
RISK LEVEL	3 and 4	4 and 5	4 and 5	4 and 5	4 and 5	4 and 5	4 to 7
LEVEL OF INTERVENTION	Suggested	Necessary	Necessary	Necessary	Necessary	Necessary	Urgent
PROPOSAL	Use of a Tool Belt			Layout Change		Layout Change	Layout Change

Figure 17: Summary of Results. Risk, Level of Intervention and Proposals for every Task are shown.

Some tasks are inevitable. Unless effective technological changes happen in the way the splitting operation is at present being done, splitting necessarily would require impacts and awkward movements and postures. So the chances of feasible and improving changes must focus on those tasks were unnecessary or unproductive movements have been identified. As a result, a set of three proposals that will be commented later on have been suggested.

5.6. H2 Simulation

To consider the influence of height we have also simulated all the previous working activities without the presence of the elevating pallet. We have named this experimentation scenario as H2. To summarize, in Figure 18, we present a results comparison between the H1 and the H2 scenarios

TASK	Previous Operations	Rough Splitting	Splitting		Sorting
			Keep	Reject	
Case H1	3 and 4	4 and 5	5	4	4 to 7
Case H2	3 and 4	5 and 6	4 and 5	3 and 4	3 to 6
Assessment H2 vs H1	Better	Worse	Better	Better	Much Better
Comments	Less duration in level 4 in H2	Higher grand scores in H2	Lower grand scores in H2	Lower grand scores in H2	Lower grand scores in H2

Figure 18: H2 and H1 Grand Scores by Task

For a 1.74 meters height splitter it is ergonomically better not to use the pallet, except in the case of rough splitting, where the grand score is then higher. It is more convenient for the splitter to work between 5 and 10 centimetres below his elbow rather than working as they currently do, i.e. between 15 and 20 centimetres. To do so, we suggest the employment of stackable drainage anti-fatigue floor mats so that the splitter can adjust exactly his working height and keep his feet dry. This would also help in absorbing vibrations and impacts so alleviating stress and fatigue in the feet, legs and back. These mats also have a non slip surface reducing the risk of slips and falls (CCOSH 2006).

6. IMPROVING PROPOSALS

The modelling process requires a thorough observation of the tasks under study. That is why the designer systematically questions the reasons behind every task and subtask. This is a very productive attitude as it eventually ends in improvement proposals to be simulated before their effective implementation. As a consequence, we propose a set of three actuations in order to improve the ergonomic and productive performance.

The first one consists of the employment of a tool belt by the splitters. The second proposal implies a feasible and almost immediate change in the workplace layout. The third proposal suggests a total change in the traditional layout scheme

6.1. The Use of a Tool Belt

The proposal of using a tool belt came up after the observation that the splitter needs to use his both hands so he is in many occasions forced to bend his back to put his tools –hammer and two chisels- on the table and pick them again later. These are unnecessary movements that should be avoided.

Although this may sound as a platitude, it is a remarkable fact that the employment of tool belts among the splitters, unlike other artisanal professionals, would be a brand new action, not only in this particular company, but in the whole sector. This simple accessory facilitates the work as it ensures comfortable reaching out to take the chisels without the need to bend forward or sideways.

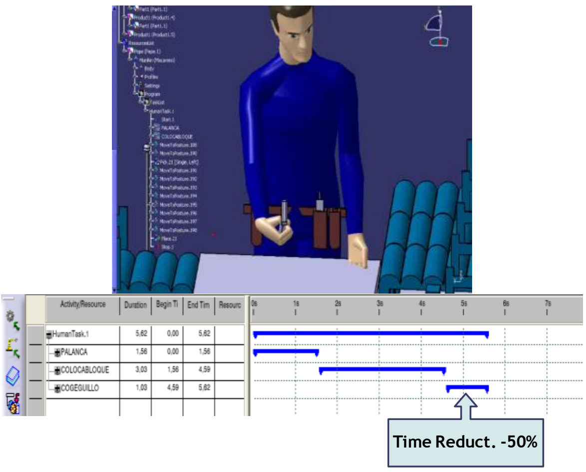

Figure 19: The Splitter wearing a Tool Belt. On the right, the Gantt Chart corresponding to the Previous Operations Task.

As shown in the Gantt chart in Figure 19, a 50% time reduction in the grasping chisel subtask is obtained. Besides, the operation is ergonomically better as risk reduces from level 4 to level 3.

6.2. Simple Layout Modification

We have simulated a simple low investment modified workplace layout. At present, the waste conveyor belt is located on the left side of the splitter so he is frequently obliged to twist and bend his trunk at the same time he is grasping and holding a variable number of plates or even a whole block. So the aim is at avoiding these lateral movements required every time a block or a lot of plates are rejected which suppose a 25% of the total sorting movements.

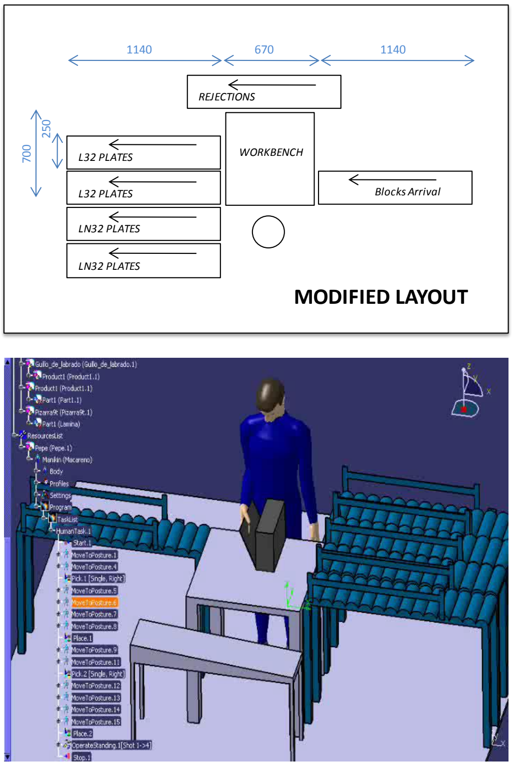

Figure 20: The Proposed Workplace Design.

The use of a front slide ramp connecting the working table with the waste conveyor belt would help reducing ergonomic risk from original level 4 to level 3. Besides, it is also a 15% faster, resulting in a more productive task.

6.3. Brand New Design: Circular Distribution

Whilst the two before mentioned proposals came up as a result of the information gathered during the modelling process, this initiative is the outcome of a specific design effort aimed at reducing the ergonomic impact and improving productivity of the sorting tasks, which show the highest grand scores.

A radial distribution scheme is then presented as an innovative conceptual design in this sector. It would imply a moderate investment since changes in layout and in production and transportation means would be required both upstream and downstream from this point.

The distribution belts have been located accordingly to their frequency of use in order to minimize the ergonomic impact and to maximize productivity. Thus, blocks arrive from the right side of the splitter. Then, the L32 plates belt is located, followed by the To Waste belt. The rejected materials are this way frontally pushed away, which is a much safer and faster operation. Finally, the less frequent movements correspond to the stacking of the two general sorts of LN32 plates.

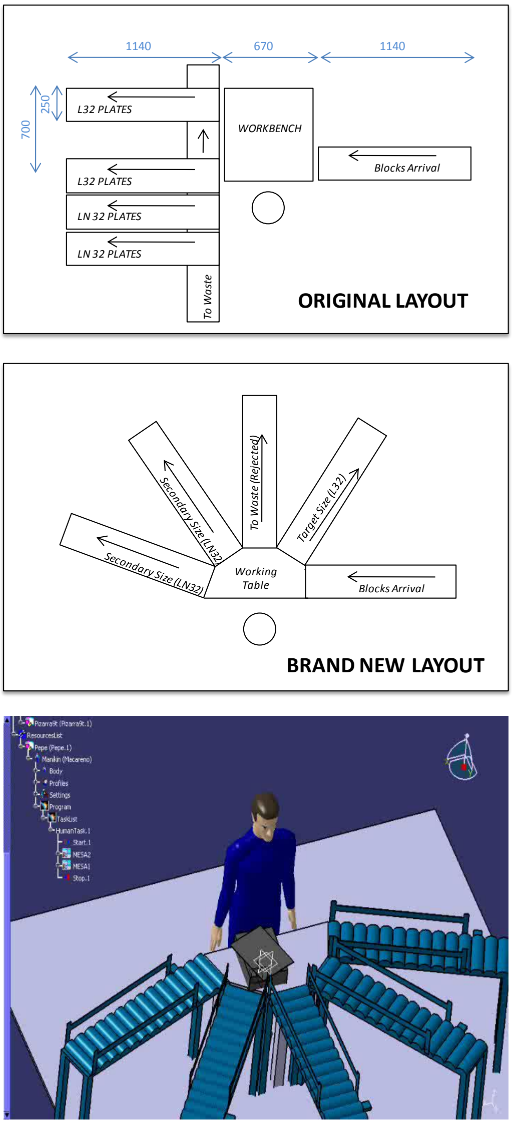

Figure 21: The Original Layout versus the The Proposed Radial Workplace Design.

This layout dramatically improves the time spent in sorting tasks. A 75% reduction in placing target size lots on its delivery rolling table is found. This also involves a less ergonomic risk as it never rises over level 3.

Table 4: Comparison in Sorting Times for several Scenarios

Time (s)	H1	H2	Radial Layout
Rejection	2,36	2,55	3,14
Target Lots	7,46	5,11	1,23
Total	11,15	8,29	4,37

CONCLUSION

A quantitative approach to a combined ergonomic and operational assessment of the slates splitters tasks has been presented. This is a brand new initiative in the slate roofing manufacturing sector. A RULA analysis has been carried out by means of a Digital Human Model (DHM) implemented in DELMIA aiming at the characterization, analysis and improvement of the whole set of tasks involved. The use of a DHM allows a systematic approach to the problem and provides a reproducible and modifiable model. After their implementation in the simulation environment, the model was then validated. The main conclusion is that this is an ergonomically hard work, especially during the sorting tasks. In addition, it is more convenient to work between 5 and 10 centimetres below the elbow rather than working between 15 and 20 centimetres. To do so we suggest avoiding the use of elevating pallets and substituting them by modular and stackable flooring mats for a good height adjustment.

A set of three improving changes was proposed and analyzed. The employment of tool belts would avoid unnecessary back bending and increase productivity. A simple ramp would change the sequence of movements required every time a rejection has to be done to a better ergonomically and faster operation. Finally, a specific new design aimed at optimizing simultaneously ergonomics and productivity was investigated, achieving these goals more than satisfactorily.

This paper summarizes the ergonomic assessment of the splitters work in the context of a broader process optimization project. So, it is not meant to be a rigorous and deep ergonomic analysis, but a means for the global improvement of the manufacturing process. Further research is still being carried out in cooperation with the company for the actual implementation of the results found.

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