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Improving Ergonomics in the Meat Industry: A Case Study of an Italian Ham Processing Company

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Abstract: Meat processing is a labor-intensive industry dealing with manual handling of heavy loads of meat at high frequency. Meat processing workers are under pressure to maintain high rates of work, performing arduous repetitive motions while keeping awkward postures. Ergonomic risk assessments reveal that manual material handling and repetitive tasks expose meat-processing workers to high physical risk. This paper investigates the impact of automated technology on manual ham-deboning lines in the meat-processing industry. The aim is to study the effects of automation on the work system and layout, analyzing the economic and ergonomic impact of semi-automatic ham deboning lines. The study introduces a non-safety cost model for the comparative and sensitive analysis of manual and semi-automatic ham deboning systems, including the cost of non-safety. The model is tested with a case study from an Italian ham processing company. The reference manual ham-deboning line is introduced, together with a new layout proposal involving the adoption of a semi-automatic ham-deboning machine. Results reveal the positive impact of the semi-automatic ham-deboning system on the company's profitability and workers' ergonomics. As a consequence, automated technology leads to economic and ergonomic benefits for workers, employers and customers.

Keywords: Ergonomics, automation, safety analysis, risk assessment, food processing.

1. INTRODUCTION

Work activities in the meat processing industry are both technically and physically demanding. Meat processing workers perform a wide range of tasks, involving manual handling of heavy loads, e.g. whole carcasses, at high frequency. Common activities include lifting, moving, turning and twisting heavy carcasses among the workstations. Other tasks involve laborious and frequent movements to cut the carcass, whilst holding the loads. Such repetitive motions are a common cause of occupational diseases, as the well-known musculoskeletal disorders. In addiction, the work environment is characterized by noise, humidity, cold and offensive odors. These characteristics make the meat processing industry both physically and emotionally demanding. As a consequence, slaughterhouse work is not an attractive option for prospective employees, particularly young people. To improve the working environment and hinder the potential insufficiency in the labor force, the meat processing industry is automating the most labor-intensive parts of the work process (Purnell, Caldwell 2012, Clarke, Nielsen & Madsen 2014). Automated meat processing reduces arduous repetitive work, whilst replacing some heavy activities with less-intensive tasks, e.g. planning and controlling the new technology (Nielsen, Fertin & Christensen 2005, Barbut 2014). Furthermore, the increasing international competition is pressuring the meat processing industry to automate the meat process and develop more efficient production methods. A recent study on the European meat industry reveals that the per capita meat consumption has stabilized in the last 20 years (Kanerva 2013). This static overall consumption increases the pressure on the meat processing companies to adopt more efficient production methods, e.g. automated technology. At the same time, automation offers consistent benefits for safety and hygiene of the meat processing work, providing higher process controllability and better working conditions (Wadie et al. 1995, Purnell, Caldwell 2012, Purnell, Grimsby Institute of Further and Higher Education 2013). For example, the reduction of manual handling and the more efficient tool sterilization in the clean slaughter line reduce the cross contamination between carcasses, improving the food hygiene and safety. Robot technology is widely used in manufacturing industry, when products are well-defined and properly designed. Furthermore, the high investments in automation require industries with high production volumes ensuring a reasonable payback time. Pork, poultry and lamb slaughtering are fully or partially automated, e.g. poultry lines work at high speeds, while the lamb production is partially automated (Madsen, Nielsen 2002, McMurray 2013). Nevertheless, several projects failed after trying to automate the whole beef slaughtering process (Purnell 1998, Madsen, Nielsen 2002), i.e. fully automatic slaughtering is more complex in beef and pork production, due to greater dimensions and weight of the carcasses. Particularly, manual workers typically perform ham-deboning work.

This paper focuses on the improvement of health and safety of meat processing workers through ergonomics and automation. The following study introduces a comparative and sensitive analysis of manual and semi-automatic ham-

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deboning systems. The aim is to investigate the effects of automation on the work system and layout, analyzing the economic and ergonomic impact of semi-automatic ham deboning lines. The comparative analysis includes a non-safety cost model for the study of non-safety cost due to accidents and injuries. The non-safety cost model is tested with a case study from an Italian ham processing company. The study of the existing meat processing plant and the work system analysis reveal critical situations posing serious risks to the workers' safety and health. The study introduces the new layout proposal for the ham production process, replacing laborious manual ham-deboning activities with automated technology. The remainder of this paper is as follows. Section 2 presents the non-safety cost model, analyzing direct and indirect non-safety costs. A brief overview of the Italian Region Emilia Romagna meat industry is introduced in Section 3, together with the detailed description of an existing ham production plant and the ergonomic risk assessment among deboning line workers. Section 4 introduces the new layout proposal, while the comparative and sensitive analysis is in Section 5. Finally, Section 6 and Section 7 discuss the results, providing directions for future developments.

2. NON-SAFETY COST MODEL

The following Section 2 introduces the non-safety cost models for the economic evaluation of the both the manual ham-deboning system and the semi-automatic ham-deboning system. The non-safety cost model analyzes the cost of the work system, c_s, together with the cost of non-safety, c_n.

Companies quantify the value of c_s including labour costs, plus investment, power supply and maintenance costs, in case of semi-automatic ham-deboning systems. Non-safety cost c_n is due to the neglected investments in safety procedures and equipment. Despite the high cost of accidents and injuries, companies frequently neglect the cost of non-safety. Workers, companies and community pay the consequences of non-safety work. Particularly, occupational accidents cause direct costs and indirect costs to the companies. The former include quantifiable costs due to the accident event, e.g. workers' compensation payments, medical expenses, and costs for legal services etc. The latter are frequently underestimated and include lost productivity, recruitment and training of new employees, costs associated with lower employee morale and absenteeism, etc. The following Equation (1) shows the overall non-safety cost.

$$c_n = (c_d + c_i) \cdot n \tag{1}$$

Given n as the number of injuries in the reference time period, c_d as the unit direct non-safety cost and c_i as the unit indirect non-safety cost, c_n is the overall non-safety cost. Studies show that the ratio of indirect costs to direct costs, k, varies widely, from a high of 20:1 to a low of 1:1. The less serious the injury, the higher the ratio of indirect costs to direct costs (Business Roundtable 1982). As a consequence, the value of k is related to the type of injury, i. Furthermore, statistics show the incidence rate of injuries as equal to h events every 100 meat-processing workers. The following Equation (2) introduces the final formulation for the overall non-safety cost.

$$c_n = \frac{h}{100} \cdot t \cdot \sum_{i=1}^{l} [\, w_i \cdot c_d \cdot (1 + k_i)] \tag{2}$$

Given the number of worker w_i exposed to the risk of injury i, the overall c_n in the reference time period t is as in the Equation (2). The following Section 3 introduces the overview of the Italian Region Emilia Romagna meat industry, together with the detailed description of the reference ham production plant and the ergonomic risk assessment among deboning line workers.

3. MEAT PROCESSING PLANT ANALYSIS

3.1 Meat processing industry in Emilia Romagna, Italy

The pork and beef slaughterhouse and processing industries play an important role in the economy of the Emilia Romagna Region (Regione Emilia Romagna 2014). The Local Occupational Health and Safety Agency (AUSL) reports that meat processing is one of the most hazardous industries in the Emilia Romagna Region. Meat and poultry workers sustain a range of injuries, including hernia and repetitive stress injuries. According to the American Bureau of Labor Statistics, injuries in the American meat industry declined from 29.5 per 100 full-time workers in 1992 to 14.7 in 2001, but the rate was among the highest of any industry (United States Government Accountability Office 2005). Nevertheless, Italian statistics show higher incidence rates, reporting 24 injuries per 100 meat-processing workers (ASL Mantova, USL Modena 2000).

Meat processing work typically requires manual workers to keep up with the high speed of processing lines. Employment policies and practices of this industry result in serious physical and mental harm to meat processing workers, preventing them from reporting injuries or drawing attention to unsafe working conditions. Furthermore, several workers are recent immigrants and face additional economic and social pressures increasing their vulnerability in the workplace (Monforton 2013). As a consequence, the meat processing is one of the most hazardous industries, as it poses a serious risk to workers' safety and health.

3.2 Reference meat processing plant

The meat processing plant of this study is from an Italian company situated in the Emilia Romagna Region. Figure 1 shows the ham processing steps in the reference meat processing plant, highlighting the hazardous manual handling activities. About twenty tractor trailers a day reach the plant, where manual workers unload the hams with a 1,800 hams per hour pace. Two different lines typically move the pork legs towards different processes. The first line is for the ham salting before the aging process and it is conventionally called "salt line". The latter is the "deboning line" and it moves the pieces towards the speck and ham steak production processes. The hams processed in the salt line are delivered to further processing plant for the aging process, whilst ready-to-eat specks and hams are packed as whole pieces or sliced packs, then delivered all over the world. Salt line workers trim about 1,300 hams per hour, whilst manual deboning line workers prepare about 3,000 hams per hour. Particularly, the hams for the deboning line are manually arranged on specific hanging racks and moved towards the processing phases.

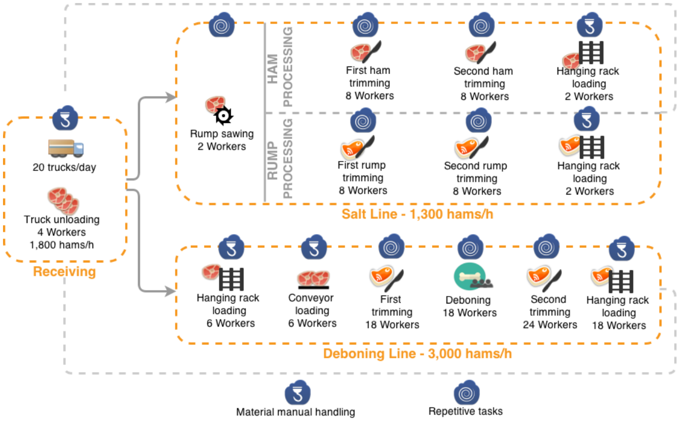

Fig. 1. Ham flow in the reference meat processing plant.

The daily work shift is of eight hours a day for each worker, while the plant runs two eight-hour shifts.

3.3 Working conditions

Hanging rack and conveyor loading, as well as trimming and deboning work, are high-intensive activities. The former require high force due to the manual material handling (MMH), while the latter involve repetitive motions (R) of the upper-limbs, mainly concerning the hands, the wrists, the shoulders, but even the neck and the trunk. The International (ISO 11228-1 2003) standard deals with MMH and is based on the 1991 NIOSH Lifting Equation (Waters, Putz-Anderson & Garg 1994). The NIOSH Lifting Equation is a method to assess the ergonomic risk of MMH in activities with repeated lifting. The Equation recommends a weight limit for lifting activities, defining the NIOSH Lifting Index as the ratio of the actual load weight to the recommended weight limit. The OCRA Check-list is the risk assessment method for the ergonomic risk assessment of upper limbs (ISO 11228-3 2007). Such tool is used for the initial screening of the exposure to biomechanical overload of the upper limbs associated with manual R. The OCRA Checklist uses an analysis system based on pre-assigned numerical values for critical risk factors, e.g. lack of recovery time, movement frequency and force. Table 1 shows the results of the ergonomic risk assessment through OCRA Check-list for repetitive tasks and NIOSH method for MMH, of six deboning line workers (Occhipinti 1998, ISO 11228-1 2003, ISO 11228-3 2007). The OCRA Check-list and NIOSH Lifting Index (LI) values in Table 1 are comparable with the ergonomic risk assessment scores for all the workers at each workstation of the reference deboning line.

Table 1. Ergonomic risk assessment scores for manual deboning line workers

Worker	Activity	Risk	OCRA Check-list	NIOSH LI	Workers performing the same activity [workers]
1	Rack loading	MMH	-	2.44	6
2	Conveyor loading	MMH	-	2.44	6
3	First trimming	R	13.5	-	18
4	Deboning	R	29.1	-	18
5	Second trimming	R	11.5	-	24
6	Rack loading	MMH	-	1.75	18

The OCRA Check-list values in Table 1 refer to the most stressed arm, for each worker. The threshold limit value for acceptable risk is 7.5. High OCRA Check-list values (greater than or equal to 22.6) characterize high-risk repetitive tasks (Occhipinti 1998, ISO 11228-3 2007), i.e. deboning activities pose high threat to the health and safety of workers. The NIOSH LI threshold limit value for acceptable risk of MMH is 1 (ISO 11228-1 2003), i.e. hanging rack and conveyor loading pose serious threat to the health and safety of deboning line workers (see in Table 1). Both Manual Material Handling (MMH) and Repetitive tasks (R) are performed in harsh working conditions, due to cold climate and spatially restricted working environment. Furthermore, workers are forced to keep up with the speed of processing lines, at overcrowded workstations in uncomfortable conditions. The analysis of the reference manual deboning line highlights high-risk situations, posing a direct threat to workers' safety and health. The following Section 4 introduces the semi-automatic system proposal, including both manual workers and automated technology for automatic deboning.

4. SEMI-AUTOMATIC DEBONING SYSTEM

The following Section 4 outlines the new ham flow proposal and the feasibility analysis, after the introduction of an ham-deboning machine for deboning activities.

4.1 Pork ham automatic deboning technology

The proposed pork ham automatic deboning system is the Mayekawa HAMDAS-R in Figure 2. The deboning process is outlined in the following Figure 3. This leg deboning machine performs the automatic deboning of 500 hams per hour. After auto-loading pig's thigh deboned hipbone, the ham-deboning machine detects right and left legs. As in Figure 3, the system includes the whole bone length measuring function that enables to react the difference between calf bone and thighbone.

Fig. 2. Mayekawa HAMDAS-R (www.mayekawa.com).

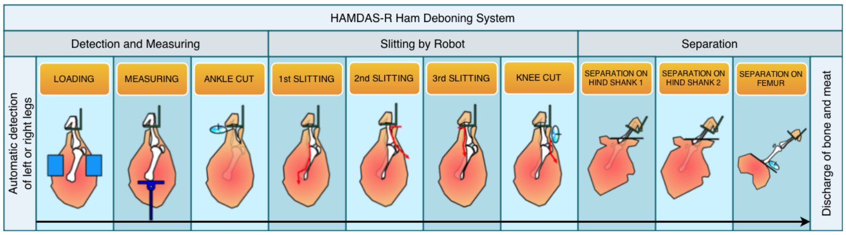

Fig. 3. Mayekawa HAMDAS-R ham-deboning process.

The vertical multi-joint robot cuts meat along the bone. Deboned hams and bones are the process outputs (see in Figure 3). The system ensures high deboning performances, i.e. the average meat loss on the bones is 60g. The meat weight loss after the semi-automatic deboning process is minimum, as the hams move through a limited number of manual workstations. The machine specifications are in the following Table 2.

Table 2. Mayekawa HAMDAS-R specifications

Capacity	Maximum 500 legs/hour with 3 pre-cut machines
	Maximum 170 legs/hour with 1 pre-cut machines
Dimensions	W137.8"xL429.1"xH118.1" with 3 pre-cut machine
	W137.8"xL307.8"xH118.1" with 1 pre-cut machine
Electricity supply	AC 3 phases, 240 V – 50 kW
Air supply	2,400 l/ min dry air at 7-12 barG Dew point 5°C at 5barG
Water supply	60°C, 2-3 barG-10 l/min
Weight	Approximately 13,500 kg

The ham-deboning machine requires conventional electricity and air supply to work. Water supply is necessary for cleaning operations, while no additional groundwork is necessary for the installation on conventional industrial floors.

4.2 New layout proposal

The new layout proposal includes the semi-automatic ham-deboning machine. The semi-automatic deboning line proposal is in the following Figure 4.

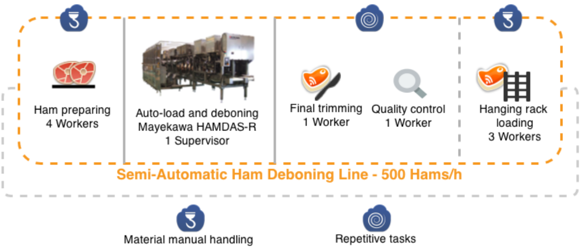

Fig. 4. Semi-automatic deboning line proposal with the Mayekawa HAMDAS-R ham-deboning machine.

Truck-unloading workers manually lay down the hams on the conveyor, as in the traditional process (see in Figure 1 and Figur 4). The robot auto-loads and detects right or left legs, replacing the pre-deboning manual material handling activities. The vertical multi-joint robot starts the deboning process and cuts meat along the bone. After the automatic deboning, the ham is free from the damages caused by knife and ready for further trimming operations. The new layout proposal in Figure 4 is not fully automated. The ham-deboning machine requires seven workers to prepare the hams and supervise the deboning process. Particularly, four workers prepare the hams before the cutting phase, while two workers check the quality of deboned hams and perform final trimming operations. Finally, one worker supervises up to three working machines.

4.3 Manual ham-deboning process versus semi-automatic ham-deboning system

The following analysis outlines the comparative analysis of the semi-automatic deboning system proposal. Table 3 outlines the comparison of the manual ham-deboning process and the semi-automatic ham-deboning system. Considering the ham flow data of the reference meat processing plant in Figure 1, six ham-deboning machines are necessary to guarantee the daily demand of deboned products. The semi-automatic deboning system allows several workers to perform safer operations than manual material handling and repetitive tasks of the reference manual ham-deboning process, e.g. machine supervision and deboned ham quality check.

Table 3. Comparison of manual ham-deboning process versus semi-automatic ham-deboning system

Variable	Manual process	Semi-automatic system
Daily demand of deboned hams [products]	3,000	3,000
Number of automatic machines [machines]	0	6
Number of workers required per shift [workers]	90	56
Manual workers per shift [workers]	90	54
Workers performing MMH per shift [workers]	30	42
Workers performing R per shift [workers]	60	12

As a consequence, the overall number of workers exposed to the risk of manual handling is lower for the semi-automatic system (see in Table 3). The overall number of manual material handling workers is higher in the semi-automatic system proposal since twenty-four workers prepare the hams for the auto-load robots. Furthermore, the ham-deboning machine performs strenuous repetitive tasks, which were previously required to manual workers. The following Table 4 shows the ergonomic risk assessment scores of five deboning line workers at the semi-automatic deboning line.

Table 4. Ergonomic risk assessment scores for workers at the semi-automatic deboning line

Worker	Activity	Risk	OCRA Check-list	NIOSH LI	Workers performing the same activity [workers]
1	Ham preparing	MMH	-	1.21	24
2	Supervising	-	-	-	2
3	Trimming	R	11.5	-	6
4	Quality control	R	7.5	-	6
5	Rack loading	MMH	-	1.75	18

Particularly, trimming and quality control workers perform both the tasks at the same workstation. The OCRA Check-list and NIOSH Lifting Index (LI) values in Table 4 are comparable with the ergonomic risk assessment scores for all the workers at each workstation of the semi-automatic deboning line. The OCRA Check-list mean value reduction is 45%. The new layout proposal involves autonomous robots lifting the hams, while workers prepare the pork legs on the conveyor (see in Figure 4). As Table 1 and Table 4 show, preparing activity is less intensive than hanging rack loading or conveyor loading, i.e. the NIOSH LI reduction is 29%. Supervising and quality control tasks do not expose workers to ergonomic risk of manual handling, while trimming and hanging rack loading are high-intensive activities, as in the reference manual system (see in Table 4). The semi-automatic ham-deboning system requires 80% less manual workers preforming R, compared with the reference ham-deboning process.

5. COMPARATIVE AND SENSITIVE ANALYSIS

The following comparative analysis aims to compare the reference ham-deboning system and the semi-automatic ham-deboning proposal. The analysis investigates the impact of non-safety cost on the hourly cost of the ham-deboning system. The cost analysis of the semi-automatic system includes fixed and variable costs, due to adoption of the semi-automatic machines. The fixed investment cost is based on a 10-year life, 4% of interest rate, and 3,520 hours of work per year and machine. Variable costs include labor, energy and maintenance costs. Particularly, maintenance costs are due to the cutting tool replacement, e.g. blades and knives, and no additional maintenance is required. The comparative analysis includes the non-safety cost model in Section 2 for the non-safety cost analysis. The Occupational Safety and Health Agency's (OSHA) $afety Pays Program estimates the values of c_d and k for occupational injuries. The following analysis includes the values of c_d and k for injuries related to MMH and R. Particularly, hernia injury is associated with MMH, while common R injury is carpal tunnel syndrome. The OSHA estimates the average c_d of hernia injury as equal to 22,548 \$, the average c_d of carpal tunnel syndrome as equal to 30,000 \$ and k as equal to 1.1 for both such injuries. The value of n depends on the number of accidents occurred in the reference time period. Statistics show the incidence rate as equal to 24 accidents every 100 meat-processing workers (ASL Mantova, USL Modena 2000). As a consequence, the expected number of accidents in the reference time period is 435 for the manual ham-deboning system and 271 for the semi-automatic system. The following Table 5 shows the impact of the non-safety costs on the results of the comparative and sensitive analysis.

Table 5. Comparative and sensitive analysis

Variable	S_1	S_2	S_3
Productive capacity [hams/h]	3,000 hams/h	500 hams/h	5,000 hams/h
Accidents with the manual ham-deboning system [accidents]	436	53	750
Accidents with the semi-automatic ham-deboning system [accidents]	271	48	455
Non-safety cost of the manual ham-deboning system [k€]	19,907.48 k€	2,433.14k€	34,285.10 k€
Non-safety cost of the semi-automatic ham-deboning system [k€]	10,895.91 k€	1,945.70 k€	18,289.56 k€
Non-safety cost saving [k€]	9,011.57 k€	487.44 k€	15,995.53 k€
Hourly cost saving [%]*	+22.98 %	-6.42 %	+28.20 %

The three Scenarios in Table 5 show the non-safety cost analysis and the impact of non-safety cost on the hourly cost of the ham-deboning system. The hourly cost saving is shown as percentage because of the company's request to cover the actual hourly cost of the ham-deboning systems. Scenario 1 shows the comparative analysis of the reference case study. The semi-automatic ham-deboning system in Scenario 1 leads to 9,011.57 k€ non-safety cost saving. The hourly cost of the semi-automatic ham-deboning system is lower than the hourly cost of the manual ham-deboning system, i.e. the percentage hourly cost saving is +22.98% (see in Table 5). Scenario 2 and Scenario 3 show the non-safety cost analysis varying production capacity and dimensions of the ham-deboning system. Scenario 2 reflects a small-sized meat-processing company with 500 hams/h production capacity, while Scenario 3 reflects a large meat-processing company with 5,000 hams/h production capacity (see in Table 5). The non-safety cost of the manual system is lower than the non-safety cost of the semi-automatic system, in Scenario 2. Conversely, Scenario 3 shows high non-safety cost saving due to the semi-automatic system, when companies' production capacity is high. The larger the company dimension, the higher the impact of non-safety cost saving and the hourly cost saving with the semi-automatic ham-deboning system (see in Table 5). The following Section 6 and Section 7 discuss the results of the comparative and sensitive analysis, providing directions for future research.

6. DISCUSSION

The semi-automatic ham-deboning proposal includes the adoption of automated technology, replacing manual workers for high-risk ham-deboning activities. The comparative and sensitive analysis in Section 4 shows the impact of non-safety cost on the hourly cost of the ham-deboning system. Three Scenarios describe the non-safety cost of the system, varying production capacity and dimensions of the ham-deboning system. Results show the positive impact of the semi-automatic ham-deboning system on workers' ergonomics and on the company's profitability. The new layout proposal leads to lower hourly cost of the ham-deboning system, compared with the reference ham-deboning system (see Scenario 1 in Table 5). The comparative and sensitive analysis shows the impact of non-safety cost, varying production capacity and dimensions of the ham-deboning system. Results show that the larger the company dimension, the higher the non-safety cost saving and the hourly cost saving with the semi-automatic ham-deboning system (see in Table 5). Despite the initial investment for the machines purchase, the semi-automatic system ensures both short- and long-term benefits for workers, employers and customers. Furthermore, the ham-deboning machine accomplishes high-risk cutting and handling activities, while workers perform safer operations, e.g. machine supervision and deboned ham quality check. The following Figure 5 shows the results of the comparative analysis from the ergonomic perspective.

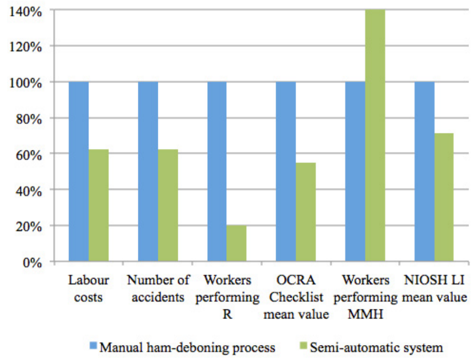

Fig. 5. Ergonomic risk assessment results comparison

The semi-automatic ham-deboning system requires less manual workers than the manual ham-deboning process (Figure 5). Labor costs and direct non-safety costs are lower, i.e. automation drastically reduces the need for MMH and R workers, leading to a significant decrease in injury and accident rates. Figure 5 shows the ergonomic effects of the manual ham-deboning process and the semi-automatic ham-deboning system on the workers' health and safety. Particularly, the semi-automatic ham-deboning system requires 80% less manual workers preforming R, compared with the reference ham-deboning process. The OCRA Checklist mean value reduction (45%) in Table 4 confirms the reduction of the exposure to R of the upper limbs, with the semi-automatic ham-deboning system. The ergonomic risk assessments results for workers performing MMH show safer working conditions with the semi-automatic ham-deboning system. Despite the higher number of workers performing MMH, the NIOSH LI mean value reduction (29%) with the semi-automatic ham-deboning system is dramatic. The robot technology further ensures high quality of the final products. As a result, the final product is standard-sized and devoid of cutting damages due to knives and blades. Furthermore, product hygiene and security improve as well, as the contact with human hands is drastically reduced.

7. CONCLUSIONS

Work activities in the meat processing industry are both technically and physically demanding. The ergonomic risk assessment among deboning workers of an Italian ham processing company confirms high ergonomic risk due to manual handling tasks. The reference manual ham-deboning line is introduced, together with the semi-automatic system proposal. The semi-automatic deboning system includes the adoption of automated technology, replacing manual workers for high-risk manual activities, e.g. manual material handling of heavy pork legs and repetitive deboning tasks. The comparative and sensitive analysis shows the impact of non-safety cost on the hourly cost of the ham-deboning system. The non-safety cost analysis reveals the positive impact of the semi-automatic ham-deboning system on the company's profitability. Particularly, results show that the new layout proposal leads to lower hourly cost of the semi-automatic ham-deboning line. Furthermore, automated technology improves the product quality, hygiene and security, leading to economic and ergonomic benefits for workers, employers and customers. Future developments of this study include the analysis of further layout re-design proposals, aiming to support manual workers through automation and improving ergonomics in the meat processing industry.

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REFERENCES

ASL Mantova & USL Modena 2000, *I profili di rischio nella macellazione: identificazione e misura degli effetti*, Servizi di Medicina Preventiva e Igiene del Lavoro.

Barbut, S. 2014, "Review: Automation and meat quality-global challenges", *Meat Science,* vol. 96, no. 1, pp. 335-345.

Business Roundtable 1982, *Improving Construction Safety Performance: A Construction Industry Cost Effectiveness Project Report*, New York, NY.

Clarke, R., Nielsen, J.U. & Madsen, N.T. 2014, "Automation in the meat industry. Cutting and Boning" in *Encyclopedia of Meat Sciences (Second Edition)*, eds. M. Dikeman & C. Devine, Academic Press, Oxford, pp. 33-42.

ISO 11228-1 2003, *System of standards for labor safety. Ergonomics. Manual handling. Part 1. Lifting and Carrying. General requirements.*

ISO 11228-3 2007, *System of standards for labor safety. Ergonomics. Manual handling. Part 3. Handling of low loads at high frequency.*

Kanerva, M. 2013, *Meat consumption in Europe: issues, trends and debates*, Universitat Bremen, Bremen.

Madsen, K.B. & Nielsen, J.U. 2002, "Automated meat processing" in *Meat Processing*, eds. J. Kerry, J. Kerry & D. Ledward, Woodhead Publishing, , pp. 283-296.

McMurray, G. 2013, "Robotics and automation in the poultry industry: current technology and future trends" in *Robotics and Automation in the Food Industry*, ed. D.G. Caldwell, Woodhead Publishing, , pp. 329-353.

Monforton, C. 2013*, Harsh working conditions in US poultry and meatpacking plants violate human rights, OAS Commission to review the claim*. Available: http://scienceblogs.com/thepumphandle/2013/06/25/harsh-working-conditions-in-us-poultry-and-meatpacking-plants-violate-human-rights-oas-commission-to-review-the-claim/ [2014, December].

Nielsen, J.U., Fertin, C. & Christensen, H. 2005, "Up-to-date equipment for pig slaughtering, cutting and boning and their influence on product safety", *Technologija Mesa,* vol. 46, pp. 62-63-66.

Occhipinti, E. 1998, "OCRA: a concise index for the assessment of exposure to repetitive motions of the upper limbs", *Ergonomics,* vol. 41, no. 9, pp. 1290-1311.

OSHA*, OSHA's $afety Pays Program*. Available: www.osha.gov/dcsp/smallbusiness/safetypays/estimator.html [2015, March, 11].

Purnell, G. & Caldwell, D.G. 2012, *Robotics and automation in meat processing*, Woodhead Publishing Limited.

Purnell, G. 1998, "Robotic equipment in the meat industry", *Meat Science,* vol. 49, no. SUPPL. 1, pp. S297.

Purnell, G. & Grimsby Institute of Further and Higher Education 2013, "Robotics and automation in meat processing" in *Robotics and Automation in the Food Industry*, ed. D.G. Caldwell, Woodhead Publishing, , pp. 304-328.

Regione Emilia Romagna 2014 *, Agricoltural and food production. The role of the Region Emilia Romagna*. Available: http://agricoltura.regione.emilia-romagna.it/produzioni-agroalimentari/temi/allevare-animali [2014, 11/4].

United States Government Accountability Office 2005, *Workplace Safety and Health. Safety in the meat and poultry industry, while Improving, could be further strengthened.*

Wadie, I., Maddock, N., Purnell, G., Khodabandehloo, K., Crooks, A., Shacklock, A. & West, D. 1995, "Robots for the meat industry", *Industrial Robot,* vol. 22, no. 5, pp. 22-26.

Waters, T.R., Putz-Anderson, V. & Garg, A. 1994, *Applications Manual for the Revised NIOSH Lifting Equation*, Cincinnati, Ohio: NIOSH.