2022

Human Ergonomic Simulation to Support the Design of an Exoskeleton for Lashing/De-Lashing Operations of Containers Cargo

Francesco Longo
University of Calabria

Antonio Padovano
University of Calabria

Vittorio Solina
University of Calabria

Virginia D' Augusta
University of Calabria

Stefan Venzl
Upper Austria University of Applied Sciences, WELS Campus

See next page for additional authors

Original Publication Citation

Longo, F., Padovano, A., Solina, V., D'Augusta, V., Venzl, S., Calbi, R., Bartuni, M., Anastasi, O., & Diaz, R. (2022). Human ergonomic simulation to support the design of an exoskeleton for lashing/de-lashing operations of containers cargo. *Procedia Computer Science*, *200*, 1894-1902. https://doi.org/10.1016/j.procs.2022.01.390

Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 200 (2022) 1894–1902

Procedia Computer Science

www.elsevier.com/locate/procedia

3rd International Conference on Industry 4.0 and Smart Manufacturing

Human Ergonomic Simulation to Support the Design of an Exoskeleton for Lashing/De-lashing operations of Containers Cargo

Francesco Longo[1a], Antonio Padovano[a], Vittorio Solina[a], Virginia D'Augusta[a], Stefan Venzl[b], Roberto Calbi[c], Michele Bartuni[d], Ornella Anastasi[e], Rafael Diaz[f]

[a]*DIMEG, University of Calabria, Via P. Bucci 45C, 87036 Rende, Italy*
[b]*Upper Austria University of Applied Sciences, WELS Campus, Wels,*
[c]*R&D Log, Gioia Tauro, Italy*
[d]*International Shipping, Gioia Tauro, Italy*
[e] *Sea Work Services, Gioia Tauro, Italy*
[f]*Old Dominium University, 5115 Hampton Blvd, Norfolk, VA 23529, USA*

Abstract

Lashing and de-lashing operations of containers cargo on board containerships are considered as quite strenuous activities in which operators are required to work continuously over a 6 or 8 hours shift with very limited break. This is mostly because containerships need to leave the port as soon as possible and containers loading and unloading operations must be executed with very high productivity (stay moored in a port is a totally unproductive time for a ship and a loss-making business for a shipping company). Operators performing lashing and de-lashing operations are subjected to intense ergonomic stress and uncomfortable working postures. To this end, the authors of this article are participating to a research project for the design of an exoskeleton that will help operators to reduce ergonomics and working posture problems while increasing, at the same time, the productivity. This paper presents the results of a human ergonomic simulation devoted to highlight major working postures and muscles strain problems that will be used, in turn, as input for the design of the exoskeleton.

Peer-review under responsibility of the scientific committee of the 3rd International Conference on Industry 4.0 and Smart Manufacturing

Keywords: Ergonomics; Working Postures; Containers Cargo; Lashing/De-lashing Operations; Simulation; Safety; Security

1. Introduction

Most of the worldwide cargo traffic moves, every-day, using containers. According to EuroStats [1], the quarterly data of marine traffic transportation (extracted as July 2021) shows that 826 million tons of goods were handled in the

[1]* Corresponding author. Tel.: +39 0984 494891; fax: +39 0984 494891.
E-mail address: f.longo@unical.it

Peer-review under responsibility of the scientific committee of the 3rd International Conference on Industry 4.0 and Smart Manufacturing
10.1016/j.procs.2022.01.390

main EU ports in the 4th quarter of 2020. Even if the COVID-19 has most certainly led to a substantial fall of the maritime transport of good, the next months are expected to show again an increasing trend due to the positive effect of the vaccine's campaigns in the different countries. Indeed, this trend is confirmed since 2005: the figure 2a [2] clearly shows that the volume of containers handled in main ports, EU-27, between 2005 and 2019 has increased from 60 million of TEUs up to almost 100 million of TEUs (the only negative trend is visible during the 2008-2010 world financial crisis). Furthermore, the average size of vessels calling at main ports, EU-27, between 2005-2019 (see figure 2b [2]), depicts a growth in the dimensions of the containerships (with a gross tonnage per vessel up to 7500 tons). The bigger are the containerships, the bigger is their TEUs transportation capacity. More containers on board means:

- more lashing and de-lashing operations to be manually performed by operators (even considering the level, in terms of piling up a major number of containers, to be reached);
- more operators' squads working on board at the same time (to assure high productivity levels).

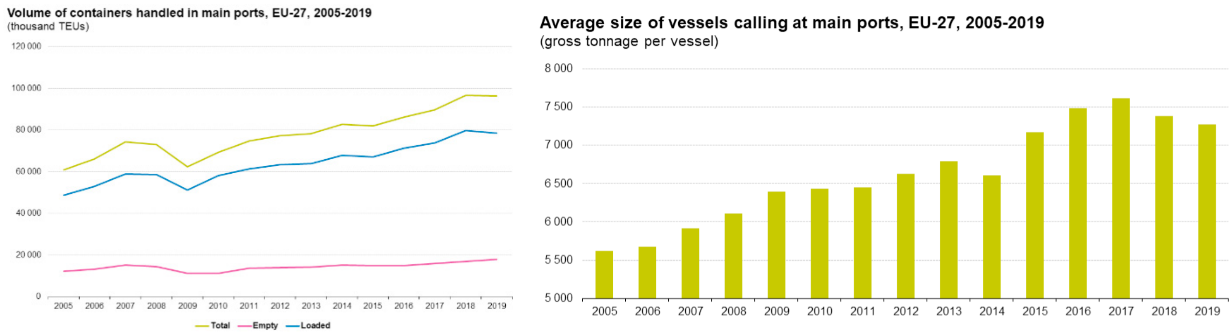


Fig. 1. (a) Volume of containers handled in main EU-27 ports (Source [2]); (b) Average size of containerships vessels in main EU-27 ports (source [2])

The productivity, intended as the capability of the port services to complete loading and unloading operations safely and in the shortest time, surely reflects how reliable a port is in serving customers and it is an indicator of the competitiveness level of one port against another [3]. There are several research works reported in the literature that investigates, in different directions, how to improve port productivity. In [4], a system performance analysis of ship to shore operation considering crane availabilities using simulation approach is presented to evaluate port performances, while [5], [6] and [7] consider quay cranes and yard trucks scheduling, iterative heuristic for simultaneous allocations of berths quay cranes and yards under practical situations and optimization and evaluation of tandem quay crane performance respectively. As a matter of fact, the port productivity (and specifically the container terminal productivity) is tremendously affected by the productivity of operators (riggers) performing containers lashing and de-lashing operations. Indeed, there are multiple research studies where the lashing and de-lashing activities are studied with the aim of increasing the operators and port productivity while increasing operators' ergonomics, safety and security. In [8], wearable IMU mocap systems with REBA (Rapid Entire Body Assessment) and RULA (Rapid Upper Limb Assessment) for ergonomic assessment of container lashing teams is proposed, while [9] proposes a musculoskeletal human model to create a framework for future observations with focus on developing a product-service-system and smart personal protective equipment tools. Ergonomics and working postures issues are not the only ones to be considered: security is another critical issue (when coming to accidents analysis due to containers stacked on deck [10]). Assuring higher security levels is always a major advantage in terms of productivity (major accidents can create more damages than small reductions of the actual productivity due to security restrictions). In this direction, several studies deal with the design and optimization of the lashing structures and bars used on containers stack on ships deck [11], [12], [13].

The research work proposed in this article focuses the attention – as also done in previous studies [14] – on working postures and energy expenditure of lashing and de-lashing operations carried out by riggers. However, in this case, the goal is to use a digital human simulation environment to investigates major ergonomics and working postures issues to be successively used for the design of an active exoskeleton for arms and shoulders (the design of the exoskeleton will be presented in a future paper, while this paper presents some of the results of the simulation study).

The remaining of the article is organized as follows: section 2 briefly presents the real environment as well as the simulation environment, section 3 summarizes the main methodologies used, the analysis carried out and the results. Conclusions and future works are presented in section 4.

2. Real and Simulation environment

The Lashing of containers is done by workers (riggers) on the ship. The workers install special lashing rods which are used to pull the containers down and fix them safely to the frame of the ship. The lashing rods consist of two parts: the lower rod (including a mechanism used to bolt both parts together) and the upper rod. The upper part is a long rod which comes in different length variations. As it can be seen in Figure 2, the lashing rods are mounted in diagonal, each from one corner of a container to the floor. Depending on the containers put on top of each other, the upper part of the lashing rods needs to be longer.

Fig. 2. Lashing rod handling operation: (a) Lashing rods (lower and upper parts); (b) posing of the upper rod; (c) maintaining the upper rod

The figures below show essential movements of workers during operations. In the left image, the operator fixes the lower part to the frame on the bottom. He places the part with both hands while the back is bent forward about to about 45°. In the middle image the worker places the lower part, so that both workers can connect the parts together. As soon as they are connected, the operator uses booth hands to lash the container by screwing the parts tightly together.

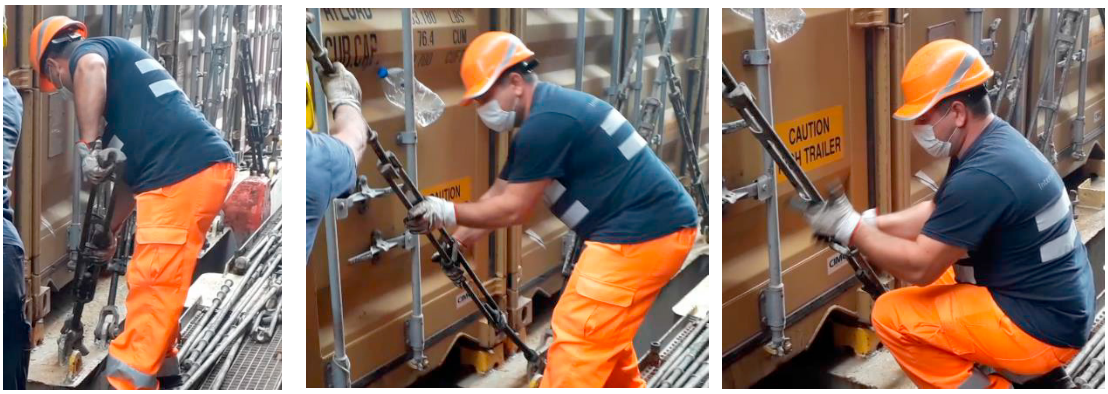


Figure 3(a) Fixing of the lower lashing rod part; 3(b) attaching the two rods; 3(c) screwing both parts together

The figures above show the rods used for lashing just one container; there are longer rods that are used for lashing two containers piled up. Lifting these longer rods is usually complex and stressful for the operator because of the length of the rods and because of their weights. The unlashing process is quite similar: each operation is repeated in the inverse order.

The 3D virtual environment in which the human simulation has been carried out faithfully recreates a real container terminal environment including the harbor, the terminal yard, the containership as well the container handling equipment. The 3D virtual environment (designed and developed at the Modeling & Simulation Center – Laboratory of Enterprise Solutions, MSC-LES, of the University of Calabria, Italy) is currently used also for other R&D projects with different goals (that's the reason for which the environment is rich in details and includes, in addition to the ship deck – that is specifically needed for this simulation – also other major parts). The Figure 4(a) shows an aerial view of the container terminal 3D Environment (in particular the represented port is the Gioia Tauro container terminal, one of the largest container terminals of South-Europe, located in Calabria Region, Italy), the figure 4(b) depicts a view of the ship deck, while figure 4(c) shows dome containers piled up to the 5th tier.

Fig. 4. (a) Overall View of the container terminal 3D Environment (Port of Gioia Tauro, Italy); (b) view on the containership deck; (c) containers piled up to the 5th tier

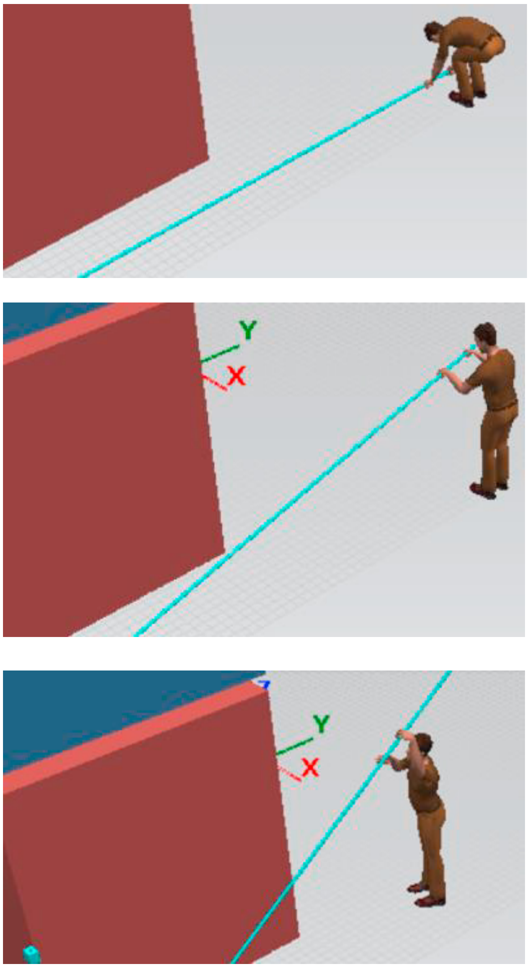
3. Ergonomic Assessment of lashing operations

Several different ergonomic analyses, executed by using the Siemens Process Simulate software, have been carried out with the aim of analyzing working postures and fatigue levels of lashing and de-lashing operations carried out by riggers (the results of these analysis are currently being used for the design of the active exoskeleton for arms and shoulders).

3.1 The OWAS Analysis

The following section reports the results of the OWAS (OVAKO-Working-PostureAnalysing-System) analysis carried out on the long rod handling operations done during lashing operations. The OWAS method was developed in 1974 at the Swedish OVAKO steelworks and, similar to the RULA method, is used to assess work situations on the basis of postures. The paper-and-pencil method contains a catalogue of 84 working posture types. These are described by a five-digit numerical code. An evaluation and classification into action classes is carried out via a percentage share in the work process. Figure 5 depicts the simulated operation as well as the results of the OWAS analysis. The results reveal that:

- 7 activities have an Action Category of 4: this means that an action to modify the working posture is required immediately;
- 20 different activities with an Action category of 3: an intervention to modify the working postures is required as soon as possible;
- 1 activity with an Action Category of 2: this means that an action to modify the working posture is required in the near future.



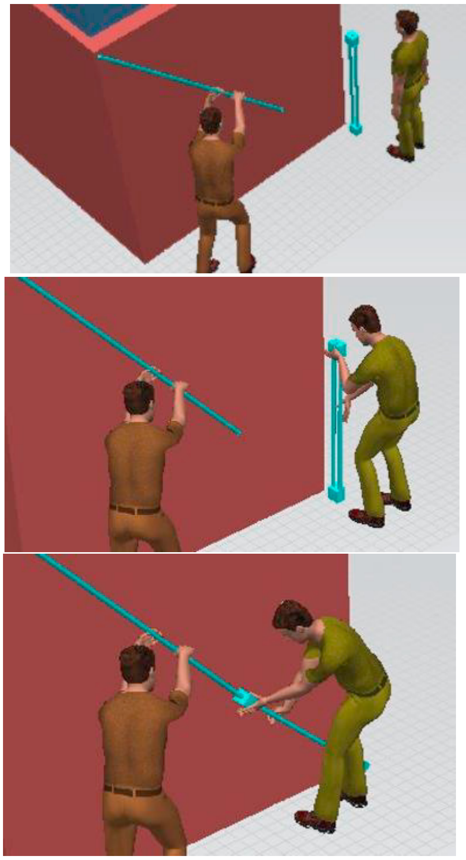
Time (Sec)	Operation	Object Weight (kg)	Action Category	Code Posture Combination					
				Back	Arms	Legs	Load	-	Head
0	Get_Long_rod_Jack_Walk	0	1	1	1	2	1	-	1
0.03		0	1	1	1	7	1	-	1
0.9		0	1	1	1	2	1	-	1
1.03	Get_Long_rod_Jack_Reach	0	2	2	1	3	1	-	1
1.1		0	3	2	1	4	1	-	1
1.87	Position_Long_rod_Jack_Reach	26	3	2	1	4	3	-	1
2.57		26	3	2	1	2	3	-	1
2.9	Position_Long_rod_Jack_1_Reach	26	3	2	2	2	3	-	1
2.93		26	1	1	2	2	3	-	1
2.97		26	1	1	3	2	3	-	1
3.07		26	1	1	3	2	3	-	5
3.2		26	1	1	3	2	3	-	4
3.33	Regrasp_Long_rod_Jack_Regrasp	26	1	1	3	2	3	-	1
3.53	Position_Long_rod_Jack_2_Reach	26	4	4	3	3	3	-	1
3.87	Regrasp_Long_rod_Jack_2_Regrasp	26	1	1	3	2	3	-	1
4.07	Position_Long_rod_Jack_3_Reach	26	1	1	3	3	3	-	1
4.13		26	1	1	3	2	3	-	1
4.17		26	1	1	3	2	3	-	4
4.23		26	3	2	3	2	3	-	4
5.07	Position_Long_rod_Jack_4_Bend_And_Reach	26	3	2	3	3	3	-	4
5.23		26	3	2	3	3	3	-	1
6.1	Position_Long_rod_Jack_5_Reach	26	4	4	3	3	3	-	1
6.13		26	4	4	3	4	3	-	4
6.2		26	4	4	3	3	3	-	4
6.23		26	4	4	3	2	3	-	4
6.47	Regrasp_Long_rod_Jack_5_Regrasp	26	3	2	3	2	3	-	1
6.87	Position_Long_rod_Jack_6_Reach	26	1	1	3	2	3	-	1
6.97		26	1	1	3	3	3	-	1
7.03		26	1	1	3	2	3	-	1
7.23	Regrasp_Long_rod_Jack_7_Transfer	26	3	2	3	3	3	-	4
7.63	Position_Long_rod_Jack_7_Reach	26	3	2	3	2	3	-	4
7.87	Regrasp_Long_rod_Jack_8_Transfer	26	3	2	3	2	3	-	1
8.03	Position_Long_rod_Jack_8_Reach	26	3	2	2	2	3	-	1
8.1		26	1	1	2	3	3	-	1
8.13		26	1	1	2	2	3	-	1
8.33	Regrasp_Long_rod_Jack_9_Transfer	26	3	2	3	2	3	-	1
8.6	Position_Long_rod_Jack_9_Reach	26	3	2	3	3	3	-	1
8.67		26	3	2	3	2	3	-	1
8.73		26	3	2	3	2	3	-	4
9	Regrasp_Long_rod_Jack_10_Transfer	26	1	1	3	2	3	-	1
9.33	Position_Long_rod_Jack_10_Reach	26	1	1	2	2	3	-	1
9.57	Regrasp_Long_rod_Jack_11_Regrasp	26	3	2	3	2	3	-	1
9.77	Position_Long_rod_Jack_11_Reach	26	1	1	3	2	3	-	1
9.8		26	1	1	3	3	3	-	1
9.83		26	4	4	3	3	3	-	1
9.87		26	4	4	3	3	3	-	4
10.17	Regrasp_Long_rod_Jack_12_Regrasp	26	1	1	1	3	3	-	1
10.33	Position_Long_rod_Jack_12_Reach	26	1	1	2	3	3	-	1
10.47		26	1	1	2	2	3	-	1
11.33	Position_Long_rod_Jack_13_Reach	26	3	2	2	2	3	-	1
11.4		26	3	2	2	2	3	-	2
11.6	Regrasp_Long_rod_Jack_14_Regrasp	26	1	1	2	2	3	-	4
11.83	Position_Long_rod_Jack_14_Reach	26	1	1	2	2	3	-	1
11.93		26	1	1	3	2	3	-	1
12.13		26	3	2	3	2	3	-	1
17.4	Put_Long_rod_Jack_Reach	26	1	1	3	2	3	-	1
17.53		26	1	1	3	2	1	-	1
18.1	Go_to_target_Jack_Arise_From_Bend	0	1	1	2	2	1	-	1
18.17		0	1	1	1	2	1	-	1
18.8	Go_to_target_Jack_Walk	0	1	1	1	7	1	-	1
19.13		0	1	1	1	2	1	-	1

Fig. 5. Different view of the long rod handling operations (to be done to perform the lashing operation) and results of the OWAS Analysis

The OWAS analysis have been carried out for the activities related to the fixing of the lower part of the lashing rod, for attaching the two rods and for screwing both parts together. In this case, the OWAS analysis reveals critical action categories almost along the entire operation as shown in figure 6 (also depicting the simulation environment). In particular, there are:

- 19 activities where the Action Category is 4 (an action is on the working posture is required immediately);
- 16 activities where the Action Category is 3 (an intervention to modify the working posture is required as soon as possible);
- 6 activities where the Action Category is 2 (an intervention is required in the near future).

Similar analyses have been also carried out considering the short rod and its positioning and screwing activities where some of the results (during the short rod handling) are slightly better due to the lower weight of the rod. Overall, the OWAS analyses (also considering the de-lashing operations) suggest that a review of the working postures is needed and this will help in understanding which postures the exoskeleton should be designed to avoid (in particular during the attaching and screwing operations of the upper and lower part of the lashing rod where most of the critical action categories have been identified).



Time (Sec)	Operation	Object Weight (kg)	Action Category	Code Posture Combination					
				Back	Arms	Legs	Load	-	Head
0	Idle	0	1	1	1	2	1	-	1
2.2	Get_Turnsile_Jack_1_Bend_And_Reach	0	1	1	1	3	1	-	1
2.3		0	2	2	1	3	1	-	1
2.43		0	3	2	1	4	1	-	1
2.73		0	4	4	1	4	1	-	1
3.43	Position_Turnsile_Jack_1_Reach	18	4	4	1	4	2	-	1
3.8		18	4	4	1	4	2	-	2
4.07	Regrasp_Turnsile_Jack_1_Regrasp	18	2	4	1	2	2	-	2
4.27	Position_Turnsile_Jack_1_1_Reach	18	2	4	1	2	2	-	1
5.23	Position_Turnsile_Jack_1_3_Reach	18	2	4	1	2	2	-	2
5.4	Regrasp_Turnsile_Jack_1_3_Regrasp	18	2	4	1	2	2	-	1
5.8	Regrasp_Turnsile_Jack_1_4_Regrasp	18	3	2	1	4	2	-	1
5.97	Position_Turnsile_Jack_1_5_Reach	18	4	4	1	4	2	-	1
7.7	Position_Turnsile_Jack_1_10_Reach	18	4	4	1	4	2	-	2
8.13	Regrasp_Turnsile_Jack_1_8_Regrasp	18	4	4	1	4	2	-	1
8.37	Position_Turnsile_Jack_1_12_Reach	18	3	2	1	4	2	-	1
8.57	Position_Turnsile_Jack_1_13_Reach	18	4	4	1	4	2	-	1
8.97	Position_Turnsile_Jack_1_14_Reach	18	3	2	1	4	2	-	1
9		18	3	2	1	4	2	-	2
9.13	Position_Turnsile_Jack_1_15_Reach	18	3	2	1	4	2	-	1
9.17		18	4	4	1	4	2	-	1
11.97	Position_Turnsile_Jack_1_24_Reach	18	3	2	1	4	2	-	1
12.13	Position_Turnsile_Jack_1_25_Reach	18	4	4	1	4	2	-	1
12.5	Position_Turnsile_Jack_1_26_Reach	18	3	2	1	4	2	-	1
12.8	Position_Turnsile_Jack_1_27_Reach	18	4	4	1	4	2	-	1
13.3	Position_Turnsile_Jack_1_28_Reach	18	3	2	1	4	2	-	1
13.57	Position_Turnsile_Jack_1_29_Reach	18	4	4	1	4	2	-	1
13.97	Position_Turnsile_Jack_1_30_Reach	18	3	2	1	4	2	-	1
14.2	Position_Turnsile_Jack_1_31_Reach	18	4	4	1	4	2	-	1
14.6	Position_Turnsile_Jack_1_32_Reach	18	3	2	1	4	2	-	1
14.83	Position_Turnsile_Jack_1_33_Reach	18	4	4	1	4	2	-	1
15.2	Position_Turnsile_Jack_1_34_Reach	18	3	2	1	4	2	-	1
15.43	Position_Turnsile_Jack_1_35_Reach	18	4	4	1	4	2	-	1
19.1	Position_Turnsile_Jack_1_47_Reach	18	3	2	1	4	2	-	1
19.8	Position_Turnsile_Jack_1_49_Reach	18	4	4	1	4	2	-	1
20.13	Position_Turnsile_Jack_1_50_Reach	18	3	2	1	4	2	-	1
20.2		18	4	4	1	4	2	-	1
20.4	Position_Turnsile_Jack_1_51_Reach	18	3	2	1	4	2	-	1
21.6	Position_Turnsile_Jack_1_55_Reach	18	4	4	1	4	2	-	1
23.67	Put_Turnsile_Jack_1_Release	18	4	4	1	4	1	-	1
24.03	Go_to_target_Jack_1_Arise_From_Bend	0	3	2	1	4	1	-	1
24.43		0	2	1	1	4	1	-	1
24.47		0	1	1	1	2	1	-	1
24.9	Go_to_target_Jack_1_Walk	0	1	1	1	7	1	-	1
26.03		0	1	1	1	2	1	-	1

Fig. 6. Different view of the operations for fixing of the lower part of the lashing rod, for attaching the two rods and for screwing both parts together and results of the OWAS Analysis

3.2 Fatigue Analysis

Fatigue analysis is used to determine suitable resting time in order to avoid injuries but also to maintain quality standards. As for the OWAS analysis, the fatigue analyses include both the long rod handling operation and the short rod attaching and screwing operations.

As far as the long rod handling operation is concerned, the following recovery times are needed after the operation (see figure 7):

- 49.1 seconds for the left shoulder;
- 28.8 seconds for the right shoulder;
- 2.3 seconds for the left elbow;
- 37.3 seconds for the left wrist;
- 19.4 seconds for the right wrist;
- 2 seconds for the left ankle;
- 20.7 seconds for the right ankle.

Therefore, an overall resting time of about 49 seconds is needed or the operation should be modified to reduce strain on the left shoulder (the muscles strains history over the time is depicted in figure 8).

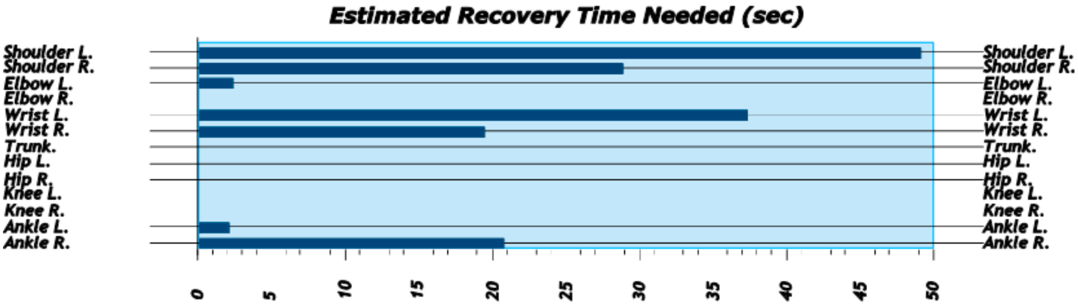


Fig. 7. Estimated Recovery Time after the execution of the long rod handling operation

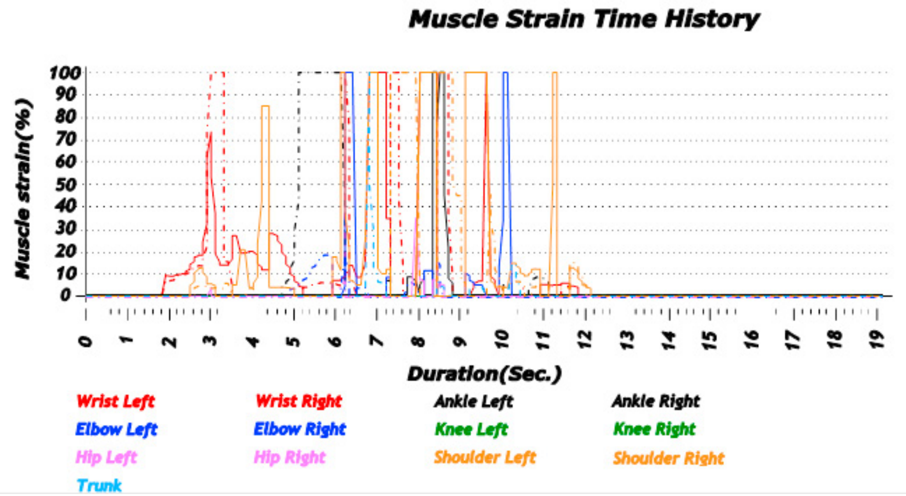


Fig. 8. Muscle Strain Time History during the execution of the long rod handling operation

As far as the short rod handling operations (including the screwing one) are concerned, the following recovery times are needed after the operations (see figure 9):

- 3.1 seconds for the left shoulder;
- 15.9 seconds for the right hip;
- 0.6 seconds for the left knee;
- 8.3 seconds for the right ankle.

Therefore, an overall resting time of about 16 seconds is needed or the operations should be modified to reduce strain on the right hip (and successively to the right ankle, see figure 10).

The Fatigue analysis clearly shows that an intervention to help the operators (by reducing their fatigue levels) is needed. While acting to avoid specific working postures (therefore reducing the discomfort), the exoskeleton could be profitably used to reduce the muscles strains over the time, the operators' fatigue and the resting time (the latter will help in increasing the productivity).

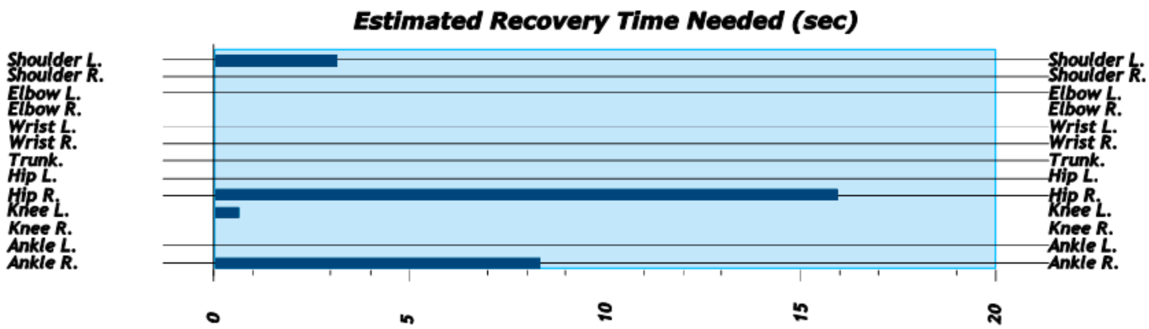


Fig. 9. Estimated Recovery Time after the execution of the short rod handling operation (including the screwing one)

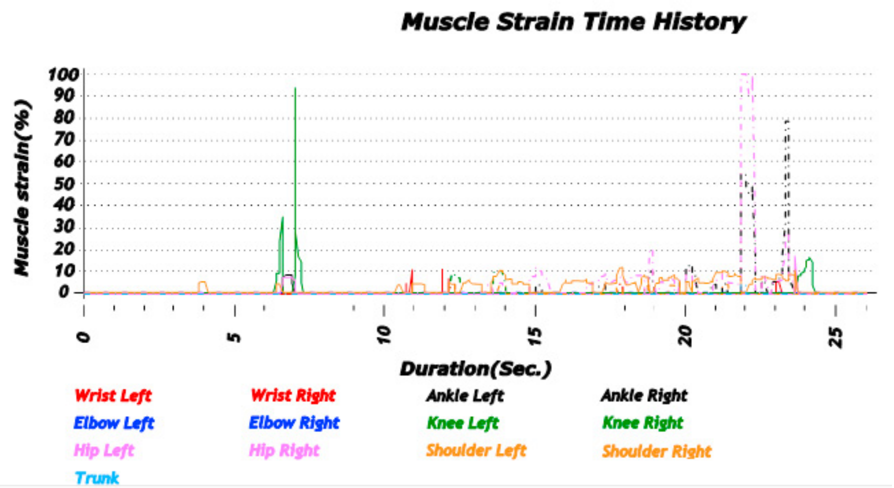


Fig. 10. Muscle Strain Time History during the execution of the short rod handling operation (including the screwing one)

4. Conclusions

Productivity, operators' safety and equipment and goods security are among the most important factors being considered by terminal operators to assure high service levels and quality to their own customers. While container terminals are moving toward high levels of automation, e.g. considering the yard management opeations, more than 20 ports in Europe have already installed equipment to automate at least a part of their operations (McKinsey, 2018), specific operations have still to be executed by operators manually. This is the case of lashing and de-lashing operations carried out by riggers. Such operations require use of intensive forces and uncomfortable working postures over the entire working shift with very limited breaks (each incoming ship must be served as soon as possible).

The authors of this paper have conducted a simulation study with the aim of understanding wrong working postures (that may create discomfort to the operators) as well as monitoring the muscles strains during the operations (and understand major muscles involved and resting times needed after the operations). The results of the analyses show that there are several activities that are categorized as critical for the working postures (interventions to modify the working postures are required immediately or as soon as possible) and some of the body muscles undergo an excessive strain. The results of the simulations are currently being used to design an active exoskeleton that will help the operators to avoid wrong working postures as well as to reduce the muscles strains over the time. The exoskeleton design will be presented as part of a future article.

References

[1] Online Publication. Maritime transport of goods - quarterly data. Retrieved online at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Maritime_transport_of_goods_-_quarterly_data.

[2] Online Publication. Maritime freight and vessels statistics. Retrieved online at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Maritime_ports_freight_and_passenger_statistics&oldid=218671#Volume_of_containers_handled_in_European_ports

[3] Siswanto, N. & Wahyuninngsih, A.T. 2021, "Discrete event simulation approach for container terminal loading and unloading productivity evaluation", Proceedings of the International Conference on Industrial Engineering and Operations Management, pp. 1181.

[4] Aqsha, B.D., Siswanto, N., Suparno & Tama, M.I. 2020, "A System Performance Analysis of Ship to Shore Operation Considering Crane Availabilities using Simulation Approach", IOP Conference Series: Materials Science and Engineering.

[5] Behjat, S. & Nahavandi, N. 2020, "Quay cranes and yard trucks scheduling problem at container terminals", International Journal of Engineering Transactions C: Aspects, vol. 33, no. 9, pp. 1751-1758.

[6] Liu, C. 2020, "Iterative heuristic for simultaneous allocations of berths, quay cranes, and yards under practical situations", Transportation Research Part E: Logistics and Transportation Review, vol. 133.

[7] Huang, S.Y. & Li, Y. 2017, "Optimization and evaluation of tandem quay crane performance", 2017 4th International Conference on Systems and Informatics, ICSAI 2017, pp. 637.

[8] Zelck, S., Verwulgen, S., Denteneer, L., Vanden Bossche, H. & Scataglini, S. 2022, Combining a Wearable IMU Mocap System with REBA and RULA for Ergonomic Assessment of Container Lashing Teams.

[9] Zelck, S., Verwulgen, S., Denteneer, L. & Scataglini, S. 2020, "Digital human modeling as a risk assessment tool for maritime workers", Advances in Transdisciplinary Engineering, pp. 398.

[10] Rahim, G.P. & Sunaryo 2019, "Container ship accident analysis due to container stacked on deck as an attempt to improve maritime logistic system", E3S Web of Conferences.

[11] Li, C. & Wang, D. 2019, "Multi-objective optimisation of a container ship lashing bridge using knowledge-based engineering", Ships and Offshore Structures, vol. 14, no. 1, pp. 35-52.

[12] Qiu, W.-., Xiao, Y.-. & Wu, S.-. 2007, "A mathematic model for tension calculation of lashing bars on container stacks on deck", Harbin Gongcheng Daxue Xuebao/Journal of Harbin Engineering University, vol. 28, no. 12, pp. 1307-1311.

[13] Shi, B., Liu, D., Wiernicki, C. & Tang-Jensen, P. 2006, "Dynamic loading approach for structural evaluation of ultra large container carriers", Transactions - Society of Naval Architects and Marine Engineers, vol. 113, pp. 402-417.

[14] Tapley, S. & Monnington, S. 2005, "Musculoskeletal (MSD) risk factors during freight container lashing operations: A field study", RINA, Royal Institution of Naval Architects International Conference - Human Factors in Ship Design, Safety and Operation, pp. 109.