Abstract

To keep the market share in today's competitive environment, supply chains (SCs) must be more interconnected than ever before. For such a purpose, SCs can benefit from having access to real-time data and information through the advent of Industry 4.0 technologies like cloud computing, big data, blockchain, and additive manufacturing, among others. This improves their adaptability and responsiveness. In addition, Lean Manufacturing concepts may play a significant role in improving SCs by helping to eliminate those wastes that arise from the process activities which do not directly contribute to provide value for customers. Therefore, the goal of this study is to explore how various Industry 4.0 technologies can revolutionize SC processes according to the Lean concepts, with the final aim to eliminate non-value-added activities.

In the first phase, two critical and extensive multi-dimensional systematic literature reviews (SLRs) are conducted. According to the results of the SLRs, one of the primary research gaps in the field of combined application of Lean and Industry 4.0 technologies in SCs has been highlighted as investigating each individual SC process, such as procurement, warehousing, delivery among the others. Additionally, the reviewed literature has revealed that it is of paramount importance to develop a structured framework to investigate logistic processes, identify, and analyze their wastes according to the Lean approach, in order to select the most appropriate Industry 4.0 technologies to either reduce or eliminate those wastes. In this context, developing roadmaps for the application of selected digital technologies based on company managers' priorities and opinions is highly desired.

To this end, warehouses, being one of the most important links in a SC that serve to keep stocks and deliver services to final customers, will be treated as a reference application area for the present research. In fact, optimizing warehouse processes and activities may lead to a significant decrease in the amount of time required for order fulfillment, as well as an improvement in the level of service provided to consumers. However, several warehouse activities do not provide value to customers due to their inefficient operating nature. In this way, Lean concepts may be used to increase efficiency in warehouse operations. As a result, in this research a framework is being developed in order to address the activities that take place in warehouses.

To that purpose, the Supply Chain Operations Reference (SCOR) model is utilized to investigate real warehouse processes across a range of relevant industries (i.e. Automotive Industry, Fashion Industry, Food Industry, etc.). Moving steps from such an analysis, the research has been conducted to create a general process mapping for conventional warehouse processes in both the raw materials and the finished products warehouse, by focusing on the SCOR processes Source and Deliver. Process mapping can be helpful to identify the wasteful, non-value-adding activities of each process. Afterward, the "5 why" technique, which is one of the Lean tools, is used to determine the main root causes of the wastes that were detected. Then, the most effective Industry 4.0 solutions for addressing the causes of each waste have been proposed according to the performed SLRs.

The theoretical development of the framework is followed by two case studies that demonstrate the applicability and adaptability of the proposed Lean Digital SC (Lean DSC) framework to different real SC settings. To this end, two companies, from the Automotive and Food industry respectively, are selected. In fact, both the Automotive and Food industry are characterized by a high technological level in their production and logistics operations, which makes them more likely to adopt Industry 4.0 technologies. However, they have different degrees of Lean Manufacturing implementation for the purpose of standardizing and making more efficient their industrial processes. For the purpose of process mapping and waste root-cause analysis in the case studies, real observations have been carried out regarding the Source and Deliver processes. Then, the most effective Industry 4.0 technologies for deployment in each company have been suggested to reduce the wastes, according to the results of real observations and discussions with top managers and responsible employees.

Then, a Multi Criteria Decision Making MCDM technique named Full Consistency Method (FUCOM) is used to prioritize the identified wastes and rank them according to the judgments of each company manager resulting from a number of conducted workshops. Next, all the managers' results are aggregated together to provide an overall ranking that can be used to construct a Lean roadmap of the most critical wastes to be addressed. To complete the Lean DSC roadmap, the collected waste weights are mapped to the Industry 4.0 technologies previously suggested for obtaining the importance of each technology. This can assist companies to know which is the appropriate deployment sequence of beneficial digital technologies to reduce their wastes. So that, the Lean DSC roadmap proposed by the present research can be recognized as a customized strategy for each company because it is built based on real observations of the logistics activities carried

out in warehouses.

In conclusion, the present research seeks to overcome the DSC gap constructing an structured approach to implement Industry 4.0 technologies for eliminating wastes in SCs by developing an application framework and decision support tool that can be tailored to the specific requirements of each company. In fact, the objective is to integrate appropriate technologies related to Industry 4.0 by applying Lean principles in two of the crucial SC processes (Source and Deliver) in order to contribute to provide a genuine value addition for the end customer. The continuation and expansion of this study might involve conducting more case studies to fully complete the validation and generalization of the framework, as well as integrating additional Lean tools.