A real simulation of automated warehouses processes: an academic experience with engineering students

Ferrari A., Mangano G., Zenezini G., Carlin A.

Dipartimento di Ingegneria Gestionale e della Produzione, Politecnico di Torino, Corso Duca degli Abruzzi, 24, 10129 – Torino – Italy (andrea.ferrari@polito.it, giulio.mangano@polito.it, giovanni.zenezini@polito.it, antonio.carlin@polito.it)

Abstract: In recent years, the changing market needs due to the dramatic increase of e-commerce and the effects of Covid-19 pandemic have caused a growing demand for supply chain operations. This dynamic business context is also associated with relevant technological and innovative modifications. In the logistics sector, automated warehouses play a crucial role in dealing more effectively with this development trend. For this reason, they are a relevant topic in universities and engineering faculties. Nevertheless, these systems mostly find application and implementation in the industrial sector, determining a significant detachment from the academic sphere. This usually results in a not complete awareness of university students related to the development and operations of such structures. Therefore, an automated warehouse made up by an innovative Automated Storage and Retrieval System and a Mobile Industrial Robot fleet recently installed in a university laboratory was showed to a group composed of 62 engineering students with different academic background. Moreover, a simulation was carried out, physically reproducing the main operations of a distribution centre, namely receiving, kitting, picking, and shipping processes. The students perception related to the automated warehouses was then evaluated through a questionnaire submitted at the end of the experience. The survey demonstrated that most of the students was interested in topics related to the industrial logistics, despite many of them never saw an automated warehouse before the laboratory test. Furthermore, the large majority of the students evaluated positively the simulation and they affirmed that the proposed experience significantly enriched their knowledge about logistics automation. Finally, many students declared that thanks to the test, the interest towards the automated warehouses increased and more than 50% started considering the idea of working in the logistics sector.

Keywords: Automated Warehouses, Warehouse Processes, University Students, Questionnaire

I. INTRODUCTION

The recent development of e-commerce sector and the effects of Covid-19 pandemic on the global markets have been determining a dramatic growing demand for supply chains (SC) operations (Queiroz et al., 2022; Zhang et al., 2022). In addition, the expanding presence of Industry 4.0 initiatives has brought to important technological innovations in the logistics sector. In this context, automated warehouses hold a key role in defining and supporting modern SC procedures (Marolt et al., 2021). Nowadays, they are largely adopted in different industrial sectors, namely manufacturing, logistics, large-scale distribution, e-commerce and healthcare. They can be defined as innovative warehouses in which a certain degree of automation in the processes is introduced (Custodio and Machado, 2020). This automation may involve the storage and retrieval operations, as well as the material handling within the facility. Automated Storage and Retrieval Systems (AS/RSs) represent one of the most effective implementations to store and retrieve unit loads without human interference and they consist of specific storage racks, input/output (I/O) locations, and S/R machines with computerized control (Schenone et al., 2020). Regarding the material handling, the unit loads movements can be allocated to innovative transportation systems called Automated Guided Vehicles (AGVs). One of the most recent and innovative type of AGVs developed are the Mobile Industrial Robots (MIRs), which are able to autonomously move along a not predefined path by planning a collision-free route from a starting point to a target position (Li et al., 2022).

AS/RSs have been studied and further developed since the 1960s (Lehmann and Hußmann, 2021). This widespread interest relies on the fact that they prompt many advantages in terms of storage capacity, warehouse performance, labour saving, inventory accuracy, safety, and damages of goods (Zammori et al., 2021). On the contrary, AGVs are largely used in different industries since they represent a reliable and flexible internal transportation system (López et al., 2022). The benefits given from the introduction of automated warehouses have caused during the years a growing interest in academics towards various aspects related to such systems. For instance, particular attention is given to assessing the system performance in terms of travel time and throughput under different conditions (Lehrer et al., 2021). Additionally, the relevant design factors affecting energy consumption and regeneration metrics have been studied (Ekren, 2020). Another topic considered is the level of automation introduced in picker-to-parts systems (Vijayakumar and Sgarbossa, 2021). Finally, optimization algorithms defining AGV path planning have been largely analysed during the years (Lian et al., 2020).

However, this important knowledge is not always entirely given to students attending both bachelor and master courses in Engineering Programs. This aspect may cause a not exhaustive and comprehensive perception related to such systems. In fact, the study of AS/RS is approached mostly at a theoretical level, without providing students an actual and practical knowledge about the operations of such systems. Therefore, this paper is based on a real experience carried out on an automated warehouse with the involvement of university students that were called to conduct the typical activities of a distribution centre. At the end of this experience, a questionnaire was then administrated in order to assess both their level of awareness and interest. In addition, the main lessons learnt that were obtained via the experiment were taken into account, by evaluating their point of view about the main impacts of automated warehouses on the processes of a distribution centre.

The remainder of this paper is structured as follows. The next section presents an overview of the most important and relevant games and initiatives aimed to provide logistics concepts to non-expert groups, as well an analysis of the student perception of logistics operations and automated warehouse themes. Then, a description of the methodology is highlighted, followed by a presentation of the main outcomes and results of this study. Finally, conclusions are drawn in the last section of the paper.

II. LITERATURE REVIEW

Traditional teaching methods show limited effects in building up the skillset needed in the evolving supply chain and logistics sector (Abele et al. 2017). Despite the strength of engineering faculties in mediating scientific knowledge, students often struggle to effectively transfer this knowledge in a continuously changing professional reality (Pittich et al., 2020). Nowadays, in the current warehouse operations, the operators skill set required in logistics operations become crucial. In fact, companies often face the shortage of qualified employees for addressing logistics needs (Arvis et al., 2016). In particular, human resources are expected to acquire more practical skills, such as the use of specific software for running logistics and warehouse activities (Ling and Chan, 2018). Thus, innovative teaching methods that bring the learning process closer to industrial practice and enhance the skills of young engineers are needed (Gento et al., 2020). Recently, learning factories, interactive demonstration platforms, and business simulations, have been gaining a lot of attention since they provide quality assurance and professional development in industrial logistics engineering education (Woschank and Pacher, 2020). These educational approaches aim to create simulated circumstances to support positive experiences that potentially lead to psychological responses or desired behavioural outcomes, such as motivation and engagement (Klock et al., 2021). Additionally, they focus on students involvement in realistic industrial contexts, in order to provide them with conceptual knowledge and the ability to transfer this knowledge in different professional scenarios (Gento et al., 2020).

A proper use of business simulations is an effective approach to make supply chain and logistics education more practical, resulting in an increased business expertise and in an enhanced awareness of business procedures (Schmuck, 2021). A well-known SC simulation game is the beer distribution game, which is largely used for teaching the dynamics of a supply chain by practically highlighting the reasons and behaviour of the bullwhip effect and by providing solutions for its minimization (Alabdulkarim, 2020). More recently, Roser et al. (2021) introduced some modifications to the beer game, in order to teach the *pletora* of causes and effects throughout supply chains, including the replenishment time effect, the communication value, pull systems, inventory variations, and the flaws and benefits of the stock levelling. In addition, it has been demonstrated that by participating to a serious game about Dutch floriculture SCs, most of the participants gained more insights about the benefits of implementing virtualization technologies and the advantages in collaborating in complex and large systems (Salvini et al., 2020). Bergström et al. (2020) developed a game facilitating group discussion and cooperation on construction logistic setups (CLS). Their solution is aimed to emphasise potential issues when developing CLS, and to support the interaction among the actors of the supply chain considered. Furthermore, a team-based logistics simulation including sales and operations strategy, transportation planning and scheduling complexity has been developed using SAP ERP commercial-software application (Angolia and Pagliari, 2018). Also, video-gaming has been employed to teach supports in-depth experiential learning focusing on supply chain and logistics management (Liu, 2017). Finally, van den Berg (2017) presented a serious game that simulates the design and construction process where each player acts as the main contractor and he assigns resources to the different project phases. The aim is to teach how complex is the field of construction SC management and how to coordinate design and construction tasks in a coherent manner.

By observing the mentioned studies, it is possible to notice that the most of the initiatives pursuing an involvement of non-expert groups in the logistics arena concern supply chain management issues, transportation processes, and decision-making experiences. It would appear that very few previous researches focus on more operative aspects of supply chains, such as warehousing and intralogistics operations. Thus, the educational benefits of bringing the learning process closer to industrial practice of modern teaching methods do not arise in such a context. As a consequence, an effective and deeper involvement of students in the topic of automated warehouses is barely achieved, and their awareness of such systems is often scarcely assessed. Therefore, this research describes an innovative teaching approach aimed to increase the awareness on automated warehouses processes of engineering students.

III. METHODOLOGY

The current study is intended to describe an original teaching method consisting of replicating the main distribution centre operations in a university laboratory. Thus, in this section, the automated warehouse used during the experience is illustrated, followed by the explanation of the test performed and the description of the questionnaire submitted to the students.

A. The Automated Warehouse

The automated warehouse is installed in a University Laboratory and it is composed of an AS/RS and an autonomous material handling technology. The AS/RS is made up of:

- A Maxi-Shuttle (MS) aisle-captive system, similar to a mini-load stacker crane, able to move totes, trays, or boxes using single, double and multiple commands;
- A single-aisle storage rack with seven tiers and eight columns, with single, double, and multiple depth storage locations;
- An I/O roller conveyor system;
- Two working stations installed within the storage rack with pick-to-light gravity flow racks for parts-to-picker operations.

The AS/RS is supported by an IT infrastructure, which integrates a Warehouse Management System (WMS) and a Warehouse Control System (WCS). The main activities of the WMS include managing the stock levels and the flow of goods from the inbound to the outbound. The WCS instead is a software application that directs the real-time activities of the AS/RS, by transforming the WMS tasks in operations and movements list for the MS and the conveyor system.

On the other hand, the material handling operations are performed by a fleet of two MIRs. Each robot is equipped with a set of laser scanners, 3D cameras, and ultrasonic scanners so to move autonomously in the laboratory without following a predetermined path. In addition, a top-module consisting of an elevator and a roller conveyor is installed on the vehicles. It facilitates the exchange of the unit loads with the conveyor system of the AS/RS. Moreover, the activities of the two robots are controlled by a Mir Fleet Management System (MFMS) which has the role to optimise internal transportation. The system automatically prioritizes and selects the most appropriate vehicle for the task at hand, based on robots location and availability. Appendix A shows the layout of the laboratory areas. On the right side there is the AS/RS with the two working stations integrated in the storage rack, while on the top left side the MIRs charging position. The remaining area of the laboratory is dedicated to inbound and outbound processes, as well as for material handling operations of the robots. The inbound and outbound areas are equal and symmetrical and each of them is made up of a table with a computer for data entry procedures, a buffer of empty totes, a pallet representing the incoming/outgoing unit load, and a support for manual activities with the totes.

The automated warehouse installed in the university laboratory is significantly smaller in size in respect to a real automated warehouse. As a consequence, its related performances (*e.g.* cycle time, throughput) can not be compared with the ones of a real system. Anyhow, the warehouse at issue allows to simulate real processes. Therefore, students were able to run into the main activities required in automated warehouse operations via the proposed experience. In this way, even the size was small, it could be possible to show to students an almost real operating system and in turn evaluate their level of awareness about automated warehouses.

B. Description of the Test

The test for the university students consisted in reproducing the main warehouse operations of a fictitious company called NewTech operating in the e-commerce sector. Specifically, it distributes a set of devices and accessories, namely Apple Smartphone (Product Code 001), Samsung Smartphone (Product Code 002), Apple Cover (Product Code 003), Samsung Cover (Product Code 004). In addition, NewTech decides to give for free a Gift Kit containing USB Flash Drive (Product Code 005), and Earphones (Product code 006) to the customers who purchase a smartphone together with a cover. The company basically operates as a distribution centre, where several processes are completed. Inbound process includes the management of goods coming from the suppliers of the company. When they arrive to the plant, they are accepted and inserted in empty totes. The association between a specific unit load and the products is registered by the operator on the WMS. Then, the operator recalls a MIR by using the MFMS. The software selects the first available vehicle, which moves towards the inbound station. When the vehicle arrives to the required position, the tote with the goods is manually loaded onto it. Then, the unit load is transported to the AS/RS, where it is moved by the conveyor to the interface point with the MS. At that point, the WCS autonomously selects a storage location and it generates the storage missions for the handling device.

Another process carried out in NewTech distribution centre is kitting. In general, the term kitting refers to the procedure of grouping together all the materials and components needed to make a product. In NewTech, working station 1 is dedicated to the preparation of Gift

Kits (Appendix A). They are created in advance and stored in the warehouse in order to ensure a continuous supply when they are needed to complete the customer orders. A gravity flow rack pick-to-light system is installed in the station to facilitate the operator in carrying out the process. At kitting order launching, the MS retrieves an empty tote that will contain the Gift Kit once the operation is completed. The unit load is automatically moved in front of the operator by the conveyor system. Meanwhile, the WCS generates the retrieval missions for the components of the kits, namely the USB Flash Drive and Earphones. The totes containing these items are transferred by the MS to the gravity flow racks. When they arrive, the pick-to-light system turns on and it indicates the product quantities to get from each unit load to the operator. The worker inserts the components into the empty tote, which is then transported by the motorized conveyor towards the MS.

In working station 2 (Appendix A), the warehouse workers carry out picking operations by retrieving smartphones and covers according to the customer orders. This process is akin to the kitting one, barring two aspects. First, the empty tote is not automatically brought in front of the operator, but it is taken manually from a feeding buffer near the station. Secondly, after picking completion, the tote is loaded onto a MIR previously called by the worker and not stored within the rack.

Finally, the shipment loads with the customer orders are automatically moved by the MIR to the outbound station. There, another operator unloads the tote and he/she places the products into a cardboard box. Afterwards, the box is loaded on a pallet waiting to be shipped to the final customer. If the customer order requires a Gift Kit, this is automatically retrieved from the warehouse by the MS. Then, it is handled by the output conveyor and after it is transferred to the outbound station by another MIR. Lastly, the operator declares the order to be closed, by using the WMS. Figure 1 depicts the laboratory experience flowchart.

The experience was performed with groups of 6 or 8 students each. For the test, the students were asked to offer their personal smartphones and covers. Each session lasted around one hour and a half and it consisted of two phases. The first in which inbound (3/4 students) and kitting (3/4 students) operations were carried out simultaneously. The second one in which picking (3/4 students) and outbound (3/4 students) processes were performed. Since the kitting and picking processes are very similar, students in charge of kitting in the first phase of the test were then assigned to outbound in the second step. On the contrary, the students working on the inbound during the first part of the experience, were associated with the picking during the second phase. A total of 10 sessions were completed with a number of students involved equal to 62.

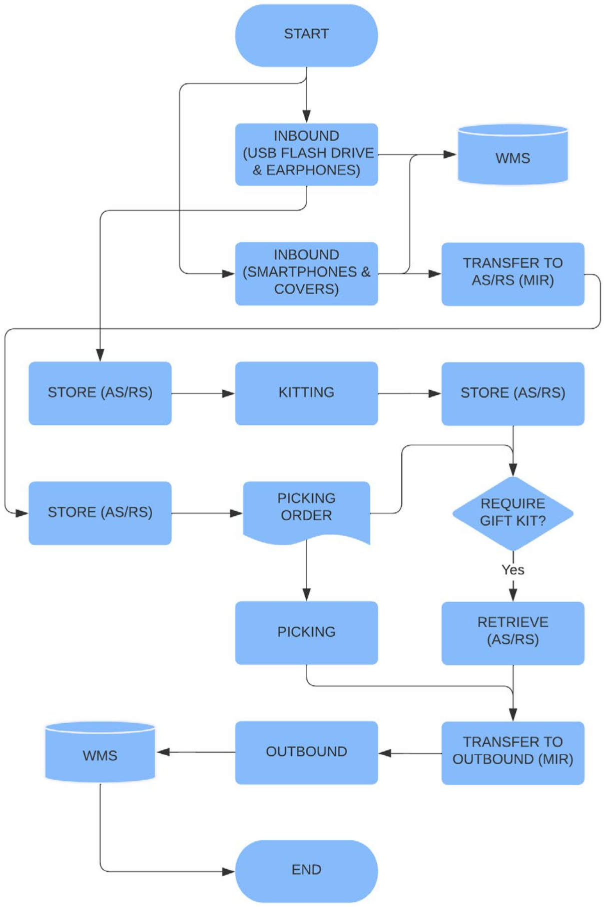

Fig. 1. Laboratory test flowchart

C. *Empirical approach*

Automated warehouses find application in many industries. For this reason, the sample involved in this study was composed of Bachelor and Master degree industrial engineering students. In the simulation games context, it has been demonstrated that questionnaires or surveys submitted before and/or after the experience are the most used data collection methods (Klock et al., 2021; Schmuck, 2021).

In general, this empirical approach is employed in order to collect as much information as possible regarding a phenomenon of interest, so that it is possible to make coherent considerations about it. Therefore, an accurate questionnaire was developed, in the sense that demographic aspects, together with level of knowledge and interest on automated warehouses were asked. More in general, the objective was to assess the students level of awareness related to these systems and to evaluate the effectiveness of the experience. All the questions included were closed-ended multiple-choice ones. Precisely, these are structured questions allowing the information to be gathered through various alternatives posed to the respondent. The questions were modulated on a 5-points Likert scale, where grade 1 represents total disagreement and grade 5 represents total agreement. The questionnaire was submitted at the end of the laboratory experience through the Google Form platform.

The survey included three sections. The first one was intended to frame the students based on a set of demographic questions related to the level of education, personal interests about industrial logistics, previous working experience in industrial sectors, and prior knowledge of automated warehouses. Then, the extent to which the laboratory experience modified their interest towards automated warehouses and their willingness in working in logistics were assessed. The second part was focused on the laboratory experience. Particularly, the student role during the test was traced, as well as general impressions about the experience, personal feeling regarding the easiness of the procedures, the degree of complexity in using the WMS, and the improvement of knowledge on these systems. The third section intended to measure how students estimate the impacts of the automated warehouses implementation. For this reason, they were asked to assess the importance of using the MIRs as a support to warehousing procedures and the level of influence that automation might have on several operations aspects, such as put-away time, storage/retrieval time, number of errors, throughput rate, surface occupation, operator fatigue, workers skillset, and simplification of human operations. Moreover, two questions derived from an observational tool named Quick Exposure Check (QEC), proposed by David et al. (2008) were added. The QEC framework is used to determine the exposure to risks for work-related musculoskeletal disorders and provide a basis for ergonomic interventions. Specifically, the students were asked to evaluate how automation can affect the work pace and how warehouse operators may have difficulties in keeping up with their work. Furthermore, since it has been demonstrated that stress is an important factor in the development of work-related musculoskeletal disorders, students were also asked to indicate the level of stress for an operator working in an automated warehouse.

IV. RESULTS AND DISCUSSION

This study focused on highlighting the effectiveness of an original educational technique in the industrial logistics context, by carrying out a real simulation of the main distribution centre operations in a university laboratory.

A total of 62 students participated in the experiment. 48 out of the total were attending a Bachelor degree program and the remaining 14 ones came from Master degree classes. Responses showed that the 90% of the sample at issue never worked in companies operating in industrial or logistics sectors. Moreover, only 35% of students saw an AS/RS prior to the experiment, mainly during lectures or classes. Concerning the industrial robots, 64% of students encountered a MIR application before the laboratory test. Surprisingly, 25% of them had the opportunity to observe a real implementation, while 30% declared to have watched a YouTube video regarding these innovative solutions. This seems to demonstrate a greater accessibility and interest towards the automated goods transportation topic rather than AS/RSs. Focusing on the experiment, 30 students were involved in kitting and outbound processes, while the other 32 in inbound and picking operations. As shown in Table 1, most of the students considered the test quite easy and it was perceived as difficult only by a couple of them. Even more students stated that the degree of complexity in using the WMS is very low, while only 14% of them argued for the contrary.

TABLE 1
PERCEPTION OF COMPLEXITY

		Experiment [#]	**WMS [#]**
Likert scale	1 (easy)	17	28
	2	29	19
	3	14	6
	4	1	6
	5 (difficult)	1	3

By focusing on the students perception of the impacts that automation could have on warehouse operations, 56% of them thought that the MIRs are very suitable in supporting AS/RSs, 35% of them assessed that the robots as quite important, and 8% viewed their implementation with very low effects. Moreover, 37% of the students stated that warehouse operators do not have difficulty keeping up with their work, while 53% assessed that sometimes the work pace can be too relentless. Then, 26% of students believed that the work of a warehouse operator could be moderately or highly stressful. The robustness of these results is also confirmed by the fact that the impact assessment was based on actual experience rather than theoretical hypothesis, since during the experiment the students had the opportunity to physically try the real tasks of a logistics operator of an automated warehouse. Appendix B depicts the frequency of the Likert scale values in the students answers for each dimension evaluated. Put-away and inbound time, storage and retrieval time, number of errors, and throughput were perceived to be Key Performance Indicators (KPIs) strongly affected by industrial automation. Moreover, a relevant number of students stated that automated warehouses implementations may have average impacts on the floor area required for implementing such systems. Then, most of the students found that operators fatigue is strongly influenced by automated warehouses, while the skillset required to work with these technologies was not perceived to be so affected by the automation implementation. On the contrary, the simplification of works for operators was recognized as an element heavily impacted.

Finally, 95% of the sample found the experience stimulating and exciting, and 90% declared to have increased the familiarity with automated warehouses. This is an important outcome, since it proves that the proposed innovative teaching approach facilitated the knowledge enrichment on these systems. Moreover, a noteworthy result is that 79% of the students stated that the laboratory test considerably changed their perspective towards the automated warehouses topic. This result underlines a prior scarce awareness about the benefits deriving from the exploitation of automated warehouses. In addition, this experiment demonstrated to be and effective lever to increase the willingness of undertaking a professional career in logistics. On the opposite, only 3 students replied that the test had a low impact on their interest in automation themes. Furthermore, 45% of students declared that the experiment reinforced their idea of working in logistics, while 51% of students started considering a future logistics position thanks to the test. Only, 1 student changed his/her mind concerning working in the logistics sector, affirming that he/she now excludes this possibility. However, it can be concluded that the real simulation improved students awareness and their involvement related to automated warehouses and logistics.

V. CONCLUSIONS

The present work explored an attempt of applying modern teaching methods to operative aspects of SCs, such as warehousing and intralogistics operations. In particular, a group of 62 industrial engineering students was tasked with performing some typical processes of distribution centre operations in a university laboratory. Additionally, the level of awareness and interest towards automated warehouses was evaluated through a questionnaire submitted at the end of the experience.

From the results obtained, it can be inferred that the proposed innovative teaching method paves the way to more comprehensive industrial logistics knowledge acquisition teaching methods. In this regard, it has been demonstrated that teaching approaches that simulate real business scenarios are effective in facilitating student scientific and professional capabilities in a continuously changing professional reality, while at the same time stimulating their motivation and engagement. This aspect plays a key role in warehouse processes. In fact, specific skills for dealing with these solutions are often not completely fulfilled by the academia even if highly required by companies.

However, in automated warehouses real operations there are higher levels of stress and volumes of orders managed. Moreover, work placements in unfamiliar circumstances for non-expert people and short time availability for completing the assigned operations may negatively impact the students degree of adaptability. Nonetheless, the prior knowledge of industrial and logistics technologies provided by innovative teaching methods could further boost the awareness of nowadays students and facilitate their integration in modern working scenarios. Thus, from this point of view, this work might be considered as a contribution in a promising research stream on the evaluation of teaching activities based on the practical involvement of students. Moreover, the proposed study might be useful for companies that are more and more introducing automation in their warehouse operations, as it increases the knowledge for students, together with their interest on logistics issues.

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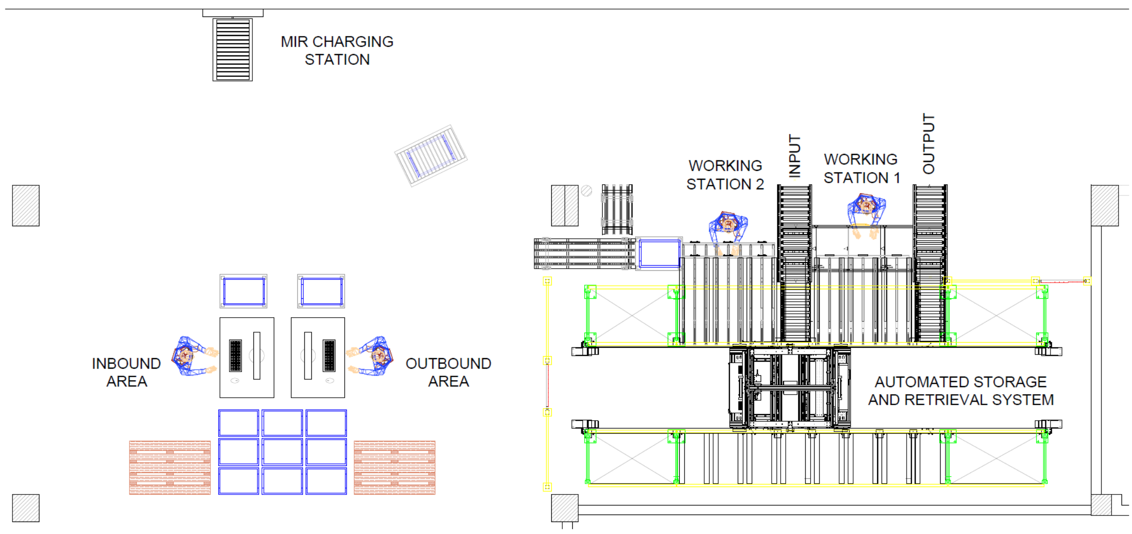
Appendix A. The laboratory layout



Appendix B. Students answers of perceived impacts