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Chapter

How to Improve Hospital Flows in the Context of the COVID Pandemic

Paul-Eric Dossou, Luiza Foreste and Eric Misumi

Abstract

In healthcare systems, the adoption of logistics 4.0 main technologies in the processes flows is essential to avoid unnecessary movements and manual work performed by people who could be performing tasks that require logical reasoning. In the context of the COVID pandemic, the adoption of new technologies to replace people in manual processes had become even more usual. This paper aims to demonstrate through simulation, the opportunities of improvement with lean manufacturing concepts and industry 4.0 technologies the hospital flows. After describing the problem and the need of improvements in hospital logistics, a literature review with concepts of Industry 4.0, Lean Manufacturing, and Logistics 4.0 will be presented. The hybrid approach used in the development of a decision aid tool that combines real data and methods of machine learning and problem-solving will be then, an example will be given for illustrating the concepts and methods elaborated.

Keywords: Healthcare logistics, Industry 4.0, Lean manufacturing, Robotics, Digital twin, Decision aided system, Artificial intelligence

1. Introduction

The term Logistics 4.0 comes from the concept of Industry 4.0, which has as main objective to optimize the production process of a factory by using new technologies (IoT, cobot, AIV, decision aided tools, etc.) and organization models (6 Sigma, lean manufacturing, etc.). Nowadays, it is possible to find several scientific and practical sources that prove the efficiency and benefits of the Industry 4.0 and Logistics 4.0 application in the production environment. However, within the health field, such as hospitals and pharmacies, these applications still have many opportunities to be explored. Indeed, the healthcare environment must reapply optimization existing concepts.

In 2020, European countries as much as the others in the world has discovered the COVID pandemic, with a high impact on hospitals organization and the appearance of many logistics and safety problems. For instance, the management of patient flow and how to heal the sick with safety for nurses and hospital workers have to be solved. The good medicines dispatching in all hospital services is also a problem to optimize. The safety patient meal preparation and distribution could also be presented as a point to improve. The requisite but dangerous collection, distribution, washing of cloths in the frame of Covid pandemic are also problems to solve. These deficiencies became even more relevant to be overcome. This is due to two main
reasons. The first one is the low availability of time and number of employees in healthcare systems. The second reason is the way the virus spreads, that is through contact among people.

Having a real need and a problem to be solved, this project carried out a study showing how the Logistics 4.0 concepts can be implemented in a way to both optimize the process and contribute to the fight against the pandemic. The study will show how the implementation of logistics 4.0 could decrease the number of unnecessary contacts and consequently reduce the number of contaminated people inside hospitals. Indeed, the implementation of new technologies is crucial for healthcare professionals to be able to focus on the high demand of patients instead of wasting time on manual tasks.

The study presents a literature that contains the main methods and new technologies in the field of Industry 4.0, Lean Manufacturing, Logistics 4.0, and Healthcare 4.0 that can be used to solve the indicated problems. Then, concepts and methodology developed for solving these problems will be exposed. The elaborated general approach based on Case-based reasoning and generalization reasoning will contribute to the definition of a hospital flows reference model. Indeed, the general structure of the decision aided tool, based on artificial intelligence and being developed for helping hospitals in the process of logistics optimization will be shown. And finally, an example will be presented for illustrating how these concepts could be applied to improve hospital logistics in the frame of logistics 4.0, named here Healthcare Logistics 4.0.

2. Literature review

The literature review of this paper aims to democratize and centralize the main concepts and new technologies used in the development of the project. Industry 4.0 concepts have been presented through Cyber-Physical Systems, IoTs, big data analytics, Artificial Intelligence (AI). With the focus on studying logistics within hospitals, research was conducted in the fields of Logistics 4.0 and Healthcare 4.0 to connect the two concepts. Finally, research was carried out into the methods used to optimize processes such as Lean Manufacturing and Lean Healthcare. Hence the chapter has a summary of each of the topics that were necessary to develop the tool and concepts presented in this article.

2.1 Industry 4.0

Based on some values and known as the fourth industrial revolution (Figure 1), Industry 4.0 is a term that emerged in Germany in the 2011 edition of the Hanover Fair, seen as a tech strategy for 2020, and remarkably based on the development of cyber systems. Modern industrial systems are complex systems that include physical, software, and networking elements into so-called cyber-physical systems [1].

Cyber-physical systems are considered as the heart and the base of the 4.0 industry [2]. The Internet of things and the Internet of services, allow to define “intelligent manufacturing”, which together with the production planning and control should play a key role within the 4.0 Industry [3, 4]. By using the Internet, Industry 4.0 matches products, services, production, and optimization to build a process based on data recorded by cyber-physical systems, without the need to involve a human being [3].

The context of Industry 4.0 is influenced by the intelligent capabilities of five basic technologies (Internet of Things, Cyber-physical Systems, Big Data and Analytics, Artificial Intelligence, and Additive Manufacturing), which have greatly stimulated the development of intelligent manufacturing [2, 4]. As a preferred
means of such integration, Cyber-physical systems, and digital twins (DT) have gained great attention from researchers and industry professionals [2]. Indeed, robot, cobot, mobile robot, intelligent machines, immersive realities, IoTs represent machines and tools that could increase the efficiency of the industry4.0 concepts. Artificial intelligence (AI) methods and tools such as expert systems, machine learning, deep learning, multi-agent systems are used for supporting Industry 4.0 concepts implementation in the company digital transformation through modeling, simulation, or decision support systems. These methods are also used for the same reasons in the frame of healthcare. For instance, Case-based reasoning (CBR) and multi-agent systems concepts are exploited in [5] for predicting risk in surgery in a non-determinist context. Case-based reasoning process is described as a cycle of four processes: Retrieve the most similar cases, Reuse the cases for solving a new problem, Revise the proposed solution, and Retain the new solution as a new case [6, 7]. This cycle is generally used in medical classification, prediction, and diagnosis problems. These concepts are adapted to hospital processes transformation and could be combined with multi-agent systems (MAS). MAS are defined as a composition of autonomous entities that interact with to certain rules in a specific environment. For instance, MAS could be used for solving problems such as the ecological and epidemiological analysis of infectious diseases [8]. In this kind of combination MAS could generate risk situation that will be compared to old cases by the CBR system for solving problems [5]. This hybrid system philosophy is also adapted for solving hospital logistics flow problems. Indeed, a decision aided system that will measure the state of healthcare logistics digital transformation could be elaborated by using expert systems theory and architecture. As described in [9], expert systems are used for supporting different application domains such as ontologies elaborated for modeling and managing the knowledge about drugs and patients [10] which flows (in this paper case) must be optimized in healthcare logistics.

2.2 Logistics 4.0

Logistics 4.0 is a relatively new term, directly linked to Industry 4.0. The development of Industry 4.0 was based on digitalization and automation, and that
for Logistics 4.0 presents not only enormous challenges but also opportunities to increase efficiency [11]. Indeed, before the advent of Industry 4.0, the concept of intelligent logistics was previously introduced to represent a technology-driven approach to the management of material flows within and outside the factory limits [12]. The concept of Logistics 4.0 means a set of solutions aimed at improving logistics processes, avoiding errors and disruptions in transport and storage processes, thanks to the continuous exchange of data between the players in the logistics system [13].

Logistics 4.0 is a combination of technical and organizational solutions aimed at improving material and information flows and adjusting them to meet the requirements of Industry 4.0 solutions. Therefore, logistics is intended to support manufacturing processes, whereby, as they evolve towards intelligent and autonomous solutions, logistics must follow this change [13].

Due to the fact that the Industry 4.0 concept is considerably affected by the use of new technologies, logistics 4.0 has been intuitively perceived from the perspective of technological achievements and applications (e.g. GPS, WMS, TMS, RFID, CPFR, etc.) [14]. In addition to the explanations mentioned above, modern companies make use of dedicated technologies such as goggles, gates, forklifts, and automatic vehicles, or even intelligent carriers. The objective of this concept is to increase the efficiency and performance of the members of the supply chain [15].

It has been assumed that the new technologies and tools are determining factors for the realization of Logistics 4.0 and that they can be used as evaluation criteria for the implementation level [14]. Through the implementation of Logistics 4.0, many advantages can be noted, among them the lower cost in human work, the high standardization in logistics functions, and the use of new technologies in the equipment of logistics companies. The disadvantages are the high investment costs and the requirement to own the information technology supply network [15]. These concepts could be used in healthcare logistics for optimizing flows but also respecting Covid pandemic distancing attitudes and saving lives.

2.3 Healthcare 4.0

Healthcare industry has been assisting in saving and extending patients’ lives through the progress of technologies adopted by healthcare professionals and through the transformations that the sector has undergone. In the health field, the practices and techniques have been developed from Healthcare 1.0 to Healthcare 4.0. In the context of Healthcare 1.0, there was a scarcity of resources and the efforts were primary since the approach was doctor centric. As the information technology field and medical technologies advanced, it was possible to replace manual records with electronic healthcare records (EHR), what has been termed Healthcare 2.0. Healthcare 3.0 had, as the main characteristic of the patient-centric approach, developed new and effective treatment methods through data processing systems and computational methods. In this context, EHR was used to help doctors to get important information faster. Healthcare 4.0 corresponds to the integration of new technologies, such as Cloud Computing, Internet of Things, Fog Computing and Telehealthcare, to facilitate the doctor-patient interface through data portability. Strong communication interface and the ability to share data enable doctors to make well-informed decisions and increase the quality of healthcare around the world [16, 17].

The adoption of Industry 4.0 main technologies, such as the Internet of Things, Cloud and Fog Computing, and Big Data analytics, has revolutionized the healthcare sector, changing the way to provide traditional products and services. IoT is supposed to integrate the virtual and physical world through interconnected devices and platforms. The Internet of Health Things (IoHT) has as main objective,
the tracking of patient medical conditions and the anticipation of critical situations through the combination of connected devices. The Internet of Medical Things aims to create a personal hub connecting implantable and wearable devices to a personal smartphone. Cloud, Fog and Mobile Edge Computing represent a huge part of Healthcare 4.0 to simplify health processes, facilitate the adoption of healthcare best practices, and inspire the adoption of more innovations. The healthcare sector can benefit from the capacity of management of a huge amount of data demonstrated by Cloud and Fog Computing. Big data and analytics are largely used in the healthcare sector, not only to store and treat patient data but also to collect enterprise data, allowing to implement studies that cover beyond the health domain (biological and medical aspects) [18] and to analyze them in detail for taking good decisions and aiding doctors in the patient support.

The implementation of Industry 4.0 core principles in the healthcare sector is far from optimal, despite the great importance of its main technologies isolated. The problem lies in the fact that a successful implementation of Healthcare 4.0 implies transformations of technical and sociocultural aspects inside the hospitals. The main barriers are associated with the development of an incorporated IT infrastructure aligned with the hospital’s strategy. This issue is proven that healthcare has been the slowest sector to adopt information technologies. To mitigate this problem, the focus must change from design and implementation processes to the end-user experience with solutions already implemented, i.e., more prototypes must be tested [19, 20]. Indeed, this transformation has to be linked with the global healthcare logistics organization.

2.4 Lean manufacturing and lean healthcare

In recent times, the enterprise environment requires the implementation of the Lean Manufacturing approach to create added value with optimal resource utilization. Aiming to present the Toyota Work Philosophy, the term ‘Lean’ first appeared in the 90s. The bases of this philosophy are waste elimination and value creation. Waste can be defined as all processes that do not create any added value. Seven types of Mudas (tasks with no added value) were developed: overproduction, wait, transport, stock, unnecessary activity, defects, and motion. The overproduction is the task that generates the most losses [21].

To implement the Lean philosophy, several tools and techniques were developed to reduce/eliminate waste. The use of the tool VSM (Value Stream Mapping) enables the decision making of the Lean through the analysis of a deterministic and static value chain observation. VSM helps to distinguish the non-waste and waste processes [22]. The implementation of the Lean Manufacturing approach is realized in three main stages: pre-implementation stage (lean readiness), implementation stage (lean approach), and post-implementation stage (results) [23].

Aiming at increasing process efficiency and mitigating non-added value processes, Lean Manufacturing methods have been extensively implemented in healthcare institutions [24]. The main uses of Lean in this context are to eliminate duplicate and unnecessary procedures, such as collecting patient information several times, unnecessary patient displacement, excessive waiting by patients for appointments, and uncoordinated processes. Despite the wide application of lean assumptions in hospitals and clinics, the prospected results are not achieved [23]. The significant number of failures can be explained by 3 main factors:

- Absence of adaptation: it is essential to adapt lean concepts to knowledge-intensive service sectors such as healthcare. This transition is not always clear, which causes a higher probability of failures [23].
• Lack of readiness: the unawareness about the Lean Manufacturing approach by most of the employees added to the inefficient training systems are the main bottlenecks encountered for an efficient lean implementation. The main problems in lean implementation projects are caused by a lack of corporate culture and change management [23].

• Lack of systemic approach: the Lean approach is widely used for specific problems, without taking into consideration all the processes [23].

With this purpose and to help the production process in SMEs (Small and Medium Enterprises), a methodology and a framework has been developed with the aim of contributing to the implementation process of industry 4.0 and logistics 4.0, with the focus on sustainability aspects [4, 24]. The next section presents concepts and methodology that could firstly be used for transforming digitally the hospitals and increasing their flow performance, and secondly be integrated in the process of both patient and hospital staff lives saving in the context of covid pandemic.

3. Concepts and methodology

Based on industry 4.0, logistics 4.0, Healthcare 4.0 and lean manufacturing concepts presented above, a general framework, a global approach and a problem-solving method have been elaborated to insure the hospital digital transformation for respecting COVID pandemic constraints and optimizing hospital flows.

3.1 The generic framework

A general framework was developed in this study, correlating the methods, concepts and tools of Industry and Logistics 4.0 applying in the context of healthcare. Based on sustainability, social and environmental criteria, the general framework for process optimization in hospitals has two main stages. With the main objective of having a good quality in the treatment of patients within the hospitals, the first stage has the patient at the center of all improvements. Then, the next stage will be to ensure the well-being, health, and productivity of health services, with the focus on increasing the efficiency of the hospital. Currently, this stage is even more relevant since the challenge of ensuring the health of nurses and doctors has become even more crucial due to the combat of the pandemic.

With this framework, the goal is to define a reference model for logistics in healthcare, aiming to achieve the following aspects: sustainability (health of professionals), social (quality in the treatment of patients) and environmental (optimization and reduction of costs of processes). The reference model will also serve as the basis for the decision-aided tool, which will be a model to be reached in the optimization of logistics in hospitals.

The Figure 2 presents the general framework illustrating the progressive transformation of the hospital, in stages, for an optimization of logistics in hospitals.

3.2 The global approach

The Figure 3 describes a global approach for implementing industry 4.0 and logistics 4.0 in the healthcare systems.

As shown in the figure above, the global approach has as its center the sustainability aspects for the implementation of the industry 4.0 and logistics 4.0 concepts. This approach uses new technologies such as cobots, mobile robots, IoTs, as
well as new organizations such as Blockchain for transforming digitally the hospital. Finally, it becomes necessary to be flexible to the changes to implement them. The global approach has the following steps:

- An initialization phase for acquiring the hospital global context and main data
- A modeling phase for representing the existing hospital organization
- A simulation phase for elaborating the hospital flows digital twin
- An analysis phase for detecting inconsistencies and points to improve
- A design phase for defining optimization scenarios by exploiting the elaborated reference model and the decision aided tool being developed for managing this transformation process.
This process has been followed in the definition of the reference model and the decision aided tool. From the modeling, the simulation, the analysis, and the design of a real existing hospital structure, generalization reasoning has been applied for defining the reference model that would be used in a hospital flows digital transformation in the COVID pandemic context. Then the transformation of the existing hospital structure could be done by using the reference model developed.

### 3.2.1 Modeling

To understand the logistical operation carried out inside the hospitals including the transportation of medicines carried out by the host pharmacy, it is necessary to collect information through data and interviews. Due to this need before the beginning of the COVID pandemic, several data on the hospital logistics process have been collected in two hospitals located in the south of the Ile de France region.

As these processes travel among different areas and long distances, in this article the focus is made on the medicine delivery processes and on the sterile medical devices. The **Figure 4** presents a complete flow of the medicine delivery processes.

To allow a clear analysis of the processes and with the interdepartmental locomotion the modeling of the processes was done following the BPMN methodology and BonitaSoft software. This methodology seeks to describe an organization’s value chains and process in the form of a graphical representation.

### 3.2.2 Simulation

After understanding the process and its problems, a simulation (digital twin) of the hospital logistics flows was performed by using Flexsim software (**Figure 5**). This simulation, besides allowing better visualization of the process, provided us information on the transport time and distance data. Another advantage of the simulation was the possibility of changing the process to optimize it, bringing a clear comparison between before and after. This information can be obtained without the need to go to the field that during a pandemic period is not possible.

**Figure 4.** Medicine delivery complete process flow.
3.2.3 Analysis

The process description and its modeling were analyzed to detect inconsistencies and to find the possibilities of improvement. Inconsistencies at this stage have been found manually. But the advantage of the decision aided system being developed will be to contain rules able to detect all inconsistencies in any hospital system. An example of inconsistency could be found in the process of food dispatching. Indeed, the existing organization uses nurses, and caregivers for taking food from the hospital restaurant and bringing it to patients. One of the difficulties for managing the actual pandemic crisis is the nurse availability (lack of time). This transfer could also be made by other people, but it would increase the possibility of contamination. Other examples of required improvement are:

- The lack of a continuous flow
- Unnecessary transport
- Non-optimized logistics
- Lack of organization
- That any of the process could be replaced by machines
- That these same problems were found in most of the other processes analyzed.

3.2.4 Reference model

Through the use of the simulation software, each process studied during the previous phases was improved in order to propose most of the tools and digital technologies to increase the level of performance and security.

For this purpose, the digital flows of hospital logistics processes were simulated. First the processes were simulated separately and after implementing the
optimization, they all were combined into a single simulation model. The objective of this model was to seek first the opportunities for improvement within the model, in which after stabilization it would be possible to bring them all together and make improvements to the combined logistics processes.

An example of improvement is the use of Automated Guided Vehicles (AGV) for the transportation of food from the hospital restaurant to the patients. Indeed, this action contributes to the loss of time by the nurses and caregivers.

### 3.3 The problem-solving method

The problem-solving method is the hospital problem context acquisition. Main properties and data must be defined during this step. According to theory of systems, the description of the system will be done by finding properties associated.

Then, this problem will be compared to old cases contained in a capitalization database (use of case-based reasoning (CBR)). For this comparison a similitude degree will be defined. If this number is less than 0.5, it means that there are no efficient possible cases in the database.

Then, the main system transformation will be by using the reference model elaborated. If the number is between 0.5 and 0.75, both possibilities could be exploited. The cases found will be extracted from the database and the reference model will also be applied for transforming the system.

Then, if the degree is more than 0.75, only cases existing in the database will be presented to ensure the hospital flows transformation for solving problems. A decision-aided tool will be developed for managing the hospital flows digital transformation.

### 4. The decision aided tool

In this chapter the framework of the software is discussed, thus containing the architecture and the information flow. Finally, the application of the AGV (Automatic guided vehicle) in the optimization of hospital logistics is also illustrated. The tool has as functionalities to:

![Figure 6. Path of the problem-solving method.](image)
• Facilitate knowledge acquisition,

• Contribute to existing models and simulations elaboration

• Compare data with old cases

• Extract old corresponding cases or reference model

• Exploit the aided structure for elaborating the hospital flows expected digital transformation.

The decision aided tool will combine different artificial intelligence concepts (expert systems, machine learning, multi-agent systems) with reasoning such as CBR, generalization, and transformation.

4.1 Expert system and machine learning

To allow hospitals to optimize the internal logistic process, a decision-making tool is being developed. Combining the concepts of Industry 4.0, Logistics 4.0 adapting them in the context of healthcare. The tool being developed is based on the use of Artificial Intelligence utilizing machine learning tools and expert systems.

In this way, the decision aided system will be elaborated by having the ability to ratiocinate and learn in its own way. For this, Case-based reasoning (CBR) system will be combined with the multi-agent system, which makes it possible to achieve this specificity in the tool. With this, the system can suggest solutions to problems or give proposals for improvement, reusing or adapting the approaches developed in previous applications.

Then, machine learning, through the repetition of a behavior, will contribute to the decision-aided tool by generating new inputs and in this way progressively enriching the database.

4.2 Software framework

The software framework is divided in 3 main parts, which are, the information input, generation of the current process with the problems and possibilities of improvement, and finally the generation of the process optimized with the results of the optimization.

As the final objective of the tool is to enable an optimization of the internal logistics of the hospital, eliminating inconsistencies in the processes and reducing the non-value-added time, the inputs required by the tool will be:

• Location of the beginning and the end of each step of the process

• Number of workers

• Type of process

• Times per day and week

• Equipment used

• Duration of the process

• Upload layout in DWG format
With those inputs, the systems can through machine learning and expert systems, compare the data collected in hospitals with the referring hospital to achieve the ideal logistic model.

This ideal logistics model will be developed after applying Lean Manufacturing and Logistics 4.0 methodologies in several processes in different hospitals, and it will be progressively improved through machine learning.

After the analysis, the second stage of the tool will generate a series of data and the simulation relating to the process, giving the user a general idea about the logistics efficiency. The software will present the problems encountered and make suggestions for improvement to the user.

In the third and last step, after the selection of the improvements, the software will implement them in the process. For this, the system will again need to use machine learning and the expert system to make the changes and generate the data regarding the optimized process.

With this decision aided tool, the user will be able to test changes within the process and see what the results will be, facilitating the logistics optimization process within hospitals as it will reduce time and cost and increase the effectiveness.

4.3 Architecture of the software

The Figure 7 represents the architecture of the model, it aims to organize the components, modules, and information flow of the software in a visual way. Since the decision aid tool will have as functionalities, learn, and update its database in an automatic way, where several components will act, a structure was chosen where the database is centralized and combined with the tool manager.

This tool is composed of the following components:

- Database: Main data storage of the software, where it will contain the reference model, the imputed data, and the results.
- Tool manager: Module responsible for performing the interactions between the components.
• The user interface: Component that carries out the interactions between the user and the tool, where he will be able to impute, modify the data as well as apply the improvements and see the results.

• Expert system: Place where the automatic learning of the system will be carried out, thus to be able to store data and to analyze the system and suggest the most appropriate improvements to the situation.

• Logistics optimizer: Module responsible for solving the problems found by the expert system.

• Measure of performance: It will perform the comparison between the two scenarios, current and optimized to measure the impacts of the changes.

• Capitalization system: Component that will be used as a storage location for the old cases and also perform the comparison between them and the current one.

• Simulation system: Module that will make the connection of the tool with the simulation software.

• Input system: Place responsible for verifying, treating, and storing automatically the information imputed by the user.

5. Illustration

This section focuses on two hospitals studies for defining their existing system finding inconsistencies and points to improving by applying the previous methodology and using adapted new technologies tools for increasing the hospitals performance. The first hospital had just integrated a new building and would like to use this opportunity for transforming digitally its logistics flow organization. The second hospital already started working with lean manufacturing for structuring its storage area and needs to reduce products dispatching and to optimize all logistics flows. The focus was made on six flows for the improvement: meals, patients, medicines, cloths, consumables, and wastes.

After the use of the methodology for defining the existing system, and finding non-added values and added values, a detailed digital transformation process has been applied on each hospital. New technologies and tools were defined for increasing the hospital flow performance. For instance, Automated Intelligent Vehicles have been chosen for transporting products and reducing waste time for nurses and caregivers. The Automated Intelligent Vehicles (AIVs) solution exemplifies how logistics applications 4.0 and lean manufacturing can contribute to help fighting against the pandemic through the personal health reduction of exposure to the virus. The Figure 8 presents the result of the transport time optimization in the first hospital. This data concerns the dispatching flows and human non-values were identified. The integration of the AIV allows to reduce the duration of tasks but also serves as a gain of time for nurses and caregivers.

In the two hospitals studied in this paper for validating concepts elaborated, nurses and caregivers spent their times by managing the logistics and transportation of food, medicines, and materials. This situation contributes to the increase of contact between professionals, patients, and different departments, thus influencing the increase of exposure to the virus. Besides, with the need for more health
professionals, to support the flow of Covid patients, the more time they must contribute to the quality of care and not to the logistics, will increase their capacity to give people the right and well-done treatment.

The study in these two hospitals even before the pandemic showed that the number of patients was increasing in the hospitals, but no increase of nurses. The results of one hospital were about 2700 additional hours to be paid to the nurses. This situation has to be suppressed probably been increased by the covid pandemic. Then, the implementation of AIVs within hospital logistics will contribute to the following aspects:

- Ergonomics of health professionals
- More staff time for service
- Less movement between departments
- Medium- and long-term cost reduction
- Decreased exposure of employees to the virus

The Figure 9 shows the model of AIVs studied in a second hospital located in the south of the Ile de France region. The referring hospital elaborated by exploiting data acquired in these two hospitals had 4 AIVs and delivered medicines and meals on 5 floors. These tools according to the digital twin developed were sufficient for ensuring all the products dispatching in each of these hospitals.

Applying the hospital logistics optimization system presented in this paper to the medicine distribution process presented in Figure 4, it was possible to find several possibilities of improvement. The most impacting was the application of the AIV system presented in this chapter since the process had 16 transport operators in which at least 8 could be replaced by AIVs and affected to more important tasks. Thus, it was possible to reduce 50% of the transport actions performed by nurses and caregivers, giving more energy and time for activities related to patient care.

In both hospital cases the desire to integrate new technologies and tools for optimizing all their flows and making their health personnel available for other tasks was high. These hospitals give data and information for defining reference models for healthcare logistics flow. The management of all these data and the diversity of

| Activities                           | Actual duration | Optimized duration |
|--------------------------------------|-----------------|--------------------|
| Meal collection (minutes)             | 45              | 18,07              |
| Waste collection (minutes)            | 135             | 53,58              |
| Meal dispatching (minutes)            | 45              | 15,48              |
| New laundry dispatching (minutes)     | 60              | 27,4               |
| Urgency collection (minutes)          | Not actually measured | 45     |
| Return of laundry, waste and meals (minutes) | 120          | 41,98              |
| Pharmacy flows (minutes)              | 60              | 13,11              |
| Total (minutes)                       | 465             | 214,62             |
| Total (hours)                         | 7,75            | 3,57               |
| Difference (hours)                    |                 | 4,18               |

Figure 8. Non-added transport time optimization.
decision to take, validate the need of a decision-aided tool for driving the digital transformation process in hospitals. The digital twins are being developed for each hospital and will participate to the improvement of the reference model for healthcare 4.0. The digital transformation of these hospital is growing up.

6. Conclusion

This project aim to show the importance of new technologies and sustainability in the digital transformation of a hospital in the Covid pandemic context. Considering the need to improve hospital logistics with the worsening of it, with the presence of the COVID pandemic, the article presents a generic model of optimization of hospital logistics, where first was presented a literature review containing the new technologies and tools of industry 4.0, logistics 4.0, Lean manufacturing and lean healthcare. After this step, the concepts and methods applied in the development of the project and containing the steps of a global approach have been presented. Finally, the decision aided tool designed to facilitate the logistics optimization process has been presented, containing its functionalities and architecture.

Many of the improvements presented in this article are already applied and consolidated as efficient technologies in the industrial field, but in the healthcare field it is still possible to reuse them to cause a great impact. Today, at such a critical moment for the healthcare field, the need to facilitate the optimization of hospital logistics has become even more relevant. As a result, the tools presented in this article will allow hospitals, doctors, nurses and patients to benefit from the results, thus reducing costs and increasing the time and quality of care.

The opportunity to validate concepts elaborated on two hospital transformations is an advantage for improving the methodology and tools that are proposed in this paper. Sustainability aspects in this healthcare logistics 4.0 concepts implementation concern social and societal dimensions but not sufficiently environmental transformation. This transformation such as waste valorization and reverse logistics, circular economy will be integrated in the study after the validation of the decision tool being developed.
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