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Using lean manufacturing and machine learning for improving medicines procurement and dispatching in a hospital

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Abstract

Industry 4.0 concepts are defined around the use of new technologies for improving industrial companies according to scientific, technological and organizational aspects. Enterprise complex problems could be solved in this frame. Many methods and concepts presented in the literature are focused on these aspects. A new method is being developed in Icam Paris-Sénart around the idea that sustainability must be the kernel of "industry of the future". Indeed, the framework proposed is a combination of the previous aspects with environmental, social and societal aspects. The actual situation of the planet is an encouragement to make all future transformations with sustainability as kernel. These concepts could be imported in healthcare logistics and transport area for solving specific problems of this domain. Icam (French Engineer school) and FEI University are collaborating for proposing to healthcare hospitals a new framework (healthcare logistics 4.0) for solving complex problems of this domain.
This paper is focusing on how to improve medicines procurement and dispatching in a hospital. Indeed, the use of Artificial Intelligence in healthcare sector is growing up. Data treated and analyzed could give important insights for solving problems and improving the existing organization. As machine learning is already exploited in many production management problems (forecasting, storage, production, etc.), the idea is to use it for developing an aided tool in addition to a lean manufacturing classical approach. After presenting the real problem of medicines procurement and dispatching detected in healthcare hospitals, concepts of lean manufacturing and machine learning will be exposed. Then, the methodology proposed for solving the problem will be shown. An illustration will be given for validating concepts presented. Finally, the link with the global "Healthcare logistics 4.0" framework will be described.

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1. Introduction

Industry 4.0 and supply chain 4.0 concepts and tools are mainly based on new technologies (RFID, IoT, Robot, Cobot, decision aided tools, etc.) and organizations (Blockchain, 6 Sigma, lean manufacturing, etc.) utilization for changing companies and improving their performance. Indeed, the use of these concepts is important for big companies, but not sufficient for SMEs. Even if technological and organizational aspects are necessary for the company evolution, brakes for using these concepts are numerous. Some of them are related to human and environmental aspects. Then, a framework is being developed in Icam (School of engineering) based on sustainability (social, societal and environmental dimensions), around which, technological, organizational aspects in addition to flexibility and changes management will be elaborated for improving company performance. Icam and FEI (Brazilian university) are collaborating for the elaboration of Healthcare logistics 4.0 concepts and tools. Many healthcare logistics problems will be solved for improving the healthcare performance. This paper presents the work done in this frame.

Thus, due to the high variance of diseases, patient allergies, big variety of suppliers and new medicines on the market an elevate number of medicines could be available in a hospital pharmacy. However, having an important stock implies to invest, and then immobilize proper funds, use a large space to stock these products. Indeed, this procurement management problem and product storage could also imply medicines expiration date problem management.

Other problems are related to the process of stock replenishment. For instance, one problem is related to medicines purchase frequency and quantity. It is necessary to use forecasting for defining the adapted purchasing plan, integrating current supplier delivery time, procurement economic quantity for each product. Then, public hospital resources associated to the purchase process management have to be optimized.

Finally, the main problem is about medicines procurement treatment. All products have to be managed simultaneously by workers. The consequence is their difficulty to organize orders, to manage products reception the products arrival and the storage processes. This abnormality drags the whole workflow chain, overloading departments and resulting in the quality service falls. The lead time management could be improved. Indeed, products life time have to be taken into account and an organization with mass procurement lots implies a long storage time and diminution of the product life time in hospital services. Due to this bad management, the storage cost is generally high for the pharmacy and the global process is not optimized (high waiting time, risk of deterioration, etc.).

In this paper, a literature review allowing to choose concepts and tools, which could contribute to elaborate a solution for increasing hospital pharmacy purchasing and procurement process managements is presented. Then, methods (based on enterprise modelling and lean manufacturing, etc.) and concepts elaborated for improving purchasing and procurement processes performance will be described. Indeed, the general structure of the decision aided tool, based on artificial intelligence and being developed for improving healthcare purchasing and procurement performance will be exposed. A use case will be shown for illustrating concepts, methods and tools presented and perspectives of this research will be exposed.

2. Literature review

The project focuses on healthcare logistics 4.0. The idea is to increase ability to save lives and the global hospital performance by solving healthcare problems such as medicines procurement and dispatching optimization. Indeed, the improvement of this performance implies to use performance criteria for measuring at each step the result of changes introduced in the hospital. In addition to quality, cost and lead time (QCD), social, societal and environmental aspects have to be used for this optimization. For instance, in a manufacturing company, suppliers

have to deliver raw materials on time in order to favorize products elaboration (on time) and customer delivery time satisfaction. The processes of purchasing, delivering, storage and dispatching have to be increased. An analogy could be made between a hospital ad a company by defining customer to satisfy (patient) and performance to increase. Then, methods and concepts of industry 4.0 and logistics 4.0 could be used for defining specific concepts in the frame of healthcare logistics 4.0. For elaborating the adapted solution to the problems explained above, a decision aided tool will also be developed. A problem-solving method, based on a general approach, exploiting DMAIC, for making sustainable supply chain efficient, will be defined. Lean manufacturing and artificial intelligence (expert systems [1], machine learning) will be used for the development of the decision aided tool.

2.1. Efficiency of sustainable supply chain by DMAIC approach

DMAIC (Define, Analyze, Innovate, Control, Standardize) is a problem-solving method generally used for manufacturing company total quality management (TQM). This method is adapted for improving continuously sustainable supply chain. The idea is to reduce lead time and cost, to increase quality of the system (being studied) and also to optimize social, societal and environmental aspects. As explained in [2] and shown in the following equations, the optimum of a system performance could be obtained by combining performance criteria.

$$L_i = \sum_{j=1}^{n} \alpha_j * l_j$$

$$O_i = \beta * L_i + \lambda * C_i + \gamma * Q_i + \mu * S_i$$

$$O = \sum_{i=1}^{m} \eta_i * O_i$$

L_i is the lead time (l_j is the lead time obtained by taking into account one parameter in each domain) and O_i is the Optimum (integrating quality Q_i, cost C_i, lead time L_i, and carbon management S_i) associated to one part of the supply chain. O is the global optimum of the supply chain. The method could be used for solving healthcare logistics problems and for:

- Integrating new concepts associated to information & decision management (IoT, tracking, RFID, big data management, decision aided tool),
- Applying organizational methods (lean manufacturing, design of experiment (DOE), flow modelling and simulation),

Then, the general approach which would be used will combine industry improvement conceptual aspects (concepts presented above and lean manufacturing) with real experimentation during DMAIC steps:

- Define: complete definition of process.
- Measure: measurement of the actual situation.
- Analyze: analysis of the existing system and the detection of inconsistencies.
- Innovate: experimentation improvement proposition.
- Control: measurement of the future system and test of its impacts.
- Standardize: making general solution sustainable and efficient (capitalization).

This new problem-solving method will be enriched by concepts of lean manufacturing presented below.

2.2. Lean Manufacturing

Lean Manufacturing Methodology is a performance improvement tool developed in the frame Toyota Production System (TPS). It is a systemic method for minimizing non-added values, eliminating waste (7 MUDA) and focusing production tasks on added-values during the product elaboration. Lean manufacturing proposes to improve the "value" by willing what the customer would pay for. To achieve the expected outcome of Lean Projects, the effort

should be to optimize the "flow" of subjects in the system and the efficiency of any individual resource of the system [3].

In the last decade, the healthcare sector has made leapfrog advancement in adapting lean principles in healthcare operations, although the way that they have been implemented differs across organizations. Though, the healthcare sector has a record of adopting Toyota Production System principles, especially in the mainly independent US healthcare system. For instance, tools such as Rapid Process Improvement (RPIW), 5S, value-stream mapping (VSM) and Kanban were used in the Virginia Mason Medical Center, an acute care hospital in Seattle [4].

Thus, a flow-based view suggests that a resource-efficient approach is problematic from a customer perspective and creates several negative effects. This view argues that a resource-based approach to efficiency generates lots of waste and hidden inefficiency. The focus is on the flow unit which moves through the organization. "Flow efficiency" measures how well a flow unit moves through all processes across the operations context. In this context of healthcare operations, the flow unit is the individual patient who arrives to the hospital [5].

2.3. Machine learning

The framework developed for healthcare logistics 4.0 (with sustainability as the kernel) and the global approach encourage the development of a decision aided tool, for solving procurement and dispatching problems, but also for integrating new technologies and organizations in the hospital performance improvement process (patient satisfaction and increasing of hospital performance). This tool being developed is based on artificial intelligence concepts, methods and tools. Indeed, expert systems, multi-agent systems [6], [7], machine learning and CBR (Case-Based Reasoning) are adapted for solving healthcare logistics problems.

Trough the last decade, the acceptance of new formalisms like neural networks and data mining methodologies for solving problems has grown up. Different applications of this concepts could be found in the literature, and tools have been developed in forecasting, modelling, simulation, clustering, classification domains. Then, various formalisms were developed such as swarm intelligence [8], neural networks [9], convolutional neural network, Deep learning [10], machine learning [11], etc.

The main difference between neural networks and statistical approaches is that neural networks make no assumption about the statistical distribution or data properties, and therefore, tend to be more useful in practical situations. Neural networks are also an inherently nonlinear approach giving them much accuracy for modelling complex data patterns.

Artificial intelligence forecasting techniques have the ability to learn like humans, by accumulating knowledge through repetitive learning activities.

Therefore, the objective of this paper is to propose medicines procurement and dispatching improvement in a hospital. In this frame, the Artificial Neural Network (figure 1) method could be used.

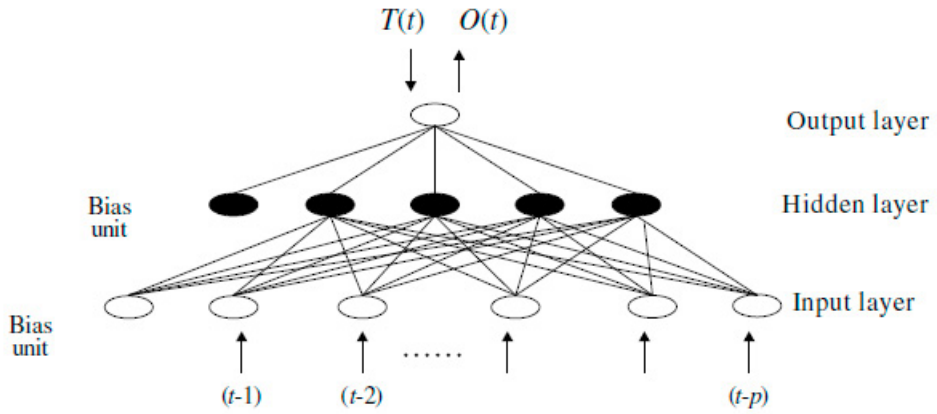

Figure 1: Artificial Neural Network

Artificial neural networks (ANN) were developed for simulating the animal brain's cognitive learning process. However, in the past decade, they also attracted substantial attention in business industry. ANNs are proved to be efficient for modeling (complex and poorly understood) problems on which sufficient data are collected [12]. ANN is a technology that has been mainly used for prediction, clustering, classification, and alerting to abnormal patterns [13]. The ability to learn with examples is probably the most important property of neural networks applications and can be used to train a neural network with the record of past response of a complex system [14], [15].

The integration of these formalisms in the development of the decision aided tool will increase the efficiency of the tool in coherence with new technologies exploitation, and finally in healthcare performance increasing [15].

3. Methods and concepts

Methods, concepts and tools of industry 4.0 and logistics 4.0 are used for elaborating healthcare 4.0 concepts. They allow to integrate new technologies and organizations (in addition to flexibility) for satisfying patient expectations. For instance, robot and cobot are already used for aiding doctors in their daily operations. AGVs are already used for following nurses during their work and aiding them for transporting medicines for patients. Indeed, the framework being developed in Icam in collaboration with FEI University is based on sustainability as the kernel of healthcare 4.0 [16].

Thus, patients have to be at the center of all changes in the hospital. The quality of their treatment, comfort and efficiency of healthcare services are main objectives. Then, workers well-being and serenity have to be taken into account for increasing the global hospital efficiency. The framework elaborated proposes to combine technological aspects with these visions around sustainability (social (patients & workers), societal (which society for tomorrow), and environmental (how to protect our earth) aspects).

The idea is to define a reference model for healthcare logistics. This model could be used for implementing healthcare logistics for the future in hospitals. This implementation is obtained by transforming progressively the hospital (figure 2).

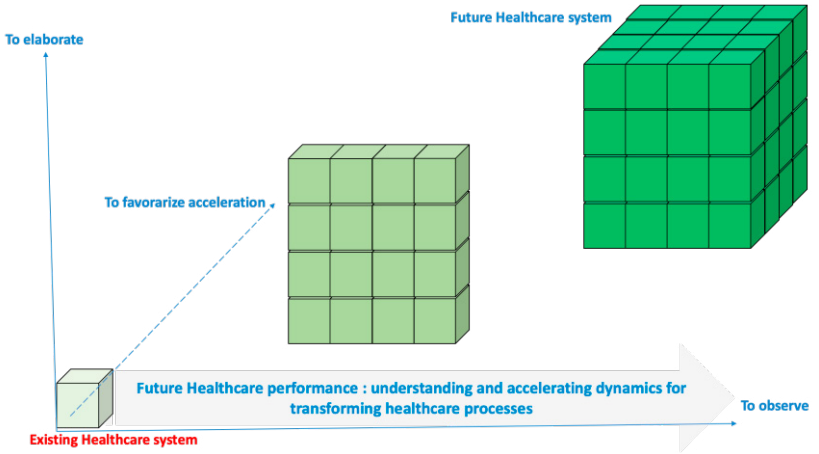

Figure 2: Framework for healthcare logistics 4.0 concepts implementation

Then, the focus on procurement and dispatching service will allow to optimize flows and to solve problems currently met in a hospital. The decision aided tool being developed in Icam will be used for aiding workers in order to be daily efficient, to satisfy patients expectations and to increase healthcare performance.

3.1. The decision aided tool

The tool being developed has to aid workers for procurement and dispatching optimization. Then the proposed structure is elaborated for solving problems and aiding globally workers to increase healthcare logistics performance. The decision aided tool (figure 3) is composed of:

- A knowledge base
- An expert knowledge acquisition system
- An inference motor
- A stock optimizer
- A learning system
- A capitalization system
- A calculator & evaluator motor
- And a user interface

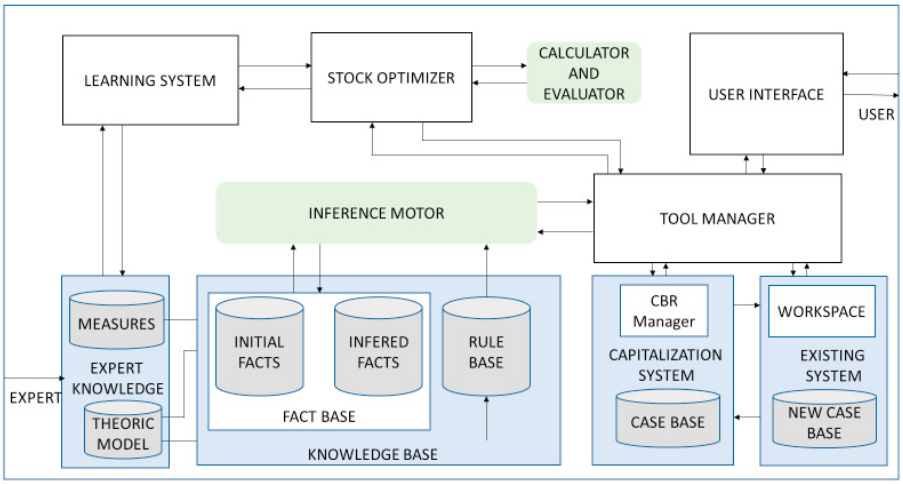

Figure 3: decision aided tool for healthcare 4.0 concepts implementation in hospitals

3.1.1. Databases

Databases are most important components in the decision aided tool as the hearth of the system. Indeed, they are present in the Capitalization System for recording old cases. In this module, a CBR manager also ensures the process of old cases reuse for aiding users to solve a new problem. They are also used in the existing system for acquiring data on the new case. In the expert system, the knowledge base contains three data bases for managing respectively initial facts, inferred facts and rules. The last module using a base is the expert knowledge management system for introducing expert new knowledge in the aided tool. The tool will have enough knowledge stocked in the data base.

3.1.2. Inference motor

The inference machine is the kernel of the expert system. It is used for creating interaction with facts and rules bases. Data stocked in theses bases would be extracted for analyzing the new case and solving problems. Basically, it is a protocol for navigating inside the database trough rules aiming to solve the problem.

3.1.3. User Interface

The user interface is the convivial connection with employees. New data could be entered in the system by this way for being analyzed and for defining adapted solutions to problems. Then, the system will also give response to users. The user interface creates interaction between employees and the system. It is the place where employees will check medicines lists and engineers will access to the configuration.

3.1.4. Stock Optimizer

The stock optimizer is the place where the software will reach out to apply stock rules and algorithms. This module is destined to manage stock and adapt medicines procurement to storage dimensions, but also to patient

needs. The idea is to calculate for each product the optimal procurement time and the economic quantity. For main management rules are used in priority according to procurement frequency and quantity.

3.1.5. Learning System

The Learning System utilizes the Artificial Neural Network for forecasting the demand and the formula adaptation by learning with data available. Each data integrated in the tool by expert would increase the learning system knowledge and improve its performance.

This tool being developed will be tested on real cases for improving concepts used in the general approach and validating algorithms developed in the tool.

4. Illustration

The illustration concerns the use of healthcare logistics 4.0 methods and concepts for solving procurement and dispatching problems of a hospital.

DMAIC method (combined with lean manufacturing and industry 4.0 concepts) represents the general methodology used for solving problems of this hospital. Each step of DMAIC was used during the project and lean manufacturing has contributed to detect inconsistencies and waste in the process (elimination of non-added values). For instance, during the 'Define' step the modeling of the existing system was done by exploiting Value Stream Mapping (VSM) method. Then, for the 'Measure' and 'Analyze' steps, lean manufacturing (MUDA) was used. For instance, the hospital didn't have place for storing all products. A delay was also noticed every time in the medicines dispatching process. The direct impact is that product availability durations were reduced for patient use. The global procurement cost of the pharmacy was high due to the quantity of storage and the global performance was low because of disturbing dispatching flows organization. So, the decision tool was used for aiding employees in their daily tasks focused on procurement process management and dispatching flows optimization.

The replenishes medicines process is an important process in the hospital pharmacy. However, its impact in the workflow is underestimated. Therefore, the replenishes process should be done every week, fulfilling the right medicines at the good time.

The software (a decision aided tool) was used for aiding the stock manager in the order elaboration. Then, rules such as 'the user interface allows the employee to ask for the best order solution' should be applied. Every time, the user could consult replenishes medicines lists. The Inference Motor controls medicines stock status furnished products stock level and proposed order solutions.

In the stock optimizer system, there is a procurement forecasting historic which is constantly analyzed. This historic compares the consumption per day for defining the adapted solution. Artificial Neural networks contributed to elaborate estimated order quantities (figure 4).

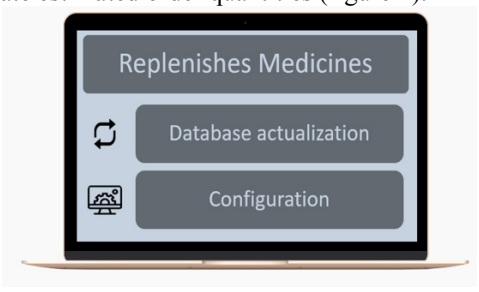

Figure 4: Replenishes medicines module

Then, the Inference Motor relates medicines needs with stock management rules. Quantities needed to fulfill the stock should be defined by the Stock Optimizer. Thus, the variation of quantities was enabled according to a specific moment of the year, ensuring a better adaptability of stock level and creating new data to integrate in the learning system.

Finally, the software tool had furnished to user quantities (required) for optimizing the process, restrictions values (lot size, supplier, urgency etc.) and appropriated replenishes medicines list. This list aims to facilitate the replenishment without causing a disturbance in the hospital workflow.

The deployment of Healthcare logistics 4.0 concept (being elaborated) in the hospital and the test of the decision aided tool process allow to show pertinence and efficiency of both methods and tools in the hospital logistics improvement.

5. Conclusion

This paper presents Healthcare logistics 4.0 concepts (being developed). They are based on a combination of DMAIC, Lean Manufacturing, with Industry 4.0 concepts. Then, the structure of the decision aided tool being developed (for aiding workers in their tasks) in order to optimize procurement and dispatching processes is shown. The specificity of the learning system and the stock optimizer (based on Artificial Neural Networks) is exposed. The importance of a good management of stock levels in a hospital and its impact in the workflow cadency, is pointed out. Difficulties for implementing an efficient management model are presented.

The illustration (exposed in this paper) explains how the working tool being developed would be able to improve the time spent in the replenishes process. For instance, it would provide an easy and complete view of stocks.

The methodology explained will allow to combine main performance criteria as quality, cost, lead time, with social, societal and environmental aspects for increasing healthcare logistics performance. The reduction of storage quantity will reduce cost but also increase product quality. The dispatching flows optimization and suggestions to users will reduce lead time and increase worker ergonomics and efficiency. They will contribute to reduce waste and avoid doing non valuable operations.

The beta version of the decision aided tool is being elaborated, based on concepts presented previously. The development of the beta version is ongoing. Then, real efficient of the tool will be tested by increasing the number of experimentations on hospitals.

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