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Healthcare Delivery System Security: the orchestration of automated and organizational solutions

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Abstract: Many studies from around the world enhance awareness of medication errors in hospitals. A French national study on Adverse Events (AE) revealed that 60 000 to 130 000 AE per year appear to be consequences of medication errors, and 15 000 to 60 000 AE are preventable. Furthermore, hospital spending represents 37% of the French healthcare costs. Enhancing medication system quality and efficiency by reducing medication errors and costs are then considered as important public health issues. Medication management is a complex socio-technical system involving multiple people and numerous steps. Automated dispensing systems have been reported to be key components of strategies to prevent medication errors and create a better workflow. Few hospital pharmacies are implementing automated nominative dispensing robot that increase secure treatment preparation as well as dispensing safety and performance. Automated storage systems and medication delivery devices also reduce hidden costs related to pharmaceutical products stock control and remove professional agent time from non-value-added tasks for a more efficient redeployment tasks.

Nevertheless, our results from auditing hospital pharmacies that are investing in automated systems revealed risks and hidden costs related to reception station, dispensing and care unit orders that should be settled by computerization and organizational actions. Our study shows that hospital pharmacy organizations require the implementation of specific actions settling software interface problems and enhancing coordination skills among health care actors in order to secure medication delivery system and prevent from hidden costs related to organizational factors. Then, automation does not seem a self-sustaining option to handle pharmacy's activity dysfunctions. Many other parameters intervene.

This paper presents a pharmacy's automation project. It takes example at a French Hospital Center in Lens in the north of France (CHL). We present a human centered automation approach that includes an identification of tasks eligible for automation and tasks that need to be supervised, controlled or operated by a human agent.

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Keywords: Automated medication dispensing systems, organization issues, hidden costs, human-human interfaces, human-centered automation, task allocation.

1. INTRODUCTION

In France, medication errors are estimated to harm at least 60 000 to 130 000 patients per year, with about 15 000 to 60 000 preventable adverse events (IGAS, 2011). Prevention of medication errors has therefore become a high worldwide priority as many studies from around the world enhance awareness of medication errors in hospitals.

Medication distribution systems also known as Automated Delivery Cabinets (ADCs) are computerized drug storage devices or cabinets that provide computer-controlled storage, delivery, and tracking of medications.

Before the implementation of automated drug delivery machines, hospitals relied on manual distribution systems, floor stock with a few control over inventory, and paper-based or fax prescriptions. This system is prone to many problems such as prescription and dispensing errors due to

manual documentation procedures, under- or over-stocking of inventory, missing or inaccurate drug charges, no tracking of drugs and drug waste.

Automated drug delivery systems provide safety and security, accessibility, and inventory control of medications, which are important for a safe medication distribution system. Thus ADCs have been identified as one potential mechanism to improve efficiency and patient safety.

Medication dispensing process efficiency is improved by the automation of pharmacists' tasks that require repetitive motions, high concentration and reliable record keeping. Dispensing time is reduced, as inventory management is driven by the pre-established minimum and maximum levels. A study to assess the effect of the implementation of an Automated Delivery System (ADS) in Valenciennes' hospital pharmacy has shown a significant decrease in dispensing errors (Cousein et al., 2014).

However, in some cases, errors may even increase with the use of ADC technology. The United States Pharmacopeia-Institute for Safe Medication Practices Medication Error Reporting Program (USP- ISMP MERP) also reported medication errors associated with the use of ADCs (Yang, 2013). Main errors were due to computer interface, miscommunication with other systems and lack of sufficient decision support. Human errors have also played a role in errors through inexperience, inadequate knowledge, interruptions and typing errors. As with any new technology, automated delivery systems can compromise patient safety if they are not managed in an appropriate manner.

Nevertheless, human-agents involved in the medication process are able to detect and correct errors and to learn from them. They have a key role in providing safety issues by ensuring that ADCs are used in a way that enhances safe medication use, and by developing patient safety initiatives such as Medication Reconciliation. Then automation in complex human systems is non-self-sustaining leverage for medication dispensing system. The safe use of ADCs is thus dependent on Human-Machine systems and Human-Human cooperation between the healthcare professions in order to plan and implement a medication safety system integrating automation technology.

However, the human operator shall not be reduced to a backup device to ensure non-automated activities, or to control man-machine systems loops. In complex systems such as hospital processes, human operator teams must be fully integrated into process, using their capabilities to ensure patient safety, and taking advantage of low-value tasks automation. These are the issues of human-centered automation design of medication dispensing process that we propose in this paper. In the following chapters, we will present Human-Machine systems issues, automation rule in human-human cooperation performance, our approach for human-centered automation design of medication dispensing process, the results related to our approach deployment at Lens Hospital Center, and finally we will discuss the results and the perspectives of our work.

2. HUMAN-MACHINE SYSTEMS

2.1 Ergonomics of human-machine systems

As medication dispensing system is a cross-organizational activity implying interconnected processes and involving numerous actors, it seems convenient to apply an integrative human-centered automation approach to handle specifications of such a complex and multi-agents' system.

In this risky system, the human is usually seen as an unreliable factor (Schmitt K., 2012). Increasing the level of automation requires involving other aspects such as ergonomics, contextual and organizational factors (Millot, 2014a). Guy Boy (2011) provides a pyramid diagram for a dynamic human-machine system. He mentions five summits and their relations called AUTOS (fig. 1): A for Artifact, U for User, T for Task, O for Organization and S for Situation. In our community Artifact is the System and the User is the Operator.

The operator is trained on the System, performs Tasks as required by the System. These tasks must be helped by the ergonomic quality of human interaction-system. Human interaction-system implies the sharing of tasks and functions between humans at supervisory team, but also the interface between operational operators.



Fig.1. The Pyramid AUTOS (Boy, 2011)

The dynamic sharing of tasks or functions between Human and Human and Human and Machine helps the operators to understand their role in the Organization, to improve cooperation and coordination, to document their Situation Awareness, to identify unusual situations, and to analyze the context, and document their decisions in order to guarantee a global system performance. Operators enhance then their Situation Awareness from the modeling, the analysis and the reconfiguration of their system.

2.2 Cooperative Human-Machine system

Medication dispensing system is a process in which human agents cooperate in order to guarantee patient safety. A cooperative system is a structure in which agents are connected to their environment and to the system they manage (Flemisch, 2012).

The integration of automated systems within the organization requires business needs analysis to define functional specifications, to allocate tasks between human and automated agents in order to implement solutions in a secure manner. We propose then an approach based on the classical design V-Model, but adapted to human-machine systems (Boy G., 2011) in order to identify the user needs and integrate them in the medication dispensing strategy design (fig. 2).

Task Allocation between automated and human operators is then build on high level requirements. This well-balanced allocation tasks must integrate management context, methods, skills and team culture in order to guarantee system security and performance. This paper proposes a model for securing medication dispensing system based on a design of Human-centered automation approach.

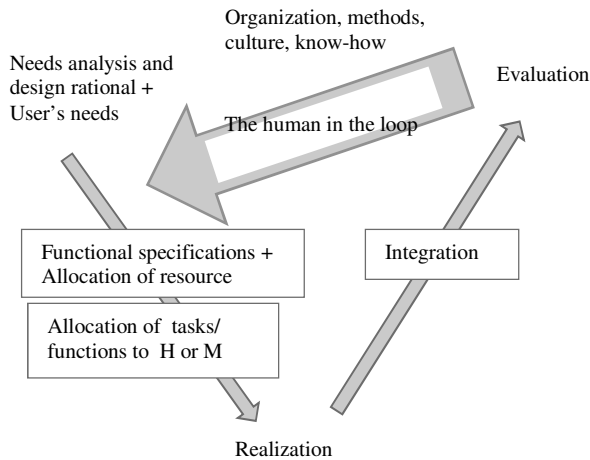


Fig.2. V-Model adapted to Human Centered Design

3. HUMAN-CENTERED AUTOMATION APPROACH

3.1. Automation approach

Automated drug delivery systems such constitute a leverage for medication dispensing system. The Global Delivery Robot manages stock, packs and dispenses medication based on unit care medication use. The Nominative Delivery Robot manages stock, and repack medication as individual doses according to the schedule, time of administration or the length of the time period according to the prescription or care plan orders.

In order to ensure a secure integration of the automated drug delivery systems in such a complex human organization, we propose an anthropocentric approach based on the following steps (Bouami H, Millot P. 2019):

- 1) Modelling the medication dispensing process,
- 2) Identification of actors,
- 3) Diagnosis and risk analysis,
- 4) Identification of tasks eligible for automation
- 5) Medication dispensing system reconfiguration.

Modelling helps to have a “better understanding” of human operators, as well as medication system itself and its environment, in order to ensure a secure integration of automated solutions in hospital organization.

We identify medication dispensing risks and hidden costs in order to prevent automated systems dysfunctions, to optimize benefits coming from automation, and to enhance organizational security and performance.

Also this approach helps hospitals to build a well-balanced task allocation between automated and human-based solutions. The challenge is to identify tasks eligible for automation and high-value tasks that need human operator analysis, actions, supervision and control. This approach enhances operator's situation awareness of medication dispensing systems risks and the rule of automated and

human agents in medication dispensing security and performance (fig.3). Modelling the process (step 1) and identifying the actors (step 2) enhance the perception by the agents of elements of manual medication delivery activity in current situation. Diagnosis and risk analysis (step 3) helps the comprehension of current situation. The identification of tasks eligible for automation (step 4) and those that need human intervention will help projection of future status of automated and reorganized medication dispensing activity. Then operators build the decision-based reconfiguration of medication dispensing process in order to improve activity security and performance.

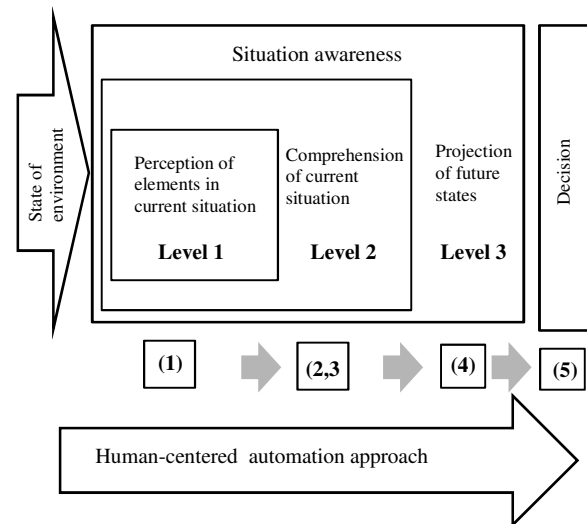


Fig.3. Human centered automation approach adapted from Endsley's SA definition (Endsley, 1995)

3.2. Modelling the medication dispensing process

Medication management process can be divided in two interconnected sub-processes: the therapy management that includes the process activities starting with medical prescription and ending with drug delivery to patient, and the supply chain management that includes all logistic activities from the requests sent to pharmacy (ie. the drug prescription by the physician), the order sent to the supplier, to the reception of drugs by the nurses. It also includes all the usual logistic activities that control material stock.

Such a cross-organizational activity implies interconnected processes. The challenge is then to identify and control risk factors and to improve workflow in order to ensure patient safety and reduce healthcare costs.

3.3. Identification of actors

Medication process involves numerous actors who share a common goal: the prescriber must choose an appropriate medication for a given clinical situation, the pharmacist checks the prescription, dispenses the medication and document the process, the nurse administers the right dose of the right medicine to the right patient via the right route at the right time.

Different risks and opportunities for error are associated with different steps in the medication process. These errors often

involve communication failures, inadequate knowledge about drug indications, contraindications and drug interactions, carelessness, fatigue, lack of training...

3.4. Diagnosis and risk analysis

Auditing the pharmacy in order to detect if critical factors for automation are met, allows identifying organizational malfunctions to be controlled and implementing the automated system in a secure and optimized environment.

To overcome the malfunctions in medication dispensing activity, our method is completed with a comprehensive study of the initial process state in order to identify improvement opportunities and to build the improvement process integrating automated and organizational solutions.

Risks that threaten either operator or patient safety, and hidden costs caused by a non-performing process, are analyzed in order to identify the root causes and estimate the time lost or invested by resources in resolving medication process dysfunctions.

3.5. Identification of tasks eligible for automation

A study of the manual delivery tasks before automation helps us to identify delivery tasks that are eligible for automation and those that must remain handled by human agents. In our anthropocentric approach, the human time that could be saved by the use of an automated system is studied as a potential resource that could be re-involved in other human functions, for instance the control by pharmacists.

3.6. Medication dispensing process reconfiguration

A modified value chain model is then built from a cooperative work between us and the hospital team project by integrating organizational or automated solutions to control and prevent the risks and hidden costs that have been identified in the study. A support is given to managers for designing their automated process and building a cooperative team by a documented task allocation between automated system and human agents, and building a secure and optimized process integrating organizational recommendations. An action plan is then implemented in order to meet critical factors for automation and secure medication delivery system.

4. CASE STUDY: HUMAN CENTERED AUTOMATION OF MEDICATION DISPENSATION AT LENS HOSPITAL CENTER

4.1. Diagnosed establishment: Lens hospital Center

Lens Hospital Center has 774 hospital beds including 538 beds for Medicine, Surgery, obstetrics, 95 for Monitoring units, 104 for Psychiatric units and 120 for Residential Accommodation for dependent Elderly People. The purposes of automation of the medication delivery and precisely nominative drug delivery are:

- A reduction of drug adverse events by controlling drug storage, preparation and delivery security,

- A preparation and a delivery of nominative unit-dose treatments,
- A redeployment of the agents on value-added tasks,
- A secure and optimized drug tracking,
- An optimization of the activity by controlling hidden costs.

4.2. Medication dispensing tasks eligible for automation

The diagnosis is within the scope of supply chain management sub-process of medication dispensing system. It includes activities such as supplier orders, distribution, reconditioning station, delivery, and drug preparation.

Tasks related to manual dispensing activity agents have been detailed and the nature of the tasks have been specified: drug delivery, drug preparation, storage, traceability, transport and carriage, management and pharmaceutical rules, orders, reception and specific processes.

The study of manual dispensing activity revealed that tasks are eligible for automation (fig 4): drug delivery, drug preparation, storage, traceability, transport and carriage.

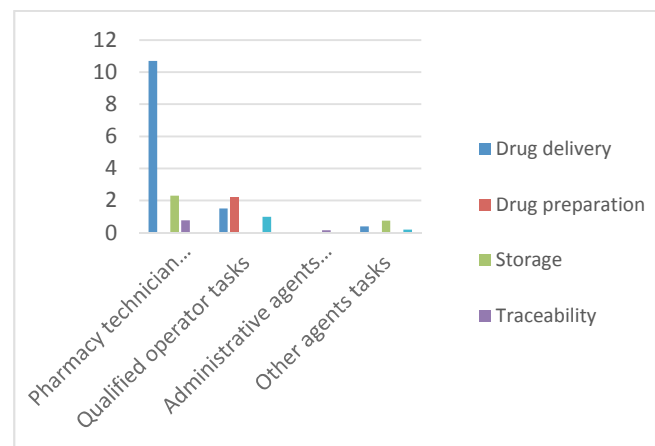


Fig.4. Agents tasks eligible for automation

Nevertheless, some tasks were noticed as not eligible for automation such as: management and pharmaceutical rules, orders, reception, and specific process (fig 5).

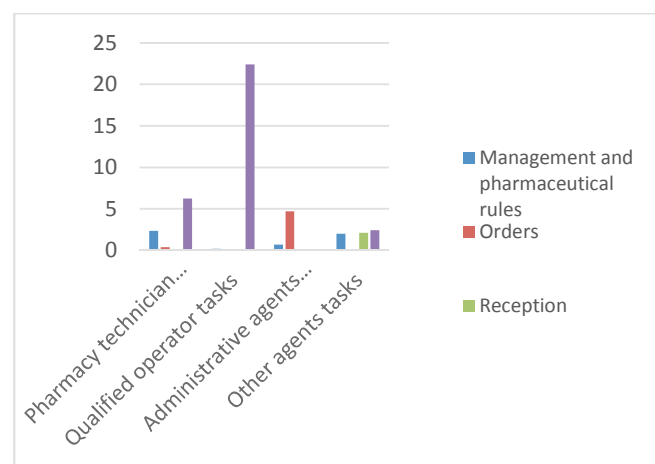


Fig.5. Agents tasks not eligible for automation

These tasks are not eligible for automation regarding to regulatory considerations, automated solutions' limits, and human agents' abilities that we have to take advantage of to ensure medication dispensing security and performance.

4.3. Automated and organizational solutions for medication dispensing security and performance

By automating some elements of medication management, hospitals can guarantee a more efficient pharmacy workflow and could free their agents from labor-intensive and non-value-added tasks, and ensure a redeployment of their agents on high-value tasks and organizational actions to secure the process.

In fact, automated systems reduce drug waste by cycling medications by expiration date, and have visibility into inventory levels and delivery needs and guarantee medication packaging and delivery security. They exempt agents from manual medication storage, packaging and delivery that are also time-consuming. They also settle picking errors due to mix-ups or misplacement among lookalike drugs.

Precisely, the analysis of hidden costs and risks root causes revealed that automation settle lack of space, conveyors, and non-value added tasks such as drug storage, financial losses bound to the non-management of returns, non-optimized inventory management, non-optimized out-of-date medicine management, non-optimized unit-dose drug preparation, non-optimized and not secured drug storage, non-optimized unit-dose delivery, non-optimized drug lot numbers tracking, the flow of urgent demands, and hidden costs caused by surplus stocks.

Nevertheless, a complementary action plan is necessary to settle risks and dysfunctions that are not handled by automation. Precisely the study of medication dispensing risks and dysfunctions revealed that 52.08% of the identified risks need organizational actions to be controlled (fig 6).

Hidden costs and risks settled by organizational actions are: flow crossing, tasks interruptions, lack of space, parcels addressing problems, not labelled cooled products, non-optimized reception platform, non-optimized product receptions, non-value added tasks, dysfunctions bound to medical gases management, and cooled products delivery.

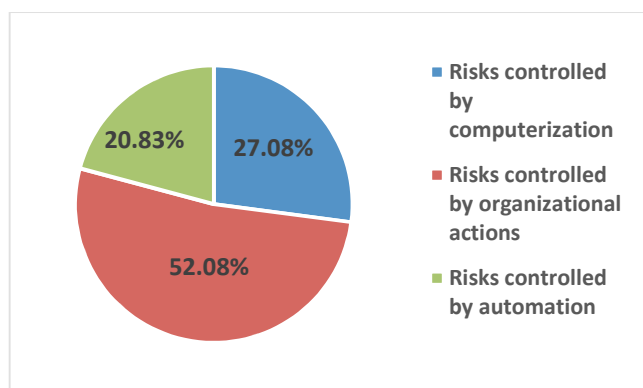


Fig.6. Repartition of medication dispensing risks controlled by automation, computerization and organizational actions

The organizational actions that have been identified to control and prevent medication dispensing risks and hidden costs are internal reorganization of pharmacy's activities, sensitizing agents, information, agents training, enhancing pharmacy's synchronization with other services, strategic actions on the scale of the hospital, and specific actions (fig 7). These actions need to free agents from low-value tasks in order to achieve the reorganization needed to secure medication dispensing process and automated solutions integration.

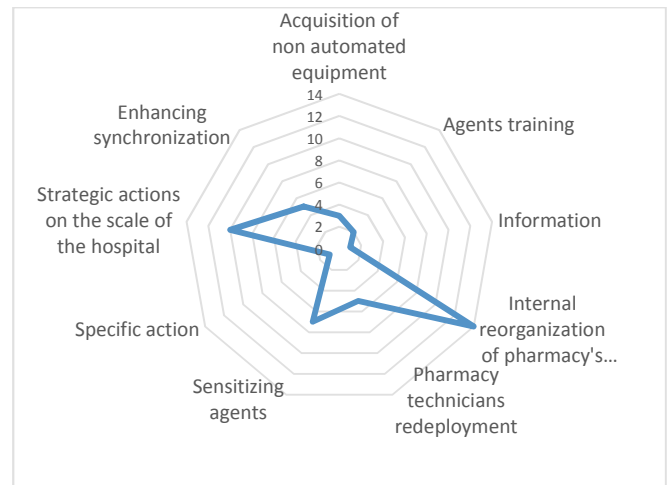


Fig.7. Organizational actions for medication dispensing security and performance

4.4 Redeployment of freed pharmacy technicians by the automation of low-value tasks

Pharmacy technicians' deployment in unit care is one of the organizational actions that have been identified to control medication dispensing risks and dysfunctions (fig 7). Their deployment will help to prevent following medication dispensing dysfunctions: Just-in-time unit care orders, lack of anticipation, medication stock in unit care not checked by nurses before orders, prepared treatment boxes unchecked, missing boxes in unit cares, prescription changes, dispensing incomplete patient treatment, weak unit care reporting on patients releases and transfers. In order to study the opportunity of freeing pharmacy technicians by automation, their tasks have been detailed (fig 8).

Pharmacy technicians' tasks allocation revealed that drug delivery represents 46.80 % of their tasks, storage is 10.09%, and traceability is 3.36%. These tasks have been identified as eligible for automation.

However, Pharmacy technicians are needed to realize tasks that are not eligible for automation such as management and pharmaceutical rules, orders, and specific process. Additionally, as the automation of eligible tasks will free pharmacy technicians, they will be redeployed in unit's care in order to handle medication dispensing dysfunctions and risks as seen previously.

They also be trained in order to supervise, control and secure the automated activity.

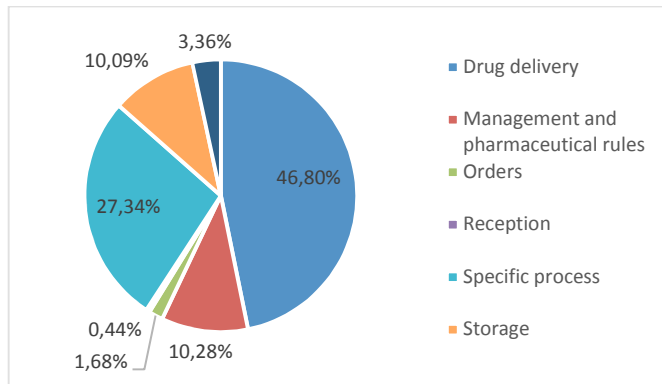


Fig.8. Manual tasks allocation of pharmacy technicians

5. DISCUSSION

Medication dispensing process is a complex human system that needs a Human-robot collaborative automation strategy to secure automated solutions implementation. Tasks allocation between automated and human agents should be documented by identifying tasks that are eligible for automation and those that need human agent intervention.

Human agent rule is then to operate tasks that are not eligible for automation. Trained human agents will supervise and control the automated activity.

Also, the redeployment in unit cares of freed pharmaceutical agents by the automation of low-value added tasks, will help handling risks and dysfunctions in the therapy management sub process, and ensure medication dispensing security and performance. Then automation is then an effective but **non-self-sustaining** leverage that is used by hospitals to enhance Human-human cooperation in order to secure medication dispensing activity. The global approach of human centered automation helps building Team-Situation Awareness of medication dispensing risks, dysfunctions, and solutions, whether they are automated or organizational, in order to secure medication dispensing process.

6. CONCLUSIONS AND PERSPECTIVES

This paper has presented a human-centered automation approach of such a risky and complex system having theretofore been manually conducting. Auditing manual drug dispensing activity and listing all the tasks done by human operators in manual processes revealed that some tasks are not eligible for automation and need human-agent capacities and abilities. A performant organizational system with a human agent cooperative team is needed to ensure medication security and performance. A complementary study is planned in order to evaluate the automated systems performance and if all the objectives formalized in our automation project have been achieved.

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