International Journal of Medical, Medicine and Health Sciences
ISSN: 2517-9969
Vol:15, No:9, 2021

Parameters Influencing Human-Machine Interaction in Hospitals

Hind Bouami, Patrick Millot

***Abstract*—**Handling life-critical systems complexity requires to be equipped with appropriate technology and the right human agents' functions such as knowledge, experience, and competence in problem's prevention and solving. Human agents are involved in the management and control of human-machine system's performance. Documenting human agent's situation awareness is crucial to support human-machine designers' decision-making. Knowledge about risks, critical parameters and factors that can impact and threaten automation system's performance should be collected using preventive and retrospective approaches. This paper aims to document operators' situation awareness through the analysis of automated organizations' feedback. The analysis of automated hospital pharmacies feedback helps identify and control critical parameters influencing human machine interaction in order to enhance system's performance and security. Our human machine system evaluation approach has been deployed in Macon hospital center's pharmacy which is equipped with automated drug dispensing systems since 2015. Automation's specifications are related to technical aspects, human-machine interaction, and human aspects. The evaluation of drug delivery automation performance in Macon hospital center has shown that the performance of the automated activity depends on the performance of the automated solution chosen, and also on the control of systemic factors. In fact, 80.95% of automation specification related to the chosen Sinteco's automated solution is met. The performance of the chosen automated solution is involved in 28.38% of automation specifications performance in Macon hospital center. The remaining systemic parameters involved in automation specifications performance need to be controlled.

***Keywords*—**Life-critical systems, situation awareness, human-machine interaction, decision-making.

I. Introduction

MEDICATION dispensing system in hospitals is a complex sociotechnical organization whose failure can result to serious adverse events. In such life-critical systems, human agents are involved in the management and control of human-machine system's performance [1].

The human-machine system designer has to make decisions to secure and improve the automation process, and handle organization's complexity [2]. Documenting human agent's situation awareness is crucial to support human-machine designers' decision-making.

Knowledge about risks, critical parameters and factors that can impact and threaten automation system's performance and security are valuable for human agents, and should be collected using preventive and retrospective approaches.

A preventive risk management approach has been conducted in Dijon, Lens and Nord Franche-Comté hospital centers that intend to implement automated drug delivery cabinets [3]-[5]. These studies have contributed to the documentation of hospitals situation awareness through the identification of potential risks that can threaten automation security and performance.

The deployment of our anthropocentric and systemic risk management approach provided the necessary prerequisites for a secure automated activity, and a documented task allocation between human and automated agents. This approach has been deployed in North Luxembourg hospital center that is equipped with an automated drug delivery cabinet for more than 11 years [6]. The purpose of this retrospective analysis was to explore automation risks and malfunctions identified in the recovery and consequences phases of automation risk management.

In this paper, an automation evaluation approach is conducted in Macon hospital center, a hospital equipped with automated drug dispensing solutions for more than 5 years. The analysis of Macon hospital center automation's feedback will document hospitals situation awareness about parameters and driving forces influencing human-machine interaction and performance. Automation needs and objectives of Macon hospital center are specified, automation deployment results and related gains are evaluated, automated equipment functional specifications formalized by the pharmacy are analyzed, parameters and driving forces influencing human-machine interaction are documented. This information will enable hospitals to make effective decisions to improve their automation project performance.

II. Models to Handle Life-Critical Systems Complexity

Handling life-critical systems complexity requires to be equipped with appropriate technology and the right human agents' functions such as training, experience, critical spirit, knowledge, and competence [7]. Automated agents provide routine operations, and tasks that need precision and high concentration. While human agents' cooperative work and competence in problem's solving, ensure automated system security and performance. The key for a secure and resilient human-machine system is to maintain a good balance between automation and human skills.

A. The TOP Model

Human-machine systems design should be human-centered,

Hind Bouami is with the Polytechnic University of Hauts de France, CNRS, UMR 8201- LAMIH, F-59313 Valenciennes, and works as a freelance at Le Monde Après, 157 rue du Faubourg Saint-Antoine, 75011 Paris (e-mail: hindbouami@gmail.com).

Patrick Millot is with the Polytechnic University of Hauts de France, CNRS, UMR 8201- LAMIH, F-59313 Valenciennes (e-mail: patrick.millot@uphf.fr).

so the automated solutions could handle human requirements and organizational constraints.

The TOP model involves Technology, Organization and People in multi-agent systems design and development [8].

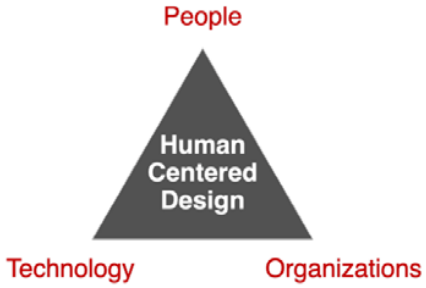

Fig. 1 The TOP model [9]

According to Boy, "technology should be designed and developed according to human-centered purposes", and more specifically people and organizations issues [9]. This model enables to predict, and analyze system's risks related to the automated solution, human agents and organization. Actions can be settled to control the identified risks and prevent their occurrence. Therefore, the TOP model helps human agents to acquire the knowledge related to automated system's systemic risks, so they can make relevant decisions, and implement specific actions. This model enhances human agents' situation awareness about human-machine system's specifications, limits, and systemic risks in life-critical systems. As the medication dispensing system is a complex high-risk system, it then seems appropriate to apply this systemic approach for a documented analysis of parameters and factors influencing this multi-agent's system.

B. Human Machine System Design and Analysis

Three phases are identified in human-machine system design process: understanding users' demands in the operational environment with existing equipment, designing a system integrating humans in the loop, and evaluating human-machine system's performance and security (Fig. 2). Automation specifications are then defined based on the understanding of operators needs and organizational constraints and specificities.

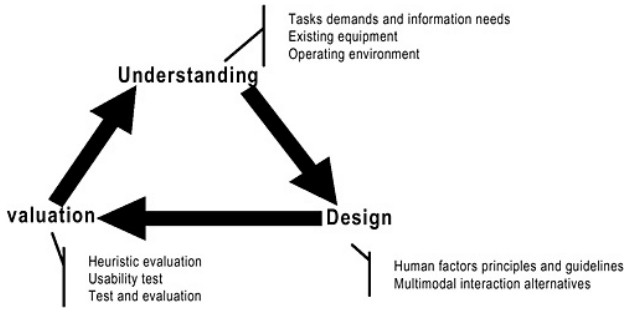

Fig. 2 Iterative cycle of system development adapted from [10]

Actions are implemented to ensure automated solutions integration security and performance in the organization.

The evaluation of the system enables to identify critical parameters influencing human-machine interaction in order to document operators' situation awareness about factors to control. Sharing these information helps enhance system's performance and security.

III. Human-Machine System Evaluation Approach

Our anthropocentric approach for automated system evaluation helps document operators' situation awareness through the analysis of automated organizations' feedback (Fig. 3). The analysis of automated hospital pharmacies feedback provides relevant information to enhance the perception and the comprehension of the system's complexity fully, environmental factors that interact with the system, and the automation process. Therefore, agents can design a projection of a secure and performant automated organization. This process documents the decisions made and trigger the implementation of actions.

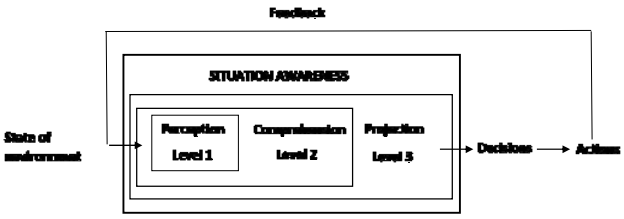

Fig. 3 Human-centered automation approach adapted from Endsley's SA definition [11]

Our approach integrates six steps that are run in automated hospital pharmacies to analyze their feedback [6]:

1) The identification of pharmacy's automation needs and objectives, and the analysis of operational environment and existing equipment,
2) The analysis of automated equipment functional specifications formalized by the pharmacy,
3) The evaluation of automation deployment results and related gains,
4) The evaluation of specific actions implemented by the pharmacy during automation process,
5) The analysis of the parameters to control for automated equipment integration security and performance,
6) The analysis of factors influencing human-machine interaction.

Step 1 and step 2 enhance the operator's perception of the pharmacy's automation needs in the current situation in an operational environment with existing equipment.

Step 3 and step 4 helps the comprehension of automation performance in the analyzed context.

Step 5 and step 6 will help projection of future status of reorganized automated medication dispensing activity, with the control of human-machine parameters and factors influencing automated solutions' integration and human-machine interaction.

Our human-machine system evaluation approach conducted in equipped hospitals helps to gain an understanding of the organization's needs, constraints, and the critical factors impacting automation security and performance from the analysis of their feedback. Feedback analysis and capitalization enables to design a secure and performant automated organization by controlling identified human-machine parameters and factors.

IV. Case Study: Feedback of Drug Delivery Automation at Macon Hospital Center

The objective of this study is to value Macon hospital center's feedback on nominative drug dispensing automation. The purpose is to analyze and define the parameters that influence the human-machine system's performance and security in automated drug dispensing activity. The analysis of Macon hospital center automation specifications reveals critical parameters and criteria influencing the human-machine system in hospitals organization. Driving forces of parameters influencing human-machine interaction will be identified.

A. Diagnosed Establishment: Macon Hospital Center

Macon hospital center has 1022 hospital beds in 2013, at the time of the call for tenders for automated drug dispensing systems. The limiting factors to the deployment of the nominative drugs dispensing in 2010 are a lack of computerized prescriptions, understaffed pharmacy's technicians that would prepare manually drug nominative treatments for all hospital beds, and inappropriate facilities. The hospital had therefore generalized the computerization of prescriptions, initiated work to bring the premises into conformity, before the acquisition of nominative drug dispensing systems. The automation of the nominative drug dispensing activity emerged as the only solution to achieve the goals of safety and performance of the drug circuit with optimized agents staffing.

B. Drug Unit-Dose Delivery Automation Deployment

Macon hospital center's pharmacy adopted a gradual plan of automation of the nominative drug dispensing activity. Two phases of automation have been planned for a staggered investment, and a capitalization of feedback related to the first stage of automation. The first automation's phase began in 2015 with the implementation of the Sinteco automated drug delivery system which ensures individual nominative drug-dispensing to 400 hospital beds. The deployment of the project extends from 2015 to 2019. The second phase of automation which is intended to supply 600 supplementary hospital beds, will be started in the next two years. The goal of the first phase of automation is achieved in 2018. The production of unit doses at Macon hospital center is particularly efficient, with 62% of the production target reached in 2015, 85% in 2016, and 96% in 2017 (Fig. 4).

C. Security and Performance Improvements and Gains

Macon hospital center's pharmacy conducted pill boxes controls before automation, and throughout the automation process in order to assess the security of treatment preparation. More than 9,000 pill boxes have been monitored per month. The error rate in pill boxes at the pharmacy is estimated at 9.33% in 2015.

Drug dispensing systems have led to a significant improvement of drug dispensing security. The error rate declined from 9.33% in 2015 to 4.66% in 2016, and 1.37% in 2017, before stabilizing at 1.26% in 2018 (Fig. 5).

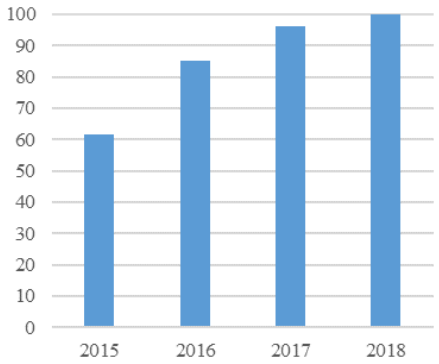

Fig. 4 Monitoring of unit-doses production goal target in Macon hospital center

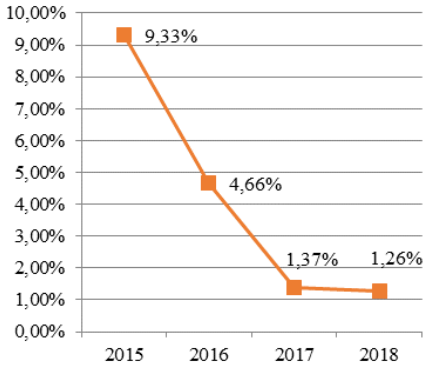

Fig. 5 Evolution of the error rate detected in the pill boxes in Macon hospital center's pharmacy between 2015 and 2019

In 2018, the number of errors in pill boxes is maintained at 1.26% throughout the year. Therefore, the first phase of automation in Macon hospital center highlights the role of automation in the security of drug dispensing activity.

An assessment of the achievement of performance objectives was also conducted. Drug dispensing systems enabled the optimization of the pharmacy operators time by relieving them of the time-consuming tasks of treatments preparation. Also, the nursing time related to the preparation of the pill boxes has been optimized. Furthermore, automation enhances dispensing security and helps to control the costs related to medication adverse events.

The first stage of automation in Macon hospital center generated more than 1.9 million euros of gains in 5 years of automation, related to pharmacy's operators time saving, and nurses' time related to pill boxes preparation optimization, and the prevention of costs related to adverse events.

Macon hospital center has amortized 84% of investment and exploitation costs related to the first stage of automation in 5 years. The return-on-investment relative to the first automation phase is reached after 6 years.

D.The Analysis of Pharmacy's Automation Specifications in Light of Human-Machine Principles

The analysis of Macon hospital center pharmacy's automation specifications (Fig. 6) revealed that 66.22% of automation requirements are technical: the distribution of a maximum of galenic forms, the insurance of unit-dose treatments traceability to patient administration, and optimized storage management, etc.

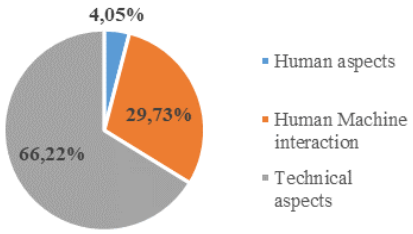

Fig. 6 Characterization of Macon hospital's center automation specifications based on Human Machine parameters

Some 29.73% of automation specifications concern human-machine interaction such as: ensuring a good synchronization between automated treatments preparation and prescriptions, the ergonomics of workstations around automated drug systems, securing the manual preparation of drugs not stored in drug dispensing systems, and the optimization of logistic flows around drug dispensing systems.

A total of 4.05% of automation specifications concern human aspects such as the ergonomic of unit-doses use by nurses, secure and easy patient privacy management after treatments administration, user-friendly equipment, easy to work with, and easy to understand how the module works.

Automated systems firms' strategic decisions and budgetary constraints	1.35%
Common functionalities in current automated solutions on the market	24.32%
Complexity of hospital's information system	4.05%
Complexity of the automated system	2.70%
Complexity of the hospital's organization	6.76%
Constraints related to the packaging of drugs by pharmaceutical firms	6.76%
Hospital's strategic decisions and budgetary constraints	8.11%
Integration of agent's ergonomic specifications in the drug dispensing systems design	9.46%
Performance specific to the automated solution chosen by the hospital	28.38%
User's requirements and constraints	2.70%
User training	5.41%

Fig. 7 Critical parameters involved in Macon hospital center automation specifications

The analysis of Macon hospital center automation specifications revealed that some critical parameters affect automated drug dispensing characteristics (Fig. 7).

Some 28.38% of Macon hospital center automation specifications' performance depends on the specificities of the chosen automated solution: the quality of interfacing with the hospital's information system, the production speed rate, automated system's productivity, automated packaging of brittle drug forms, the modalities of production in failure mode, etc.

A total of 24.32% of Macon hospital center automation specifications are common functionalities in the current automated solutions on the market: galenic forms distribution, simultaneous management of different batch numbers of the same drug, automated drug returns management, insurance of drug unit-dose traceability, automated cutting of most dry forms in blisters, etc.

Some 9.46% of Macon hospital center automation specifications are related to integration of an agent's ergonomic specifications in the drug dispensing systems design: workstation ergonomics, soundproofing of automated production, easy use of unit-doses to be administered by care units, etc.

The remaining 38% of Macon hospital center automation specifications are related to the hospital's strategic decisions and budgetary constraints, the complexity of the hospital's organization, the complexity of the hospital's information system, the constraints related to the packaging of drugs by pharmaceutical firms, users training, the complexity of the automated system, and users' requirements and constraints.

E. The Analysis of Parameters Influencing Human-Machine Interaction in Macon Hospital Center's Automated Organization

A previous study [6] conducted in Luxembourg hospital center revealed that five factors should be managed to secure human-machine interaction (Fig. 7): understanding the system's complexity, defining relevant levels of automation, determining human and automated agents' authority, determining human and automated agents' autonomy, and understanding the human complexity.

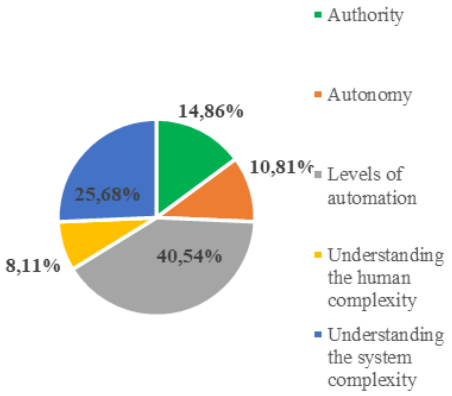

Fig. 8 Characterization of Macon hospital's center automation specifications based on parameters influencing Human-Machine interaction

The levels of automation define 40.54% of the specifications relative to the automation scope, automated storage capacity, and automated drug unit-doses production performance. It also sets the complementary manual tasks to achieve in addition to automated drug dispensing production.

Understanding the system's complexity helps to improve the performance of 25.68% of automated solutions specifications through the control of their interfacing with the hospital's information system, ensuring a good correlation with the edition of prescriptions and care units' constraints, improving drug returns management. Also, understanding hospital constraints in terms of capacity, infrastructure, financial budget, and sustainable development requirements, guides automated solutions firms in the proposal of adapted solutions with the best cost-benefit ratio.

Human and automated agents' authority represents 14.86% of Macon hospital's center automation specifications. Agents' authority allocation defines emergency automated production modalities, production priorities, control and verification tasks allocation, etc. Project support and users training help human agents to develop the skills needed to handle the tasks allocated under their authority.

Some 10.81% of automation specifications deal with automated solutions autonomy in failure mode, automatic processing of computerized prescriptions, alerts triggering according to unit-doses treatments production needs for stock management, pill boxes production and sorting without manual intervention, etc.

Understanding the human complexity helps improving the ergonomics of automated solutions and workstations. Ergonomic specifications represent 8.11% of automation criteria that have been specified and prioritized by Macon hospital center.

F. Parameters Influencing Human Machine Interaction in Macon Hospital Center's Automated Organization

Driving forces of the five parameters influencing human-machine interaction in automated drug dispensing organization (Fig. 9) have been analyzed.

The study revealed that the levels of automation depend on the automated drug dispensing system's specifications and functionalities, and a system's complexity. The proposed functionalities are supposed to meet the needs of the hospitals, and the constraints of profitability of automated systems firms. Also, the level of automation is limited by the constraints related to the packaging of drugs by pharmaceutical firms. Some pharmaceuticals products are not eligible for automation due to inadequate size and shape. These products are then delivered manually. Two automated and manual organizations therefore coexist in the drug dispensing system. Levels of automation depend lastly on the automation perimeters defined by the hospital. Other steps of the drug circuit can also be automated such as scanning of treatments at administration to patients. The level of automation will therefore depend on hospital strategic choices and budgetary constraints.

Understanding the system complexity involves the analysis and integration of the specificities of three subsystems: hospital's organization, automated solutions, and human agents. Understanding the hospital's organization is an important issue in such a complex cross-organizational system. Drug dispensing system's performance depends on hospital information system's operability, and the integration of the requirements and constraints of all the agents and services involved.

Automated drug dispensing requirements evaluated by Macon hospital center

Authority	**14.86%**
Common functionalities in current automated solutions on the market	6.76%
Constraints related to the packaging of drugs by pharmaceutical firms	1.35%
Performance specific to the automated solution chosen by the hospital	1.35%
User's requirements and constraints	1.35%
User's training	4.05%
Autonomy	**10.81%**
Common functionalities in current automated solutions on the market	4.05%
Performance specific to the automated solution chosen by the hospital	6.76%
Levels of automation	**40.54%**
Automated systems firms' strategic decisions and budgetary constraints	1.35%
Common functionalities in current automated solutions on the market	13.51%
Complexity of the automated system	1.35%
Constraints related to the packaging of drugs by pharmaceutical firms	4.05%
Hospital's strategic decisions and budgetary constraints	8.11%
Integration of agent's ergonomic specifications in the drug dispensing systems design	1.35%
Performance specific to the automated solution chosen by the hospital	10.81%
Understanding the human complexity	**8.11%**
Integration of agent's ergonomic specifications in the drug dispensing systems design	6.76%
User's requirements and constraints	1.35%
Understanding the system complexity	**25.68%**
Complexity of hospital's information system	4.05%
Complexity of the automated system	1.35%
Complexity of the hospital's organization	6.76%
Constraints related to the packaging of drugs by pharmaceutical firms	1.35%
Integration of agent's ergonomic specifications in the drug dispensing systems design	1.35%
Performance specific to the automated solution chosen by the hospital	9.46%
User's training	1.35%

Fig. 9 Parameters influencing Human Machine interaction in Macon hospital center organization

Automated drug dispensing systems' design should integrate the constraints related to drugs packaging. Automation performance relies on common drug dispensing systems' functionalities and functionalities specific to the chosen solution. Automated solutions' complexity should be controlled to ensure drug dispensing activity performance and security. In order to optimize automated solutions operation, users should be trained. The integration of users' ergonomic specifications in automated solutions design will also improve automation performance.

The performance of human-machine interaction in the automated drug dispensing system depends also on the authority allocation between human and automated agents. Human agents' authority relies on the integration of users' requirements and constraints, and users training.

Automated agents' authority is dependent on automated drug dispensing systems' common and specific functionalities. Automated drug dispensing systems' autonomy relies on its common and specific functionalities.

Human-machine interaction performance requires a good understanding of the human complexity throughout the integration of agents' ergonomic specifications and users' requirements and constraints, in automated solutions design and function.

G.Performance Evaluation of Functionalities Related to the Automated Solution Chosen by Macon Hospital Center

As seen previously, 28.38% of Macon hospital center automation specifications' performance depends on the specificities of the chosen automated solution.

The performance evaluation of automation functionalities revealed that 80.95% of specifications related to Sinteco's automated equipment are performant (Fig. 10). Therefore, the fulfilling of automation specifications related to the automated solution chosen by Macon hospital center are met.

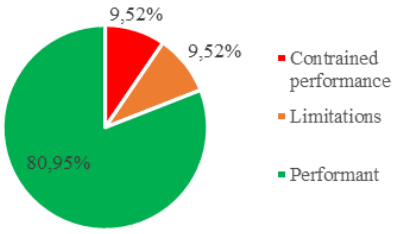

Fig. 10 Performance evaluation of functionalities relating to the automated solution chosen by Macon hospital center

The performance of the remaining critical parameters involved in automation specifications depends on the hospital's strategic and budgetary decisions, organizational actions implemented by the hospital's pharmacy to control the organization's complexity, and users training and involvement in the automation project to integrate their requirements and their constraints. The imposed pharmaceutical firms' constraints related to drug packaging and the common automated solutions functionalities were considered to identify and handle the automated organization's limits.

V. Discussion

Our anthropocentric approach for automated system evaluation and feedback analysis in hospitals provides relevant information that helps to document operators' situation awareness. The comprehension of the system's complexity and factors influencing human-machine interaction enables to design a projection of a secure and performant automated organization.

The analysis of Macon hospital center pharmacy's automation specifications revealed that 66.22% of automation requirements are technical, 29.73% concern human-machine interaction, and 4.05% relate to human aspects.

Critical parameters involved in automated solutions specifications and performance that have been identified through Macon hospital's automation feedback are: the specificities of the chosen automated solution, hospital's strategic decisions and budgetary constraints, the complexity of the hospital's organization, the complexity of hospital's information system, the constraints related to the packaging of drugs by pharmaceutical firms, users training, the complexity of the automated system, and users' requirements and constraints.

The five parameters influencing human-machine interaction that should be managed to secure automated systems are: understanding the system's complexity, defining relevant levels of automation, determining human and automated agents' authority, determining human and automated agents' autonomy, and understanding the human complexity.

This study revealed the driving forces of the five parameters influencing human-machine interaction.

The level of automation depends on automated systems functionalities common to all automated solutions or specific to the chosen solution by the hospitals, the constraints related to the packaging of drugs by pharmaceutical firms, and the hospital's strategic decisions and budgetary constraints. Understanding the system implies the integration of the specificities of three subsystems: hospital's organization, automated solutions, and human agents.

Automation systems authority involves human agents' authority through the integration of users' requirements and constraints, and users training. It is also dependent on automated agents through their common and specific functionalities. These functionalities determine automated solutions' autonomy.

Understanding the human complexity requires the integration of agents' ergonomic specifications, requirements and constraints in automated solutions design and function.

VI. Conclusions and Perspectives

This paper has revealed the driving forces of the parameters influencing human-machine interaction through Macon hospital center pharmacy's automation feedback. The deployment of our human-machine system evaluation approach revealed the critical parameters involved in automation specifications' performance. Automation's specifications are related to technical aspects, human-machine interaction, and human aspects. The evaluation of drug delivery automation performance in Macon hospital center has shown that despite the performance of the automated solution chosen by the hospital, the performance of the automated activity depends on the control of systemic factors. In fact, 80.95% of automation specification related to the chosen Sinteco's automated solution are met. The performance of the chosen automated solution is involved in 28.38% of automation specifications performance in Macon hospital

center. The remaining systemic parameters involved in automation specifications performance need to be controlled: the hospital's strategic decisions and budgetary constraints, the complexity of the hospital's organization, the complexity of the hospital's information system, the complexity of the automated system, the constraints related to the packaging of drugs by pharmaceutical firms, users training, the complexity of the automated system, and users' requirements and constraints, and the integration of agent's ergonomic specifications in the drug dispensing systems design. The analysis of automation feedback reveals relevant information of automation performance parameters and driving forces that document human agents 'situation awareness, and support hospitals decision making.

ACKNOWLEDGMENT

The authors thank Macon hospital center and Dr Dorine CASTILLO, Pharmacist and automation project manager, who provided expertise that greatly supported our research.

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