Combining workflow modelling with scenario planning tools: Process improvement in a Clinical Analysis Laboratory

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Abstract - Private clinical pathology laboratories operate in a highly competitive market, driven by technological developments, and are under pressure to remain efficient and to increase the quality of their services. This dynamic context has been accompanied by external changes, as the current pandemic, which make more important for these managers to make informed decisions based upon evidence and helped by sound decision support methodologies. This thesis developed a methodology to support clinical pathology lab managers to analyze strategies to improve the efficiency of the core lab under uncertainty, based upon an innovative, socio-technical approach, combining discrete-event simulation with scenario planning. A simulation model is developed to reflect the current context of the core lab, calibrated with real production data, and validated. In parallel, and through workshop sessions with the participation of lab professionals, by following a scenario planning approach, relevant external factors are identified and plausible scenarios with possible impact on the lab tests production in the core lab are constructed. Parameters to run the simulation model for selected scenarios are elicited by lab professionals, the model is run for these scenarios, and managerial changes to the lab are analyzed. Three scenarios were selected as the most relevant futures for analysis: an approximated *Business As Usual* scenario*,* in which significant changes are not expectable; another scenario foresees a reform in the health sector; and another scenario anticipates contractual changes to pathology labs. The analysis of results of running these scenarios in the simulation model reveal that the approximated *Business As Usual* and the one that predicts contractual changes would make it necessary to increase the capacity of the production system, while in the scenario that anticipates a reform in the health sector, the lab operating period could be reduced and the lab test results reported more quickly, leading to a faster clinical decision-making process.

Keywords: Process Improvement; Clinical Pathology Lab; Decision Support Models; Discrete-Event Simulation; Scenario Planning; Uncertainty

1. INTRODUCTION

Private healthcare organizations, involved in a highly complex environment, are competitive and driven by technological development. Although between 2014-2019 there has been an increase in the healthcare expenditure with the agreed sector of complementary diagnostic tests and therapy (CDTT) [1], the profit margins of private clinical labs are low and they are constantly under pressure to increase the quality of their services, while reducing costs, in order to improve efficiency [2]. This is particularly important in today's value-based healthcare era. Improving efficiency in clinical labs is a motivation for providers seeking to improve service quality versus cost ratio.

The complexity of the clinical lab sector results from the high number of interacting parts (including multiple health stakeholders and many evolving technologies) that make it impossible to predict the behaviors of the system, and cause uncertainty in the delivery of healthcare services [3]. This uncertainty inherent to the sector has been accompanied by other source of uncertainty, the current pandemic. The times of disruption and volatility caused by COVID-19 pandemic, and the consequent market evolution in the face of this rapid changing environment make the uncertainty in the external context of the organizations in this sector, the major challenge their management faces, which reveals the need to anticipate and explore plausible future contexts. Although it is known that organizations that seek to match their business to the changing environment can improve their performance [3], managers are often reluctant to change, due to the risk and possible implications resulting from such changes. It is necessary to present evidence that the changes that are intended to be implemented effectively bring added value to the organization. Thus, in such environments, the decision must be sustained [4]. This is where decision-support methodologies come into play, as they significantly improve the quality of the decision-making process, and contribute to efficiency improvements at the organizational level, as this process relies on evidence [4]. This study focuses on a private provider of clinical pathology and it is integrated in a SIEMENS Healthineers (SH) Enterprise Services (ES) project. The objective of this study consists in the development of a methodology that supports the lab management to

analyze strategies to improve the efficiency of the production process in the core lab under uncertainty. The methodology is developed based upon a socio-technical approach, combining discrete-event simulation (DES) with scenario planning. DES, an effective and widely used technique to manage the dynamics and complexity of healthcare services [5], allows to develop the model of the core lab and to explore and analyze the actual clinical lab production system, and the impact of plausible future scenarios. Scenario planning enables to anticipate future trends and possible external factors of uncertainty, culminating with the development of future scenarios with possible impact on the organization's core lab, therefore, complementing simulation in addressing uncertainty [6]. By integrating this technique with simulation, the results become more tangible, allowing the impact of the scenarios to be explored through simulation. Accordingly, the development of the simulation model and of scenarios is supported by workshop sessions that allows to overcome managers' reluctance to change, making them aware of such needs. Since organizations tend to neglect the impact of uncertainty, the proposed approach motivates a strategic thinking among lab professionals and seeks to raise awareness of the need and importance of exploring scenarios, in disruptive times and rapidly changing environments, as a way of accounting for possible impacts and consequences of uncertainty on the organizational decisions.

2. CASE STUDY AND OBJECTIVES

This study focuses on the core lab of this private provider of clinical pathology. The core lab processes around 70-80% of the whole lab workload, where an automation system manages the samples' flow and drives the tubes to the respective places where they need to go, to perform the required set of lab tests. The major challenges identified in the system include the samples' arrival pattern at the lab, which is not uniform throughout the day, and overloads the system during the sample's arrival peaks, and the need to identify bottlenecks in the system. From a more strategic perspective, the challenges relate to the need to anticipate future challenges for the lab derived from external factors with impact in the production of lab tests along the automation system, as well as the need to prepare in advance the response to these new contexts. Therefore, the objectives of the study consist of supporting the lab professionals in identifying external factors relevant to the development of scenarios with possible impact on the lab tests production in the core lab (along the automation system), develop a simulation model of the automation system that describes the current context and to evaluate the performance of the model in this context and the impact of plausible future scenarios through a set of key-performance indicators (KPIs) and finally, provide lab management with evidence from the model to support decision making in light of these plausible futures.

Therefore, this study intends to develop a methodology to help this lab to improve the efficiency of their processes in the core lab, under a highly uncertain context.

3. LITERATURE REVIEW

The set of activities defining how to achieve organizational goals and to produce outputs that create value to the customers forms the business process [7]. Business process improvement has become a popular topic for companies, which apply it to keep track of the changing business environment, by adapting themselves to the continuous challenges faced [8]. Improvement methodologies are essentially indicated for an organization to have the possibility of growing and scaling up [9]. Furthermore, the increasing competition requires companies to revise their processes and implement improvements to highlight at the market. In the healthcare sector, process improvement is crucial to high quality healthcare service provision [10]. In the case of clinical labs, in which lab tests provide the great majority of the information for clinical decision making, it is critical to provide clinicians with quality information in a timely manner, and that is why clinical labs seek to improve the efficiency of their processes to be able to provide quality results in a timely manner. There are different approaches to process improvement. Lean focuses on finding and removing activities that do not provide value to the process [11], while Six Sigma concentrates on identifying and eliminating process variability [12]. Hybrid solution combining both are usually applied to improve process efficiency by reducing waste. Mathematical programming provides an analytical solution and works fine for simple problems that are easily described by a valid mathematical model. However real-life problems tend to be too complex to be described by a mathematical model, excluding the possibility of achieving an analytical solution. To model real-life complex problems, characterized by uncertainty and dynamic interaction between system variables, the utilization of optimization methods, becomes too complex [13].

For the purposes of improving processes in a clinical lab, simulation provides a number of advantages over mathematical programming as it is a much more intuitive technique, and therefore, the proposed plans tend to be more easily accepted and implemented by the end-users [14]. When compared to lean and six-sigma, simulation

proofs to be much more robust, as, it is able to assess the effects of variation, enables the effects of the proposed changes to be validated prior to its implementation in real-life, is able to identify improvement opportunities and to assess the interactions between system components [15]. Moreover, it envisions how the system reacts in response to potential changes and improvement efforts, allowing to account for the complexity and variability of the system.

3.1 Discrete-Event Simulation in clinical lab settings

DES are discrete, stochastic and dynamic models, characteristics that generally describe real-world problems, which explains why this technique is so commonly used in a variety of domains, namely, in the complex healthcare settings. DES provides a visual understanding of the behavior of a dynamic system along the time, important to communicate its performance [16], and allows the evaluation of the impact of changes applied to the system and the assessment of different managerial strategies for the operation of the system. By modeling the system as a whole, considering its interdependencies, DES enables the development of a reliable and realistic view of the real system and enables to anticipate and estimate consequences of changes in the system, without the need of performing those experiments in the real system. DES seems to be the most effective type of simulation to describe the complexity and variability inherent to a clinical lab, as time-to-event is best described stochastically, instead of with fixed-time intervals [17], it provides a visual understanding of the system under study [16], allows its analysis through a comprehensive set of KPIs, accounts for the interdependencies and interactions between system components [15], and it has been widely used in clinical lab settings to improve workflows and lab operations [18]. These studies approached the improvement process in an exclusively operational way via DES. Research on strategic process improvement is required to account for the future uncertainty and volatility that may impact the system's response.

3.2 Strategic foresight and scenario planning

Managers should be aware that due to the inherent uncertainty and volatility, the future a company will face may not resemble the past [19]. Strategic foresight is a set of future-oriented methodologies that can be applied to develop perspective and insights, which contribute to systematic examinations of the future [20]. According to Vecchiato [21], strategic foresight should be "understood as the processes that assist decision-makers (DMs) in charting the firms' future course of action". These approaches involve an initial phase to observe, perceive, identify emergent trends, capture factors likely to foster changes and considers the implications of present actions on future events, and then, a second stage to deal with these changes, by defining organizational responses to overcome plausible future occurrences previously identified in the process [20]. Scenario planning is a strategic foresight technique [19]. Scenarios can be defined as "… plausible and often simplified descriptions of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces and relationships", as cited in [22]. By considering present evidence, scenario planning explores how the future may unfold and the plausible transformations it may suffer leading to a future that may be substantially different from the present [19]. Scenario planning consists in a well-established planning methodology, with the aim of preparing an organization for changes, stimulating the anticipation of alternative future environments, combining their implications, and defining and testing logics of strategic decisions [19], being strongly recommended in organizations that are characterized by high complex and uncertain environments, and high volatility contexts [23]. It is a collaborative process that allows a share of perspectives and the development of a common vision of the present and the future, stimulating organizational changes [24][25].

3.3 Combining DES with scenario planning

The literature lacks studies on strategic process improvement, as the studies on process improvement found in literature approach the problem only in an exclusively operational way. Research on strategic process improvement is required to account for the uncertainty of the current times that may impact the system's response, which is the aim of the present study. Evaluating improvement opportunities considering not only an operational perspective, but also considering strategic aspects and, therefore, accounting for uncertainty, makes the decision-making more consistent and informed for plausible future developments.

The need for socio-technical approaches is evident, since for the development of the scenario planning exercise and a simulation model, social processes are strongly recommended.

The integration of both techniques in an innovative way complements the lack of literature on this subject. Despite lacking information and evidence to support this synergy, both techniques individually are widely used and well-established.

Figure 1 proposes a framework to integrate both techniques.

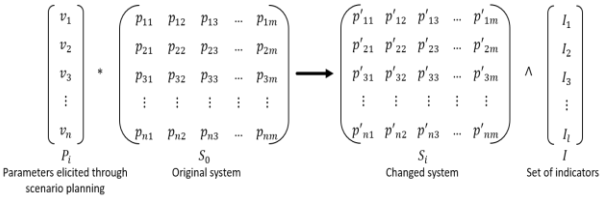

Figure 1 Schematic representation of the integration of scenario planning and DES.

Figure 1 suggests that, for each scenario, a set of input parameters of the model (P_i) is elicited. These parameters act on the system model (S_0). After running the model for a given scenario, its state changes from (S_0) to (S_i). From this changed state of the system, (S_i), a set of indicators (I) may be derived and analyzed, allowing to measure the impact of each scenario in the system. The process is then repeated for all scenarios considered [26].

4. METHODOLOGICAL FRAMEWORK

The integration of DES and scenario planning seems to be an appropriate and effective approach to support the decision-making process in a highly complex and uncertain environment. Therefore, this framework aims to inform lab management on how plausible future scenarios may impact the lab tests production in the core lab. The proposed framework, illustrated in Figure 2, can be divided in four phases, all composed by technical and social components.

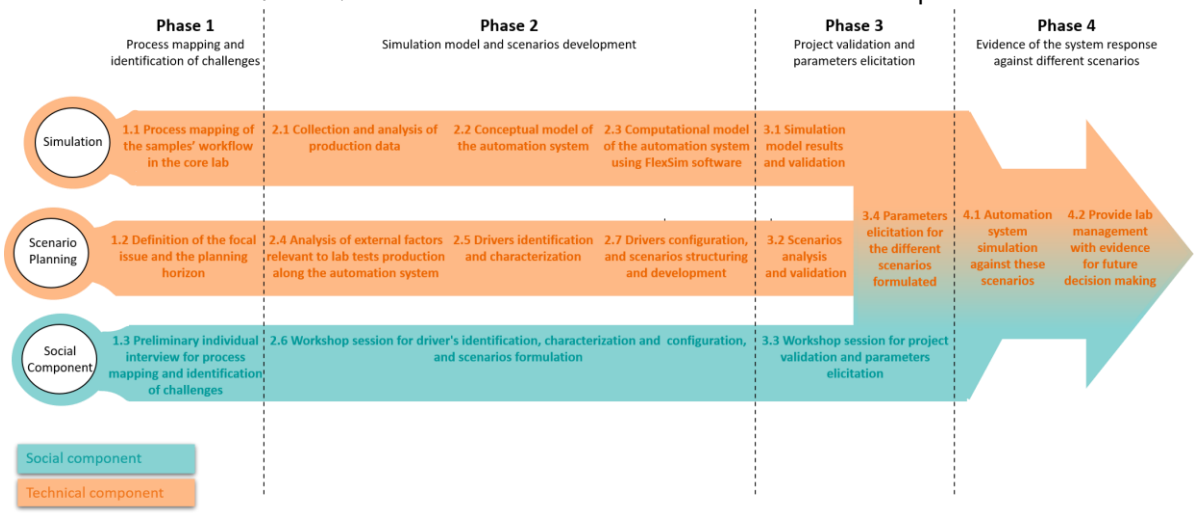

Figure 2 Proposed methodological framework within a socio-technical structure.

4.1 Phase 1: Process mapping and identification of challenges

This phase has the purpose of identifying the major challenges faced by this lab, that support the definition of the focal issue in which the scenario planning process will focus on, as well as the planning horizon, and describe the processes along the system under study, to support the process mapping. On-site visits and an interview with a senior member of the lab allow to gather important information regarding the main steps involved in the lab tests production, the overall pathway of the test tubes in the system and understand which resources are required in each step of the process. Based on this information, the processes along the system under study are mapped, through a flowchart, to then support the construction of the simulation model.

4.2 Phase 2: Simulation model and scenarios development

The initial step for the development of the simulation model is the collection and analysis of production data which, together with the flowchart developed allows the identification of the system variables. Then, a conceptual model is developed to support the construction of the simulation model, including the process-flow and a detailed description of the system under study, the assumptions considered, a summary of the model input variables and the KPIs considered for evaluation. Regarding the latter, when structuring the model, it is important to define its outputs in terms of KPIs that allow to measure improvements in the performance of the model. Their choice is of great importance, since the decisions made by the DM will be based on the performance measures used to validate the model. After gathering all this information, system modeling in the simulation software begins. In parallel, a set of steps of scenario planning are approached in the scope of a workshop session attended by some lab professionals. The workshop agenda includes the analysis of external factors relevant to the central question, using PESTLE framework, that allows participants to structure their thinking regarding

possible external factors in the different domains covered by this framework (political, economic, social, technological, legal and environmental) that may impact the central question that drives the scenario planning exercise [27]. For each factor identified, participants are asked what the possible evolutions for that factor are. This leads to the identification of the system drivers, i.e., the key external factors that may impact the central question and the driving forces that shape the system [6]. These drivers can be either uncertain or predetermined factors and they are characterized by the participants according to their predictability and impact in the central question. Critical uncertainties are the most uncertain driving forces, or less predictable events, that have a great impact in the central question, being the differentiating factors of the scenarios. The scenario structures are then developed by combining the extremes of the drivers and then, the scenario narratives can be developed [6].

4.3 Phase 3: Project validation and parameters elicitation

This phase has a triple objective which include the final validation of the simulation model, the analysis and validation of the scenarios developed, and the elicitation of a set of parameters to run the model for the different scenarios formulated. To carry out these tasks, a second workshop session is proposed. The validation of the simulation model allows it to be used to analyze the impact of the scenarios. Verification and validation of the simulation model are essential steps to ensure that the model is a correct, complete and thus, a meaningful representation of the real-world system under study, thus, proving its utility in real-world problem-solving and supporting the decision making process [13][16]. The validation of the simulation model, should not be attempted exclusively at the end of its development, and therefore, an interaction on a continuous basis with the DM and lab professionals is proposed during the development of the simulation model [13]. Thus, the verification and validation processes start with the validation of the conceptual model, then, the verification that the conceptual model was correctly translated into the computational model, and the validation of the computational model itself, which includes “face validity”, showing the animation of the simulation model to people knowledgeable about the actual system and asking them about the accuracy of the logic behind the model and whether it is able to truly mimic the actual system, and the comparison of the simulation outputs with quantitative real data [28]. In what concerns the scenario planning technique, the objectives comprehend the analysis of the scenarios developed in the previous workshop and their validation. Scenario narratives should be carefully analyzed by the participants to ensure they are meaningful and reflect the concerns of the lab professionals regarding plausible future occurrences with impact in the focal issue. The last activity of the workshop agenda is the parameters elicitation, which bridges the scenarios developed and the simulation model, as it allows the combination of both techniques, so that one can anticipate and analyze the impact of the scenarios in the simulation model, based on a set of KPIs. The model input parameters that can be changed in light of those scenarios is presented, and the lab professionals present in the workshop provide estimates on how some parameters might be adjusted to reflect the essence of the scenario.

4.4 Phase 4: Evidence of the system response against different scenarios

In this phase, the simulation model is run for each scenario, in order to capture the impact of the changes caused by each scenario in the system under study.

The performance of the simulation model is assessed based on the KPIs defined and used to validate the model, and a discussion session with the lab DM takes place to present evidence from the model when it is simulated against the plausible future occurrences addressed by the scenarios developed. Therefore, the results provided by the simulation model against the scenarios allow to evaluate model variations in these different scenarios and provide insights regarding the evolution of the system in these contexts. The analysis of these results informs lab management and supports the organization in defining possible managerial changes to be applied in the lab in light of those scenarios, to ensure their preparation and adaptation to overcome these plausible future contexts. It also provides lab professionals with a more comprehensive knowledge on how the combination of external factors from different domains may impact the system, providing the possibility of making decisions that are informed for plausible future occurrences. Moreover, the managerial changes that are required to be applied to overcome the possible realization of those scenarios, may result in an overall improvement of the efficiency of the system.

5. IMPLEMENTATION AND ANALYSIS OF RESULTS

This chapter comprises the implementation of the proposed methodological framework. In light of the current pandemic situation that has overwhelmed clinical pathology labs, the social processes proposed in the methodological framework had to be simplified and adapted to the current context.

5.1 Phase 1: Process mapping and identification of challenges

The structuring of the problem started with an interview with a senior member of the lab, who provided a detailed description of the processes the samples undergo in the core lab, since their arrival, until the results of the lab tests are sent, complementing the on-site visits and supporting the mapping of the processes. Additionally, an explanation of the lab organization, the main types of tubes processed in this lab, the types of samples whose lab tests are performed in the core lab, through the automation system, were also provided. The main challenges faced by the core lab were identified, which allowed to define the central question or focal issue to guide the scenario planning process as:

"How will lab tests production along the automation system evolve in 2 years?"

Considering the rapid changing environment in the current disruptive times, leading to a highly uncertain context, the interviewed considered two years an adequate time horizon to be scrutinized through the scenario planning exercise.

5.2 Phase 2: Simulation model and scenarios development

This phase started with the analysis of the production data provided and the parametrization of the model input variables, trying to make use of stochastic processes whenever possible, instead of using fixed values directly in the simulation. The arrival rate of samples to the core lab, the number of tests each specimen requires and the frequency of occurrence of each samples profile are important sources of uncertainty and were described by stochastic processes. The arrival rate of samples to the lab was described by non-stationary Poisson processes. The period of time of the simulation run was divided in subintervals and for each one, a different value of lambda was defined based on the data provided and assumed to be constant within this time window. The number of lab tests required for each specimen and the frequency of occurrence of each samples profile were defined by empirical distributions based on the available production data. Due to the characteristics of seasonality verified, the simulation model developed tried to reproduce one of the busiest days at the lab. Next, the topics that integrate the conceptual model of the core lab are presented.

Description of the system under study:

The system includes a set of components: the RIM (entrance), the decapper, the aliquoter, the desealer, the IOM, the sealer, the storage and the storage robot. There are 9 analyzers connected to the system. The tube has a barcode that is read by the system components, allowing to manage its pathway within the system, according to its request. The system allows a maximum of 385 tubes inside, at the same time. When the tube has performed all the required tests in the automation system, if its request includes tests in sections outside this system, the tube is conveyed to the IOM, where it leaves the system to the respective section, transported by a lab technician. When the required tests in this section are completed, the tube re-enter the system by the IOM, to be stored. Once in the storage, when the tests results are delivered by the analyzers, lab technicians quickly check the results and when they find some deviation from the reference range for these tests, the system is informed that the respective tube must re-enter the system, for it to repeat the required test(s). When the sample request also includes tests to be performed in external labs, the tube is directed to the aliquoter where it takes a small sample from the primary tube to secondary tubes that leave the system by the IOM, while the primary tube follows its path inside the automation system, to complete all the required tests. Every day between 7:30 am to 10:30 am, the analyzers undergo maintenance, and around 10:30 am they are ready to start processing tests. Lab technicians finish their workday when the analyzers finish the processing of the requests of this day (the daily service). In the busiest days of activity in the lab, they currently finish the daily service at around 00:45 am.

Summary of model input variables:

The variables defined prior to the simulation model implementation include: the different modules of the automation system, the number of analyzers connected to the system, as well as their specifications, such as the throughput, the duration of the tests carried out by them, the samples' pipetting times, the processing logic of the different analyzers, and the percentage of test repetition per analyzer. The number of samples that enter the system and the input distribution pattern throughout the day, the different samples' profiles, and their frequency of occurrence. The sequence of processes that the different samples' profiles undergo in the system, the throughput of the storage and its sample loading capacity.

Some input variables required processing and in-depth analysis, as the case of the percentage of test repetition per analyzer, the number of samples that enter the system and the samples' input pattern into the system throughout the day, the different samples' profiles, its frequency of occurrence and the sequence of processes each one undergoes, among others.

Performance measures to evaluate the model:

The set of KPIs identified as the most relevant to measure the performance of the actual system are

presented in Table 1.

Table 1 List of KPIs to appraise the performance of the model, their definition, and the calculation behind.

KPI	Definition	Calculation
Turnaround Time (TAT)	Time it takes for the system to process the required tests associated to a tube.	Time interval between the moment the tube arrives at the system until the last required test for this tube is finished.
Cycle Time	Time the tube remains in the system.	Time interval between the moment the tube arrives at the system until the tube enters the storage and its tests do not require repetition.
Analyzers Utilization Rate	Percentage of analyzer utilization throughout the day.	Ratio between the number of tests being performed by the analyzer and its maximum capacity, times 100%.

Computational model of the automation system using FlexSim

The model was implemented in FlexSim. Besides all the input variables presented before, a layout of the core lab was imported to the software and the model was built on top of it, making use of the different environments: the 3D objects and the process flow activities. The model implemented is complex due to the complexity of the system and the links between the entities. Moreover, the logic that guides the tube pathway in the system was implemented so that each tube moves only to the required places, as in the real system. Since it is a highly customized system, all this logic had to be directly programmed in the Code Editor. Most of the decisions were taken based on attributes (labels assigned to the objects). The implementation of the computational model tried to replicate, as much as possible, the real system. The simulation model of the automation system built in the 3D objects environment is illustrated in Figure3.

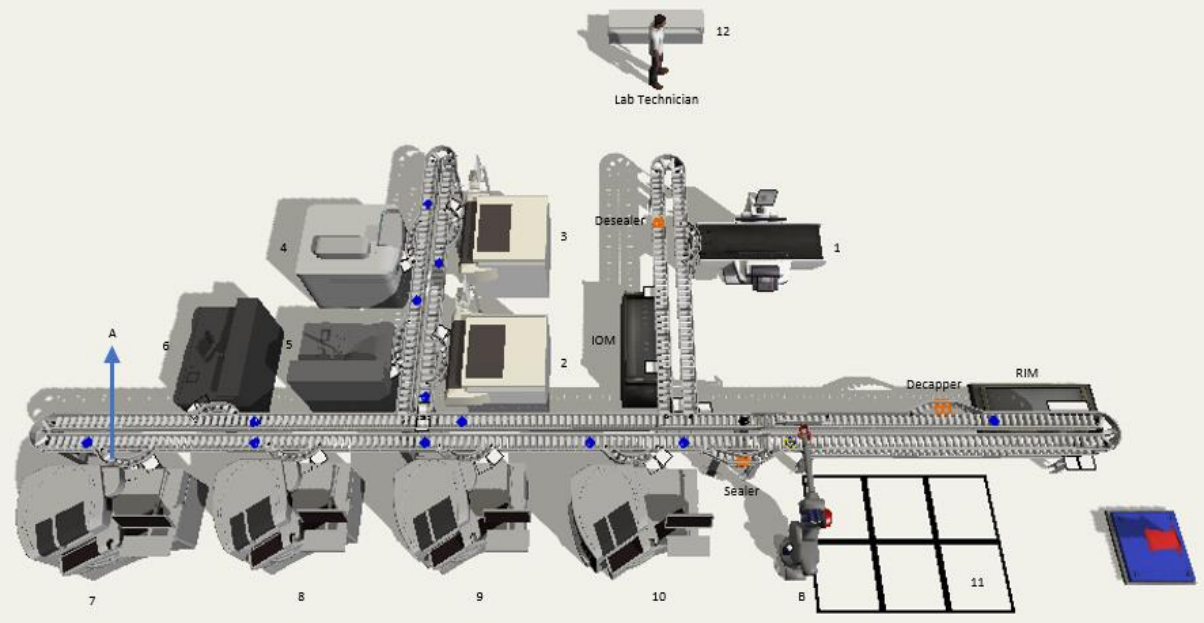

Figure 3 Part of the simulation model of the automation system build in the 3D objects environment.

When entering the system, a set of labels was assigned to the tube, allowing to define its pathway and the processing logic by the analyzer. The system components were identified by a number: number 1 is the aliquoter, numbers 2-10 are the different analyzers, 11 is the storage and 12 the section outside the automation system where the tube may have tests to perform. The tube enters the system by the RIM, it is forwarded to the decapper, and then, according to its request, it is directed to the required places. To each tube, a label in a table format was attached to store different information on it: the tube pathway, the status, indicating whether each step of the process has been completed, the number of tests performed in each analyzer and in which analyzer the tube had tests to repeat. Apart from this, other labels were attached to each tube to control its flow in the system. The storage robot performs two tasks: remove the tubes from the automation system after being processed and place them again in the system when they have tests that need to be repeated. The blue objects in Figure 3 were used to direct the tube to the required places in the system, according to a set of conditions, most of them stored in labels. The process flow environment was used to control the number of tubes inside the system, to implement the tube-test(s) logic in the analyzer, according to its specificities, and to calculate the TAT and the utilization rate of the analyzers.

Scenario planning – workshop session

The agenda proposed for the workshop session had to be adapted and included the analysis of external factors relevant to the production of lab tests in the core lab and the characterization of the drivers. Supported by the PESTLE framework, participants thought and discussed external factors that could have an impact on the production of lab tests along the automation system, resulting in the system drivers. These drivers were characterized according to their predictability and impact in the focal issue, using the scenario structuring space (SSS).

Drivers configuration and scenarios structuring and development:

From the results of the workshop, three critical uncertainties were clearly identified, and they are presented in Figure 4, as well as their possible evolutions by two extremes.

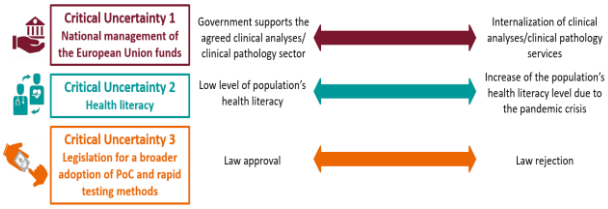

Figure 4 Critical uncertainties for the lab tests production and their possible outcomes.

The scenario structures were then constructed based on all possible combinations between the extreme outcomes of each critical uncertainty, resulting in eight scenarios. For each one, the scenario narrative was developed.

5.3 Phase 3: Project validation and parameters elicitation

The validation process was continuously carried out along the simulation model development, as suggested by the methodology, and a final validation took place at the end of the simulation model implementation, by showing its animation and asking lab professionals whether the model truly replicated the actual system, and by comparing the model outputs with the real data available.

Analysis of the simulation model outputs:

The simulation model calibrated with the real data provided was run using thirty replication runs. The average number of samples daily processed in the lab was of 3974, with a standard deviation (std) of 76. The results obtained for the TAT and cycle time are presented in Table 2.

Table 2 Results of the KPIs for the original model, evaluated with different statistical measures. Comparison of the TAT obtained from the simulation model with real data

KPI	Statistical Measure	Original Model	Actual System
TAT (min)	Average	40.4	43.2
	Std	34.3	35.1
	Minimum	10.98	11
	Maximum	369	381
Cycle Time (min)	Average	44.2	-
	Std	43.0	-
	Minimum	2.90	-
	Maximum	548	-

The model obtained its final validation using both qualitative and quantitative methods.

Scenario analysis:

Scenario structures and narratives were carefully analyzed by the lab professionals and validated. They selected three scenarios as the most relevant futures for analysis through the simulation model. One of them was perceived by the lab professionals as an approximated *Business As Usual*, since it considered the testing paradigm was maintained, without internalization of services by the NHS, in a society with low health literacy. The "Reform in the sector" scenario anticipated the internalization of several clinical pathology services with a more comprehensive use of rapid testing methods, in a society with low health literacy; and the "Contractual changes in the sector" scenario foreseen the internalization of a small part of the clinical pathology services, maintaining the testing paradigm, in a society with low health literacy.

Parameters elicitation for the selected scenarios:

Parameters to run the simulation model for the selected scenarios were elicited by the lab professionals, based on some calculations. For the approximated *Business As Usual* scenario, they anticipated a 15% annual increase in the lab tests requests to be processed in the core lab. They considered that the "Reform in the sector" scenario would result in a 5% annual decrease in the lab tests requests and, for the "Contractual changes in the sector" scenario, an annual increase of about 6% in the lab tests requests to be processed in the core lab was anticipated.

5.4 Phase 4: Evidence of the system response against different scenarios

The model was then run for these scenarios, and the results are present in Tables 3 and 4.

Table 3 Statistical measures for the number of samples daily processed in the core lab in the different scenarios.

	Statistical Measure	Original Model	*Business As Usual*	Reform in the sector	Contractual changes in the sector
Number of samples processed (daily)	Average	3974	5098	3674	4374
	Std	76	70	70	76
	Minimum	3816	4911	3500	4194
	Maximum	4165	5244	3810	4552

Table 4 Comparison between the results of the KPIs for each one of the selected scenarios and the original model, evaluated with different statistical measures.

KPI	Statistical Measure	Original Model	*Business As Usual*	Reform in the sector	Contractual changes in the sector
TAT (min)	Average	40.4	89.7	36.8	48.9
	Std	34.3	67.0	28.6	45.0
	Minimum	10.98	10.98	10.98	10.98
	Maximum	369	672	275	542
Cycle Time (min)	Average	44.2	117.5	32.1	68.1
	Std	43.0	89.4	28.2	63.2
	Minimum	2.90	2.90	2.90	2.90
	Maximum	548	712	467	547

Table 3 presents different statistical measures for the number of samples daily processed along the automation system for the different scenarios. The impact of each scenario in the automation system functioning was assessed individually for each scenario, by comparing, at a time, the KPIs in each scenario with those obtained for the original model, based on Table 4.

In the approximated *Business As Usual* scenario, bearing in mind that the automation system has the ability to support a maximum of 385 tubes simultaneously, a huge number of tubes accumulated in the RIM (system entrance), forming a queue to enter the system. The system was overcrowded from about 3:45 pm to 4 pm (most of the working day). This was mainly due to the fact that the rate at which the storage robot took the samples from the system was not proportional to the rate at which new tubes arrived in the system to be processed, which impaired the time the tubes spent inside the system, with the cycle time, showing an average increase of about 168% compared to the original model. The TAT showed an average increase of 125% compared to the reference model, reaching about an hour and a half, on average. This has shown that the automation system would not be able to respond in a timely manner to this high number of samples. In the “Reform in the sector” scenario, there was no accumulation of tubes to enter the system and the queue formed to enter the storage was substantially smaller. In this scenario, it was found that the storage robot was able to carry out both tasks, as the number of samples entering the system was lower, and the rate at which new tubes entered the automation system was not much higher than that at which the tubes were removed by the storage robot. This was reflected in lower cycle times, with a reduction of about 27%, on average, compared to the original model. Likewise, the TAT also decreased, in about 10%, on average. Finally, in the "Contractual changes in the sector" scenario the system became overcrowded. A large number of tubes accumulated in line to enter the storage, during a great part of the working day and a queue of tubes to enter the system was also formed. This has led to a 55% increase in the cycle time, on average, with respect to the original model, and the tubes remained more than an hour, on average, inside the system. The TAT increased in 23%, on average, compared with the reference model. Moving to a deeper analysis, Figure 5 illustrates the utilization rate of the busiest analyzers (Centaurs) for the different scenarios.

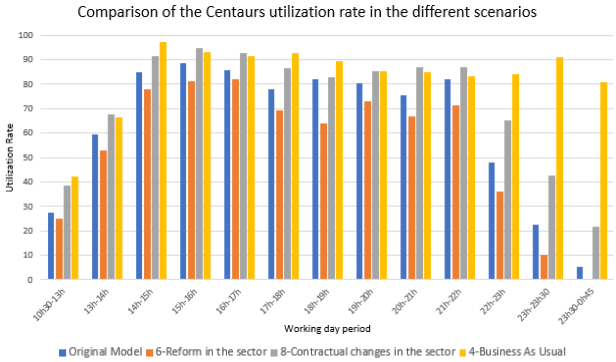

Figure 5 Utilization rate of the Centaur analyzers along the various periods of the working day.

Due to the system's capacity being limited to 385 tubes at the same time, the increase in the number of daily samples had a delaying effect on the process, so the system would have to be in operation for longer, to be able to process all daily requests. In the “*Business As Usual*” scenario, in contrast to the other scenarios, the utilization rate of the analyzers did not show a decrease from 10 pm, remaining very high until 12:45 pm, the end of the current working day. This revealed that, at the end of the current work period, in this scenario there would still be many tests to be performed by the analyzers. Therefore, in a growth perspective for this lab, it would be required to review and analyze the functioning of the system or to invest in new solutions. Maintaining the original solution (the automation system), an option would be to establish work shifts, ensuring the lab operation at full time, or at least, during a longer period. An alternative would be explore with the SH providers, the possibility of increasing the capacity of the automation system, so that it could respond in time to this increase in demand, focusing on what seem to be the main constraints of the system: the rate at which the tubes are removed

from the system, and the maximum number of tubes allowed within it. It is worth noting that although these are the factors that most clearly need to be reviewed, the Centaur analyzers showed to have high utilization rates during a long period of the workday, even in the current context. This means that a solution should be explored that integrates improvements to the system at various levels, leading to the improvement of the overall efficiency of the production system, bearing in mind that a non-holistic approach to improving system performance may not result in its overall improvement. Ideally, anticipate the arrivals of samples at the lab allowing the beginning of the working day before 10:30 am, and ensure they arrive at the lab more uniformly distributed, would help to improve the situation and to maximize the use, and therefore, monetize the available resources.

6. CONCLUSION

The decision-support methodology developed in this study was the result of a social-technical approach by combining two techniques widely used individually in the literature: DES and scenario planning, complementing the existing literature with an approach that supports process improvement in the context of high uncertainty. The choice of these techniques allowed to combine a strategic perspective and explore the inherent uncertainty of the current times of disruption with operational aspects typically covered by the business process improvement approaches. Despite the benefits that strategic foresight presents at the organizational level, managers are generally not sensitized to think strategically, tending to focus on more operational aspects of their daily work routine. Engaging lab professionals in the participatory activities for the scenario planning exercise was a challenging but rewarding task. It stimulated strategic and prospective thinking, which they are not used to doing, developed lab professionals capacity to anticipate trends and to foresee possible external factors of uncertainty, and to explore plausible future scenarios with impact on the organization's core lab, which is particularly interesting in a complex system, in the current times of external turbulence and disruption. Moreover, the study provided the lab DM with evidence on possible managerial changes to be implemented in light of those scenarios, ensuring the organization is able to deal with their possible realization. In fact, the study showed that if the demand for lab tests continues to increase, the production system will have to be reviewed to ensure that it is able to respond in a timely manner. The objectives of the current study have been accomplished and this decision support methodology has seen its value recognized by the end-users. Regarding further improvements on the implemented methodology, the main suggestions consists on: conducting all the stages of the scenario planning exercise in the presence of stakeholders and involving more participants in the workshop sessions, to obtain a representative view of the organization's concerns and aims. For the simulation, the main suggestion would be to use more data to calibrate the model.

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