Process Improvement in health care units: Scenarios Planning with Discrete Event Simulation Model applied to a Nuclear Medicine Unit

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Abstract

Health care services are a highly competitive, complex and technology driven market. In the discussion of National Health Care Systems, a level of context uncertainty adds to the existing, intrinsically, within units examination operations. In this work, a novel combination of the methodology of Scenarios Planning with Discrete Event Simulation is developed and explored to addressed this problem in Atomedical, a private Nuclear Medicine practice unit, localized in Lisbon, Portugal. The objectives of the unit managers decision problem were focused in the examination operations performance (service quality and operating costs). The use of a Scenarios Planning methodology allowed to overcome the challenges of unit environment. It also guided the definition of scenarios that covered a wide range of problem context uncertainties. By using a new approach focused in operations, this methodology provided further understanding of Atomedical through a structured system analysis, with the identification of relevant variables within the problem. This gave support to the development of coherent scenarios and strategies for succeeding system study. Discrete Event Simulation was used to address the uncertainty regarding the procedure in operations. This simulation methodology allowed the evaluation, inside Scenarios Planning, of the drawn strategies and scenarios through complementary setups of an Atomedical unit model. Model and simulations were implemented using the SIMUL8 simulation software. The results of this methodology do not intend to provide unit managers with a solution for their problem, but rather a deeper understanding of it. The Scenarios Planning methodology was successful in systematically explore both operations system and environment context uncertainties of a multi-variable problem as in Atomedical, although it requires many technical choices. Learning how different contexts influence the unit, and the impact of different strategies, provides unit managers the tools to handle future realization of paths explored in scenarios.

Keywords: Scenarios Planning; Discrete Event Simulation (DES); Uncertainty; Nuclear Medicine Diagnostic; Scenarios; System Analysis; Operation Management; Scheduling

1 Introduction

The complexity of health care systems resides in various stakeholders on the process that drive a multi variable uncertain environment context for unit operations. In such situation, problems that managers face are often complex, and the implications of options and context changes can only be solved with the aid of decision support tools [1].

This work addresses a problem in Atomedical, a private diagnostic unit of Nuclear Medicine located in Lisbon, Portugal. The field presents unusual operational complexity, mainly due to the dynamic of the used radionuclides. It justifies the difficulty to overcome uncertainties regarding its management without real experimentation of strategies. This type of uncertainty in Atomedical can be addressed using simulation models. It allows to study the result in quality indicators of different modification to the system. Atomedical was previously studied using a Discrete Event Simulation (DES) model [2]. However, even though the developed model remains actual, the environment context has changed. Atomedical saw a reduction on the number of clients, as a result of national economic situation. Besides the operational complexity in Atomedical, the uncertainty of environment context arises as the main problem of management. It is necessary to complement the DES methodology to provide a decision support tool to operations management decisions under those levels of uncertainty. A new Scenarios Planning methodology that focus on the operational level of the problem is explored as a way to analyze systematically the field of scenarios and strategies in the problem, addressing the uncertainty at the level of the unit environment context. This approach allows one use DES as part of Scenarios Planning methodology, in order to evaluate the impact of designing scenarios and strategies for specific Atomedical unit system variables.

This work starts with the characterization of the problem. It drives the literature review of analysis and uncertainty of systems, as well as the use of simulation methodologies, namely the DES, and scenarios planning. Next, a methodology framework of Scenarios Planning is presented to Atomedical and explored using: problem analysis; variables identification and classification; scenarios and strategies construction and signpost definition. The resulting scenarios and strategies are evaluated in an improved DES model of Atomedical operations in different simulations setups. The results of the signposts are used to perform an analysis of the uncertainty drivers, which provides unit managers further knowledge of their unit and options and hence supporting future decisions.

2 Case Study: Atomedical

Atomedical provides diagnostic services in the field of Nuclear Medicine, among some therapeutic services and echographies. Today is the largest unit in the field, operating in Portugal, with four Gamma Cameras. There are three feature exams, that correspond to a higher demand and major revenue generation: the Myocardial Perfusion Study (MPS), the All Body Bone Scintigraphy (ABBS) and the Thyroid Scintigraphy (TS).

The workforce of Atomedical consists in 34 people: 2 Physicist, 5 medical doctors (2 Nuclear Medicine Specialist Doctor (NM Doctor), being one the Clinical Director, 2 cardiologists and 1 specialist in internal medicine), 5 workers in administrative, management and consultative tasks, 10 Nuclear Medicine Technician (NMT), 7 secretaries (working in the reception and exam pick-up), 1 nurse, 1 pharmacist and 3 medical and cleaning auxiliaries. The Decision Makers of Atomedical are the unit managers: Prof. Dr. Fernando Godinho, the Chief Executive Officer (CEO); and Dr[a]. Guilhermina Cantinho, the unit Clinical Director.

One can gather the relevant zones in the unit operations of examination in self explanatory groups: Waiting Rooms, Administrative Facilities, Preparation Rooms, Examinations Rooms and Support Facilities. Unit operations focus in the Preparation and Examination Rooms. In Preparation Rooms, the patients are administrated with the Radiopharmaceutical (RF) for the following exam or just for a treatment. From the Preparations Rooms, the Radiopharmacy is the place where the Technetium Generator is located, and all the RF are prepared. In the Examination Rooms, the different tasks of the examinations are performed, namely images acquisition in the Gamma Cameras and the Strain Studies. Gamma Cameras are the core of Atomedical operations.

Atomedical resources provide to the unit a capacity to perform a certain number of exams. It depends either on long term decisions, for instance, facilities and the number of existing equipments (usually irreversible), either on short/medium term decision, for instance, staff and consumables. While the number of exams are the driver of revenues, the unit capacity will determine the level of expenditures. The analysis of the evolution of exam type distribution allowed to observe a higher decrease of a certain exam types starting in 2010, Table 1. For instance, on the Renograms and Bone Scintigraphy exams. It changes the context of unit operations. To avoid profit reduction or even loss, it is vital to develop strategies that reduce the capacity and, consequently, the costs, which can be either long or short/medium term.

Nuclear Medicine is a distinct technique inside diagnostic and treatment methods in health care. The use of radionuclides is the center of this distinction, due to the need of specific equipment and a strict resource management, the variability in the distribution of the administrated RF, the activity needed and the acquisition times of different exams and radionuclides. Since units need to deal with a resource that has a short life span, exam management has to take into account limitations of the resources, in order to maximize its use and provide a quality service. Any Nuclear Medicine unit presents strong constraints that result in complex systems, making difficult to predict its behavior. This operational uncertainty is important in any consideration of the problem at Atomedical.

2.1 Decision problem

In the previous context, unit managers have adjusted the complex exams schedule and workforce to the new reality, in order to maintain the unit final profit sustained in the high reputation of Atomedical. However, these adjustments were done empirically, based on the experience of mainly the Clinical Director. Despite of the efforts, further adjustments need to be performed in order to sustain unit viability. Unit managers need a decision support tool prepare them to the possible switches of the current environment of unit operations, namely at the level of procurement.

The management of RFs perishable products, the diversity and number of exams, with procedure constraints, and significant workforce size make managers believe that they can perform in a greater level of efficiency, adopting some organizational changes. The objective is to reduce operational costs, maintaining or even improving service quality (examination quality and patient waiting time). Unit managers state decision problems regarding:

- Exam scheduling weekly plan, increasing the efficiency of the use of resources, for the set objectives and radioactive products stock constraints.
- Setting minimal staff for the proposed schedule and set objectives.
- Predicting the effects of possible strategies in unit performance in uncertain operational and environment contexts.

Table 1: Evolution in the number of patients and number of exams per year from 2007 to 2011.

	2007	2008	2009	2010	2011
Total Exams	32408	31749	32145	29775	21265
Exam Distribution					
Bone Scintigraphy	32,22%	32,01%	31,39%	29,52%	27,55%
Myocardial Perfusion	37,43%	39,62%	41,39%	47,64%	51,32%
Thyroid Scintigraphy	10,27%	10,19%	9,65%	8,87%	9,61%
Renograms	6,79%	6,43%	6,28%	3,44%	3,43%
Other Exams	13,29%	11,74%	11,29%	10,52%	8,1%

The scope of the problem is Atomedical unit operations, its performance regarding the influence of the multiple internal factors, and how external factors could play a role in determining the conditions in which the unit performs. Uncertainty is the essence of the Decision Problem, at two different unit levels: operations and environment. At the operations level, uncertainty resides in the behavior of the unit regarding either changes in procedures and context, or intrinsic uncertainty of procedures (for instance: exam durations or radionuclides activity) and inputs (for instance: number of patients).

3 Literature review

3.1 System Analysis

The development of a decision support tool needs to consider Atomedical operations as a system. A system can be viewed as a set of entities acting and interacting with each other in order to accomplish some logical end [3]. In order to conduct a study of a system, it is possible to use a model that offers the possibility to study a system using a model, which allows to overcome the difficulties that a real system study presents [3]. The use of a model of the system suits the problem of Atomedical [2]. In management, the most frequently used are the mathematical models as they can be studied analytically[4]. Although analytical models can address uncertainty in the system components, the complexity of the system interactions limits the practical use of analytical models to study Atomedical.

In its operation, Atomedical uncertainty and complexity is the result of the influence of scheduling exam appointments in the system performance. Health care units usually schedule “customer” arrivals in service. The performance of this appointment scheduling is considerably affected by the operating environments. Their adaptability to the available information of service and demand variability can simultaneously reduce waiting times and provider idle time [5]. The idle time of the service provider is the time while the professional is not working, which is critical since staff represents one of the major cost in health care [6]. Some literature has addressed scheduling problems using for instance: multiobjective models (for example, in faculty scheduling assignments [7]); dynamic programming (for instance, in crew scheduling [8]) or multicriteria scheduling [9]. In the reviewed literature, most common methodology uses simulation models. DES is widely used in recent simulation papers [10–13], given the complexity of multi-variable problems, as the one of Atomedical. Even though, in opposition to more analytical methodologies, DES alone fails to help one optimize configurations of a model. Therefore, it is expected to find combinations with other methodologies, namely as part of optimization techniques, for instance, in the evaluation of the performance of a model in a given configuration, as an alternative to the use of an analytical approach [14]. In the field of Nuclear Medicine, highly specific, scant literature is found, particularly outside general hospitals. A work developed a DES model of a hospital Nuclear Medicine department in order to study different patients and resources scheduling rules [15]. Other paper addressed the problem of capacity planning in this type of services [16]. In the Portuguese context, one can found previous work about Nuclear Medicine units, as in the unit of Hospital Privado de Almada [17] and, more specifically, also in Atomedical [2], which showed how DES is suited to study this type of services operation. The simple use of DES does not address the problem that Atomedical currently faces regarding the definition of its environment. To address this type of uncertainty some tools study simulation models response to variations using sensitivity analysis [18]. A methodology to consider scenarios for Atomedical. Scenarios Planning is an existing tool to perform a systematic approach of scenarios construction.

3.2 Scenarios Planning

When one is not able to use more objective tool, some “soft techniques” exist to support a more systematic and accurate procedure to provide valuable system alternatives. Scenarios Planning arises as the methodology to address the environment uncertainty in Atomedical problem. A definition of Scenarios Planning is: “That part of the strategic planning that relates to the tools and technologies for managing the uncertainties of the future”[19]. In literature, Royal Dutch/Shell is a classic example of how scenarios planning helped an organization prepare for an uncertain future [19].

Predictable elements can be more easily addressed by methods and techniques of forecasting. Scenarios

Planning is suited to deal with a reasonable uncertainty in the not too far distant future. Simplifying the view of future, scenarios provide a clustering of possible trajectories into distinguishable and meaningful groups [20]. An application of Scenarios Planning in Nuclear Medicine unit operations is something new since this methodology is usually applied in institutions policies, and not in such specific operational context to obtain scenarios and strategies. While retaining a strong linear structure, the process is multistage, interactive, iterative and data driven, with some steps needing a high level of creativity, where managers should be actively involved [21]. Over short to moderate timescales (known as tactical and operational planning), the Atomedical problem is viewed as one of strategic positioning based on relatively small time horizons such that the emphasis is placed only on plan agility/flexibility and robustness [20].

Scenarios may also take the form of variations of parameters of a system model, which can be mathematically defined [22]. Robust scenarios construction provides internally consistency that should support the consideration of plausible uncertainties, even if not directly addressed, and challenge managerial thinking [23]. Although, this approach do not prevent management surprise regarding the future [24]. There is a lack of literature in the use of scenarios planning with other problem solving methodologies. Although, in order to support strategy, Scenarios Planning may be integrated with other tools, namely System Modeling [25, 26], Decision Analysis [27], Programming [28] and Bayesian Networks [29]. Combination of DES with a simpler Scenarios Planning methodology was explored successfully in literature [26, 30].

In Scenarios Planning literature, scenario terminology is usually used to describe the external system context while strategies are related to the internal system. However, in the Atomedical problem, it is crucial to make use also of operational scenarios. They are the result of the factors which managers could not interfere, and strategies, which can be direct addressed by the managers. Therefore, a new framework of Scenarios Planning needed to be developed to address this application of existing techniques. Scenarios Planning in the case of Atomedical needs to perform a complete problem analysis of multi variable systems and be focused in the operations impact, rather in environment scenarios.

4 Methodology framework for Scenarios Planning

In scenarios planning methodology, no standardized process exists. However the various approaches show a basic structure. The proposed methodology is an articulation of two previous works [24, 31], and considering the specificity of the Atomedical unit problem. By focusing in the examination operations, was used some complementary tools to address it, as suggests by both authors. Those methodologies lack, in some order, in the use of more quantitative tools, needed to support the study of the unit processes. It will rely in the use of a simulation model, some steps/tools will be introduce, as well as other relevant considerations from complementary literature.

4.1 Phase 1: Analysis of Atomedical problem

Identify the focal issue, question or decision The first method steps aim to analyze the problem faces and set the system parameters to be addressed. This step is generally performed with a workshop, gathering multiple visions within the organization.

Problem analysis This step allows the identification of relations and interactions of components set related to the problem, describing it as a system. Besides the recognition of inputs and output of the system, internal relations and interdependencies are also pointed, in order to give assistance to variables identification in the problem context.

Identification of problem variables After an initial description of the processes related to the problem, a process of teasing out variables and reviewing the mechanisms connecting them is enriched through another workshop, which could make use of diagrams representations for posterior validation by the participants, unit managers in this case. To identify significant variables, it is beneficial to focus in the problem/decision objectives, and identify what can contribute to its success or failure, by taking into account the previous steps on system characterization [31].

Identification of Key Variables In the scenarios planning methodology, identification of key variables is crucial as they are the ones on which the system mainly depends. Key variables identification in scenarios planning consists in isolate variables by their impact in the system, uncertainty and independence [24]. Key variables are the ones which have a significant impact in the system. Also, key variables are those with some degree of uncertainty since others can be predicted or manipulated, and, therefore, are either a unchangeable of the problem, or can be addressed in a strategic approach [31]. A set of tools is suggested in order to help the decision maker to establish the key variables: a structural analysis tool for classification of variables direct and indirect dependence and influence using a dependency structure matrix; and a tool to analyze variables impact versus uncertainty. They are complementary to the process, however, necessary to structure the ideas. They cover all key variables criteria, and will help the judgment of workshop members in identify the key variables of the system as:

Scenario: A scenario variable is a key variable, therefore, it must have an impact or importance to the dynamics of the problem system. It must be also an influential variable to the system. This type of variable is characterized by a lack of knowledge or control, being, therefore, a system uncertainty. It is also relevant to variables represent some degree of possibility, thus having the possibility of change in the future, or be associated to frequent events.

Strategy: A strategy variable is also a key variable, so it must also have an impact or importance to the problem system dynamics. It may be also an influential variable to the system. However, this type of variable is characterized by the possibility of control by unit managers. Therefore, it makes no sense to think in the possibility of frequency since it is ultimately a strategic decision.

Signpost: A signpost in not usually a key variable, but has contributions to the problem objectives, having an importance or impact in the problem. Therefore, it usually presents a high dependence of other variables and is prior unknown and uncontrollable by unit managers.

4.2 Phase 2: Construction of Scenarios and Strategies

Scenarios and Strategies Construction Scenarios and strategies construction is based in the set of key variables identified for the Atomedical problem. On one hand, one must attempt to reduce key scenarios questions uncertainty, using experts and data. On the other hand, one must help unit managers considering strategic options for modifying the system in the identified problem.

The procedure of scenario construction is rather subjective, but the use of a some techniques can help decision maker to obtain meaningful possible future scenarios on which will perform the described system. One of them is the morphological analysis that uses a blocks method to first explore the variables into subsystems [31]. Since this methodology is applied to a more operational context, in opposition to most literature, the focus of scenarios will the result of events in operations. Different events may be gathered in a similar behavioral scenario, for instance, the number of patients that reach the unit. Reducing the importance of fully defining of the story behind scenarios, reduces the need for complex analysis of the unit environment.

In strategy construction, one uses the key variables that were not considered to scenario construction, namely those which behavior could be solely changed or influenced by the decision maker. Only important and predicable variables, which behavior decision maker can control, are relevant to strategic options since others will be part of the system model parameters, and will not change in different scenarios/strategies. In spite of the multiple possibilities, it is noteworthy to look for coherence in strategic options, looking for compatibility with corporate identity and objectives, as well as, to the considered scenarios. Again it is possible to use morphological analysis to perform this, allowing the reduction of the final set of strategic options to be evaluated under each scenario.

Selection of leading indicators and signposts In order to evaluate the performance of the system in the possible scenarios and strategies configurations, one must identify the leading indicators and signpost of the Atomedical system. These will allow one to determine the behavior of each strategy under each scenario in the pursue of the problem objectives. Leading indicators and signposts must be, therefore, relevant to the Atomedical problem, and allow directly or indirectly to gage the defined objectives parameters.

4.3 Phase 3: Evaluation of Scenarios and Strategies

Evaluation of Strategies under Scenarios The proposed final step methodology is to evaluate the strategic options under the different scenarios, for which performance indicators are determined. In this work, due to the system under study, the proposed evaluation is made throughout DES of Atomedical unit model. In order to use DES, the system must be represented by a model, focusing in the unit operation and including the key variables under study. The model includes the influences and dependencies between them and allows to follow and measure the defined leading indicators and signposts. The model must allow the definition of a set of parameters in order to represent the scenarios and strategies defined before. For each strategy and scenario, a simulation is made in the defined set of conditions.

In a robust Scenarios Planning methodology, one is able to analyze the results, in order to predict the evolution of the system under different context/scenarios. Scenarios planning allows, at this level, a sort of sensitivity analysis that provides unit managers additional knowledge about their unit, and their options impacts, supporting eventual decisions. It also allows a better preparation to act accordingly even if scenarios not exactly equal to the ones consider arising in the future.

5 Phase 1: Analysis of Atomedical problem

Atomedical problem was already identified. The analysis of the problem was performed through meetings with the decision makers and unit visits. One focused in the identification of the operation components of the problem rather in the already fully description of the unit operation [2]. The analysis was based in an initial flow chart of the main unit processes, Figure 1, providing main processes, existing relations, and potential management interventions on it. This analysis allowed one to find the problem vari-

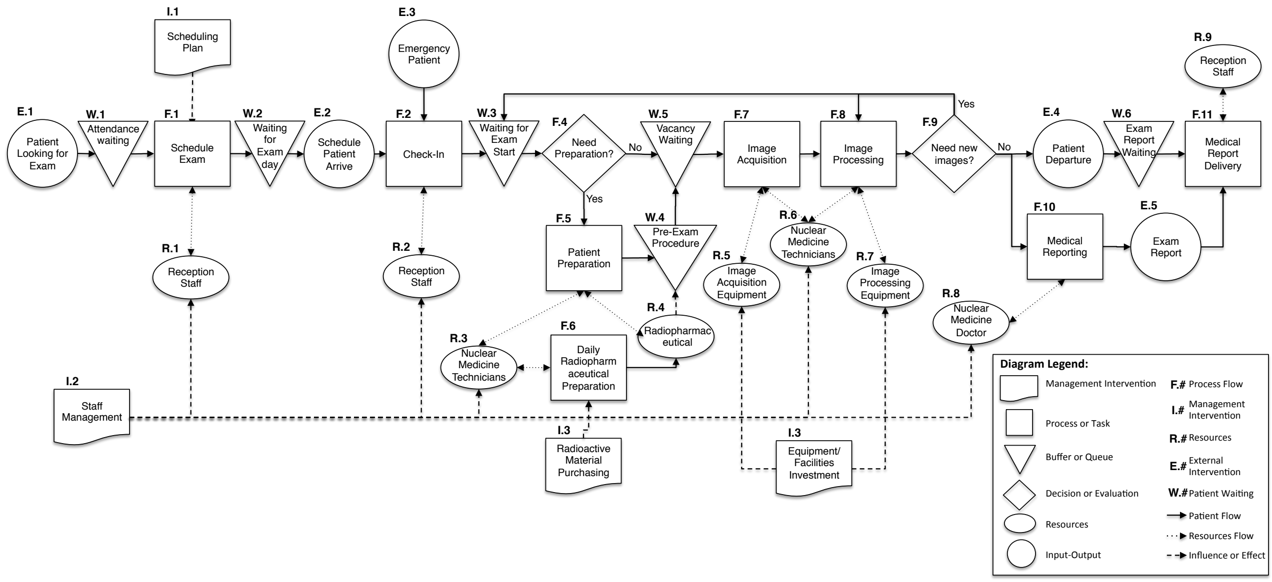

Figure 1: Atomedical general examination process flow chart. Management interventions (I.#) are those appointed by the unit manager as their possible interventions on the system.

ables that directly result from the unit examination operation. These were not necessarily the same variables to were addressed in scenarios and strategies.

5.1 Problem Variables

System analysis must also focus in the problem objectives, to identify variables that influence them since many of them do not reside in the unit operation, but on its context. Therefore, one had to understand the contributions to the Atomedical objectives of reducing operating cost and maintain or improve the defined current service quality, which was done using cause and effect diagrams, which were not included in this paper.

5.2 Problem Key Variables

A system is described not only by its components, but also by the relationships between them. In order to characterize them, one must establish the relations between different variables, and determine those criteria for each variable. For this purpose, it was used the variables dependency structure matrix using MICMAC [1] to classify variables regarding their direct and indirect influence and dependency [31], together with a complementary impact versus uncertainty analysis tool [24]. Methodology tools and their results aimed only to assist this classification. Atomedical unit managers had the final word when choosing what were the key variables and those that should stop being considered at this point. As a result, one obtained from the initial pool of 66 variables, 20 scenarios variables and 15 strategies variables for scenarios and strategies construction. An of set 14 signpost variables was identified for posterior evaluation of simulation.

6 Phase 2: Construction of Scenarios and Strategies

6.1 Scenarios

Construction of Scenarios for the Atomedical problem is based in the scenarios key variables. Methodology framework suggests the use of morphological analysis such as block method to the multiple options. This methodology aims to reduce to a group of meaningful, coherent and broad enough final scenarios. Blocks method suggest gathering variables within subsystems. Those subsystems can be drawn from the system components of Atomedical operations, represented in the process flow chart of Figure 1. These tools were used to help unit managers to analyze variables and establish the scenarios to be studied. Some variables remain outside they influence at a financial level of operations, not addressed in the simulation model. The resulting system variables of interest for the study under the scenarios variables were:

- E.1 - Patient Looking for Exam Number and per exam distribution of patients
- F.7 - Image Acquisition Probability of equipment stoppage for repair
- F.9 - Need new image? Probability of need for increased exam time

Given the type of problem in study, one suggested considering the number of incoming patients as an anchor variable scenario building, combining it with the

[1] MICMAC is the French acronym for Matrix of Crossed Impact Multiplications Applied to a Classification. It is available as a software in http://en.laprospective.fr/methods-of-prospective/softwares/59-micmac.html .

remain scenarios variables. Only some combinations were considered relevant, resulting in the following scenarios:

2009 2009 Exams Data (Optimist Scenario)
2011 2011 Exams Data (Current Scenario)
2011-75 75% of the 2011 Exams Data
2011-75B 75% of 2011 Bone Studies
2011-50 50% of the 2011 Exams Data (Pessimist Scenario)
2011-Chamber 2011 Exams Data and Gamma Camera malfunction probability of 2%
2009-Chamber 2009 Exams Data and Gamma Camera malfunction probability of 2%
2011-Time 2011 Exams Data and 10% increase on the average time of images acquisition
2009-Time 2009 Exams Data and 10% increase on the average time of images acquisition

6.2 Strategies

This step does not intend to provide a definitive strategy setup, but to give Atomedical unit managers a view of how their actions can influence the system, and its impact in different scenarios, as an approach of sensitivity analysis. For this purpose, one must take into account strategic key variables. Figure 1, was used to put key variables into operational context groups:

- I.1 - Scheduling Plan, I.2 - Staff Management and I.3 - Radioactive Material Purchasing: Articulated weekly exam schedule with number of staff in each period and available radioactive products
- I.4 - Equipment/Facilities Investment: Number of equipments and time duration of exam acquisitions

A set of combination of scenarios and strategies have to make sense in providing unit managers an understanding about Atomedical, preparing them to the future. In order to simplify the strategies focused in the equipment/facilities, they are only evaluated against an optimist, current and pessimist scenario of procurement. The set of strategies and scenario to be considered together are presented below:

Strategy 0 Current Strategy (as defined in model calibration for 2011). Scenarios for evaluation: 2009, 2011, 2011-75, 2011-75B, 2011-50, 2011-Chamber, 2009-Chamber, 2011-Time, 2009-Time.

Strategy 1 Reduction on the working period of the unit from 8h30 until 18h00. Scenarios for evaluation: 2011, 2011-75, 2011-50.
Scenarios for evaluation:

Strategy 2 Decrease the number of Gamma Cameras to 3. Scenarios for evaluation: 2009, 2011, 2011-50.

Strategy 3 20 % reduction on the image acquisition duration in Cardiac Studies. Scenarios for evaluation: 2009, 2011, 2011-50.

6.3 Signposts

Signposts are a preparation to the next phase of scenarios planning. Signposts are of extreme importance in the simulation model design and its implementation since simulation results must provide information about them. One can divide the previously identified signpost variables in the following categories:

Resources Workload *# 4 Schedule - Extra working hours of unit staff*, *# 5 Reception staff workload*, *# 6 Nuclear Medicine Technicians (NM Technicians) workload*, *# 7 NM Doctors workload* and *# 19 Equipment workload*

Used Products *# 33 Quantity of Technetium generator bought*, *# 35 Quantity of "Cold Kits" bought*, *# 36 Unused Technetium*, *# 38 Unused "Cold Kits"*

Patients *# 48 Schedule availability*, *# 65 Patient waiting time in unit*

Operational Performance *# 41 Image retake*, *# 51 Number of examinations # 66 Atomedical operations costs*

7 Phase 3: Evaluation of Scenarios and Strategies

The use of a DES model provides one a tool to address the uncertainty related with the unit processes by considering in the model a statistical variation of its events. Scenarios and strategies were combined with DES using the model inputs and parameters, which allowed the definition of different simulation setups instances.

7.1 Atomedical Simulation Model

For the purpose of evaluating scenarios and strategies drawn in the previous part of scenarios planning methodology, one used a DES model of Atomedical [2]. The processes described in 2010 remain the same nowadays, despite the changes of environment. The used DES model of Atomedical was reviewed and enhanced in order to satisfy the needs of the actual problem. The simulation model, Figure 2, was implemented in Simul8 Simulation Software [2].

The Atomedical model focus in the processes of unit examination (administrative operations were not modeled). They can be divided into three subsystems: Scheduling; Examination and Reporting. Those subsystems connect between them through a sequence feeding of work and resource sharing. One

[2] Simul8 Simulation Software is a commercial software focused in process improvement from the Simul8 Corporation. A student license was used for the purpose of this work. More information available in http://www.simul8.com/

provides a representation of the unit parts modeled in Figure 2. In the model, exam procedures were restricted by directly simulating the most relevant exams, in terms of revenues, and gathering the remain into two typical types of procedures, Table 1. The model explicitly simulates the following exams: Bone Scintigraphy, Myocardial Perfusion Study, Thyroid Scintigraphy, Renograms. The Renogram procedure in the model represents the different types of renograms performed.

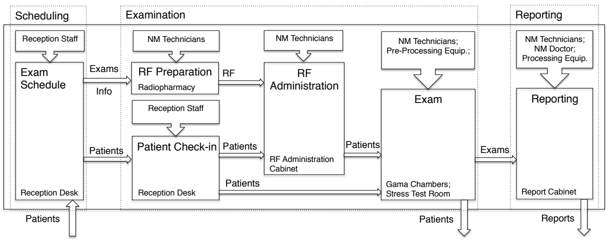

Figure 2: Systems and sub-systems of simulation model. Modeled tasks are represented inside sub-systems.

In order to simulate correctly the Atomedical operations in the Simul8 DES Model, one has to calibrate it using the model parameters and inputs, so it represents the actual procedures. For this purpose, the existing real data or information provided by the staff was used. Parameters for procedures and tasks times were considered together with unit managers to remain the same of 2009 [2]. They are intrinsic to the unit operations, despite changes in that values may be used for new setups in scenarios/strategies evaluation. Data regarding 2011 was used to define the initial context of the number patients that look at Atomedical services, and the distribution of the type of exams, in which 21265 exams were performed, Table 1. Regarding the exam schedule plan and staff shifts, the ones used in September 2011 were considered.

An initial simulation was performed, regarding Strategy 0 for scenario 2011, for one year runtime and half-year warm-up period, in order to validate the model regarding the real data existing to the unit. Although, 2011 was a year of changes, the model assumes steady parameters through the simulation. Despite of that, the model was considered to be a valid approximation of it, being, therefore, able to sustain evaluation in Scenarios Planning. The base model has to be adapted to represent the drawn scenarios and strategies. In each of them, specific system parts are addressed and the simulation parameters were changed accordingly to the scenarios/strategy in study.

7.2 Discrete Event Simulation results

The quantity of data that can be extracted from a simulation can be enormous and difficult to analyze. However, this methodology does not imply a fully study of the unit operations. Focusing in the trends, in the selected signpost, one was able to provide more information about the problem reducing the complexity of the analysis. Simulating only some scenarios for the obtained strategies provides a simpler, but robuster, sensitivity analysis of the problem. For this purpose, the results are compared to a control simulation. These simulations changes, based on the main change that the scenario/strategy combination provides. Strategy 0 in the 2011 scenario was considered a base simulation. For the remain, the results in Strategy 0 were compared with the 2011 one since it was only changed the number of patients. For the remain Strategies, other variables are changed. Therefore, in order to remain focused, those simulations are compared with Strategy 0 in the equivalent scenarios of procurement. In Tables 2, 3, 4, 5 and 6, changes are highlighted using arrows near the comparison values. They represent 10% to 20% different, highlighted as yellow, and more than 20%, highlighted as green (increase) and red (reduction).

The discussion of results focused in the data statistical analysis of each patient performed exam, scheduled to a day after the warm-up period. More data was also extracted from the day summaries in the result collection period. The used signposts indicators for results can be divided into three groups: service quality, unit performance and unit workload. It is presented the average (AVG) results for the unit performance since they give a broader representation of the impacts.

Table 2: Unit performance results for Strategy 0 under the procurement scenarios.

Simulation	Strategy 0								
	2011	2009		2011-75B		2011-75		2011-50	
Total Exams	10332	15768		9651		8014		5339	
	AVG	AVG	%	AVG	%	AVG	%	AVG	%
Number of Patients per Day	79,48	121,29	↑ 153%	74,24	→ 93%	61,65	↓ 78%	41,07	↓ 52%
% Schedule	63%	96%	↑ 152%	60%	→ 95%	49%	↓ 78%	32%	↓ 51%
Last Patient Out	18,53	20,69	↗ 112%	18,33	→ 99%	17,83	→ 96%	16,81	→ 91%
Reports per Day	79,50	97,28	↑ 122%	74,30	→ 93%	61,65	↓ 78%	41,07	↓ 52%
Wait in Clinic	18,62	83,45	↑ 448%	18,20	→ 98%	16,46	↘ 88%	13,68	↓ 73%

Table 3: Unit performance results for Strategy 0 under the operational scenarios.

Simulation	Strategy 0							
	2011-Chamber		2009-Chamber		2011-Time		2009-Time	
Total Exams	10332		15768		10332		15768	
	AVG	%	AVG	%	AVG	%	AVG	%
Number of Patients per Day	79,48	→ 100%	121,29	→ 100%	79,48	→ 100%	121,29	→ 100%
% Schedule	63%	→ 100%	96%	→ 100%	63%	→ 100%	96%	→ 100%
Last Patient Out	18,53	→ 100%	23,43	↗ 113%	18,56	→ 100%	20,92	→ 101%
Reports per Day	79,50	→ 100%	97,26	→ 100%	79,50	→ 100%	97,27	→ 100%
Wait in Clinic	18,82	→ 101%	163,87	↑ 196%	21,66	↗ 116%	98,53	↗ 118%

The impact on operations, by variations on the examination times, is minimized by flexibility of operations, but influence the waiting time of the patient. The number of Gamma Cameras are the key to the flexibility of the exam management. The option of

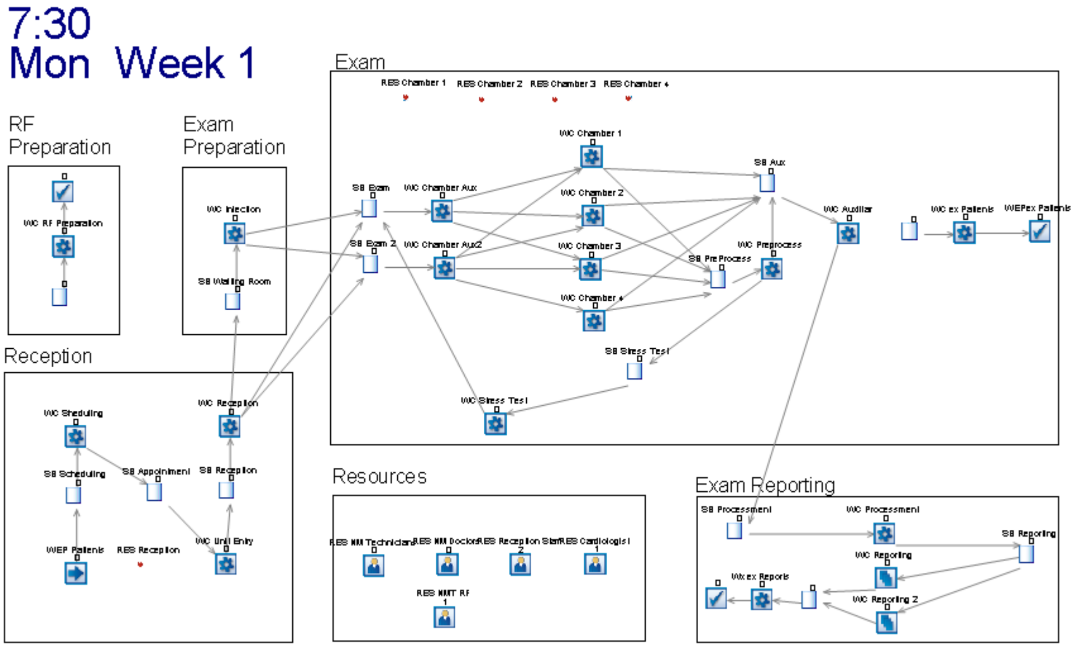

Figure 3: Atomedical Simul8 Simulation model.

their reduction, in the context of low procurement, allows to decrease costs, but sacrifices the service quality regarding patients waiting time. Even if the schedule fulfillment is not near completion, it may result in the reduction of the number of exams since the fit to unit capacity of the schedule of patient entry in the unit, influence the waiting times inside.

Table 4: Unit performance results for Strategy 1 under the procurement scenarios.

Simulation	Strategy 1					
	2011		2011-75		2011-50	
Total Exams	8943		7518		5334	
	AVG	%	AVG	%	AVG	%
Number of Patients per Day	89,84	113%	57,98	94%	41,03	100%
% Schedule	74%	117%	46%	94%	32%	100%
Last Patient Out	21,12	114%	17,92	101%	16,84	100%
Reports per Day	74,12	93%	57,97	94%	41,03	100%
Wait in Clinic	59,95	322%	17,50	106%	15,38	112%

Table 5: Unit performance results for Strategy 2 under the procurement scenarios.

Simulation	Strategy 2					
	2011		2009		2011-50	
Total Exams	10332		15768		5339	
	AVG	%	AVG	%	AVG	%
Number of Patients per Day	79,48	100%	121,29	100%	41,07	100%
% Schedule	63%	100%	96%	100%	32%	100%
Last Patient Out	18,85	102%	23,42	113%	16,95	101%
Reports per Day	79,51	100%	97,27	100%	41,07	100%
Wait in Clinic	43,98	236%	166,48	199%	26,63	195%

Strategy 1 allows to reduce the working period, and, thus, costs. However, the studied schedule plan was not optimized, which resulted on increased waiting times and inefficient resources use. This strategy is not recommended to procurements above 75% the scenario of 2011, due to significant loss in the number of exams and service quality. Strategy 2 allows to increase the usage of the Gamma Cameras; however, it increases the waiting times on all procurement scenarios tested. Given the irreversibility of this option, the cost reduction might not justify the loss of service quality.

Table 6: Unit performance results for Strategy 3 under the procurement scenarios.

Simulation	Strategy 3					
	2011		2009		2011-50	
Total Exams	10332		15768		5339	
	AVG	%	AVG	%	AVG	%
Number of Patients per Day	79,48	100%	121,29	100%	41,07	100%
% Schedule	63%	100%	96%	100%	32%	100%
Last Patient Out	18,50	100%	20,62	100%	16,82	100%
Reports per Day	79,50	100%	97,28	100%	41,07	100%
Wait in Clinic	18,01	97%	77,49	93%	13,20	96%

Strategy 3 allowed the improvement of service quality, namely regarding the Myocardial Perfusion exam, however, with the studied schedule, the improvements in the general unit performance indicators were not significant. Despite corroborating some effects of the options in study, the level of impact of some of them sustained further review and study regarding the efficiency and effectiveness in current and future scenarios.

8 Final remarks

The new Scenarios Planning methodology provided a tool to address the problem uncertainty, both in the Atomedical context and the unit operations. This was possible by integrating a full procedure of Scenarios Planning with the methodology of DES in the study of Atomedical operations. Although the inherent subjectivity of the analysis and scenarios/strategies construction, the use of complementary quantifying tool allowed to correctly describing the known and the background relations that drive the problem. The identification of the key variables of the problem is the core part of the methodology. Problem analysis supported a more objective choice regarding those variables and the considered options.

The use of DES within the Scenarios Planning methodology supported a sort of sensitivity analysis of the system that enrich the knowledge obtained. Despite of that, further work could use the results to study the financial performance of Atomedical and optimize unit operation parameters, now that the existing uncertainties were identified and characterized. Further work in Scenarios Planning could take advantages of the integration of optimization techniques, focused in the key strategic variables.

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