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An Integrated Framework for Optimization of Resources in Emergency Departments

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***Abstract*—The study of healthcare systems has become of great significance lately. Hospital departments, such as the Emergency Department (ED) or the operating theatre face many challenges. Modelling and analysis of healthcare systems play a key role in assisting healthcare managers to make correct decisions regarding capacity planning, resource allocation and scheduling. Review of literature clearly shows that multi-objective simulation modelling of the ED's patient flow is one of the most frequently studied topics in healthcare management. Patient length of stay, waiting times, resource utilizations and number of patients treated are commonly used performance indicators of an ED. A framework for an integrated simulation and Genetic Algorithm (GA) is presented. The GA focuses on optimization of resource levels throughout the ED, which directly affects patient flow. Two simulation tools are utilized in the framework, Discrete Event Simulation (DES), which replicates the performance of that ED with optimized resources, and System Dynamics, which models the entire healthcare system, studying the interrelationships that exist between the ED and the rest of the hospital. DES of an existing ED found in literature is presented. Results of simulation confirm the need for an integrated framework to assess the performance of a healthcare system.**

Keywords*—*healthcare management; emergency department; patient flow; resource optimization

I. INTRODUCTION

Up till recent years, the study of healthcare systems and their operations have become more and more popular. Effective management of hospital systems is a vital tool to be able to meet the high patient standards. Increasing demands and diminishing resources all increase the pressure on healthcare managers to meet many conflicting objectives such as minimizing healthcare costs, maximizing the utilization of resources, as well as improving the overall performance of the hospital system. Poor management in healthcare can cause many dilemmas and it is crucial in this type of field that any complications be minimized or eliminated if possible. One of the global issues faced in many healthcare systems is overcrowding, which may increase the risk of mortality, decrease the quality of care, and result in more patients leaving without being cared to. Thus, many decisions have to be made, regarding capacity planning, policy changes and resource scheduling. To tackle such problems, and meet the various objectives, many Operations Research (OR) techniques are utilized, functioning as analysis and decision making tools in the healthcare industry.

The Emergency Department (ED) is one of the most commonly studied departments in the hospital system, due to its complexity and criticality. Such a department deals with unpredictable patient arrivals, in addition to scarce resources, therefore effective decision making considering resource configurations is a necessity. Various models have been found in literature studying ED. Models' objectives, key performance measures, and different solution techniques utilized are all highlighted through a detailed review of previous works. The review showed that multi-objective Discrete Event Simulation (DES) modelling of the patient flow is one of the most frequently studied topics. Furthermore, the review revealed that healthcare management research has not treated hospital systems as one whole organization, but rather divided it into subunits with that aim of improving those subunits individually. In particular, the ED performance directly affects the remainder of a hospital; yet, no researches appear to study those interrelations that exist, despite the importance of that for a realistic depiction of the system and understanding of its overall performance. Clearly, the ED is highly related to other areas including the Intensive Care Unit (ICU) and Operating Theaters (OT); therefore, the study of the ED individually as an isolated subsystem of a hospital is not enough.

In reaction to the problem identified, a generic framework for modelling and optimizing an ED, considering the entire healthcare system linked to the ED, is proposed. The framework suggests the integration of two simulation techniques, Discrete Event Simulation (DES) and System Dynamics (SD), in addition to Genetic Algorithm (GA). Many have debated the importance of perhaps using SD modelling rather than DES, to capture the whole healthcare system, representing all the important relationships that link all the departments together. However, both simulation tools are of great importance, therefore they are proposed to work alongside one another in the framework. To the knowledge of the authors at the time of this publication, combining Simulation Optimization (SO) with SD has not been conducted previously, making it a contribution to research in healthcare management.

DES of an existing ED found in literature is presented. However, rather than using the optimization technique incorporated in the proposed framework, optimized values that were reported in literature for that specific case study are used [1, 2]. Detailed analysis of simulation output confirms the need for an integrated framework to assess the performance of a healthcare system.

The remainder of the paper is organized as follows. Section II reviews the relevant research work found in literature review. It discusses the approach taken to gather publications in the area of healthcare management, as well as presenting a review of previous works in healthcare. Literature regarding the management of EDs mainly is focused on, reflecting all the different parameters and objectives commonly used in that particular department, as well as the modelling and solution techniques; Section III describes the problem at hand, specifying the purpose of such a research; Section IV describes the proposed integrated multi-objective, multi-level framework in detail; Section V describes the DES model built for the ED found in literature, presenting the experimentation conducted as well as the analysis of the results; and Section VI is the concluding section of this paper, summarizing the contribution and importance of the paper, as well as presenting future research directions.

II. LITERATURE REVIEW

A. Approach to Literature Review

In order to make sure that high quality and relevant material has been selected during the review, certain search terms where used and examined. Only academic and scientific databases were explored, such as Science Direct, Emerald Insight and Springer, in order to find papers in the area of healthcare management. Each one of the papers reviewed is related to healthcare management in general and is of useful contribution to this research. With more than 75 publications reviewed, many different topics were covered, ranging from the scheduling of surgeries in the OT to increase the throughput, to the bed management of inpatient wards to improve bed occupancy. All those various constructs were very helpful in gaining understanding in the research area of healthcare, and the complications that managers may truly face. However, these topics have been reduced to serve the purpose of this paper and to establish the required focus on ED specifically.

B. Classification of Healthcare Departments

The healthcare system is a vast and complex field, and there are many approaches to study and analyze it. Typically, hospitals are highly integrated systems, made up of many interacting subunits; introducing complexity to the system due to these interactions. Each one of those subdivisions has their own operational problems. Nevertheless, the overall performance of such a system is highly dependent on the performance of those individual departments working together as a network. Based on the works reviewed, it is observed that such systems are not discussed as a whole interrelating hospital system, but rather dissected into individual departments, each with their own operational issues. A typical healthcare system is commonly made up of the following sub units: Outpatient Departments [3, 4], EDs [5–7], Inpatient Wards [8, 9], OTs [10, 11] and the ICU [12, 13], as represented in Fig. 1.

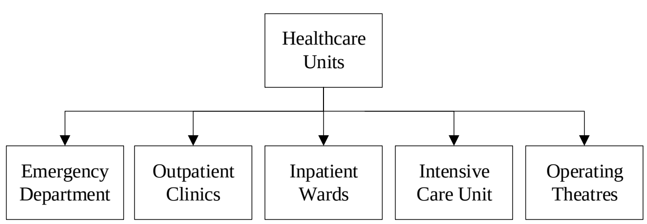

Fig. 1. Classification of healthcare units

The ED is the most frequently studied area in healthcare, covering 34% of the total literature gathered, followed by the outpatient departments making up 31% of the papers gathered. As for the studies concerning the ICU’s and OT’s, they make up approximately 8% each of the total gathered papers and the inpatient wards contribute to 7% of the literature. Even though it is of great importance to study the larger picture, and given the fact that all those units are somehow highly related, the system as whole has not yet been modelled in the gathered literature. Still, 11% of the researches attempted to study the relationships between two or more connected areas [14, 15].

The ED appears to be one of the most critical and complex departments in any hospital system, dealing with random and increasing patient demands. Poor decision making in such a unit may have extreme consequences, all of which may lead to increased mortality rates. ED’s main concern lies in capacity restrictions; whether it is human capacities or physical capacities.

Accordingly, the next section discusses previous works studying the performance of ED's mainly, highlighting the commonly used performance indicators, objectives, as well as the modelling and solution techniques.

C. Previous Works

1) Problem Type, Model Objectives and Performance Measures

EDs deal with many dilemmas, including unpredictable patient arrivals, as well as scarce and diminishing resources, resulting in overcrowding and many other issues, all in which lead to extreme consequences including increased mortality rates. As a result, effective decision making considering resource configurations in the ED is the most reoccurring problem addressed, focusing on determining the optimal level of resources, such as the number of beds, doctors or nurses, required in the ED to improve the performance [2].

Due to the complexity of the ED in the hospital system, it is very difficult to narrow down the problem objectives. Very few of the works reviewed evaluate the ED based on a single objective. Improving only one goal requires many simplifying assumptions in the modelling stage, to the extent where the work is no longer a realistic representation of the healthcare unit under study. Healthcare managers generally need to simultaneously address many issues in the ED; many of which are often related, but may also be conflicting, such as cutting down the costs whilst improving the quality of care, as well as reducing the patient's experience time and waiting times, whilst increasing the number of patients treated. Due to the complex nature of the ED within the hospital systems, it is more applicable to try and improve multiple objectives, and that is evident through the literature reviewed where authors present works improving multiple objectives rather than a single one [16, 17].

The most frequently used objectives and performance indicators used to evaluate an ED include a combination of two or more of the following: the Average Length of Stay (ALOS), waiting times, the number of patients treated, and resource utilization. Simulation of the patient flow of an ED unit in Kuwait [18] was carried out in order to determine the optimal number of doctors, lab technicians and nurses to maximize the patient throughput, as well as reduce the patients' waiting time, achieving those objectives through a hierarchal approach. Results showed a 28% increase in the throughput, and a 40% reduction in the time spent in the system. Similar work was done in a Jordanian ED [19] that only aimed at finding the optimal number of nurses to maximize the sum of weighted objectives, specifically the patient throughput and the nurses' utilization. Results showed an increase of 1% and 16% in the throughput and utilization respectively.

2) Modelling and Solution techniques

When it comes to modeling and solution approaches to address the performance of an ED, multiple OR tools are utilized. Many different techniques have been adopted in literature, and they can be widely categorized as analytical, simulation and meta-heuristic techniques. Each one of those techniques can be further classified as presented in Fig. .

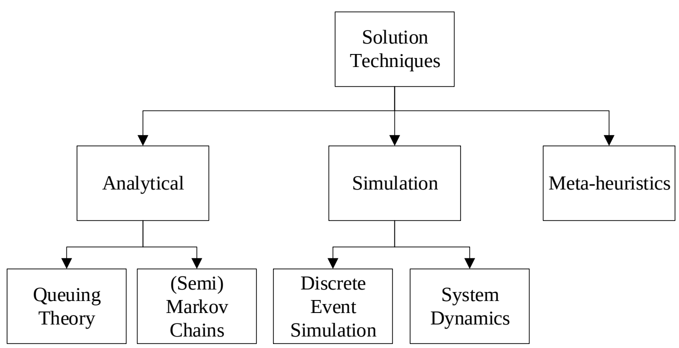

Fig. 2. Classification of solution techniques

a) Analytical Techniques

Analytical solutions are mainly mathematically defined problems, where a solution can be found for a set of equations. They are most commonly used to address bed management and assignment problems, evaluating parameters such as the bed occupancy, patient waiting times, ALOS, and rejection rates. The most common analytical approaches used to study the ED can be sub-categorized as queuing models [20] and Markov models [21]. However, authors who used such tools in the healthcare area are a minority. This is a consequence of the complex behavior that EDs reveal, making it difficult to replicate a realistic representation of the system, solely by the use of analytical methods. As a result, researchers turn to simulation as a solution technique, due to its ability to handle the complexity of healthcare units, and model the many entities and parameters that make up the entire system.

b) Simulation Modelling and Solution Techniques

Different computer simulation modeling techniques had been used to imitate the patient flow in an ED; as well as to analyze the operational performance, such as DES, agent based simulation, and SD. The most widely used simulation technique in healthcare management in general is DES. It is an operational tool that studies individual healthcare units on a detailed and micro level, offering flexibility to experiment with the model, implementing many what-if situations. Also, many measures can be obtained from DES modelling, in order to assess the performance of the system. DES is extensively used to model EDs, in order to evaluate the attainment of the common multiple goals mentioned in the previous section, and to predict the optimal resource levels and their allocations [22–24].

It is clear that the ED does not work independently in the hospital, but its performance is highly related to many other departments within the hospital, and those links are often neglected when DES is used as a modelling technique. This may negatively impact the rest of the system; therefore it is important to consider the use of SD in this field of research. Although SD is not widely used in healthcare, recently many have been negotiating the importance of its application in healthcare, instead of DES [25]. Unlike DES, SD is a dynamic approach commonly used on a strategic level, to analyze the overall dynamic behavior and interrelations within the healthcare system. It does not consider entities as an individual, but rather focuses on the large and aggregated picture; where, the system elements are connected. SD models are made of two different components, a qualitative aspect, identifying feedback loops that are the cause of the dynamic behavior, and a quantitative one, converting the model into stock and flow diagrams, to graphically and mathematically describe changes that occur within a system over time, making it useful for strategic level decision making. The authors of [26] applied SD to the part of the healthcare system dealing with emergency care. The model simulated the patient flow, experimenting with various changes in the service configurations and demand rates, to evaluate its effects on the bed occupancy. Results showed that emergency admissions of elderly patients had the greatest effect on the bed occupancy, as they used up a lot of time and space in the hospital. D.C. Lane, C. Monefeld, J.V Rosenhead [27] are a another example of the application of SD in the ED, used to investigate the relationship between the number of beds and the patient waiting times. Results showed that reducing the number of beds does not negatively impact the waiting times for emergency patients as one would have imagined, but rather increased the number of cancellations of elective admissions.

Instead of having to choose between two very important simulation techniques, both DES and SD modelling can be combined in a hybrid approach. This allows the realistic assessment of the performance of an ED, evaluating how the department is impacted by the entire hospital. Both tools complement one another, as DES is suitable for studying the ED in great detail, analyzing its operational performance, and the SD model will help provide an aggregate view of the ED within the healthcare system. To the knowledge the authors at the time of this publication, no works reviewed have actually integrated the ED with the entire hospital system using the latter techniques; however a few researches modelling different parts of the hospital system on a much smaller scale exist. Sally C. Brailsford, M. Shivam Desai and Joe Viana [25] joined SD and DES models together in order to analyze the performance of a clinic. The SD modeled the disease transmission in the community, generating a patient demand which was then fed into a DES model of a clinic. In return, the DES model processed the demand, and simulated the patient flow, considering the different processes, capacities of doctors and nurses, as well as capacities of the waiting areas, providing output in terms of the number of patients treated. This performance measure was returned back into the SD model, in order to provide an accurate and realistic calculation for the patient throughput, considering external factors of the community.

c) Meta-heuristic Techniques

Meta-heuristics are general solution procedures that can explore a large solution space, capable of finding near optimal results. Although many of the analysts are heading towards simulation, as an evaluation tool, none the less they are not satisfied by only a simple analysis of the system, but rather yearn to optimize it. Therefore, optimization using simulation is commonly used in the healthcare management area, to find the best set of decision variables that meet the specified objectives. Several publications reviewed integrate both DES and Meta-heuristic optimization tools, such as Tabu search and simulated annealing, to model and optimize healthcare departments. Yet, based on the literature gathered, the most commonly Meta-heuristics that is integrated with simulation to optimize the ED is the GA. Smaranda Belciug and Florin Gorunscu [28] used queuing theory to model the patient flow. Such a model is applicable to any department in the hospital including the ED, optimizing the bed occupancy and resource utilization with the use of GA. J. Yeh and W. Lin [29] presented a framework where DES was used to model the ED, and the GA was also used to optimize the resource levels and schedules. However, unlike the majority of publications studying the ED, only one single objective was used, the patient waiting time. The GA generated solutions that where fed into a DES model for performance estimation, and the simulation outputs where fed back into the optimizer, undergoing the common GA procedures. This process is continued until a sub-optimal solution is met.

III. Problem Description

As concluded from the gathered literature, the ED is the most frequently studied area in the hospital. It generally suffers from many dilemmas including overcrowding, long patient waiting times, as well as high elopement rates; all as a result of poor decision making. Managers often require assistance when making choices regarding the level and allocation of resources to be used in the ED. As a result, they reach out to the use of OR tools to study and evaluate the system, accordingly making ED and the healthcare system in general a popular topic amongst researchers. However, improving the performance of the ED as a sole department may not be enough, as it plays a major role in the hospital system, and is interrelated to many other departments, such as the OT, the ICU, and inpatient wards.

As noted from the previous section covering the literature, multiple objectives are often used when modelling the ED, in order to better grasp a realistic image of the unit. Parameters commonly include time measures, such as the ALOS and patient waiting times, in addition to the number of patients treated and resource utilization. Furthermore, due to the complexity of the ED operations, the most frequently used modelling technique is DES, as it is able to model many parameters in detail, and experiment with various scenarios, testing out different resource levels, such as the number of beds, doctors and nurses. A few authors proceed to take their work to another level, through the integration of the DES with GA, in order to be able to reach near optimal results, satisfying the multiple goals.

Fig. 3 below illustrates the complexity of a healthcare system as a whole, highlighting the patient flow throughout the entire system, starting from their arrival to their discharge. Patients may arrive to the hospital through many sources, such as elective or scheduled patients in the OT or outpatient department, or patients transferred from another hospital that could not tend to their resource needs. The position of the ED within the system is also represented, along with the different departments and the interrelationships between them all. The figure clearly shows that the patient stay does not necessarily end in the ED, and so optimizing the operations of the ED may negatively impact the rest of the system related to it, causing a shift in the bottleneck. Patients may proceed to be admitted into the hospital; therefore, questions need to be asked, such as whether there are available beds in the hospital? Will the patient have to continue waiting in the ED, using up its resources in the process, until a bed becomes available, or will they be transferred to another hospital? If such interrelationships are neglected, a drop in the performance of the entire system is highly likely. The following is an example of the negative effect that may result on the rest of the system when improving only the performance of the ED; if more patients in the ED are treated, increasing the hospital admission rates, the inpatient wards may not have the required capacity to accept this large number of patients and tend to their needs. This may lead to new problems, such as overcrowding in rest of the hospital and higher rejection rates of admission patients, causing them to be transferred to other hospitals.

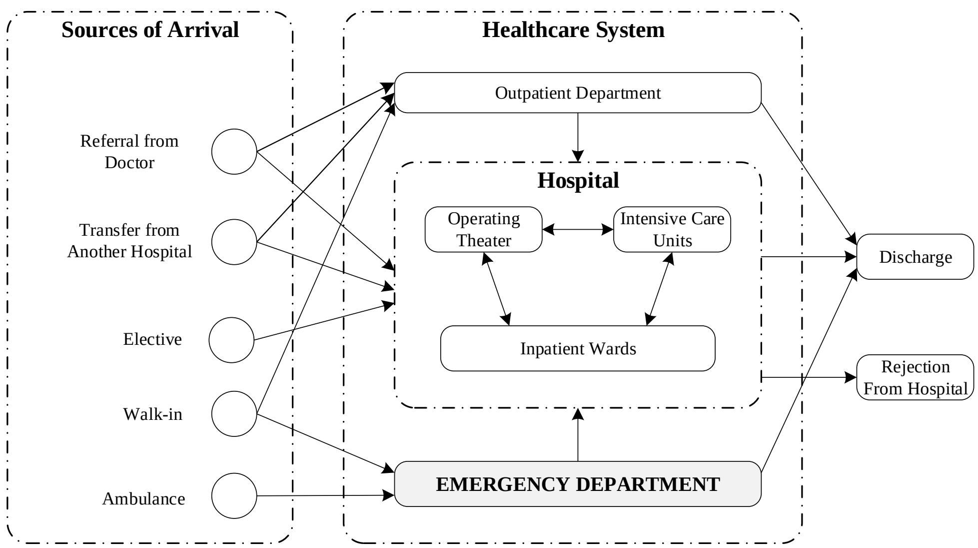

Fig. 3. The interrelationships existing in the healthcare system

Typically the ED deals with different patient types, all arriving randomly, whether by ambulance or as walk in patients. Each patient requires certain treatment procedures and resources based on their conditions, which differ from one patient to the other, leading to variability in the patient routing throughout the ED. All the process times are random, depending on the patient health and their treatment needs. In addition, patients do not simply require one resource, however multiple resources, whether human or physical, are used during the entire patient experience in the ED, and these resources may not necessarily be available at all times. Due to such complexity and randomness in the ED, it is most feasible to use DES when modelling the operations of the ED, as no other modelling techniques are able to capture such details, complexities and interdependencies within the system.

Moreover, despite the small number of research utilizing SD as a modelling tool for healthcare systems, and the negotiations on whether to utilize DES or SD when modelling the ED, it is thought necessary that both tools should be applied. The entire hospital system is a compound network that must work together in order to be able face the variable demand and scarce resources, in order to improve the quality of care, and only SD is capable of easily capturing such links.

In view of all that, the purpose of this research is to propose an integrated two-level generic framework to optimize resource levels in an ED, using multiple performance measures. Three different tools are incorporated in the framework. DES is used to model the operations and patient flow in the ED in detail and computes the fitness function. The GA is used to search the solution space for near optimum resource levels. Finally, SD is used to model the entire healthcare system, showing how the ED performance is linked to the rest of the system. The following section describes the mechanism of the framework.

IV. Multi-Level Approach to Optimize An ED

This research proposes a generic framework for an integrated multi-level approach to optimize the multi-objective system of an ED, combining three different techniques; a GA procedure, a DES model, and a SD model. Fig. 4 graphically represents the framework proposed, and is described in detail in the next sub section.

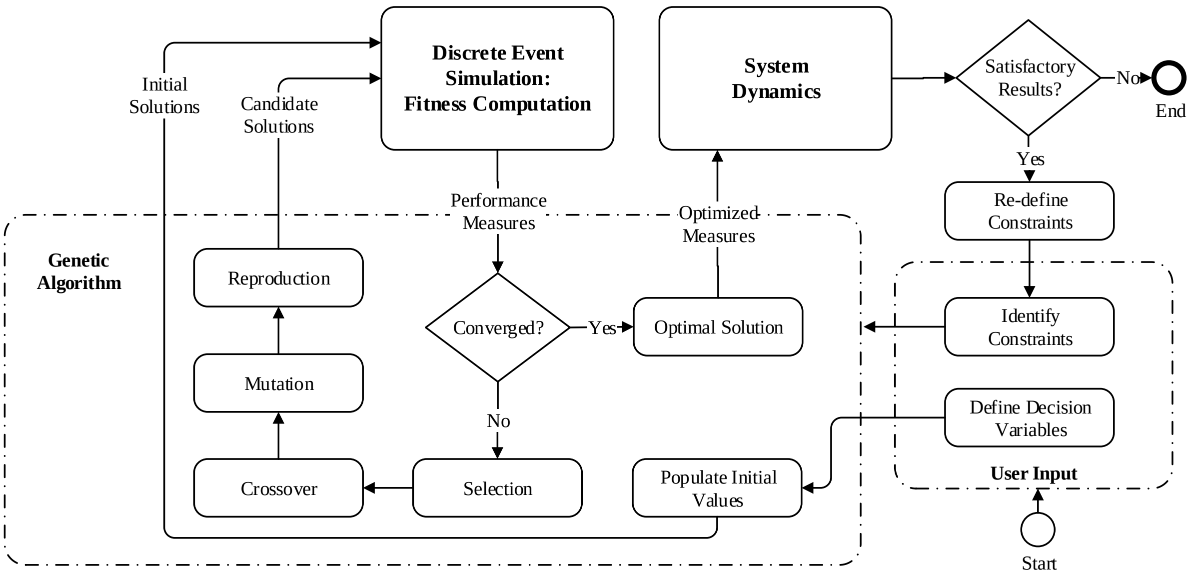

Fig. 4. Framework integrating GA, DES and SD.

The first level of the framework is very similar to the optimization strategy of the work presented in [31], where both a DES model and GA algorithm where integrated to optimize the patient flow distribution in a healthcare system, using multiple objectives. This research uses the same framework integrating both DES and GA; however the aim is to determine the optimal resource levels within the ED, rather than focusing on the patient flow distribution. The DES simulation model is developed in the ExtendSim v9.2 simulation environment, and the GA procedure as well is conducted in the same software, using its built-in evolutionary optimizer. Although the performance of ED can be optimized by using both DES and GA, it is not necessary that such improvements will have a positive impact on the entire hospital system. Therefore the SD is useful, as it can study the different interrelations between the ED and the other areas in the hospital system. Accordingly, the second level of the framework suggested, aims to combine both SO described above, with a SD model of an entire healthcare system, in order to analyze the performance wholly and realistically. The SD model is built using the Vensim environment. The framework processes are all continually repeated, and end only if satisfactory results for the system as a whole are achieved.

A. First Level of the Framework

The first level of the framework concerns integrating both DES modelling and GA. DES models are stochastic and flexible models, making them well suited to model the random and complex processes of the healthcare systems. They are useful in making operational level decisions and for that reason they are suitable in the proposed framework, for making decisions concerning the optimum resource capacities in an ED. The DES model suggested is a replication of an ED, simulating the typical ED processes, as well as the patient flow. The main purpose of the DES model is to compute the fitness function which basically assesses the quality of a solution, and measures its success in terms of various criteria. As for GA, it is an optimization technique inspired by the Darwinian theory of evolution. It is a technique that searches the solution space for near optimal results, in which individuals with better characteristics have the ability survive longer, producing a population with more superior individuals and less inferior ones. The concept of such a procedure is based on the struggle between different possible potential solutions, known as the chromosomes, and each chromosome contains a set of decision variables known as the genes. In the proposed framework, those genes may include different resource levels such as the beds, doctors or nurses. To start with, the user defines a set of decision variables, for each decision variable the maximum and minimum allowable values are defined, as well as any other identified constraints that affects the ED. The GA is used to set the values of the different decision variables in an attempt to find a near optimum value for the fitness function.

The values of the decision variables that are set by the GA are fed to the DES and in return, the DES estimates the values of several performance measures, generally including the patient's ALOS, waiting times, number of patients treated and resource utilization. Those performance measures are either optimized individually as single objectives, or collectively using a utility function that combines two or more measures. Those DES outputs accordingly act as the fitness function used when evaluating the performance of the successor generations of chromosomes produced by the GA procedure, and those outputs are returned back to the optimizer. The entire process is repeated until a successful new generation is created, that meets the required criteria. Convergence can be according to a solution that satisfies a set of constraints or an objective function, or a fixed number of generations elapsed. The selection, crossover, and mutation procedures performed by the evolutionary optimizer of ExtendSim works differently than traditional GA. The complete optimization process in ExtendSim is illustrated by the flowchart given in Fig. 5. This is described in details next.

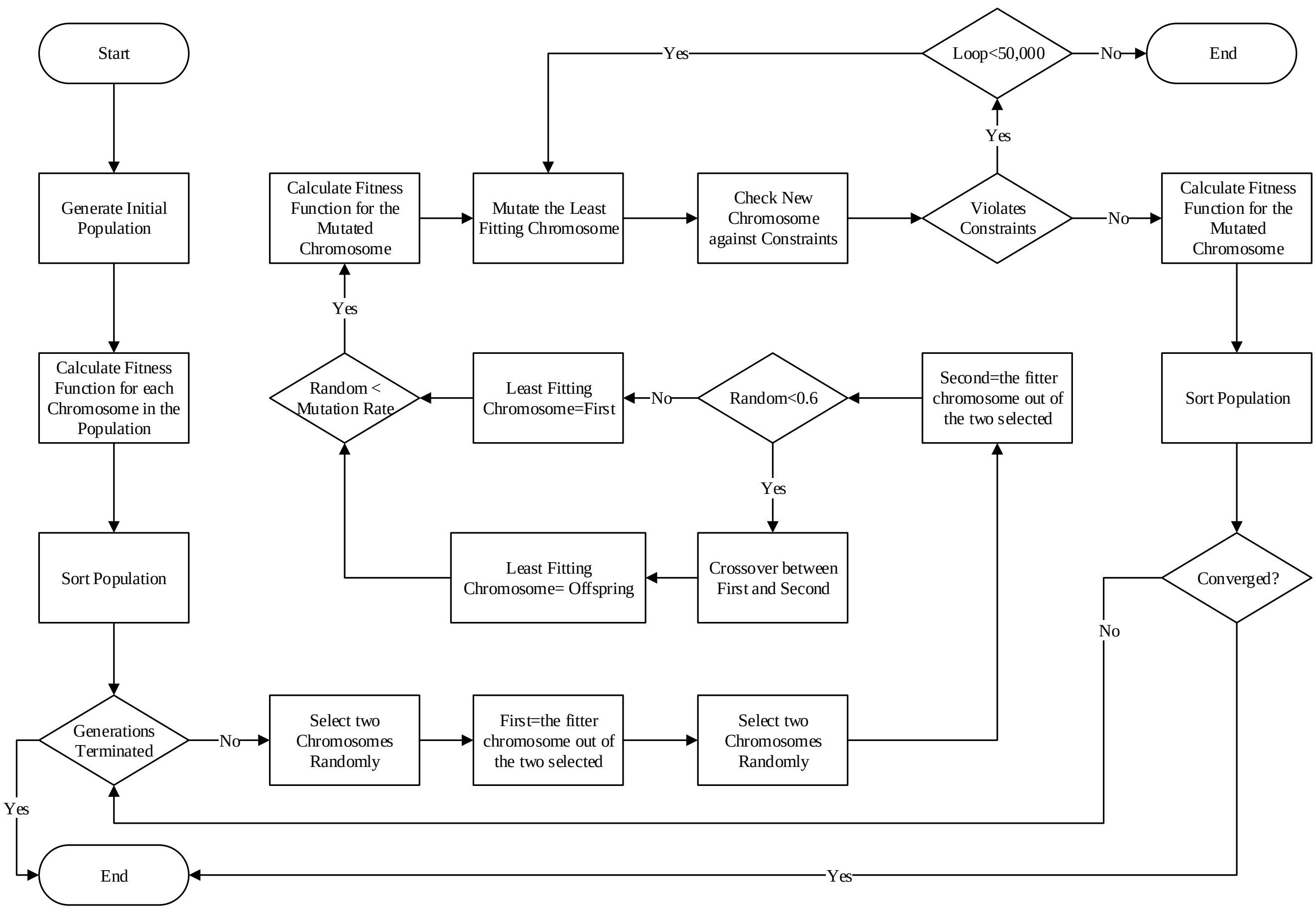

Fig. 5. ExtendSim optimization procedure

1) Initialization

The initial population is composed of a set of chromosomes and each chromosome is composed of a series of genes. Each gene represents a parameter in the optimization problem. Initially, the values of all genes are set randomly but within the upper and lower bound of the corresponding parameter. Each formulated chromosome is checked against the constraints and if it violates any constraint a new chromosome is generated. If the process of generating new chromosomes in response to constraint violation fails 50,000 times in a row, optimization is aborted and an error is reported. The fitness function is calculated for each chromosome in the population and accordingly the population is sorted. The chromosome at the top location of the population is the most fitting chromosome, while the chromosome at the zero location in the population is the worst fitting chromosome.

2) Selection and Crossover

Two chromosomes are chosen randomly from the population to have a crossover with a fixed crossover rate equal to 0.6. The crossover is performed by applying a function to each gene in the two parent chromosomes to generate the offspring chromosome. The genes of the first selected parent chromosome is multiplied by a random weight and added to the corresponding genes from the second parent chromosome multiplied by the complement of the weight (1 – weight). For example, a new gene with a value (x_{new}) results from the crossover between a gene with a value (x_1) of the first parent and a corresponding gene with a value (x_2) of the second parent according to (1).

$$x_{new} = w * x_1 + (1 - w) * x_2 \qquad (1)$$

3) Mutation

Mutation is performed only on the least fitting chromosome. Not all genes in that chromosome are mutated, but mutation is performed according to a mutation rate. The mutation rate is calculated using the number of decision variables (DV) of the optimization problem as in (2). Mutation is performed by changing the gene's value randomly. A random number from a Gaussian distribution centered on the origin with the standard deviation (σ) is generated. The standard deviation is equal to the quarter of the range of the gene and is calculated as shown in (3). Since the Gaussian distribution is centered on the origin; thus, the random number generated can be positive or negative and is added to the gene's value. Hence; after the mutation process, the new chromosome is subjected to a constraint check and again if the constraints check fails then the mutation process is repeated. The repetition of this process consecutively is limited to 50,000 times; otherwise the optimization is aborted with an error. The fitness function for the mutated chromosome is calculated and the population is again sorted to be updated by the new offspring and mutated chromosome if any.

$$Mutation\ Rate = 2/(DV + 3) \qquad (2)$$

$$\sigma = \frac{1}{4} * (Max - Min) \qquad (3)$$

4) Reproduction

The process of crossover and mutation together is called a generation. This process is repeated until either the number of generations has exceeded the number given by the user or the values of the fitness function have converged within a tolerance given by the user. Second Level of the Framework

The second level of the framework is a combination of the procedures described above for optimizing the ED, with a SD model of the entire healthcare system. Not many works propose a hybrid model of such, however, by incorporating both SO and SD, a more realistic and well-rounded representation of the hospital system could be proposed. DES models are confined to modeling the operational performance of the ED in detail, neglecting the interrelations that exist between it and other areas in the hospital, such as the outpatient clinics, the ICU, and the internal wards. In addition, optimizing the performance of ED system solely could be achieved as described in the previous section of the first level of the framework; however this may create further problems downstream, and as a result negatively impact the rest of the system as a whole. This is where the role of SD comes in handy, as it is able to represent the position of the ED in the hospital, reflecting on the interrelations within the entire health care system, and analyzing the effect of any changes made in the ED on the remainder of the hospital units.

The mechanism of the SD model in this framework is as follows; the near optimal solutions achieved through the integration of both DES and GA, are fed into the SD model and simulated over time, to observe and evaluate the impact of the relationships between the ED and the entire healthcare system, on the performance measures. Such decision variables that improved the performance of the ED, may not have the same positive effect on the rest of the hospital, but rather may lead to a shift in the bottleneck from the ED to another part of the hospital system. As a result, if the results are not satisfactory, the SD feeds back into the GA, redefining the constraints and decision variables, and triggering occurrence of the processes that take place between the GA and the DES model once again. The entire practices between the GA and DES, and the GA with the SD, continually repeat until satisfactory results are achieved.

V. An Emergency Department Case Study

A DES model replicating the performance of an ED has been built for this research using the ExtendSim v9.2 simulation environment. Data used to drive the simulation is based on a case study reported in literature for a University Hospital in Dublin, Ireland, which comprises 570 beds and an average of 60,000 patients served annually by the ED [1]. For a more detailed description of data gathered concerning the patient arrivals, the different ED processes and their servicing times, the patient flow, and the different resource available and their capacities, the reader is advised to refer to references [1, 2]. Using the optimized resource levels for nurses and doctors reported in the thesis, the DES model is run and able to measure and evaluate several performance measures. Those are then used to measure the impact of the change of the simulation input on the performance of the ED.

A. Simulation Model Development

The DES model built is able to capture the complexities in the ED resulting from the different patient types and the different routes they follow, depending on the treatment procedures they require. The routing possibilities for the different patient types are all modelled according to specified probabilities. In addition, all the different resources used in every treatment stage and the servicing times are represented. The patients' journey within the modelled ED starts upon patient arrival with the triaging process, where the severity of the patients' health is analyzed. Based on the triage analysis, patients are categorized into four types; immediate, very urgent, urgent, and non-urgent/standard patients. The more acute patients are prioritized over the least severe cases, and must achieve immediate care. The treatment process is dependent on the availability of the doctors, nurses and beds. Once the required resources become idle, the first patient in the queue proceeds to be placed in a bed and examined by a physician assisted by a nurse. Following the patient assessment, a decision is made on whether the patient is to be discharged or admitted to the hospital. The prior stages described are relevant for all the patients. Other stages are present which involve only some of the patients, but not all of them, depending on the patient type. Those stages include diagnostics, where the patient may follow through with certain blood tests, scans or x-rays, and the results of those need to be examined by the doctor again. The ED staff may also refer the patient for consultation from a medical/surgical doctor, to confirm whether a patient requires to be admitted into the hospital, or to be discharged. Between all the services, the patient is subject to waiting time, where the less critical patients are more likely to have longer waiting times.

B. Simulation Experimentation

Based on the fact that the model has been built using optimized resource levels aiming to improve the ED performance, hospital managers may be tempted to increase demand levels, and admit more than the current 60,000 patients to the ED annually, as after optimizing its resources, extra gained capacities of both doctors and nurses can now be utilized to serve more patients per year. Inspired from that concept, several experiments are conducted on the DES model, increasing the yearly patient arrivals, in order to determine the best demand that would positively affect the quality and performance of the ED, by increasing the number of patients treated, the resource utilizations, and by keeping the ALOS and waiting times for all patients at an acceptable level. Such an acceptable level for the ALOS may vary from one hospital to another, however as stated in the thesis referenced for the case study; an acceptable patient experience time within the ED should be less than 6 hours.

Currently, based on 60,000 patients admitted to the ED yearly, the ALOS for both patients admitted to the hospital and those discharged and sent home are 1.2 and 1.1 hours respectively, both of which are within the acceptable level. The ALOS for the four different patient types mentioned above has been broken down and analyzed also, indicating that immediate patients in fact have the lowest ALOS, when compared to the rest of the patient types, whether they are admitted into the hospital or discharged, as the priority is always given to more critical patients. Also, it appears that all non-urgent patients are discharged, and have the longest ALOS, given that they are of the least priority in the ED, confirming that these types of patients are most likely to wait longer for resources to become available. As for the nurse and doctor utilizations are around 66% and 85% respectively; reflecting the potential of the ED to serve more patients.

C. Analysis of results

Based on the simulation model results, an increase in the annual number of patients admitted into the ED from 60,000 to 69,000 patients shows promising results. Fig. 6 graphically represents the results of the what-if analysis conducted, varying the demand levels. The changes in the nurses' and doctors' utilizations as the annual patient demand increases are reported, in addition to ALOS for both the patients admitted to the hospital as well as those discharged from the ED.

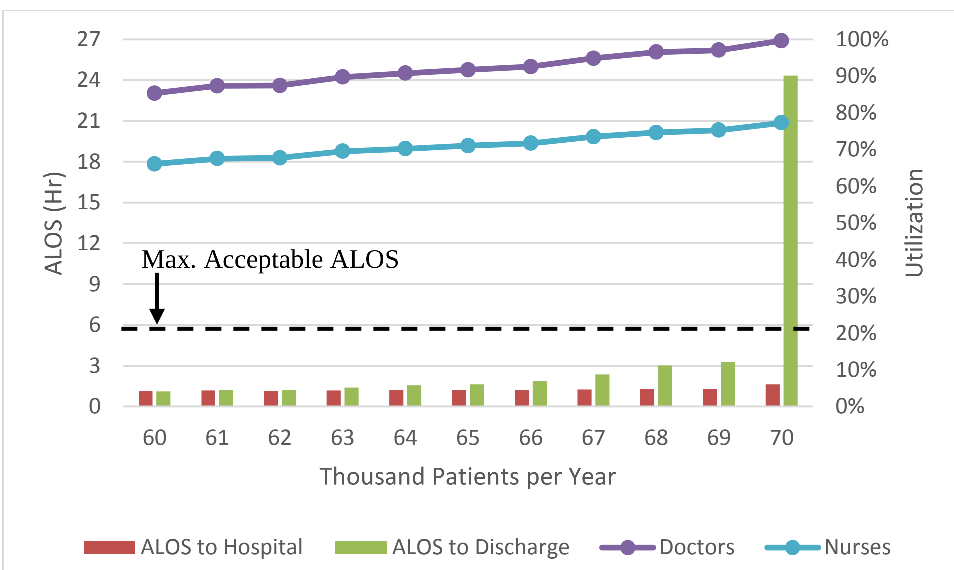

Fig. 6. Changes in the ALOS and utilizations as patient demand increases

As the patient demand increases, as shown on the graph, the resource utilizations also increase, however the ALOS of all patients increases as well. It is apparent from the chart that if the patients' demand exceeds 69,000 patients per year, the doctors reach their full utilization, and the ALOS regarding patients that are discharged exceeds the maximum acceptable limit significantly. Generally patients who complete their treatment within the ED and get discharged, require more time in comparison to other patients who are referred to and admitted to the hospital to continue their treatment, making them more sensitive to lack of resources. As a result, the ALOS of discharged patients is significantly higher than that of the patients admitted to the hospital, in the case that the doctors are fully utilized.

Accordingly, it is recommended that the ED can accommodate up to 69,000 patients annually, whilst still complying with the required standards of an ALOS less than 6 hours, with an ALOS of approximately 1.3 hours for patients admitted into the hospital, and just above 3 hours for those discharged. Furthermore, a greater benefit gained is that doctors' and nurses' utilization increase by around 14% each, when compared to the base scenario.

Other factors are affected in addition to the ALOS of all patients and the resource utilizations. For instance, such an increase in demands causes patients to wait longer to see a doctor or a nurse. Currently, based on the original case scenario, patients on average wait only around 10 to 12 minutes to be seen by the physician or the nurse, whereas increasing the demand to 69,000, causes much longer average waiting times of approximately 67 and 56 minutes per patient to be seen by the doctor and nurse respectively.

Another important measure affected by accommodating more patients in the ED is the number of patients treated and admitted into the hospital for further treatment. Originally, patients leave the ED to the hospital at an average rate of 1.33 patients per hour, which is just above 11,600 patients a year. Consequently, by increasing the patients' demand in the ED from 60,000 to 69,000, the number of patients leaving the ED to be admitted into the hospital also increases by approximately 15%, which is about 5 extra patients admitted per day. Over a period of one year, these extra 5 patients would equate to almost 1,800 patients admitted into the hospital per year. This may possibly negatively affect the performance of the entire hospital system as a whole, as by improving only the ED, the bottleneck can be shifted elsewhere within the system. This is why the integration of such an optimized DES model of an ED with an SD of the rest of the hospital is of great necessity.

VI. CONCLUSION

In this research, over 75 papers in literature have been reviewed in the area of the healthcare management as a whole, but the authors only reference those that serve the aim of this research. Publications have been categorized according to the different healthcare departments, leading to one of the most important findings of the review; that the most critical of all the departments is the ED and the management of the different resources in such a compound unit is of great importance. Various models have been found in literature studying ED, resulting in a detailed review of previous works in that unit, highlighting the model objectives, key performance measures, and different solution techniques utilized. The review showed that resource optimization of multi-objective Discrete Event Simulation (DES) modelling of the patient flow is one of the most frequently studied topics. Furthermore, research has not treated hospital systems as one whole organization, but rather divided it into sub units, and; although, the ED performance directly affects the remainder of a hospital, no researches appear to study those interrelations that exist, despite the importance of a realistic depiction of the system and understanding of its overall performance. As a result, many authors debate the benefits of utilizing SD as a modelling tool.

In response to the review of previous works, a multi-level generic framework is proposed for the optimization of resource levels in the ED and the rest of the healthcare system, improving multiple objectives. The most important OR tools required when studying the ED are integrated in this framework. DES is used to replicate the processes of the ED functioning mainly as the fitness computation for the optimization procedure. The model experiments with different decision variables, generated by the GA procedures. The main focus of the GA is to optimize the resource levels throughout the ED. Solutions are repeated continually between both models, until near optimal results are reached. Optimized results from the GA are fed into the SD model, which replicates the interrelationships that exist between all the different departments in the entire healthcare system. The solutions are analyzed, evaluating their impact on the dynamic behavior of the rest of the system. If relevant, the optimized results are re-defined, and are returned back into the GA, to be further processed and analyzed using the DES model. The entire process described is repeated continually, until satisfactory performance of the whole system is achieved.

A DES model is built replicating the performance of an ED. Data used to drive the simulation is based on a case study used to optimize the number of doctors and nurses for a University Hospital in Dublin, Ireland. As concluded from the experimentation on the DES model of the ED, and by the analysis of the results, the ED theoretically is able to accommodate and treat as much as 69,000 patients annually, in order to make use of the extra gained human resource capacities. Despite the increase in the average patient waiting times to be treated, and the slight increase in the ALOS of all patients, the ED is still able to comply with certain time standards given the rise in the demand. In addition, results imply the better use of the ED resources when patient demands were increased, as nurses' and doctors' utilization were improved respectively. Another benefit to the ED for accepting more patients is the increased throughput rate, and larger number of patients treated. However, increasing the throughput rate may only be of gain to the ED as a sole department, never the less, it may not necessarily be an advantage to the rest of the hospital to be subjected to such an increase in the number of patients to be admitted in general.

Future research will revise the optimization strategy of ExtendSim presented in Section IV, in an attempt to improve the optimization results. Also, SD will not be neglected in the research, but will also be combined with the SO in order to consider the effect of an improved ED on the whole healthcare system.

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