Using Computer Simulation for Reducing the Appointment Lead-Time in a Public Pediatric Outpatient Department

Miguel Ortiz-Barrios[1](✉), Genett Jiménez-Delgado[2], Sally McClean[3], and Giselle Polifroni-Avendaño[4]

[1] Department of Industrial Management, Agroindustry and Operations, Universidad de La Costa CUC, Barranquilla, Colombia
mortizl@cuc.edu.co

[2] Department of Engineering in Industrial Process Engineering, Institución Universitaria ITSA, Barranquilla, Colombia
gjimenez@itsa.edu.co

[3] School of Computing, University of Ulster, Coleraine, Co., Londonderry BT52 1SA, UK
si.mcclean@ulster.ac.uk

[4] Department of General Management, Sofast Ingeniería S.A.S., Barranquilla, Colombia
gisele2127@gmail.com

Abstract. Pediatric outpatient departments aim to provide a pleasant, effective and continuing care to children. However, a problem in these units is the long waiting time for children to receive an appointment. Prolonged appointment lead-time remains a global challenge since it results in delayed diagnosis and treatment causing increased morbidity and dissatisfaction. Additionally, it leads to an increased number of hospitalization and emergency department visits which augments the financial burden faced by healthcare systems. Despite these considerations, the studies directly concentrating on the reduction of appointment lead-time in these departments are largely limited. Therefore, this paper proposes the application of Discrete-event Simulation (DES) approach to evaluate potential improvement strategies aiming at reducing average appointment lead-time. Initially, the outpatient department is characterized to effectively identify the main activities, process variables, interactions, and system constraints. After data collection, input analysis is conducted through intra-variable independence, homogeneity and goodness-of-fit tests followed by the creation of a simulation model representing the real pediatric outpatient department. Then, Mann-Whitney tests are used to prove whether the model was statistically comparable with the real-world system. After this, the outpatient department performance is assessed in terms of average appointment lead-time and resource utilization. Finally, three improvement scenarios are assessed technically and financially, to determine if they are viable for implementation. A case study of a mixed-patient type environment in a public pediatric outpatient department has been explored to validate the proposed methodology. Statistical tests demonstrate that appointment lead-time in pediatric outpatient departments may be meaningfully minimized using this approach.

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1 Introduction

Patient waiting time is an important indicator of healthcare quality of service. Patients perceive long waiting times as a barrier to obtaining services, while they can also be stressful for both patients and healthcare professionals [1]. Waiting time reduction is a multi-faceted problem, encompassing diagnosis, prioritization, and triage of patients, monitoring and management of wait times, provision of adequate physical resources, and appropriate provision staff human resources and equipment [2]. In particular, prolonged appointment lead-time remains a global challenge across many medical specialties leading to delayed diagnosis and treatment as well as increased morbidity and dissatisfaction. Also, for most specialties, lengthy waits can lead to increased hospitalization and emergency department visits which exacerbate the overall problems for healthcare systems.

Despite attempts to ensure that pediatric outpatient departments provide a pleasant, effective and continuing care to children, there have frequently been problems with long waiting time for children to receive an appointment. In addition to the known consequences of prolonged wait times for adults, including further suffering, emotional distress and economic hardship, young patients particularly vulnerable as "children often require treatment at critical times to ensure appropriate development" [2]. Also, pediatric care, often involves many confounding factors, such as the degree of parental anxiety, the urgency of the illness and availability of appropriate services [3].

Discrete Event Simulation (DES) has been widely used systems for many years to model health-care and some previous work has used this approach to provide waiting time improvement strategies in general, and also specifically for outpatients [4]. For example, a simulation model was described to improve the performance of a healthcare facility by providing a simulation model for reducing outpatient waiting time by focusing on schedules of the healthcare providers [5]. A recent example is provided by [6] who analyzed the appointment scheduling system in an Obstetrics-Gynecology Department as the basis of a simulation-based decision support system for the evaluation and optimization of scheduling rules and waiting time. This system was used to identify a number of critical factors that influenced patient waiting times and proposed strategies to reschedule outpatient appointments and significantly improve patient waiting times. In general, such simulation and analysis of patient flows can contribute to the efficient functioning of a healthcare system as discussed by a recent paper which provides a number of examples and also some exploratory simulation tools [7].

In spite of such previous work, the number of earlier studies that focused on the reduction of appointment lead-time in pediatric outpatient departments is limited. As such, this paper proposes the application of Discrete-event Simulation (DES) approach to evaluate potential improvement strategies aiming at reducing average appointment lead-time for pediatric patients. The main activities process variables, interactions, and system constraints are identified and used to create a simulation model representing the pediatric outpatient department. Following validation, three improvement scenarios are considered, namely improving appointment scheduling policy, improving capacity and decreasing consultation time through eliminating non-value activities.

The remainder of this paper is organized as follows: In Sect. 2 the legal framework that motivates this intervention is presented whereas the proposed methodology is explained in Sect. 3. In Sect. 4, a case study in an outpatient pediatric department from Colombia is described. Finally, Sect. 5 illustrates the conclusions and future work.

2 The Legal Framework

Healthcare has been considered in the Colombian Political Constitution, as an essential public service that is in charge of the Government and should be therefore provided under its very strict regulation, monitoring, and control [10]. It was initially conceived as a right of a pragmatic nature, however, it has been recognized, by the constitutional jurisprudence, as a fundamental right that “comprises the prompt, efficacious, and high-quality access to healthcare services for preserving, improving and promoting the health” [11]. The Colombian Constitution of 1991 enshrines the right to health as a fundamental guarantee of children, by establishing the prevalence of their rights over the rights of other groups; this is due to the special protection provided by the Government. Law No. 1751 (2015) stipulates that healthcare given to groups object of special protection, including the adolescent population, “will not be limited by any type of administrative or economic restraint”; however, having regard to the principle of progressivity, the Government must adopt policies that aim towards expanding access to healthcare services and improving its delivery [11] as needed in the outpatient pediatric department that will be studied in Sect. 4.

In view of the foregoing, the Ministry of Health and Social Protection, by the Resolution 429 (2016), adopted a Comprehensive Healthcare Policy (CHP) whose operational framework corresponds to the Comprehensive Model for Healthcare which comprises, as one of its factors, the regulation of Integral Routes of Healthcare (IRH) [12]. The IRH contains, among other components, the Integral Route for the promotion and maintenance of health and wellness. Such route covers the sectorial and inter-sectorial actions directed towards the health promotion and disease prevention through the comprehensive assessment of health and the early detection of impairments. For the IRH design and implementation, the members of healthcare sector must use the methodological manual adopted by the Resolution No. 3202 (2016) providing the life course approach as a transverse approximation supporting the continuous monitoring of individuals’ health. One of the life stages contained in this approach is the Early Childhood which covers the period from pregnancy up to the first five years of life and is the essential cycle for the further development of human being. Another life stage is Childhood referring to the time between the ages of 6 and 11 years old. In such a period, the healthcare sector must be a guarantor of the integral development of children. This has to be also extended to the Adolescence (from 12 to 17 years), a period in which the individual’s socialization process is defined [13].

3 Proposed Methodology

For providing a good representation of outpatient pediatric departments, it is necessary to take into account the child heterogeneity, multiple care options and the existing interactions with other healthcare services (i.e. surgery, hospitalization, and emergency). In this regard, it is very important to ensure that the simulated model is statistically comparable with the real-world department in terms of assumptions, architecture, and performance [8, 9]. Integrated decision support systems should be then incorporated by health service managers to address the complexity of outpatient departments and the need for improving their performance under restricted resources. Such systems must be underpinned by robust methodological approaches that allow decision makers to identify and tackle process drawbacks. An example of these approaches can be seen in Fig. 1. This framework has the potential to support performance analysis and operational evaluation of potential improvement interventions across the outpatient pediatric systems.

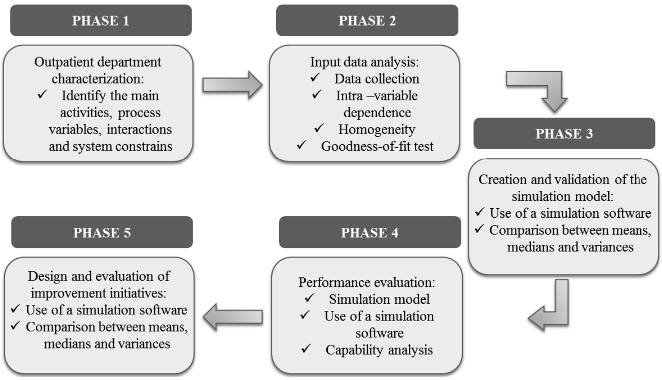

Fig. 1. The proposed framework for modelling outpatient pediatric departments and designing cost-effective initiatives

- **Phase 1** ***"Outpatient department characterization"***: In this phase, the health service managers, doctors, nurses and administrative staff are asked to give information that helps to elicit the different stages (e.g. Scheduling, Billing, and Outpatient Care), system restrictions and assumptions within the outpatient pediatric department. A conceptual model is then developed (using flow diagrams) to be later incorporated into a DES. The exogenous/endogenous variables and costs associated with the outpatient care journey are also identified to fully represent the performance and uncertainty of the department under study.
- **Phase 2** ***"Input data analysis"***: In this step, the data corresponding to the variables and parameters identified in Phase 1, are gathered from the information sources of the outpatient pediatric department under analysis. Such information must be properly filtered and assessed to avoid the inclusion of low-quality data into the DES model. The use of suitable data is important to ensure the equivalence between

the simulated model and the real-world outpatient department. The next step is to undertake an intra-variable independence test (i.e. statistical auto-correlation test) to determine whether the data follow a probability distribution or depends on other variables. A heterogeneity analysis is later carried out to detect (if possible) sub-groups of data in each variable. Statistical tests such as Kruskal-Wallis and log-rank can be applied to this particular aim. If the data are not found to be homogeneous, a probability distribution must be used to represent each sub-group; otherwise, one probability distribution is enough to model the whole dataset. Finally, a goodness-of-fit technique is performed to verify whether a statistical distribution function suitably fits the data and consequently calculate the distribution parameters that will be introduced into the simulated model.

- **Phase 3** ***"Creation and validation of the simulation model"***: In this phase, a simulation software (Arena 14.5 ®) is employed to give a virtual illustration of the real outpatient pediatric department. This promotes effective user engagement by animating the patient flows, clinical settings, and resources linked to the patient journey within the department. The conceptual model described in Phase 1 and the results of input data analysis (see Phase 2) are jointly incorporated in the software for transparency validation and further process analysis. To ensure the suitability and robustness of the results provided by the simulation software, it is necessary to rigorously examine the model transparency and conduct validation tests. To do these, key performance indicators and simulation run length need to be outlined. In this regard, 10 runs should be initially performed to estimate the sample size (number of runs) that will be used to conclude whether the simulated model is statistically equivalent to the outpatient pediatric department under study. To validate this hypothesis, a comparison between means/medians can be carried out. If the resulting p-value is greater than the alpha level ($\alpha = 0.05$), the model is considered to be a good representation of the real version and it is, therefore, useful for analysis and prediction. Alternatively, it should be examined and improved to guarantee high accuracy and applicability.
- **Phase 4** ***"Performance evaluation"***: After cross-checking the simulation results with the outcomes derived from the real outpatient department, the health service managers can proceed with the performance assessment and analysis. In this phase, the *appointment lead-time (ALT)* has been selected as the main performance indicator. The current ALT should be compared to the target (Upper specification limit – USL = 8 days) in order to determine how well the process meets the standard established by the Ministry of Health [14]. In this phase, process capability indicators Pp, Ppk, DPMO and sigma level are calculated to conclude on the current process behavior.
- **Phase 5** ***"Design and evaluation of improvement initiatives"***: Health service managers are also interested in evaluating and comparing different initiatives with a view to improving the ALT in outpatient pediatric departments. The interventions should be designed with the aid of the managers and medical staff to guarantee that they are realistic and can be executed without violating preexisting conditions. Such interventions are later modeled and initially run 10 times in Arena 14.5 ® software. After this, the final sample size is achieved and the scenario is run again according to the calculated simulation length. The results, in terms of ALT, are then

statistically compared to the current performance using a test between means or medians. In this case, if the p-value is less than the alpha level (0.05), the proposed intervention is deemed cost-effective and may result in a reduced ALT. Otherwise, it is not considered as satisfying and should not be then implemented in the real outpatient pediatric department.

4 An Illustrative Example: Modeling an Outpatient Pediatric Department from the Public Sector

4.1 Outpatient Department Characterization

A conceptual model was provided to analyze the patient journey within an outpatient pediatric department from the public sector. In detail, three autonomous stages (Scheduling, Billing and Outpatient Care) and two appointment types (First-time and monitoring) were identified (refer to Fig. 2). Our model was underpinned by a 1-year prospective dataset obtained from the User Information System (UIS) and consisting of all the pediatric appointments scheduled between 24 December and 31 December (n = 8309 appointments). In this period, 4011 (48.27%) requests were first-time appointments and the rest (4298) were asked for monitoring purposes. The patients are children between the ages of 1 and 10 years old.

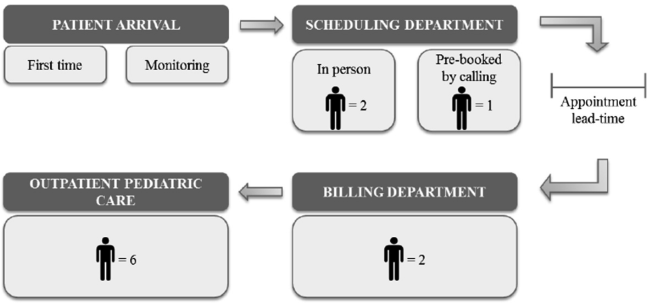

Fig. 2. The conceptual model for the outpatient pediatric department

The pediatric appointments are initially booked in the Scheduling department by two servers (SD_1, SD_2) who operate according to the shifts S_1 (8:00 am–12:00 pm; 2:00 pm–5:00 pm) and S_2 (8:00 am–1:00 pm; 3:00 pm – 5:00 pm) respectively. The appointments can be also telephonically programmed with the aid of the server SD_3 whose shift work is S_1. The scheduling policy consists of booking in accordance with the availability of pediatricians, consultation rooms and type of appointment. However, this process is currently affected by the arrival of new urgent patients, cancellations of medical agenda and equipment breakdowns. These factors increase the complexity of the scheduling problem and new approaches can be therefore needed for addressing the dynamic scenario here described. The patients are asked to arrive 1 h before the appointment time in order to deliver the service authorization to one of the servers (SB_1, SB_2) who operate in the Billing department during the S_1 and S_2 shifts respectively. This unit verifies whether the patients are already registered in the UIS and if their corresponding data are complete. If the aforementioned conditions are fully satisfied, the servers proceed with generating the invoice and service order. Afterwards, the patients go into the waiting room and stay there until they are seen by a pediatrician. In this department, there are six pediatricians who serve according to the shifts depicted in Table 1. On the other hand, it was detected that all the pediatricians arrive late every day. In addition, they tend to cancel their medical agenda every three weeks.

Table 1. Work shifts of pediatricians

Pediatrician code	Monday	Tuesday	Wednesday	Thursday	Friday
001	8:00 am–12 pm	8:00 am–12 pm	X	8:00 am–12 pm	X
002	X	X	X	8:00 am–12 pm	X
003	X	X	8:00 am–12 pm	X	X
004	X	8:00 am–12 pm	X	8:00 am–12 pm	8:00 am–12 pm
005	X	1:00 pm–5:00 pm	X	1:00 pm–5:00 pm	1:00 pm–5:00 pm
006	8:00 am–12 pm	X	X	X	X

With these considerations in mind, we defined six process variables: (1) time between arrivals for first-time appointments, (2) time between arrivals for monitoring appointments, (3) service time in Scheduling department (in-person attention), (4) service time in Scheduling department (by phone calls), (5) service time in Billing department, and (6) service time in outpatient pediatric care.

4.2 Input Data Analysis

After gathering the data corresponding to the identified process variables, an independence test was conducted to validate the randomness assumption. The results are detailed in Table 2. In this case, all the variables were found to be random since the p-values were greater than the alpha level (0.05). Once the independence was verified, a heterogeneity analysis was conducted for each dataset in order to discriminate pipelines (refer to Table 3). In this respect, an Analysis of Variance (ANOVA) concluded that the *time between arrivals* should be modeled separately based on the pediatric appointment type. This is because the p-value (0) was found to be less than the established error level (0.05). In contrast, *service time in Scheduling department, service time in the Billing department,* and *service time in outpatient pediatric care* were concluded to be homogeneous since the resulting p-values (0.8114, >0.15, >0.15) provided enough support to accept the null hypothesis (homogeneity).

Table 2. P-values emanating from the independence tests

Process variable	P-value
Time between arrivals (first-time appointments)	1.0
Time between arrivals (monitoring appointments)	1.0
Service time in the Scheduling department (in-person attention)	0.537813
Service time in the Scheduling department (by phone calls)	0.453305
Service time in the Billing department	<0.05
Service time in outpatient pediatric care	<0.05

Table 3. ANOVA outcomes

Process variable	P-value
Time between arrivals	0
Service time in the Scheduling department	0.8114
Service time in the Billing department	>0.15
Service time in outpatient pediatric care	>0.15

After validating the independence assumption and data homogeneity, the probability distributions representing the process variables were identified using Goodness-of-fit tests. For instance, the chi-squared test ($\chi^2 = 2.46$, d. f. = 1, p-value = 0.126) validated the Weibull assumption of *time between arrivals (monitoring appointments)*. The rest of the probability distributions and parameters are presented in Table 4.

Table 4. Probability distributions of process variables

Process variable	Probability distribution
Time between arrivals (first-time appointments)	EXPO (45.5) min.
Time between arrivals (monitoring appointments)	2.13 + WEIB (1.42, 4) days
Service time in the Scheduling department	NORM (3.70; 1.77) min/appointment
Service time in the Billing department	UNIF (2.4; 5.7) min/appointment
Service time in outpatient pediatric care	NORM (35; 5.7) min/appointment

4.3 Creation and Validation of the Simulation Model

A simulation model was created to offer a virtual illustration of the outpatient pediatric department under study (refer to Fig. 3). To guarantee the robustness and reliability of the simulation results, we ran the virtual model for a time period of 372 days with 9 h per day (opening period). After initial analysis, we concluded that 100 of these days were needed as a warm-up period. Such period helps the model to reach a steady condition and offer reliable and realistic outcomes. Furthermore, a pre-sample (10 replications) was conducted to calculate the required sample size for suitably representing the process uncertainty. In this case, 40 replications were concluded to be enough for this particular aim. Afterwards, the results in terms of the *average appointment lead-time* per replication were gathered and processed to evaluate the hypothesis (H_o: μ = 7.66 *days/appointment*|H_a: $\mu \neq$ 7.66 *days/appointment*). To do this, a 1-sample t test (Confidence level = 95%) was carried out using Minitab 17 ® software. The p-value (0.638) and t-statistic (0.47) evidenced that the simulation model is statistically equivalent to the real outpatient pediatric department. Hence, it can be employed for performance evaluation and analysis of potential interventions.

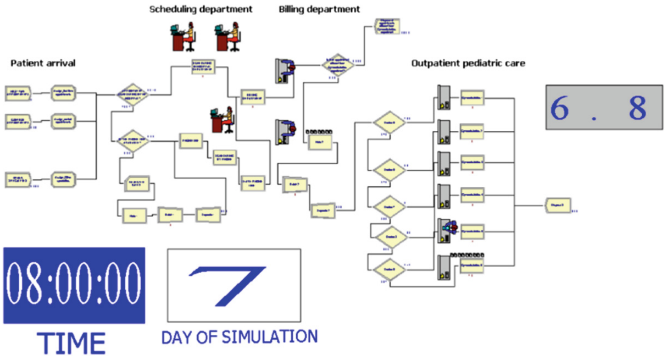

Fig. 3. DES model for the outpatient pediatric department

4.4 Performance Evaluation

Once the validation process was finished, the next step was to assess the capability of the outpatient pediatric department to meet the standard established by the local Ministry of Health (Upper specification limit = 8 days/appointment). After performing this analysis, the *average appointment lead time* was found to be 7.66 days/appointment with a standard deviation of 4.98 days/appointment. According to the capability analysis, 366959 out of 1 million of appointments will have an ALT > 8 days. In addition, the Ppu (0.05), Ppk (0.05) and sigma level (1.84) indicate that the process is not satisfactory and requires immediate intervention. It is thus necessary to create and pretest initiatives addressing the long appointment lead time (Fig. 4).

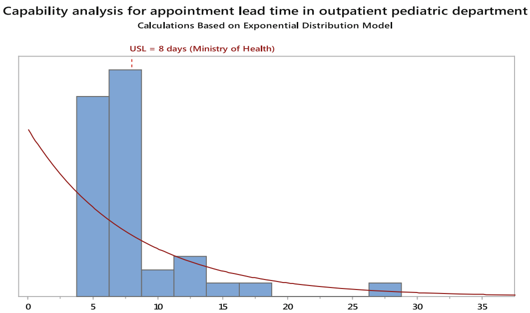

Fig. 4. Capability analysis in terms of appointment lead time

4.5 Definition and Evaluation of Improvement Initiatives

The simulation models give an opportunity to pretest improvement scenarios in outpatient departments in a satisfactory and safe manner. Despite this consideration, little evidence has been reported regarding the use of DES for this particular target [15]. The present research then attempts to fill this gap in the literature. Specifically, three initiatives were proposed by the health service managers to address the long ALT problem: (1) *Changes to appointment scheduling policy* (2) *Increase installed capacity* and (3) *Diminish the consultation time through eliminating non-value activities*. These interventions were then modeled and simulated with the aid of Arena 14.5 ® software. The results of each scenario were contrasted with the current performance in terms of ALT using the comparison test between medians (confidence level: 95%).

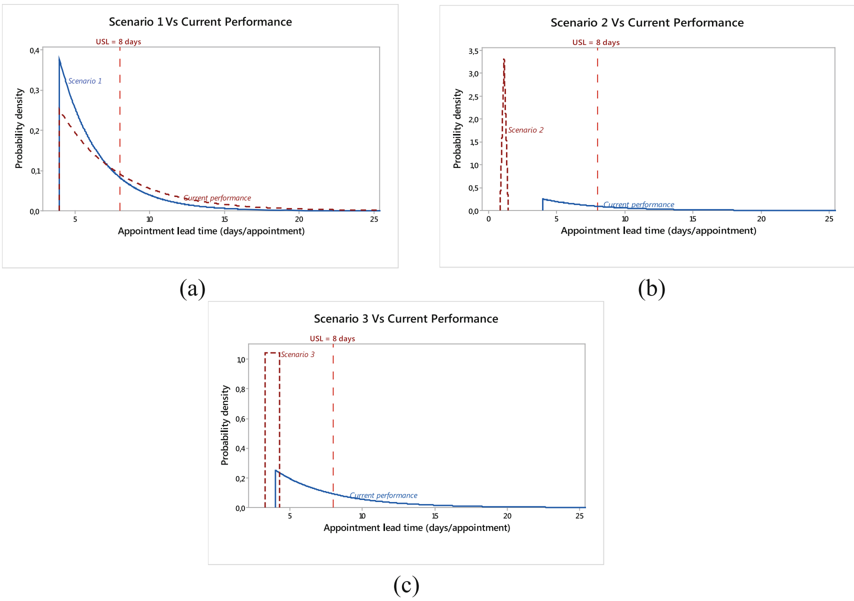

Fig. 5. Comparative analysis regarding appointment lead time between the current performance and (a) Scenario 1 (b) Scenario 2 (c) Scenario 3

Scenario 1 proposes that pediatricians 002 and 003 adopt the work shift of doctor 001. After simulation and analysis (Mann-Whitney test; CL = 95%), the ALT was found to be statistically equivalent (refer to Fig. 5a) in comparison with the current performance (p-value = 0.097; W = 565). On the other hand, Scenario 2 (refer to Fig. 5b) suggests the addition of 1 pediatrician with the same work shift established for pediatrician 006. In this case, the results evidenced that ALT can be meaningfully reduced (p-value = 0; W = 55). Ultimately, Scenario 3 (refer to Fig. 5c) considers the elimination of the time lost in interrogation. Such inefficiency is a consequence of outdated patients' medical records. After pretest and statistical examination, it was proved that the resulting ALT is meaningfully lower contrasted with the real-world department.

5 Conclusions and Future Work

Modelling outpatient pediatric departments has become a challenge for researchers and practitioners due to the presence of multiple pathways and interactions. It is hence fundamental that modelers receive support from the health service managers and medical staff to guarantee that the simulation models are robust and reliable. To this end, the collected data must be filtered and suitably processed so that high-quality information can be incorporated into the models. The acquisition of such information strongly depends on the engagement from the outpatient departments and their continuous assistance along the intervention.

Our proposed methodology develops integrated models for outpatient pediatric services and provides effective decision-making support for resource planning and process management. Nonetheless, this approach can be extended to cover interrelations with emergency care, radiology, laboratory diagnosis, and other health services so that more complex and informative scenarios can be assessed. Moreover, we plan in future work to combine this framework with cost models in order to also evaluate improvement scenarios financially.

The case study here presented evidences the functionality of simulation models when diagnosing outpatient pediatric services and pretesting improvement scenarios. In particular, it was concluded that the process is not capable to meet the standard set by the Ministry of Health regarding the appointment lead time. In addition, the results proved that Scenario 2 and Scenario 3 are beneficial for improving the performance of the department under analysis; however, both strategies should be financially evaluated before deciding on their implementation.

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