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BPMN-BASED SIMULATION ANALYSIS OF THE COVID-19 IMPACT ON EMERGENCY DEPARTMENTS: A CASE STUDY IN ITALY

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ABSTRACT

The COVID-19 outbreak, which has been recognized as a pandemic in March 2020, has brought the need to timely face an extraordinary demand of health-related resources and medical assistance. The objective of this work is to analyze the structural and procedural changes that have been enacted in an emergency department (ED), according to guidelines provided by national authorities. Specifically, guidelines deal with how to manage the access of COVID-19 patients, ensure the isolation of suspected cases, execute a proper triage, and identify the appropriate treatment path for all patients. The paper describes a process modeling and simulation-based approach to analyze the treatment of patients accessing the ED of an Italian hospital. The approach makes use of the Business Process Model and Notation standard to specify ED treatment processes before and during the pandemic, so to evaluate different scenarios and effectively support process improvement activities by use of simulation-based what-if analysis.

1 INTRODUCTION

In March 2020, the World Health Organization recognized the international outbreak caused by the SARS-CoV-2 virus (coronavirus) as a *pandemic* (World Health Organisation 2020). The SARS-CoV-2 disease 2019 (also known as COVID-19) has introduced a significant challenge for the health care system of many countries, due to the extraordinary demand of health-related resources and medical assistance that is required to deal with severe COVID-19 cases. Many hospitals and other health-care facilities have been forced to change their operational and organizational structure in order to plan and setup new treatment processes, promptly provide the appropriate care to infected patients, adequately train physicians and other health-care professionals to reduce the contagion risk, and ensure the provisioning of the necessary medical services to non-COVID patients.

Hospitals have been faced with a significant challenge as soon as it was clear that admitting patients to *emergency departments (EDs)* without any planned and dedicated paths would have been a very likely cause of increased spread of the virus, which in turn would have produced additional load for the hospital resources and structures (Alhammadi et al. 2020). In the management of any health-related emergency, an ED plays a central role as it represents the first and most important medical treatment facility where patients ask for medical assistance in urgent and often critical situations. As a consequence, an ED is highly exposed to the risk of being a spreading hotspot of COVID-19. In order to avoid such a risk, national and international guidelines (Lazio Region 2020; SIMEU 2020) have been published both to promote an accurate evaluation of patients arriving to an ED, so to promptly identify any suspected COVID-19 cases, and to identify the need of creating separated areas, teams and processes for treating both COVID and non-COVID patients.

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This paper reports about the use of process modeling and simulation-based analysis to evaluate the benefits of applying national guidelines for managing the COVID-19 emergency. Such guidelines are intended to define effective treatment processes and identify adequate procedures for ensuring the safety of the hospital environments for both hospital personnel and patients. In this respect, this paper specifically addresses the case of the ED at the Polyclinic of Tor Vergata (PTV) in Rome (Italy).

The first objective of this paper is to collect data describing the pre-COVID treatment processes executed at the PTV's ED and map them to process models specified in Business Process Model and Notation (BPMN), the reference standard for process modeling (OMG 2011). The BPMN model is then simulated, in order to validate the model and look for opportunities to improve ED performance. The second objective is to update the BPMN model in order to assess the impact of the procedural and structural changes, as provided by national guidelines, to minimize the risks associated to COVID-19 spread. The updated model is then simulated to analyze alternative resource allocations, to carry out a what-if analysis and evaluate various scenarios in terms of response times and resources utilization.

Modeling and simulation approaches have traditionally proven to be effective for investigating the patient flow and the allocation of health care resources at EDs, as reported in studies dating back to 70's (Hannan et al. 1974). Since then, various techniques based on different paradigms have been applied to analyze ED performance, such as agent-based modeling and simulation (Escudero-Marin and Pidd 2011), simulation-based optimization (Weng et al. 2011; Vanbrabant 2020) and difference equations (Brown et al. 2020). Applications to specific EDs can also be found in literature, such as in (Rado et al. 2014), which illustrates a simulation model to analyze patient flows in the ED of a hospital in Hong Kong, and in (Carvalho-Silva et al. 2018), which provides models to forecast arrivals to the ED of an hospital in Portugal, in order to properly manage both human and bed resources.

This paper is not intended to propose a new or improved modeling and simulation approach, but rather to show the effectiveness of BPMN-based process modeling, in conjunction with process simulation, to quickly react to unexpected emergency management scenarios, such as the one brought about by the COVID-19 pandemic. BPMN-based process modeling provides several advantages in terms of model understandability and automated process simulation and implementation (Antonacci et al. 2016), which are essential to quantitatively assess the operational performance and assist in the decision making process, either before or after the process implementation.

The remainder of this paper is organized as follows: Section 2 introduces the PTV's ED case addressed by this work and illustrates the proposed BPMN-based modeling and simulation approach. Section 3 discusses the impact of COVID-19 pandemic on the operations of the addressed ED. Finally, Section 4 summarizes concluding remarks.

2 PTV's ED PROCESS MODELING

As clarified in Section 1, one of the objectives of this work is to analyze the treatment processes used in an hospital to investigate the actual effectiveness of national guidelines. In this respect, data collected and analyzed by this work are referred to as the concrete case of the Italian Polyclinic of Tor Vergata (PTV), which is located in the south-eastern quadrant of Rome, close to the Faculty of Medicine facilities of the University of Tor Vergata. PTV is one of the largest hospitals in the region and is the reference point for receiving highly qualified medical assistance for the entire south-eastern area of the Lazio region, serving over 1.5 million people. According to the national classification of EDs (Italian Ministry of Health 2013), PTV is recognized as a *first level ED*, as it provides an *observation and short stay* unit and an *intensive care unit*, as well as diagnostic-therapeutic interventions of general medicine, general and orthopedic surgery, and cardiology. Section 2.1 outlines the adopted analysis methodology, while Sections 2.2 and 2.3 describe the BPMN model that specifies the treatment process enacted by the PTV's ED and the related model parameterization, respectively. Finally, Sections 2.4 and 2.5 illustrate the simulation and the validation of the model in a pre-COVID scenario, as well as the analysis of potential improvements.

2.1 Methodology Overview

The simulation-based analysis of the treatment processes enacted by the PTV's ED has been carried-out according to the following steps:

1. **Data Gathering:** The PTV operational and organizational structure has been analyzed and the currently adopted national and international guidelines have been used to identify and specify the relevant data;
2. **Model Specification**: A process model describing the ED has been specified in BPMN, according to the data collected at the first step. The so obtained model is referred to as the *pre-COVID model*;
3. **Model Parameterization:** In order to make the BPMN model suitable for being executed (simulated), data related to patient treatment has been used to parameterize the model by specifying, e.g., the different classes of incoming patients, the type and number of different resources executing process activities, as well as the time properties of each activity included in the process flow;
4. **Simulation and Validation:** The pre-COVID model has then been simulated and the simulation results have been compared with actual data, in order to validate the model. Such steps ensure that the model adequately represents the real process, thus allowing analysts to use the model for carrying out *what-if* analysis and compare/evaluate different configuration alternatives.

The *data gathering* step takes into account the national guidelines on the Intra-Hospital Triage of the Italian Ministry of Health (Italian Ministry of Health 2012) and the guidelines of Lazio Region (Lazio Region 2019), so to capture all relevant processes in execution at the PTV ED.

The *model specification* step consists of the definition of a BPMN model, which has then been given as input to the *model parameterization* step, so to make it ready for execution on a simulation engine. Finally, at the *simulation and validation* step, the process model has been executed and the simulation results collected and validated. The model specification and simulation steps have been carried out using the BPMN editor and process simulation functions of the Bizagi Modeler process management tool, respectively.

The adoption of such a simulation-based analysis methodology allows involved stakeholders to appropriately understand the process to be analyzed and, possibly, improved. The simulation-based analysis of a business process allows process analysts to investigate the process behaviour under different perspectives. Simulation outcomes help to determine the utilization degree of the resources involved in the process, in order to identify bottlenecks. In addition, simulation-based *what-if* analysis is used to assess the impact of alternative process configurations and different allocation policies of activities to resources. Finally, the business process performance can be evaluated in terms of time- or economic-related indicators, under different conditions and configurations.

2.2 The pre-COVID BPMN Model of the PTV's ED

The BPMN model specifying the pre-COVID patients treatment process at the PTV's ED is described in Figure 1. BPMN is largely used both at design time, for specifying and analyzing processes to be implemented, and at execution time, for supporting the continuous improvement of existing processes. The process description is carried out by building business process models composed of *flow objects*, i.e., the core elements provided by BPMN. Flow objects can be *events*, *activities* and *gateways*. An activity represents a step (i.e., a generic piece of work) in the process and can be either atomic (task) or compound (sub-process). An event represents the start or the end of a process, as well as something that happens during the course of a process. A gateway specifies the divergence and convergence of execution flows, in order to model the several kinds of branching in execution flows (i.e., decisions, fork, join, merge, etc.).

According to the BPMN terminology, the ED is represented as a *Pool*, which is structured in six different *lanes* that identify the various department sections, namely: the *Registration* area, the *Triage* area, three different complexity areas (*Low and Very Low, High, Very High*), according to the Emergency Severity Index (ESI), and the *OBI* area, which is dedicated to short and intensive observation.

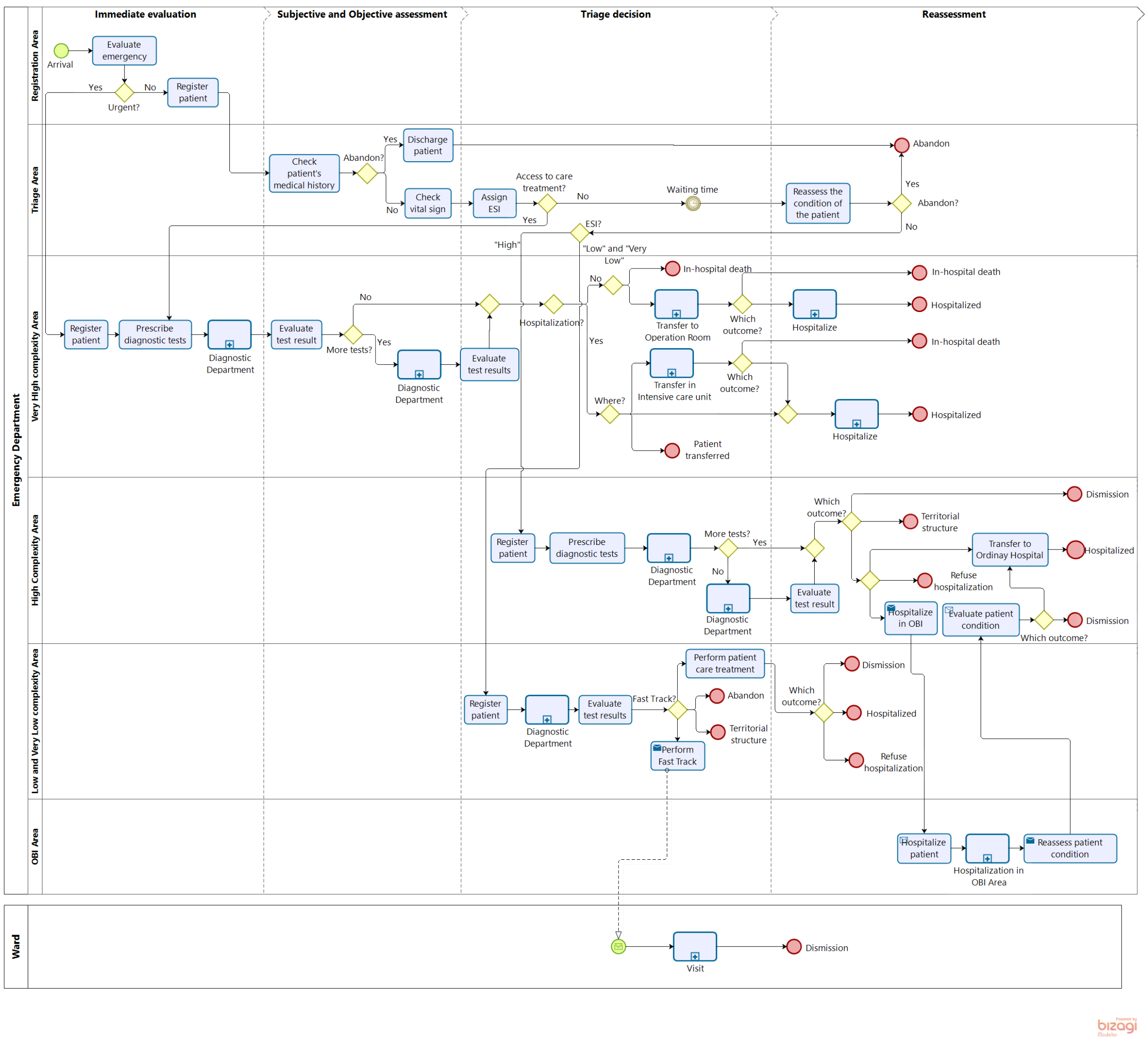

Figure 1: The ED pre-COVID BPMN model.

Table 1: Maximum waiting time

Category	ESI	Maximum Waiting Time
Critical	Very High	Immediate Access
Emergency	Very High	15 min
Urgent	High	60 min
Standard	Low	120 min
Non-Urgent	Very Low	240 min

Patients that enter the ED are routed to the Registration Area. The Triage process can be divided into four sequential phases (Lazio Region 2019; Italian Ministry of Health 2012), specified in BPMN as process sub-partitions: *Immediate evaluation*, *Subjective and Objective assessment*, *Triage decision* and *Reassessment*. The immediate evaluation phase allows the identification of patients in critical conditions, which need to be immediately taken care of. This category of patients are classified as *very high ESI* and are rushed to the intensive care units to be immediately treated. Non-critical patients, after the registration, are evaluated by a triage nurse, who associates the correct ESI category to each patient, so as to determine the adequate priority level for receiving the required treatments.

The ESI classification includes four different categories of patients: "Very High" (critical and emergency), "High" (urgent), "Low" (standard), "Very Low" (non urgent). By convention, one color is associated to each degree of severity: red color for "Very High", yellow color for "High", green for "Low" and white for "Very Low". In the remainder of this paper the "Low" and the "Very Low" categories are treated as a single category, being in practice exposed to the same treatment flow. The "Very High" severity index includes two types of patients: *critical* and *urgent*. Even though both fall into the same category, they are recognized to have different maximum waiting times before accessing the treatment, as detailed in Table 1.

Depending on the patient's severity index, and therefore the area of treatment involved, different treatment activities have to be carried out. The *OBI* identifies an intensive short observation unit, that is a specific function of the emergency medicine dedicated to clinical observation and completion of the diagnostic procedure. This function is reserved to patients that require additional observation to be fully evaluated (in no more than 8 hours). Patients can exit the process in different ways: dismissed, hospitalized, transferred to external facilities (EF) or other hospitals, or moved to the morgue (in case of death). In addition, some patients might decide to leave the ED due to, i.e., an excessive time spent before receiving a treatment or because they refuse hospitalization. The next section illustrates the data analysis carried out for parameterizing the model shown in Figure 1.

2.3 Parameterization of the Process Model

Data related to the execution of emergency health care activities (in case of both emergency services and first aid activities) are regularly collected by hospitals' information systems. Such local data are continuously sent to the National Health Information System and to the Regional Health Information System, so to effectively support the national and regional planning of the healthcare service. In this work, the BPMN model presented in Section 2.2 has been parameterized according to data collected by the Emergency Health Information System (SIES) and published as a report entitled "Report on hospitalization for acute patients in the Region of Lazio" (Lazio Region 2018). The data analysis has considered the different flows the patient might take to receive the required treatment, from ED arrival to ED dismissal. Specifically, for the initial parameterization of the model and its validation we considered the activities carried out at the PTV's ED in 2018. The considered data include the number of total arrivals to the ED during 2018, with the related ESI assigned during the Triage phase, and the average times in the ED, as detailed in Table 2, as well as the percentage of different outcomes, as detailed in Table 3.

The ED under study has served 54,015 patients in 2018 (Lazio Region 2018). It is assumed that the number of daily arrivals to the ED was constant throughout the year, that is approximately 150 patients/day.

Table 2: Data related to Emergency Severity Index and Average Time in ED

Access to ED (min)	**Triage (%)**					**Time in ED (min)**
	Red	*Yellow*	*Green*	*White*	*Not seen*	
56	5.2	23.9	63.6	6.6	0.7	286

Table 3: Data related to ED outcomes

Outcomes (%)						
Abandon	*Dismissed*	*Hospitalized*	*To other Hospital*	*Refuse*	*To Morgue*	*To EF*
11.4	44	16.4	2.6	8.7	0.6	16.3

Table 4: Staff in the ED model by lane and number of workers

Lane	**Staff**	**Num**
Registration Area	Administrative Staff	1
Registration Area Triage Area	Triage Nurses	2
Very High Complexity Area	Doctors	1
	Nurses	2
High Complexity Area	Doctors	1
	Nurses	2
Low and *Very Low* Complexity Area	Nurse	1
OBI Area	Nurse	1
Ward	Doctors	2

The ED process includes several types of human resources, such as doctors, nurses and administrative staff, as reported in Table 4, which shows the allocation of personnel in the various sections corresponding to different lanes in the BPMN model.

To provide 24/7 service, the ED requires staff working in different work shifts (8 hours per shift including a meal break), to cover the patients' demand over an entire day. To satisfy the expected quality of services, the ED aims to achieve the following service targets, as recommended by the national guidelines of the Ministry of Health (Italian Ministry of Health 2012):

1. the triage must start within 5 minutes from patient arrival to the ED;
2. a maximum waiting time for access to treatment areas is defined for each severity level, according to Table 1;
3. the maximum time in the ED, from preliminary patient evaluation to complete ED treatment, is 8 hours.

The collected dataset has been used to parameterize the BPMN model, in order to simulate the pre-COVID model and carry out its validation against real data, as discussed in the next section.

2.4 Model Validation

According to the data from previous section, a constant flow of 150 patients per day has been considered. Specifically, the interarrival time has been modeled as a negative exponential distribution, with an expected arrival time of a patient every 9.7 minutes. Starting from the data obtained from the SIES and the information about human resources involved in the ED process, the validation of the pre-COVID model has taken into account two different categories of simulation result:

Table 5: Simulated and actual values for the Triage phase.

		Triage					
		Very High	*High*	*Low*	*Very Low*	*Not seen*	***Total***
Simulation	%	6	24.7	68		1.34	100
	value	9	37	102		2	150
Real Data	%	5.2	23.9	69.6		0.7	100
	value	8	36	105		1	150

Table 6: Simulated and actual values of ED outcomes.

	Simulation		**Real Data**	
	Value	%	Value	%
Abandon	16	10,7	17	11,4
Dismissed	66	44	66	44
Hospitalized	20	13,4	25	16,4
Transfer to EF	29	19,4	24	16,3
Refuse Hospitalization	15	10	13	8,7
Transfer to morgue	1	0,6	1	0,6
Transf. to other Hospital	3	2	4	2,6
Total	150	100	150	100

Table 7: Simulated and actual values of Average Time and Maximum Time.

	Avg. Time (min)	**Max Time (min)**
SIES	287	not available
Simulation	295.24	715.84

1. **Complexity and Patients Outcomes:** A first validation step has taken into consideration the patient's categorization (in terms of the assigned severity index) and the outcomes. Table 5 and Table 6 summarize the comparison between real and simulated data for the triage evaluation and the patient outcomes, respectively.
2. **Critical Process Performance:** The second validation step has addressed the simulation outcomes in terms of critical parameters such as the time spent by patients in the ED. The comparison between real and simulated data is described in Table 7 in terms of average time, as retrieved from the SIES (which only provides average values), and the maximum time, to be compared with targets set by national guidelines.

The comparison of simulation results and actual data shows a significant overlap in almost all cases, with the exception of the maximum time in the ED, which is not available in terms of actual data. However, the value obtained from the simulation is higher than the value of the maximum time specified in the guidelines of the Ministry of Health, i.e, 8 hours (480 min).

The simulation of the pre-COVID model also revealed other potential directions for improving process performance. Results show that the utilization of many ED resources is lower than 60%. Triage nurse utilization is 52.9%, doctors and nurses dedicated to the *urgent* patients utilization is 32.8% and 17.6%, respectively. Support staff utilization is 12.6%. This is motivated by the fact that treatment of patients of *Very High* and *High* severity index categories is mostly carried out outside the ED. Differently, the simulation results show that the resource with the highest utilization (96.5%) is the nurse dedicated to the treatment of patients with *Low* and *Very Low* degree of urgency. This is also due to the significant percentage of patients with such degrees of urgency and the amount of resources dedicated to their treatment, as reported in Table 1.

2.5 Potential Improvements

Possible directions for improvements could be easily evaluated by using the same BPMN model and the simulation-based analysis under various configurations of resources allocation.

As an example, an alternative scenario could be represented by a process configuration with two *Nurse* resources assigned to the *Low and Very Low* complexity area. The simulation results for this alternative allocation of Nurse resources are summarized in Table 8, which shows the resource utilization in the two considered scenarios. As expected, the increased number of *Nurse* resources significantly reduces utilization. Moreover, the increased staff availability in the considered area also leads to a reduction of the average time and the maximum time spent in the ED. In particular, the maximum time obtained from the simulation is around 229 min, largely lower than the maximum time specified in the guidelines of the Ministry of Health (480 min).

Table 8: *Nurse* resource utilization in the considered scenarios.

	1 Nurse	**2 Nurses**
Utilization	96.48%	63.56%

An additional investigation that can be easily carried out using the simulation-based analysis deals with the impact of the patients arrival rate on the performance of the treatment process. As an example, we have considered different values for the patients arrival rate, ranging from 110 to 200 arrivals per day, for process configurations with 1 or 2 nurse resources. The simulation results are summarized in Table 9, which shows the utilization of the Nurse resources for different values of the arrival rate (arrivals per day), and in Table 10, which summarizes the average and maximum times spent in the ED.

Table 9: Utilization results analysis of the *Nurse* resource as patients number increases (simulation results).

	1 Nurse	**2 Nurses**
110 patients	90.15%	48.12%
130 patients	89.04%	53.41%
150 patients	96.48%	63.60%
200 patients	96.62%	91.16%

Table 10: Average and Maximum Time for different numbers of *Nurse* resources and an increasing number of patients (simulation results).

	1 Nurse				**2 Nurses**			
	110 pt.	***130 pt.***	***150 pt.***	***200 pt.***	***110 pt.***	***130 pt.***	***150 pt.***	***200 pt.***
Avg. Time	103.34	175.67	295.24	1021.25	58.27	67.77	85.93	215.82
Max. Time	274.9	498.55	715.84	2028.16	179.11	180.78	229.32	436.16

As expected, an increasing number of incoming patients leads to a greater flow of patients in the *Low and Very Low* complexity area which, in turn, impacts the utilization of the critical *Nurse* resources. Even with 2 nurses assigned to this area, with an arrival rate equal to 200 patients per day, the utilization for the *Nurse* resource is going to exceed 90%. On the other hand, it should be highlighed that, despite the fact that utilization for the *Nurse* resource is close to 90% and could result in possible resource saturation, the maximum time in the worst case, which is 436.16 minutes (i.e.,7 hours and 16 minutes), remains below the threshold specified by the ministerial guidelines (8 hours).

3 COVID-19 IMPACT ANALYSIS

As discussed in Section 1, in order to adequately deal with the COVID-19 pandemic, any organization providing health care services has been forced to promptly change its operational and organizational structure in order to tackle the sanitary emergency and to enact the required countermeasures to mitigate the risk of further spread of the virus among patients, physicians and employees. Among the several organizational actions undertaken by hospitals, the most relevant ones have involved ED operations such as the reorganization of the patients flows, the redefinition of the triage procedures and the redistribution of health care resources. This section addresses the organizational activities that have been carried out at the PTV's ED. Specifically, the next subsections clarify how the ED treatment processes have been modified in order to face the COVID-19 pandemic and how such countermeasures impact the BPMN model specified in Section 2.2. The updated model, denoted as *COVID-aware process model*, has then been simulated to evaluate the process performance.

3.1 Pre-Triage Area

The first change that the ED treatment process has been exposed to is the creation of a novel *Pre-Triage Area*, according to the safety procedures promoted by regional guidelines (Lazio Region 2020). In such an area, the patients temperature is first measured. Patients are also required to complete a questionnaire to assess the possible risk of being infected or being in contact with people infected by the SARS-CoV-2.

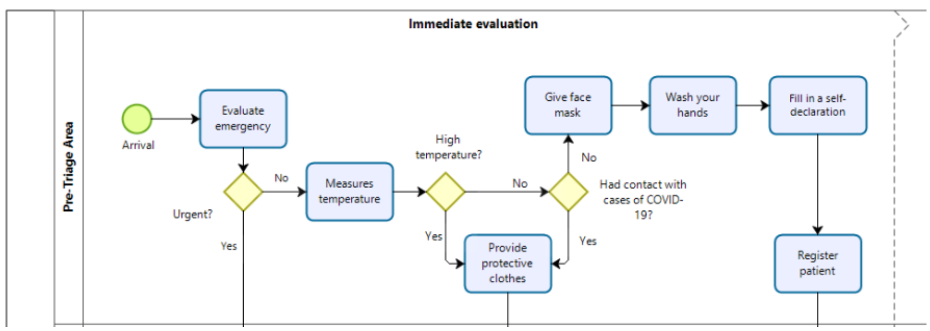

Figure 2: Pre-triage Area in the COVID-aware BPMN model.

3.2 Bridge and COVID-19 Areas

In the pre-COVID model, patients classified with a *very High* complexity level are given immediate access to treatment. Patients in such critical conditions cannot be checked in advance for possible COVID-19 infection, and thus they are treated as COVID-19 patients. Patients with a normal temperature and not suspected to be infected by the SARS-CoV-2 (according to questionnaire answers) continue the treatment process as specified by the ED pre-COVID model. Finally, patients that are recognized to be potential COVID-19 cases are evaluated by use of a nasopharyngeal swab. In this respect, a new *Bridge Area* is introduced in the model, as shown in Figure 3.

Based on the swab test results, negative patients are allowed access to the Triage area. Positive patients are instead sent to a new area dedicated to the treatment of COVID-19 patients, as shown in Figure 4.

3.3 Simulation of the COVID-aware BPMN Model

Data regarding the ED operations during the pandemic is not yet completely available, due to the emergency situation still in progress in Italy. For this reason, the parameterization of the COVID-aware process model has been based on a survey that collects information about ED access in Lazio region in 2020 (Pinnarelli

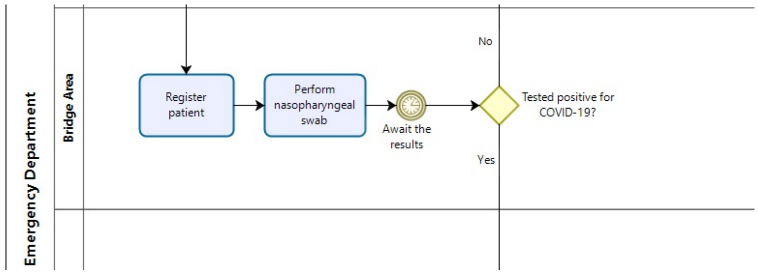

Figure 3: Bridge Area in the COVID-aware BPMN model.

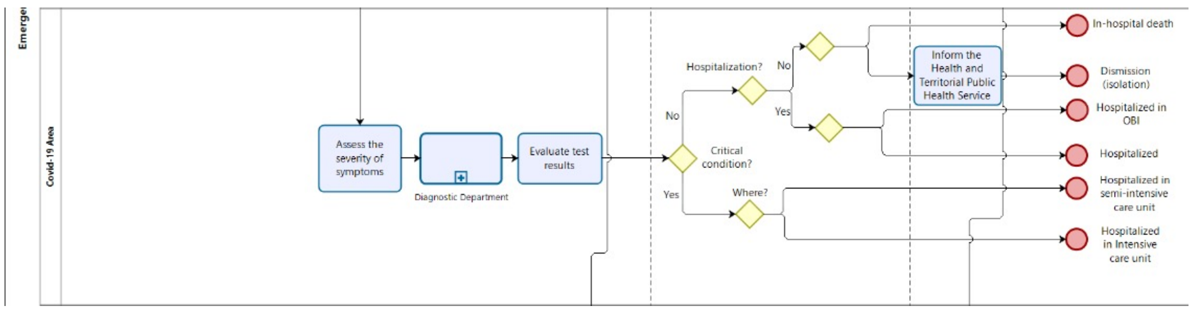

Figure 4: COVID-19 Area in the COVID-aware BPMN model.

Table 11: Average and Maximum Times for COVID-19 patients (simulation results).

		Avg. Time (min)			**Avg. Time (min)**		
Swabbing	***COVID-19 pos.***	***110 pt.***	***150 pt.***	***200 pt.***	***110 pt.***	***150 pt.***	***200 pt.***
50%	*20%*	94.37	194.92	501.49	240.75	583.46	1295.61
	40%	71.87	145.65	384.94	144.93	387.61	924.41
70%	*20%*	78.3	187.58	499.95	198.67	560.46	1287.49
	40%	95.57	223.32	435.23	224.36	461.48	1050.35

et al. 2020). According to such a contribution, in the first three months of the year 2020, accesses to the EDs in the Lazio Region counted 353.806 patients. In 2019, the access in the same period counted 429.972 patients, thus obtaining a 21.5% reduction in terms of patients arrival. In order to estimate the patients arrival rate for the COVID-aware process model, the same reduction has been considered in 2021, thus obtaining a value of 118 patients per day. However, in order to evaluate increasing arrival rates, the simulation-based analysis has considered three different values for the patients arrival rate: 110, 150 and 200 patients per day. Similarly, the data summarized in the aforementioned survey have been used to identify two different scenarios for the percentage of patients exposed to nasopharyngeal swab (50% and 70%), with a percentage of positive cases of 20% and 40%.

Table 11 shows the simulation outcomes realated to the average and the maximum time spent in the ED for the various cases. As expected, as the number of incoming patients increases, the average and maximum stay times also grow. Such values are sometimes higher than the same value obtained in the pre-COVID model simulation, highlighting the impact of the COVID-19 procedures to ED operation.

Moreover, a growth in the positive cases rate of the nasopharyngeal swab test leads to a decrease of the average and maximum times in both cases of 50% and 70% incoming patients that are tested.

This results can be explained by the fact that, once COVID-19 positive patients have been identified and the first patient assessment visits have been made, the path inside the ED ends, because the care treatment is no longer in charge of the ED. This is also stressed in Table 12, which reports about the degree of

Table 12: Utilization of critical resources (simulation results).

		Utilization					
		Pre-Triage		Bridge and COVID Area		Low/Very Low Area	
Swabbing	***COVID-19 pos.***	***150 pt.***	***200 pt.***	***150 pt.***	***200 pt.***	***150 pt.***	***200 pt.***
50%	*20%*	62.73%	63.20%	42.02%	42.94%	91.28%	97.12%
	40%	63.40%	70.62%	52.50%	68.10%	87.44%	94.85%
70%	*20%*	62.49%	62.90%	54.50%	56.20%	90.26%	95.38%
	40%	67.70%	69.87%	89.83%	94.69%	70.08%	84.37%

Table 13: Simulation results for Average and Maximum Times (improved model).

		Avg. Time (min		Max. Time (min	
Swabbing	***COVID-19 pos.***	***150 pt.***	***200 pt.***	***150 pt.***	***200 pt.***
50%	*20%*	78.05	166.5	240.01	373.78
	40%	69.54	155.39	182	385.52
70%	*20%*	68.15	140.49	296.79	374.6
	40%	68.86	137.94	181.3	329.96

Table 14: Resources utilization analysis (improved model).

		Utilization					
		Pre-Triage		Bridge and COVID Area		Low/Very Low Area	
Swabbing	***COVID-19 pos.***	***150 pt.***	***200 pt.***	***150 pt.***	***200 pt.***	***150 pt.***	***200 pt.***
50%	*20%*	79.48%	92.75%	25.21%	30.58%	56.48%	71.51%
	40%	79.33%	93.25%	34.22%	44.24%	44.24%	61.85%
70%	*20%*	74.42%	90.46%	33.64%	41.73%	53.74%	70.83%
	40%	76.65%	89.90%	49.52%	60.92%	38.63%	54.28%

utilization of three resources considered potentially critical. While the Pre-Triage nurse has a high but not critical degree of utilization, the other two considered resources exhibit significantly higher values. Data regarding these two resources shows that an increase in positive cases to the COVID-19 test implies an increase in the degree of utilization of the resource of the Bridge and COVID-19 Area.

The values shown in Table 11 are in some cases not acceptable if compared to the guidelines of the Ministry of Health. For this reason, the COVID-aware BPMN model has been improved by adding one unit to the resource dedicated to the COVID-19 Area and one nurse dedicated to the “Low” and “Very Low” Complexity Area. The results of the simulation of such an improved model, in terms of average and maximum times and resources utilization, are reported in Table 13 and Table 14, respectively. In such a case, it is easily seen that the maximum time spent in the ED satisfies the national guidelines even in the worst case scenario of 200 patients per day.

4 CONCLUSIONS

This paper has reported about a process modeling and simulation-based approach to evaluate the operations of the ED of an Italian hospital before and during the COVID-19 pandemic. Specifically, the treatment processes executed at the ED of the Polyclinic of Tor Vergata in Rome have been taken into account. The simulation-based analysis has been applied to evaluate the ED operations before the COVID-19 spread, in order to build a BPMN model of ED operations and validate the model against actual data. Then, the BPMN model has been updated to incorporate the changes suggested by national guidelines to properly deal with COVID-19 cases, and the updated model has been simulated to get insights about the ED performance, as well as to suggest potential improvements. Work is in progress to extend the application of the proposed approach to additional hospitals and to use updated and more detailed data as soon as they are available.

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