Process analysis for a hospital Emergency Department

ANTONIO DI LEVA
University of Turin
Department of Computer Science
Corso Svizzera, 185 - Torino
ITALY
dileva@di.unito.it

EMILIO SULIS
University of Turin
Department of Computer Science
Corso Svizzera, 185 - Torino
ITALY
sulis@di.unito.it

Abstract: This paper provides an application of the BP-M* methodology to care pathway for patients in a health-care Emergency Department. On the basis of an analysis of the context, a decision support framework made of several Key Performance Indicators is performed. By using the model, managers were able to run different scenarios, to identify bottlenecks and to explore solutions that can lead to better performance. The model takes into account not only the flow of patients but also: a) the timing of the activities and resources used (both personnel and equipment), b) the severity of the patient's pathology, c) the distribution in time of arrivals of patients. By running several experiments with different configurations, the analysis of these scenarios has provided useful information for management of the department and for the re-engineering of the process.

Key–Words: Business Process Management, Business Process Modeling, Process Analysis, Emergency Department, Simulation

1 Introduction

In this paper we apply a methodology called BP-M* (Business Process Methodology*) [6] to an Emergency Department (ED) of a public hospital[1]. A feature of BP-M* concerns the use of simulation during the analysis and the restructuring of processes. While several studies have shown the usefulness of computer simulations, real case applications are still lacking, especially in the field of public administration. At the same time the public sector is increasingly required to provide better services at lower cost, strengthen its customer focus and monitor control processes.

A core area for governments is healthcare, as the topmost agenda includes providing and improving healthcare facilities to the population. Nevertheless, in many countries costs are increasing in a resource-limited setting and improving performance become a key element. For instance, the pre-crisis growth of OECD countries resulted in average public expenditure on health increasing at an annual rate of almost 4%. After 2010, growth in spending came almost to a halt overall with reductions in many cases[2].

In this context, tools and techniques to help the re-engineering process are urgently needed. We focus on one of the more complex area in a public hospital, i.e. the emergency field. An aim of this paper is to demonstrate the usefulness of our approach to analyze EDs.

EDs are facing to lack of resources, long wait times, overuse of emergency services. Workers often complain dissatisfaction in an high stress work environment. Some patients could decide to leave without being seen. These problems can lead to well-known situations of inefficiency, medical risk, and financial loss [14].

Several indicators coming from real data are initially collected. With this information, we document the current situation as it is (As-Is model). Then, simulation can be used to see how entities flow through the system and to detect and understand inefficiencies, bottlenecks, constraints, and risks. Finally, the analysis of the As-Is model in different scenarios may suggest changes in the model and the effects can be studied without the commitment of any physical resources or interruption of the real system.

The current work includes at least three main point of interests:

i. *Real Data*: we based the simulation on real data coming from the department under analysis. Similar relevant works considered patient arrival pattern based on the average of data collected from other hospitals [7], or adopted a constant pattern due to the unavailability of detailed data from the real system [15].

[1] The case relates to a medium sized city (about 40,000 inhabitants) located in northern Italy.

[2] Cfr. OECD Health Statistics 2016, at http://www.oecd.org/els/health-systems/health-data.htm

ii. *Set of KPIs*: a relatively high number of KPIs can be taken into account, in comparison with similar works which include only a small subset, i.e. waiting time and/or length of stay.

iii. *Costs*: the simulation of the ED process includes an analysis of ED staff and hospital services based on real costs. Expenses for doctors, nurses and operators can be covered, as well as charges for laboratory analysis, blood tests and radiological examinations.

The paper is organized as follows. Section 1.1 introduces a review of related work. In Section 2 we briefly describe our methodology. Sections 3 focuses on the simulation model, presenting the results of tests with different scenarios. Section 4 discusses our results.

1.1 Related Work

The Process Modeling usually refers to methods, techniques, and software used to analyse and support business processes. Typical procedures concern design, control, and analysis of operational tasks which involve humans, documents, organizations or applications [31]. A standard notation called Business Process Modeling and Notation (BPMN) was created to present business processes [3, 28].

Business Process simulation was already applied in industrial reengineering [27, 24]. The more common simulation modeling methods are System Dynamics (SD) [9], Discrete Event Simulation (DES) [15], and Agent-Based Modeling (ABM) [11]. Simulations demonstrated their utility in modeling public services [12], as in the cases of public administration process [17], political decision-making [25], contact information for public health and social care services [32]. In the Health sector, some applications include the simulation of the functioning of healthcare clinics [8], spreading of diseases [20], assessing costs of care [21], planning radiation therapy treatment [33].

In addition to more traditional statistical approaches [19], DES emerged as an alternative method to model EDs [2, 6, 23]. DES was already applied to improve the patient throughput time [26] or the scheduling of staff members [13], as well as to reduce patient waiting times [7]. Other works deal with the impact of staff scheduling on overall utilization and burnout issues [30]. Moreover, a simulation-based optimization to staff levels can be performed [10]. Some systems focused on the trade-offs between different alternatives such as adding more beds or altering the admission rate [16]. Few studies deal with costs of personnel and equipment, as in [4] where personnel costs and hospital total charges are considered.

The validation of the simulation model includes the comparison between indicators given by the model with real data. To evaluate simulation results, most ED studies consider basic performance indicators as the Length-of-Stay (the time from patient arrival to patient's discharge, shortened in LoS), the Door-To-Doctor-Time (from patient arrival to seeing a doctor or a mid-level provider, shortened in DTDT) and the amount of patients who Left Without Being Seen (LWBS).

A recent review identifies at least 202 indicators from 127 articles that belongs to main four typologies: satisfaction, process, structural, and outcome [18]. A wide set of Time intervals is detailed in [29]. The most studied categories are process-related performance indicators, as length of wait/stay or ED occupancy/crowding. Nevertheless, most works include only few indicators (an average of 1.6 KPIs per article).

2 The BP-M* Methodology

The BP-M* methodology analyses functional, behavioral, and organizational aspects of the object system, and it strongly enforces an event-driven process-based approach as opposed to traditional function-based approaches.

BP-M* was briefly described in [6] and consists of four logically successive phases:

1. **Context Analysis**

   The context analysis phase aims to fix the overall strategic scenario of the enterprise and to determine the organizational components which will be investigated.

2. **Organizational Analysis and Process Engineering**

   The purpose of this phase is the determination of the activities that constitute the process and of the causal relationships existing between them. The process is then reconstructed starting from external input/output events and/or objects. A process must be validated with stakeholders involved in the process, using animation and simulation of its specification, obtaining the so called As-Is model. This model provides managers and engineers with an accurate model of the enterprise as it stands, out of which they can make: a) a good assessment of its current status and b) an accurate estimation of available capabilities.

3. **Process Diagnosis and Reorganization**

   The purpose of this phase is to trace back from the problems highlighted in the previous phase to possible solutions to be taken in order to restructure the As-Is model generating in this way the new To-Be version.

4. **Information System and Workflow Implementation**

   When the To-Be model has been approved, it has to be transmitted to engineers for implementation. In the BP-M* methodology, two implementation aspects are considered: 1) the specification of the Information System environment, and 2) the specification of the Workflow execution environment.

Because the aim of this paper is the analysis of a real process, the treatment of patients in an emergency department, we will deal primarily with Phase 2 of the BP-M* methodology and Phases 3 and 4 will not be discussed.

In the following, we describe the specification language used in the methodology and the set of KPIs adopted in our work.

2.1 BPMN

A key element of BP-M* is the Process Diagram (PD), which is used to describe the process. The diagram is specified by the BPMN language [19] which is a graphical notation that describes the steps in a business process. BPMN describes the end to end flow of a business process. The notation has been specifically designed to coordinate the sequence of processes and the messages that flow between different process participants in a related set of activities.

BPMN consists of four basic categories of graphical elements: Flow Objects, Connecting Objects, Swimlanes and Artifacts.

Flow Objects are events, activities, and gateways. An event is something that “happens” during the course of a business process. Events affect the flow of the process in different moments: Start, Intermediate, and End. Events are simply represented by circles with open centers to allow internal markers to differentiate them. Activities are single task or sub-processes. The representation of an activity is a rounded-corner rectangle. A sub-process is distinguished by a small plus sign in the bottom center of the shape. Finally, gateways are elements that control the flow of execution of the process. Internal Markers will indicate the type of behavior control. A gateway is represented by a diamond shape.

Artifacts are used to provide additional information about the process, such as data, text, inputs and outputs of activities.

Connecting Objects. Connecting objects are used to specify how flow objects interacts. A connector can be a *sequence*, a *message* or an *association*. Sequence and message flows are represented by arcs which impose temporal constraints between flow objects. An association connects artifact objects to activities and is represented by a dotted line.

Swimlanes. Pools and lanes are used to group the primary modeling elements related to functional capabilities or responsibilities. A Pool represents a participant in a Process, it acts as a graphical container for partitioning a set of activities from other Pools. A Lane is a sub-partition within a Pool which is used to organize and categorize activities.

In our approach, BPMN was extended by inserting the possibility of introducing descriptors for each element of the diagram in order to specify the semantics of process execution and to introduce all the quantitative parameters of the process, i.e. the duration of activities. In fact, the standard version of BPMN only allows the specification of the flow of activities but this is only one aspect of the system, it is also necessary to take into account resources that the company allocates to the process and workload characteristics in order to proceed with the process simulation on a discrete event simulator. The simulator used in our article is iGrafxProcess2015 [1] and its use and the BPMN language extensions will be illustrated with the help of our case study.

2.2 Key Performance Indicators

Key performance indicators (KPI) are measurements used to identify and quantify business performance. As illustrated in Table 1, we identified, for the ED, three main categories of KPI: Outcome, Process/Time and Structural.

Among the outcome indicators, Mortality (Mor), Hospitalization (Hos) and Transfer (Tra) respectively represent patients who die in the ED, are hospitalized in the wards or are transferred to other facilities (eg other specialized hospitals). The rate of patients who abandon (LWBS) can be related to quality and patient satisfaction.

The Process/Time category is related to total times the patient spends in the ED (Length of stay - LoS, Length of work - LoWo and Length of Wait - LoWa) and to the intervals between the crucial events in the treatment like the arrival, the beginning and the end of the triage, the pre-visit and the visit, and so on.

Structural indicators describe the amount of patients admitted in the ED (Adm), with their related Type of disease (Dis) and Severity of illness (Sev). Moreover, Resources allocated to activities

Table 1: KPIs by categories.

Cat.	KPI	Abbr.
Outcome	Left Without Being Seen	LWBS
	Mortality	Mor
	Hospitalisation	Hos
	Transfer	Tra
Process/Time Intervals	Length of stay	LoS
	Length of work	LoWo
	Length of wait	LoWa
	Arrival – Init. triage	A-I
	Arrival – Visit	DTDT
	Arrival – Cl-dec (diagnosis)	A-C
	Init.Triage – Triage completed	ED Tri
	Pre-visit – Visit	v-V
	Pre-visit – Cl-dec (diagnosis)	v-C
	Pre-visit – Discharge	v-Dis
	Cl-dec (diagnosis)– Discharge	C-Dis
	Pre-visit – Hospitalization	v-Hos
	Cl-dec (diagnosis)– Hospitalization	C-Hos
Structural	ED Admissions	Adm
	Resources	Res
	Types of Disease	Dis
	Severity of illness	Sev

(Res) must be described in terms of types and numbers.

In our approach, the initial setting of the As-Is model includes both Outcome and Structural KPIs. This data can easily be obtained from the hospital information system.

By performing the process simulation, the simulator provides a complete set of results from which is easy to derive the simulated values of Process/Time type KPIs. Comparing the simulated values with those detected experimentally in the department it is possible to evaluate the accuracy with which the As-Is process model approximates what actually happens in the real world.

Once the As-Is model has been validated, it is simple to run on the model several types of "What-If" analysis by changing the values of Structural KPIs. For example, we can change the resources assigned to the activities and the simulation allows us to see how the values of Process/Time KPIs are changed. This type of data is particularly useful in deciding how to restructure the As-Is model, but the restructuring step will not be considered in this paper.

Table 2: Staff in the ED model by lane, number of workers and hourly labour costs per capita.

Lane	Staff	Num	Cost
ED	Doctors	3	50
ED+TA	Nurses (generic)	2	27
TR+WA	Nurses (specialized)	3	30
RA+EF	Employee	2	25
IC+OB+EF	Generic operators	4	20

3 The Case Study

The ED under study serves about 55,000 patients annually. Patients move through various sections of the department depending on the type of care they require. The main sections are the Registration area, the Triage area and the ED (Visit area) which consists of 3 basic ambulatories (Medical, Orthopedic and Surgical).

Patients access to ED in the Registration Area. Then, a qualified nurse evaluates the Emergency Severity Index (ESI) and provides a pre-visit (Triage area). There are four classes of severity ranging from "very high" (level 1) to "very low" (level 4). An empirical data analysis shows a larger presence of "low" severity (73.5%), followed by "very low" (18.8%), "high" (7.3%) and "very high" (0.4%) cases.

While some patients could decide to leave the ED (only in not urgent cases, as for 3 and 4 ESI level cases) others continue in their path.

Most cases are visited in the three basic ambulatories of the ED: orthopedics, surgery and general medicine, but a smaller number of cases, however, is transferred in others internal clinics (ic). While most patients are discharged (dis), some ones can be hospitalized (hos) or transferred to external healthcare structures (ef). Finally, very few patients die in the ED (dea). Immediately after triage or after the visit some patients may be moved to specialized internal clinics.

Following interviews with managers, doctors and nurses, and through an accurate quantitative analysis, we were able to build the As-Is process model of the ED which is illustrated in Figure 1.

The visit is a complex task, which is detailed in the sub-process of Figure 2. It includes the collection of patient history (anamnesis), a preliminary diagnosis and the assignment of a therapy. During the visit it is possible to request exams (i.e. blood test) and/or radiological tests.

3.1 Human Resources

The ED process includes several kinds of human resources, from doctors to generic operators. To provide

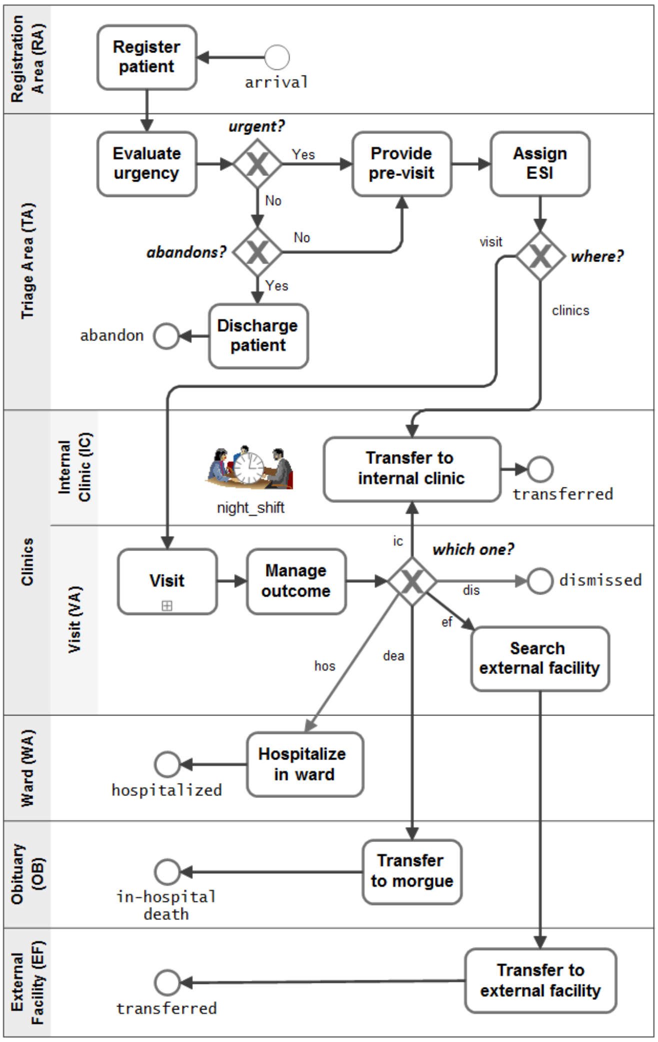

Figure 1: The ED As-Is model.

24-hour services, the ED requires operators working in different shifts (8 hours a shift including a meal break). Basically, there are three shifts starting at 6 a.m., at 2 p.m. and at 10 p.m.. A total amount of 14 workers are modeled accordingly to table 2 in which staff costs have been introduced. The night shift which starts at 10 p.m., involves 2 doctors, 2 generic nurses, 1 specialized nurse in the TA and 1 generic operator.

3.2 Patient Arrival

The arrival of patients is driven by three main characteristics. First, it depends on seasonal illness or incidents. Second, the flow fluctuates depending on days of the week: more arrivals are observed on Mondays and Fridays than the rest of the week [5]. Third, two peaks are observed in morning/afternoon with a break during lunch time [22]. As we are interested in aggregated patient flow data, we do not distinguish between

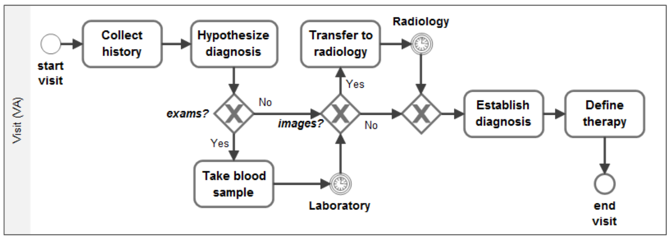

Figure 2: The Visit sub-process.

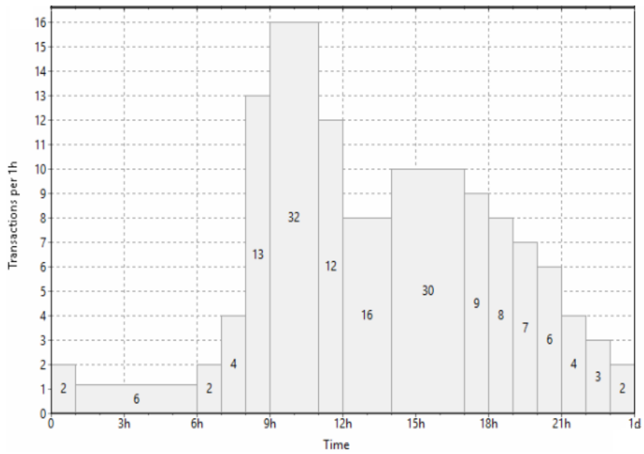

Figure 3: Patient arrival in ED by hour.

walk-in and ambulance patients. The average arrival pattern is modeled with a hourly distribution as detailed in Figure 3.

Quantitative information on patients concerns aspects related to different categories or diagnosis:

- Diagnosis correspond to four different kinds of medical care. The main three ambulatories involved are orthopedics (ort) with the 31,5% of all cases, surgery (sur) with the 15,7%, and general medicine (med) with the 21,8%. The remaining patients (31%) are sent directly to the internal specialist clinics.

- Patients can exit the process in different ways. 86% of patients are dismissed (shortened in "dis" in Figure 1), 12% are hospitalized to a ward (hos), 0,2% are transferred to other clinics (ic) and few cases (0,03%) are moved to the morgue. In addition, some (1.7%) patients may choose to leave the ED due to, for example, of excessive delays.This results in a loss of revenue for the hospital and potential risks for the patient.

3.3 Activities

An ED includes both well standardized activities and more complex ones. In the BP-M* methodology activities are characterized by their duration and the resources used to implement them. Moreover, some activities depend also from the kind of disease. For in-

Table 3: Duration of activities (minutes) by level of ESI.

Activity	ESI 3-4	ESI 1-2
Register patients	Tri(2,6,3)	0-2
Evaluate urgency	Tri(1,4,2)	0
Provide pre-visit	3-10	1-3
Manage outcome	7-15	2-4
Hospitalize in ward	15	15
Transfer to morgue	7	7
Search external facility	60-480	60-480
Transfer to external facility	10	10
Collect history	1-4	1-2
Hypothesize diagnosis	Tri(1,5,2)	1-2
Take Blood Sample	3-8	1-2
Laboratory (delay)	5-15	3-5
Transfer to radiology	Tri(5,15,8)	2-4
Radiological exams (delay)	10-20	7-12
Establish diagnosis [med]	5-25	3-5
Establish diagnosis [sur]	3-12	3-5
Establish diagnosis [ort]	3-7	3-5
Define therapy	2-5	5-10

stance, to establish diagnosis is faster for orthopedic or surgery patients, while others may require additional consultancy which increase the whole average time. Table 3 summarizes different duration depending on severity. In this Table two different probability distributions are used, the triangular distribution Tri(min,max,mode), and the uniform distribution in the remaining cases.

In the model, the execution order of activities (patient pathways) is controlled through the gateways. As in the case of the duration of the activities, the percentage of activation of the different pathways may depend on the patient's severity. For example, in the Visit sub-process, requests for blood and/or radiological exams are modeled accordingly to the type of patient's disease. Abandons are modeled as a probabilistic function only for not urgent patients, having an ESI levels of 3 or 4 (0.7 and 3.5 percent probability, respectively).

3.4 Validation of the model

As discussed before, the As-Is model includes both Outcome and Structural KPIs values obtained from the hospital information system. In the BP-M* approach, the validation of the As-Is model involves two steps:

1) verify that data concerning the Outcome and Structural KPIs had been properly considered in the model. Table 4 shows the simulation results relative to

Table 4: Simulated and real values of activities.

	Simulation		Real data	
	value	%	value	%
Dismission	46,557	81.47	46,047	81.21
Transfer to IC	3,064	5.36	2,977	5.25
Hospitalize in ward	6,572	11.54	6,640	11.71
Abandon	893	1.56	973	1.72
Transfer to EF	44	0.08	49	0.09
Transfer to morgue	19	0.03	15	0.03
Total	*57,148*	*100*	*56,701*	*100*

Table 5: Simulation results for several scenarios.

	b-D	b+D	b+N	i10%	i20%	Em.
Time	+137.2	-3.7	-1.2	+2.8	+7.9	+70.7
Costs	-0.25	+0.2	+0.1	+2.6	+5.4	+12.7

one year of activity of the department. As can be seen, results are in good agreement with the experimental values;

2) compare real and simulated data regarding some critical KPIs. The LoS (Length of Stay), i.e. the patient's average time spent in the department, is the most used metric. In our case the value obtained with the simulation, about 82 min, is in good agreement with the real value, 82.8 min, derived from data in the information system.

3.5 What-If analysis

In our experimental setting, several different scenarios are compared. Starting from the basic As-Is model, variables related to resources (adding or removing some professionals) as well as to patient diseases have been changed, obtaining the scenarios that will be discussed below with reference to Table 5 which contains results of the simulations. For each scenario we indicate the percentage difference from the value of the As-Is model, both for time and costs (costs are related to personnel expenses, to medical consumables and to physical examinations).

3.5.1 Resource scenarios

The variation of the staff is one of the most interesting experiment for an organization. We carried out three different scenarios, adding or removing a Doctor ("b+D" and "b-D"), as well as adding a Nurse ("b+N"). Due to the small size of the ED, removing even one nurse is not possible as it cause a block in the model. The results show that an increment of a doctor increases performance times of about 4%, while the increment of a nurse improves of 1%. Decreasing a doctor have dramatic impact with a worsening of about 130% of time. This justifies the fact that a doctor is removed only in the night shift.

3.5.2 Patient scenarios

By this experiment, we simulate an increment of some kinds of patients' disease. For instance, the spread of influenza virus infection in winter time will increase the arrival of patients having specific needs. We slightly increase of 10 percentage points ("i+10%") and 20% ("i+20%") the arrival of patients' directed to the general medicine ambulatory, i.e. instead of orthopedic or surgery. Finally, a last scenario ("Em") simulates an emergency, where urgent cases increases (10% for the ESI level 2 and 5% for the ESI 1). As expected, in both cases there is an impact over ED time performances.

3.5.3 Impact on operational costs

The analysis of results presented in Table 5 suggests that the impact of the changes is significant especially for what concerns the increase of patients (for example, in the case of epidemics).

4 Conclusions

This paper shows how simulation techniques allow a quantitative analysis of the emergency department in the public hospital of a medium-size Italian city.

The article has demonstrated the validity of the BP-M* methodology for what concerns the construction of an As-Is model of the process that describes the patient care pathway in the department. The key feature of the model is the ability to run the model with a discrete event simulator thereby obtaining an estimate of the main indicators of the model to be compared with real values. In this way the model is a very helpful environment for studying the behavior of the system in different working conditions obtaining useful tips for management of the department and for the re-engineering of the process.

5 Acknowledgments

The *Cittá della Salute e della Scienza* of Turin (Italy) has funded the working group on the analysis of business processes, including the research work of Emilio Sulis.

References:

[1] iGrafxProcess 2015. http://www.igrafx.com.

[2] W. Abo-Hamad and A. Arisha. Simulation-based framework to improve patient experience in an emergency department. *European Journal of Operational Research*, 224(1):154–166, 2013.

[3] T. Allweyer. *BPMN 2.0: introduction to the standard for business process modeling*. BoD–Books on Demand, 2016.

[4] J. G. Anderson, W. Harshbarger, H. Weng, S. J. Jay, and M. M. Anderson. Modeling the costs and outcomes of cardiovascular surgery. *Health Care Management Science*, 5(2):103–111, 2002.

[5] F. Chetouane and K. Barker. *Integrating simulation and risk-based sensitivity analysis methods in hospital emergency department design*, pages 67–82. Springer Milan, Milano, 2012.

[6] A. Di Leva, S. Femiano, et al. The bp-m* methodology for process analysis in the health sector. *Intelligent Information Management*, 3(02):56, 2011.

[7] C. Duguay and F. Chetouane. Modeling and improving emergency department systems using discrete event simulation. *Simulation*, 83(4):311–320, 2007.

[8] R. B. Fetter and J. D. Thompson. The simulation of hospital systems. *Operations Research*, 13(5):689–711, 1965.

[9] J. W. Forrester. Industrial dynamics. *Journal of the Operational Research Society*, 48(10):1037–1041, 1997.

[10] K. Ghanes, O. Jouini, M. Wargon, and Z. Jemai. Modeling and analysis of triage nurse ordering in emergency departments. In *Industrial Engineering and Systems Management (IESM), 2015 International Conference on*, pages 228–235. IEEE, 2015.

[11] G. N. Gilbert. *Agent-based models*. Number 153. Sage, 2008.

[12] T. R. Gulledge Jr and R. A. Sommer. Business process management: public sector implications. *Business Process Management Journal*, 8(4):364–376, 2002.

[13] W. M. Hancock and P. F. Walter. The use of computer simulation to develop hospital systems. *ACM SIGSIM Simulation Digest*, 10(4):28–32, 1979.

[14] N. R. Hoot and D. Aronsky. Systematic review of emergency department crowding: causes, effects, and solutions. *Annals of emergency medicine*, 52(2):126–136, 2008.

[15] J. Jun, S. H. Jacobson, and J. Swisher. Application of discrete-event simulation in health care clinics: A survey. *Journal of the operational research society*, 50(2):109–123, 1999.

[16] R. K. Khare, E. S. Powell, G. Reinhardt, and M. Lucenti. Adding more beds to the emergency department or reducing admitted patient boarding times: which has a more significant influence on emergency department congestion? *Annals of emergency medicine*, 53(5):575–585, 2009.

[17] A. Kovacic and B. Pecek. Use of simulation in a public administration process. *Simulation*, 83(12):851–861, 2007.

[18] M. Madsen, S. Kiuru, M. Castrèn, and L. Kurland. The level of evidence for emergency department performance indicators: systematic review. *European Journal of Emergency Medicine*, 22(5):298–305, 2015.

[19] B. P. Model. Notation (bpmn) version 2.0. *OMG Specification, Object Management Group*, 2011.

[20] M. E. Newman. Spread of epidemic disease on networks. *Physical review E*, 66(1):016128, 2002.

[21] M. Pitt, T. Monks, S. Crowe, and C. Vasilakis. Systems modelling and simulation in health service design, delivery and decision making. *BMJ quality & safety*, 25(1):38–45, 2016.

[22] O. Rado, B. Lupia, J. M. Y. Leung, Y.-H. Kuo, and C. A. Graham. *Using Simulation to Analyze Patient Flows in a Hospital Emergency Department in Hong Kong*, pages 289–301. Springer International Publishing, Cham, 2014.

[23] M. Raunak, L. Osterweil, A. Wise, L. Clarke, and P. Henneman. Simulating patient flow through an emergency department using process-driven discrete event simulation. In *Proceedings of the 2009 ICSE Workshop on Software Engineering in Health Care*, pages 73–83. IEEE Computer Society, 2009.

[24] H. A. Reijers. *Design and control of workflow processes: business process management for the service industry*. Springer-Verlag, 2003.

[25] J. Rouchier and S. Thoyer. Votes and lobbying in the european decision-making process: application to the european regulation on gmo release. *Journal of Artificial Societies and Social Simulation*, 9(3), 2006.

[26] C. E. Saunders, P. K. Makens, and L. J. Leblanc. Modeling emergency department operations using advanced computer simulation systems. *Annals of emergency medicine*, 18(2):134–140, 1989.

[27] A. W. Scheer and M. Nüttgens. Aris architecture and reference models for business process management. In *Business Process Management*, pages 376–389. Springer, 2000.

[28] H. Smith and P. Fingar. *Business process management: the third wave*, volume 1. Meghan-Kiffer Press Tampa, 2003.

[29] C. M. Sørup, P. Jacobsen, and J. L. Forberg. Evaluation of emergency department performance–a systematic review on recommended performance and quality-in-care measures. *Scandinavian journal of trauma, resuscitation and emergency medicine*, 21(1):1, 2013.

[30] M. Thorwarth, A. Arisha, and P. Harper. Simulation model to investigate flexible workload management for healthcare and servicescape environment. In *Proceedings of the 2009 Winter Simulation Conference (WSC)*, pages 1946–1956. IEEE, 2009.

[31] W. M. Van der Aalst, J. Nakatumba, A. Rozinat, and N. Russell. Business process simulation. In *Handbook on Business Process Management 1*, pages 313–338. Springer, 2010.

[32] M. Vinai and E. Sulis. Health and social public information office (spun) simulation, 2015 (accessed September 15, 2016). https://www.openabm.org/model/4778/version/2.

[33] G. Werker, A. Sauré, J. French, and S. Shechter. The use of discrete-event simulation modelling to improve radiation therapy planning processes. *Radiotherapy and Oncology*, 92(1):76–82, 2009.