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Autor: Ricardo Mateo, Liliana Neriz, Francisco Ramis, Alicia Nunez

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Departamento de Control de Gestión y Sistemas de Información
Facultad de Economía y Negocios de la Universidad de Chile

Quantitative relationship among Crowding, Efficiency and Patient Vulnerability in an Emergency Department: Empirical Evidence from a private hospital.

Authors

Ricardo Mateo, PhD, Business Department, rmateo@unav.es
University of Navarra, Campus Universitario 31080, Pamplona, Navarra, Spain
Phone: 34-948425600
Liliana, Neriz, PhD, University of Chile
Department of Management Control and Information Systems
Santiago, Chile
Francisco Ramis, PhD, University of Bio-Bio
Department of Industrial Engineering
Concepcion, Chile

Alicia Nunez, PhD, University of Chile
Department of Management Control and Information Systems
Santiago, Chile

Abstract

Introduction: Emergency department (ED) crowding is recognised as an important problem for any health care system. While there is agreement that crowding could harm patients, there is less agreement about the best way to manage ED crowding. The research proposes a new management model of ED crowding linked to the patient's emergency severity index named patient vulnerability. In addition, a quantitative connection between crowding, efficiency and patient vulnerability was done.

Methods: The research conducted a cross-sectional study of one ED in a Hospital. Independent observations of patient vulnerability, efficiency and crowding were done. Quantitative analysis and linear regression model were applied.

Results: The main contributions of this paper are: first, to highlight that efficiency is a patient safety variable; second, the creation of a new variable named patient vulnerability to manage emergency departments and finally the quantitative analysis of relations between patient vulnerability, crowding and efficiency in an emergency department.

Discussion: The use of indicators to measure patient vulnerability as a quantitative variable may improve the management of EDs. Therefore, excellence in efficiency and crowding management of EDs should reduce vulnerability and increase patient safety. Patient vulnerability could be used as a new key variable in any ED.

1. INTRODUCTION

Emergency departments (EDs) are a key component in any health care system. Full accessibility for everybody is the best guaranty for an excellent urgent health care system. Nevertheless, there has been an increase in the number of patient visits to emergency departments and a crowding of these services have been occurring. This threatens the access to and quality and safety of emergency services not only for those who need them the most but for everyone. Crowding has reemerged as a widespread and growing problem across the world. In this millennium several authors have been concerned with the problem in emergency medicine literature[1-7]. ED crowding could be defined as a mismatch among supply and demand within the emergency health care system. The bottom line is very simple: ED crowding is a serious issue that affects millions of ill citizens that need urgent attention around the world.

Crowding could be defined as the situation in an emergency department where the number of patients being attended or waiting at every moment exceeds its capacity to attend them on time. This situation may be the result of a combination of factors, such as an excess of patient demand or a reduction in the capacity because of a lack of resources.

Efficiency is one of the most important objectives to achieve excellence in a health care system [8-11]. Efficiency is defined in this paper from the point of view of the patient as the ratio of Value Added Time divided by Cycle time of attention i.e. time required for all activities that are necessary for the patient attention divided by total time of attention (from the patient arrival until its departure). Efficiency means the use of all personnel, resources and capabilities in order to attend patients, reduce cycle time of attention and avoid any delay. Therefore, efficiency should reduce the Length of Stay (LOS) and crowding. Nevertheless, inefficiency and crowding are compatible mainly because of excess of demand given ED capacity. This point is key to understand the importance of efficiency. You can be efficient or inefficient when your demand is less than your capacity but you can’t be efficient when your demand is higher than your capacity, mainly because of waiting times. There are many factors for explaining inefficiency, perhaps waiting times, professional movements, availability of personnel and beds are the most important in ED environment. However, the combination of inefficiency because of movements or lack of resources and excess of demand is catastrophic for quality and patient safety in EDs [12].

Patient vulnerability is a new variable to control the fulfillment of standard time of attention for each patient given the emergency severity index. The variable is defined as an indicator about how many times "standard time of attention" have you required for each patient. This variable has the advantages to adapt for each patient, is easy to use and facilitate the management of efficiency and crowding in emergency departments.

An investigation to analyze the above situation in a private hospital was conducted. A private hospital has been selected as an environment where efficiency is extremely important because of the optimization of resources and financial aspects. This environment helps us understand the interaction of efficiency, crowding and vulnerability in an organization where efficiency is a top priority.

There is a conceptual and qualitative connection in the literature about crowding, efficiency and vulnerability [6 9 13 14]. In addition, there is a relation between crowding and patient vulnerability. With most critical patients, any attention delay may increase patient vulnerability, risk of mortality and therefore patient safety [12]. The Emergency Severity Index (ESI) is an indicator for prioritizing patient arrivals. The use of time limits linked to ESI allows EDs to control vulnerability. Vulnerability is associated to the compliance of the standard time of attention in EDs given the Emergency Severity Index (ESI). Therefore, on time attention may reduce vulnerability.

According to Espinosa, the main causes of crowding are hospital related factors such as waiting for a physician, results or a bed and/or transportation of a bed in the hospital, waiting for procedures performed outside ED or consultation with a specialist[15]. Most are efficiency related, but other authors present excess of demand as the most important cause of crowding [3].

Efficiency and crowding generate an impact on vulnerability. The question is how do these variables interact? Despite the magnitude of the problem of ED crowding and efficiency, and due to the lack of suitable data, little empirical and quantitative research has been conducted to determine the real impact of efficiency and crowding on patient vulnerability. Many authors have linked these concepts as qualitative research but few have developed a quantitative approach to measure the real impact of these factors.

The remainder of the paper is structured as follow. Section 2 briefly describes the method, variable definitions and patient data base for analyzing crowding, efficiency and vulnerability. Section 3 presents the main results. Finally, section 4 offers some concluding remarks and practical implications for EDs.

2 METHOD

For the empirical analysis of the paper, we used electronic data records from one ED located in Chile. The dataset includes 8,852 individuals attended in the ED from February to August 2013. The dataset covers information about on time scheduling of attention in ED, ESI, gender and age.

Our aim was to find a model linking ED crowding to patient vulnerability. A multiple regression model was used, in which the dependent variable was patient vulnerability and the independent variables were efficiency, crowding, interaction effect between efficiency and crowding, age, care pathway, weekday, employee shift, and gender.

In this study vulnerability is defined as the time it takes to be seen by a doctor in relation with the time limits associated to the ESI triage valid in Chilean hospitals (see table 1). Thus, the formula to assess vulnerability is equation 1.

$$(1)\ \text{Vulnerability}\ (\upsilon_i) = \frac{\text{Time elapsed before to see a doctor}}{\text{ESI}}$$

Table 1: Time Limits associated to ESI Triage*

ESI Level	Severity	Time to doctor limits recommended
C1	Highest priority	<= 1 minute
C2	High-risk	<= 30 minutes
C3		<= 90 minutes
C4	Low acuity	<= 180 minutes
C5		<= 240 minutes

*The time limits were defined based on the following Chilean hospitals: O'higgins, Curico and Arica.

Additionally, efficiency is defined as the time a patient is attended by a healthcare professional, value added time (VAT), in relation to the total time the patient spends in the ED. The times needed to evaluate the efficiency variable were obtained through a simulation of the activities and movements of actual patients considering their arrival time and care pathways via Flexsim Healthcare software. Thus, the formula to assess efficiency is presented in equation 2.

(2) Efficiency (η_i)= $\frac{VAT}{\text{Cycle Time (CT)}}$, where

CT= Value added time + Waiting time + Moving time

The demographic characteristics of the population included in the study are men and women from the first income quartile. Throughout the months studied, there were no significant changes in demand for emergency services. A description of the variables is presented in table 2 and descriptive statistics in table 3. The statistical software used was Stata 7. Throughout the research all ethical principles and the anonymity of data were respected.

Table 2: Description of the variables

Variable	Measurement scale	Definition
Vulnerability	Ratio/Continuous	Time elapsed before to see a doctor divided by the time limits associated to ESI (0.07 to 5.56)
Efficiency	Ratio/Continuous	Ratio of Value Added Time divided by Cycle Time (0.16 to 0.98)
Crowding	Interval/Discrete	Number of patients that are in the ED at the moment of patient i arrival (including patient i) (1 to 22)
Interaction	Ratio/Continuous	Interaction between the variables efficiency and crowding (0.21 to 15.65)
PCIFlexim	Nominal/Discrete	Care pathway: 1=Gastroenterology, 2=Respiratory, 3=Trauma, 4=Surgery, 5= Internal Medicine, 6=Neurology, 7=Procedure, 8=Urology, 9=Cardiology, 10=Other
Age	Interval/Discrete	Age in years (3 to 102)
Gender	Nominal/Discrete	Gender: 0=male and 1=female
Shift	Nominal/Discrete	Healthcare workers shift: 0 =8:01am-20:00pm , 1= 20:01pm to 8:00am
Weekday	Nominal/Discrete	Weekdays: 1=Monday, 2=Tuesday, 3=Wednesday, 4=Thursday, 5=Friday, 6=Saturday, 7=Sunday

Table 3: Descriptive Statistics

Variable	Mean	Standard Deviation	Min	Max
Vulnerability	0.7737861	0.6974426	0.0706833	5.561
Efficiency	0.6634968	0.2186602	0.1638133	0.9846171
Crowding	6.504519	3.354996	1	22
Interaction	4.176219	2.401395	0.2100935	15.65124
PCIFlexim	3.58789	2.381495	1	10
Age	37.29361	15.57032	3	102
Gender	0.6652734	0.4719215	0	1
Shift	0.3194758	0.4662999	0	1
Weekday	3.936512	2.007677	1	7

The results are presented in two different parts. In the first part, we present some descriptive data about vulnerability, crowding and efficiency levels. In the second part, a regression analysis is used to estimate quantitative effects.

3 RESULTS

As shown in Table 4, vulnerability response is higher when efficiency is lower. For example, the average vulnerability for patients who arrived at EDs when efficiency is greater than 90% is 0.388 while vulnerability for people who arrived at EDs when efficiency is lower than 20% is 3.53.

Table 4: Efficiency and Vulnerability

Efficiency (η_i)	Vulnerability Mean (υ_i)	SD (υ_i)	Total cases
$\eta_i <= 10\%$			0
$10\% < \eta_i <= 20\%$	3.53319	1.43859	9
$20\% < \eta_i <= 30\%$	1.40242	1.10278	584
$30\% < \eta_i <= 40\%$	0.89966	0.72566	1,308
$40\% < \eta_i <= 50\%$	1.12638	0.64635	337
$50\% < \eta_i <= 60\%$	0.85379	0.51432	726
$60\% < \eta_i <= 70\%$	0.54578	0.34336	1,427
$70\% < \eta_i <= 80\%$	0.65812	0.56901	1,046
$80\% < \eta_i <= 90\%$	0.84837	0.78756	2,237
$90\% < \eta_i <=100\%$	0.38834	0.14222	1,178

Table 5 presents the means of vulnerability and efficiency for each level of crowding. An interaction of vulnerability, efficiency and crowding could be observed. The effect of crowding in vulnerability is clear. For instance, when census is 15, vulnerability for patients who arrived at EDs is 1.4366 while vulnerability for people who arrived at EDs when census is 4 is 0.62979. Additionally, the capacity of this hospital is 6 rooms and 6 beds for observation. It is possible to remark the efficiency of this hospital at their capacity level. But at high levels of crowding, at a capacity of 12, the hospital collapses because of a lack of capacity. This is a clear example of how we can analyze the interaction between efficiency, crowding and vulnerability, separating the demand and supply problem. When crowding is less than bed capacity (12) you may or may not be efficient, but when the number of patients is greater than 12 you need to manage the situation with additional resources to avoid collapsing the ED.

Table 5: Crowding, Vulnerability and Efficiency

Crowding (N)	Vulnerability (υ_i)	Efficiency (η_i)
1	.62254	.71879
2	.56985	.72738
3	.63255	.69533
4	.62979	.68931
5	.67133	.69833
6	.67968	.67416
7	.78316	.65024
8	.86439	.64028
9	.87062	.63520
10	.91258	.63036
11	.94904	.61235
12	1.1051	.59170
13	1.0897	.60078
14	1.3204	.54374
15	1.4366	.51449
16	1.5834	.53874
17	1.6036	.49049
18	1.8000	.53319

19	1.6120	.55005
20	1.7304	.46924
21	2.5356	.37790
22	1.8394	.45254

As is previously shown, there is a relationship among efficiency, crowding and vulnerability. In Table 6 a linear regression model considering vulnerability as a dependent variable is presented. Therefore, this research confirms the relationship between crowding, efficiency and vulnerability. Patients that arrived to ED when crowding is higher than capacity are more vulnerable than those at low census at arrival. In the case of efficiency, more efficiency means less vulnerability.

In addition, some graphs and tables are presented. Graph 1 and table 7 show the relation between vulnerability and efficiency by crowding. Crowding in this case is formed by groups. For instance, the mean of vulnerability for every patient that arrived to ED when crowding was between 7 to 9 people in the ED, was 0.83 and the mean of efficiency was 0.64. Graph 2 and table 3 present the relation among vulnerability and efficiency for each cluster formed by nine groups of 10%, starting at 20% and finishing at 100%. There are no cases where efficiency is under 10%. For example, the mean of vulnerability for all patient attention, where efficiency was greater than 40% and less or equal than 50%, was 1.12638.

Finally, a clear importance of diagnosis tracks and shifts appeared in the regression model. A mix of diagnosis and shifts are important to explain vulnerability. Each diagnosis has its own group of activities and uses similar resources. In addition, shifts have different resources and patient arrivals. For any ED it is relevant to know the mix-shift relation and adapt the operations to this particular case. The indicator R-squared value is 0.5176, which means that there is a great deal of unexplained variance and this is a limitation of the research. More data is necessary to improve the model. But the goodness of Fit is enough to state the relation among crowding, efficiency and vulnerability.

Table 6: Linear Regression Model for vulnerability

Estimation Results			
Key Variables	**Coeff.**	**SE**	**t**
Constant	1.476	0.077	(19.03) ***
Efficiency	-1.295	0.085	(-15.17) ***
Crowding	0.110	0.004	(22.81) ***
Interaction	-0.122	0.007	(-17.09) ***
Age	0.001	0.000	(3.23) ***
PCIFlexim			
Respiratory	-0.361	0.024	(-15.01) ***
Trauma	-0.343	0.041	(-8.37) ***
Surgery	-0.285	0.023	(-12.02) ***
Int. Med.	1.471	0.022	(66.53) ***
Neurology	-0.987	0.046	(-21.23) ***
Procedure	-0.288	0.023	(-12.09) ***
Urology	0.105	0.022	(4.69) ***
Cardiology	-0.093	0.035	(-2.60) ***
Other	0.660	0.065	(10.06) ***
Weekday			
Tuesday	-0.023	0.018	(-1.28)
Wednesday	-0.010	0.019	(-0.53)
Thursday	-0.006	0.019	(-0.35)
Friday	-0.016	0.019	(-0.84)
Saturday	-0.026	0.019	(-1.36)
Sunday	-0.009	0.019	(-0.49)
Shift	0.058	0.011	(5.18) ***
Gender	0.054	0.010	(4.94) ***
R^2	51.76%		
Sample	8852		

Note: Z-score in parentheses and indicates significance level as follows: ***$p \leq 0.01$, **$0.01 < p \leq 0.05$, *$0.05 < p \leq 0.1$

(Insert Graph 1 about here)

Table 7: Mean of vulnerability and efficiency by crowding

Crowding	Mean of vulnerability	Mean of efficiency	Frequency
1-3	0.61	0.71	1,768
4-6	0.66	0.69	2,890
7-9	0.83	0.64	2,635
10-12	0.97	0.62	1,134
13-15	1.2	0.57	326
16-18	1.6	0.52	78
19-22	1.8	0.49	21

(Insert Graph 2 about here)

4. CONCLUDING REMARKS

This paper analyzes the vulnerability relationship by means of studying the impact of crowding and efficiency rates for patient attention in one private Emergency Department. Besides the relevance of this analysis in the context of the new situation of crowding of EDs around the world, the major contribution of this paper is the quantification of crowding and efficiency interaction in order to measure their impact on vulnerability for each patient. This quantification has been done using one specific method with new variables such as: vulnerability, efficiency and crowding. These new variables and concepts may be used in all EDs to improve the management of the emergency units with a quantitative approach.

The main results may be summarized as follows. First, we quantify the impact of crowding and efficiency on vulnerability for each patient. In fact, there is a negative impact when efficiency is lower and when crowding of the emergency department is higher. In addition, an indirect effect among crowding and efficiency was detected. Based on this result, we can conclude that efficiency has a direct effect on vulnerability and an indirect effect through crowding. Therefore, efficiency may be considered as a safety clinic variable not only because it affects operation and financial aspects of emergency departments but patient vulnerability.

Second, there is a relation between diagnostis, shift and age with vulnerability and there is no relation with the day of the week. The relation of age is clear as a consequence of the long stay of elder patients. In the case of diagnosis, the relation is due to the different activities that you must do for each patient.

Third, vulnerability appears as a fundamental variable to control patient safety. Thus, the creation of a new indicator of vulnerability for each patient could be deduced from this research. This indicator allows the director of the unit to know when their patients are becoming vulnerable and manage the vulnerability by shifts, days, age, diagnosis, etc. A green signal indicates a state of low vulnerability, i.e. between 0 and 1. A yellow signal is a warning indicator where the patient's vulnerability is greater than 1 and less than 2. When indicator exceeds 2, a red light would go on.

Since hospitals do not always have systems that control the physicians time of attention, an alternative way to have an indicator to manage vulnerability is a head counter in the emergency unit. Obviously, this indicator does not include service times and the variety of patients, but it can give a rough idea of the level of vulnerability which is happening in the emergency unit.

Fourth, a new method for analyzing the quantification of crowding, efficiency and vulnerability is proposed. Although the situation of each ED is different and the results will depend on each case, the methodology to analyze the problem and the introduction of new indicators are valid for any Emergency Department.

Finally, some limitations and future research are proposed. The sample of 6 months and the private hospital size is small. For this reason, more research may be analyzed in order to contrast the method in bigger hospitals.

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