Using Discrete-Event Simulation to Forecast the Volume of Hospital Emergency Services to be delivered at the Regional Level

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Abstract: This paper describes a discrete-event simulation model to estimate the volume of services to be provided by emergency departments located in one sub-region of Lower Silesia, the southernmost province in Poland. Forecasts of the predicted categories of services to be delivered in the following year in emergency departments in the region are formulated based on the simulated demand level. The process of input data analysis is described in detail, and basic assumptions for the simulation model are formulated. The results provide some insights into the relation between sub-regional demographic trends and population needs in relation to hospital emergency arrivals.

1 INTRODUCTION

This paper presents a discrete-event simulation model (DES) to forecast the next year's volume of services to be delivered in hospital admission units (AU) and hospital emergency wards (EW) located in one sub-region of Lower Silesia, Poland, to cover the demand for emergency medical treatment directed to the AUs/EWs located in the area.

Simulation methods have been used to successfully analyse the healthcare industry for many years and different taxonomies of healthcare simulation models have been proposed by many authors. Jun et al. (1999) surveyed the application of simulation models in two domains: patient flow and allocation of resources. Fone et al. (2003) found that simulation modelling was used to study a broad range of healthcare issues including hospital scheduling, communicable disease, screening, costs of illness and economic evaluation. Brailsford et al. (2009) proved that simulation methods are dominant in planning and system/resource utilisation. Based on the study conducted by Hulshof et al. (2012), who focused on resource capacity planning and control decisions in healthcare, it may be concluded that computer simulation is applied on each level of hierarchical decision making (strategic, tactical and operational) to support every type of healthcare services (ambulance, emergency, surgical, inpatient, home and residential). Mielczarek and Uziałko-Mydlikowska (2012a) observed that DES is the most common modelling technique among the different simulation approaches applied to health services. This method proved to be an effective tool in the study of complex systems characterised by uncertain and variable demand, an unpredictable nature of acute events, and a high level of human factors. DES is well-suited to addressing problems in emergency departments, where the arrivals of patients are highly variable, resources are scarce, and human involvement in the performance of systems is significant. This article attempts to evaluate the capabilities of using the DES approach when shaping short-term health policy strategies on the regional level in relation to the services delivered in AUs/EWs.

In Poland, hospital services are offered to elective and emergency patients. AUs and EWs serve as the points of admission where the patient is qualified for hospital care and, if necessary, medical treatment is given. AUs/EWs are obliged to serve every patient who arrives with an acute condition. Both types of emergency units provide consultancy and basic medical interventions. EWs may additionally perform the medical treatment necessary to stabilise vital functions. Both the AU and the EW may, after the consultation, qualify the patient for further hospital treatment.

The total prior-year demand registered in the hospital AU/EW is one of the main factors

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considered by National Health Fund (NFZ) when negotiating future contracts. The goal of this paper is to use a discrete event simulation to estimate the next year's demand for hospital emergency services in the region. This, in turn, will help forecast the volume of services to be contracted with providers to cover the future needs of the population.

2 LITERATURE REVIEW

The substantial AU/EW simulation literature has focused on the patient flows and throughput times inside emergency departments (ED). Some authors also incorporate the issue of staff scheduling. Duguay and Chetouane (2007) used the DES model to reduce patient waiting times and improve service delivery in an ED in a regional hospital in Canada. Based on simulation experiments, the authors formulated a number of qualitative suggestions. Ahmed and Alkhamis (2009) integrated simulation with optimisation to analyse patient flows and evaluate different staffing distributions. They were able to find the optimal number of ED staff members to maximise patient throughput and reduce patient waiting time. Paul and Lin (2011) utilised the DES model to identify the main causes of reduced ED throughput. Zeng et al. (2012) used a discrete simulation to improve the quality of care at an ED. A simulation-based decision support system to assist with planning processes in EDs was presented by Abo-Hamad and Arisha (2013). The authors tested a number of scenarios, e.g., variation in medical staffing and "zero-tolerance" policy regarding exceeding a 6-hour boarding time. They were able to define the factors that have a great impact on reducing the average lengths of stays.

Patient flows and staff scheduling are the elements of a more complex problem, i.e., emergency department overcrowding. Because all ED patients must be provided with medical assistance, overcrowding is a serious problem and simulation has proven to be an effective tool to improve system performance. Paul and Reddy (2010) searched the ED simulation literature from 1970 to 2006 and found 43 papers that modelled the EDs and performed computer simulations. The majority of the models were stochastic and the preferred modelling technique was discrete event simulation. Based on the review, the authors discussed useful insights into the problems of ED crowding. They were also able to list important limitations that had to be addressed by future simulation models.

In most published papers, the object under study is an isolated ED unit and the goal is to improve the unit's internal processes. These models concentrate on the current work of EDs, try to identify the causes of overcrowding and suggest strategies to overcome them. Our approach may be defined as upper-level strategic modelling because it concerns the broader issue of covering the demand for hospital emergency services in an entire region. Our work makes the following contributions. First, we try to forecast the next year's demand for hospital emergency services to be met by all EDs in the region. Second, we estimate the expected volume and structure of the services to be delivered by particular EDs to cover the next year's emergency needs separately for every ED. The general idea behind the study was described in (Mielczarek and Uziałko-Mydlikowska, 2012b).

3 REGIONAL EMS SYSTEM

Lower Silesia is the fourth largest region in Poland. It is divided into 5 sub-regions, 29 administrative districts and 169 communes. The capital of the region is Wroclaw, which is a large academic and industrial centre. In 2010, there were 91 hospitals located in the area with 39 AUs and 13 hospital EWs. Our study concerns the services offered in 2010 by AUs and EWs located in 2 (of a total of 5) sub-regions. These 2 sub-regions are referred to in the paper as the *Wrocław Region* (WR). This area encompasses the capital of Lower Silesia (Wrocław) and 8 other nearby districts (for a total of 9 districts). In 2010, 12 AUs and 5 EWs operated in WR.

Data for the study were obtained from the NFZ regional branch in Wrocław for the year 2010. Two basic data sets were analysed. The first included information on 183,517 emergency visits by patients residing in WR who arrived in AUs/EWs located in the Lower Silesia area. The records from the second data set revealed 201,636 patients with any residence codes who were registered in AUs/EWs deployed in the WR. To protect anonymity, personal data were deleted from the files.

Regionalisation is not employed in the Polish healthcare system. This means that patients can decide where to go for medical assistance. In most cases, the neighbourhood hospital is selected. However, to properly estimate the next year's demand for hospital emergency services with regard to WR units, we had to consider patient choices for the place of treatment.

4 MODEL DESCRIPTION

4.1 Patient Flows

The analysis of the historical demand for hospital emergency services allowed us to identify 3 main sources of emergency patients arriving at 17 AUs/EWs in WR (see Figure 1):

Flow 1. Patients who are residents of 9 WR districts. In most cases, these patients select one of 17 AUs/EWs located in WR but sometimes, hospitals in another sub-region of Lower Silesia are preferred.

Flow 2. Patients who are residents of Lower Silesia outside WR. These patients may sometimes select AUs/EWs located in WR.

Flow 3. Patients who reside outside Lower Silesia and select AUs/EWs located in WR.

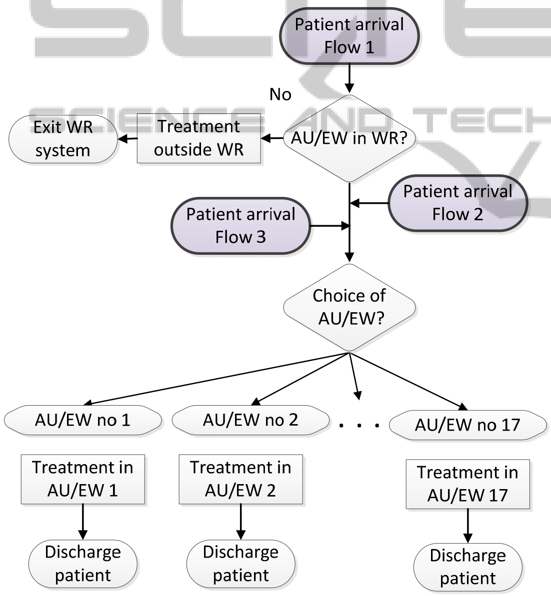

Figure 1: Flowchart of patient flows in the WR emergency system.

The patient arrivals were modelled as dynamic random Poisson processes according to exponential distributions with time-varying parameters. There are 11 input patient flows in total: 9 distributions describing incoming patients from 9 WR districts, 1 distribution describing patients from Lower Silesia (people resident in districts outside WR), and 1 distribution describing all other patients. The parameters were defined according to the results of the historical data analysis and depend on the calendar month. Table 1 presents a fragment of the arrival parameters estimated according to the 11 input flows and 12 calendar months. Each parameter describes the average number of patients per hour. The flows fluctuate considerably depending on the calendar month: more arrivals are observed in the summer whereas fewer patients register in the winter.

Patients residing in WR may select AUs/EWs outside WR and an additional random distribution was applied to model this process; see Table 2.

Table 1: Average number of patients per hour: a fragment of input arrival parameters from among 12 annual values.

District	Minimum value	Maximum value
Lower Silesia	0.92 (December)	1.30 (February)
outside LS	1.17 (January)	1.60 (June)
District 1	0.25 (December)	0.34 (April)
District 2	1.07 (April)	1.71 (June)
District 3	0.35 (January)	1.95 (June)
District 4	0.21 (December)	1.28 (July)
District 5	0.30 (October)	1.08 (March)
District 6	0.89 (January)	1.31 (June)
District 7	0.48 (January)	0.71 (June)
District 8	1.56 (January)	2.22 (March)
District 9	11.23 (January)	14.27 (June)

Table 2: Distribution of daily number of emergency patients (in %) residing in WR who select an AU/EW outside WR.

Gamma	Test statistics
$\beta = 0.00385$ $\alpha = 5.47$	Square Error = 0.002523 Chi Square *p-value* = 0.357 Kolmogorov-Smirnov *p-value* > 0.15

4.2 Choice of Hospital

The patients admitted to AUs/EWs located in WR are defined by the *choice of a hospital* attribute. This attribute is strongly correlated with the place of residence. Patient preferences with regard to the place of treatment are sampled from 10 discrete probability distributions. There are 9 discrete distributions defined for 9 WR districts and 1 separate distribution defined for all other patients.

4.3 Emergency Treatment in AU/EW

The service received directly in AU/EW is described by the number and type of the performed activities, called *unit products*. The patient may, for example, receive a medical consultation, some medical tests may be performed for the patient's benefit or some medical treatments and interventions may be provided to the patient. Every *unit product* is associated with a *unit weight,* which is the economic description of the cost related to the performed activity. For example, the *medical examination* activity costs 1 point whereas the *image diagnosis with CT/NMR* activity costs 5 points. The total number of different unit products performed for the patient's benefit allows the patient's *category* to be determined. The NFZ defines 5 categories that relate to the total number of points collected from the activities performed during the patient's treatment in an AU/EW; see Table 3.

Table 3: Patient *categories* as defined by NFZ.

Category	Overall weight of the activities	Weight of the category
Ctg1	1 - 2	1
Ctg2	3 - 4	3
Ctg3	5 - 6	5
Ctg4	7 - 9	8
Ctg5	> 9	10

Discrete random distributions were defined separately for every AU/EW in WR to generate: (1) the number of *unit products* received by every patient in every ED and (2) the *categories* patients are assigned to. Table 4 presents the percentage parameters used to describe patient *categories* in every AU/EW in WR.

Table 4: Percentages of patient categories in 17 AUs/EWs in WR.

AU/EW	Ctg1	Ctg2	Ctg3	Ctg4	Ctg5
Unit 1	79.8%	14.1%	5.7%	0.4%	0.0%
Unit 2	54.3%	36.1%	7.8%	1.5%	0.3%
Unit 3	30.1%	36.5%	18.4%	11.2%	3.9%
Unit 4	47.6%	15.0%	14.2%	13.8%	9.4%
Unit 5	20.4%	34.4%	30.7%	8.4%	6.1%
Unit 6	99.8%	0.2%	0.0%	0.0%	0.0%
Unit 7	90.9%	6.9%	1.7%	0.4%	0.1%
Unit 8	73.1%	21.6%	4.5%	0.6%	0.1%
Unit 9	39.2%	32.6%	20.1%	5.9%	2.3%
Unit 10	64.2%	24.0%	11.3%	0.4%	0.1%
Unit 11	49.4%	21.6%	9.2%	10.0%	9.9%
Unit 12	40.4%	40.5%	14.4%	4.2%	0.6%
Unit 13	36.0%	7.1%	7.1%	18.8%	31.0%
Unit 14	99.1%	0.8%	0.0%	0.0%	0.0%
Unit 15	99.0%	0.9%	0.1%	0.0%	0.0%
Unit 16	46.3%	23.4%	16.4%	9.6%	4.4%
Unit 17	27.7%	26.8%	13.0%	31.7%	0.8%

For example, in Unit 1, patients are usually assigned to Ctg1 (79.8% of patients) whereas the most costly category, i.e., Ctg5, was not registered in this unit (0.0% of the patients). In Unit 13 there is, on average, a similar number of patients in Ctg1 (36.0%) and Ctg5 (31.0%).

After basic medical treatment is provided in the AU/EW, the decision regarding whether to send the patient home or begin treatment in the hospital ward is made within a few hours. The *LOS at AU* parameter is usually equal to 1 day. An EW may, however, start treatment immediately and keep the patient for one to a few days. The *LOS at EW* parameter is usually equal to 1 or 2 days, but sometimes patients stay at the EW for a longer period (3 to 10 days). After the consultation and/or medical treatment at the AU/EW, the majority of patients is sent home but a small percentage is referred to a hospital ward.

4.4 Modelling Approach

The simulation model to trace the patients in the WR hospital emergency system was conducted using Arena 14.0 software (Rockwell Automation, Inc.). The simulation begins in an empty and idle state and lasts 365 days. There was no need to warm-up the model because the goal of the simulation is not related to operational activities or internal queues. We are interested in the volumes and types of medical services performed on daily basis for the benefit of patients in every AU/EW and the observed output measures do not depend on the system's prior performance. Every experiment is replicated 10 times.

5 SIMULATION RESULTS

5.1 Verification and Validation

The model has been validated using three techniques: face validation, hypothesis testing and historical validation (Law and Kelton, 2000). The conceptual model and the final results were discussed with NFZ personnel. The distributions developed from the historical data were validated using the Kolmogorov-Smirnov goodness-of-fit test with a 5% significance level. Then, the simulation model was used to forecast the annual number of patients assigned to each *category* in every AU/EW based on the fitted arrival parameters. The simulation output was compared with the historical values taken from NFZ registries. The absolute differences between actual and simulated results range from 0.16% to 11.31% when comparing the total number of patients served in AUs/EWs and from 0.47% to 1.29% when comparing the total number of patients within the patient *categories*, (see Figure 2). The average absolute differences including 17 units and 5 categories were also separately calculated for both ranges. The highest difference is observed for Unit U15. This unit performs the smallest number of services (the next unit, U7, performs twice as many services). A more extensive statistical analysis of the simulation output compared with the reference standard was conducted. Based on the validation procedure, it may be concluded that the simulation model properly predicts the expected volume of emergency services directed to 17 AU/EWs within 5 patient categories.

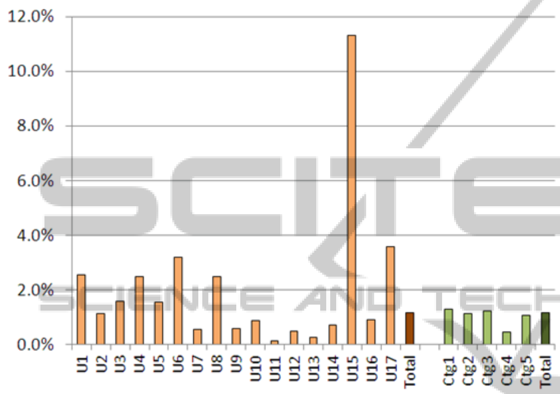

Figure 2: Absolute differences between simulation results and historical data in relation to 17 AUs/EWs (U1-U17) and 5 patient categories (Ctg1-Ctg5).

5.2 Simulation Experiments

A series of scenarios were developed to evaluate the impact of external demographic trends on future emergency needs. Each experiment tests changes in the volumes and structures of hospital emergency services on two dimensions: (1) in every AU/EW and (2) across the patient *categories*.

Scenario 1. The data obtained from NFZ indicate a slight increase (2.71%) in WR emergency demand in 2011 compared to 2010 (baseline scenario). The simulation shows that this increase, which is equally applicable to every district, is spread irregularly between AUs/EWs. Units U14, U15 and U17 registered the highest growth in performed services whereas U2 experienced the most modest growth, see Figure 3. The lowest increase was observed among services belonging to Ctg2 (2.20%) and the highest increase was associated with Ctg4 (2.53%), see Table 5.

Scenario 2. Demographic data and the analysis of past demand show that the structure of the population inhabiting the WR area is changing. There are districts that register constant population growth. These are the suburbs of the capital, which attract young families who decide to leave the city and move to the outskirts. We tested the impact of a 20.05% increase in demand, according to the actual trend, in one outskirt district. Small fluctuations are observed across the region (Figure 4) but the unit located in this district (U1) will have to face a rapid increase in the level of demand. The lowest increase was observed among services belonging to Ctg5 (0.21%) and the highest increase was associated with Ctg1 (1.84%), see Table 5.

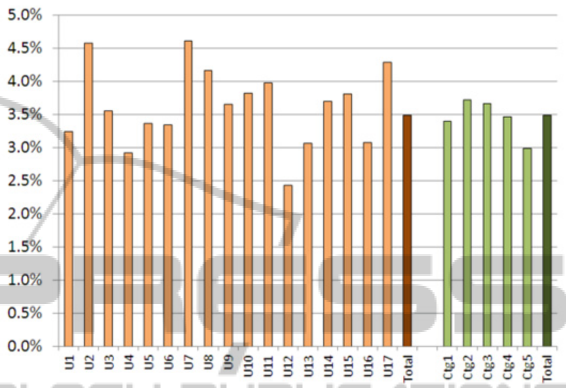

Figure 3: Scenario 1. Increase in the number of services when total demand increases by 2.71%.

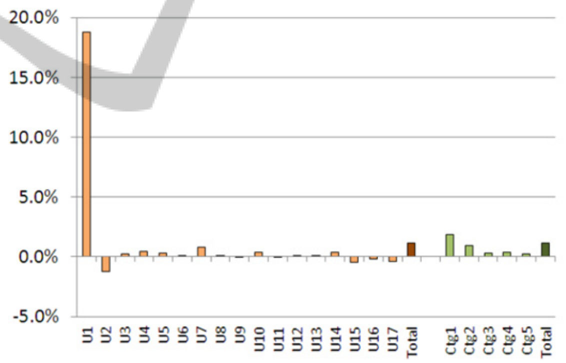

Figure 4: Scenario 2. Observed changes in the number of services when demand in one of the satellite districts increases by 20.05%.

Scenario 3. The population of Wrocław, the capital of Lower Silesia, has been gradually decreasing since 2006. We tested the impact of a 0.3% demand decrease in the capital on the services delivered in 17 AUs/EWs. The majority of units registered a decrease in delivered services, except for Units U8, U11 and U13, see Figure 5. The more detailed analysis shows that the forecasted growth of 0.3% in U11 could be related to the specificity of this unit, which is classified as a clinical hospital and deals with the most complicated cases. The decrease was observed in Ctg1 (-0.18%), Ctg2 (-0.45%), Ctg3 (-0.61%), and Ctg4 (-0.48%), but simulation shows also the small increase in Ctg5 (0.42%), see Table 5.

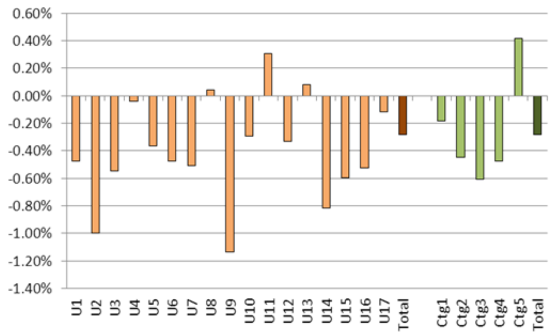

Figure 5: Scenario 3. Changes in the number of services when demand in the capital decreases by 0.3%.

Table 5 provides some descriptive statistics obtained using the DES model. The standard deviations of average number of patients classified into 5 categories show that the volumes of services provided within the categories are quite sensitive to the random demand and differ significantly for different simulation scenarios.

Table 5: Scenarios 1-3 results. Simulation predictions for number of services in 5 categories (average values from 10 replications) in comparison with baseline scenario.

Scenario	Ctg1	Ctg2	Ctg3	Ctg4	Ctg5
Baseline scenario					
demand Std. Dev. 95% CI	93,853 394 244	46,164 296 183	28,564 239 148	17,850 92 57	15,287 91 57
Scenario 1: 2.71% demand increase in WR					
demand change Std. Dev. 95% CI	96,140 2.44% 354 219	47,179 2.20% 241 150	29,279 2.51% 153 95	18,301 2.53% 92 57	15,670 2.50% 137 85
Scenario 2: 20.05% demand increase in one outskirt district					
demand change Std. Dev. 95% CI	95,580 1.84% 342 212	46,585 0.91% 235 146	28,661 0.34% 248 154	17,912 0.35% 104 65	15,329 0.21% 115 71
Scenario 3: 0.3% demand decrease in the capital					
demand change Std. Dev. 95% CI	93,682 -0.18% 295 183	45,957 -0.45% 95 59	28,391 -0.61% 138 85	17,765 -0.48% 172 106	15,351 0.42% 97 60

6 CONCLUSIONS AND FUTURE PLANS

The paper presents the DES simulation model for emergency services delivered on the sub-regional level. The model described in the paper, unlike most DES hospital emergency applications, is not focused on specific AUs/EWs; instead, we are interested in the level of emergency services that should be contracted by NFZ for the following year to cover the forecasted demand in WR. The intended use of the DES model is to assess the number of services performed for the benefit of patients in every AU/EW and within 5 medical *categories*. The DES model dynamically simulates 3 flows of emergency patients served at 17 AUs/EWs located in WR from when the patient enters the system until she or he is discharged or admitted to a hospital ward. We do not model patient pathways through particular AUs/EWs in detail but are rather interested in the types and number of services performed per patient.

The model can be used at the regional policy level to investigate cause-and-effect relations, such as the effects of demographic changes on the number of services delivered at AUs/EWs located in the region. In the long run, the model might help NFZ decision makers to plan the number and value of hospital emergency services to be contracted with providers for the following year to meet the needs of the population and ensure that the cost of the actual services delivered in emergency units will be reimbursed by the contract.

Future research will more deeply examine the relationship between WR demographic parameters and the emergency needs of the WR population directed to different AUs/EWs. External forecasts of demographic trends (published by Central Statistical Office) will be used and the DES model input parameters will be estimated accordingly. We also plan to include epidemiological issues and be able to connect the health parameters of the population with emergency needs.

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