The digital transformation of health care systems engineering

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Abstract: The purpose of the present research is to develop a new management model to beyond the limits of currently available triage process. The model aims to propose a digitized procedure that enable more efficient automation and better decision making in order to avoid incorrect attribution of the triage code. The proposed approach integrates GIS algorithm, big data and multi-criteria analysis. The model is a pilot study simulated through Flexsim Software© on a real case study concerning the emergency management occurred in a petrochemical company.

Keywords: Healthcare engineering, Disaster Management, Big data, Triage, Simulation.

1. Introduction
In recent years, after disasters that have affected industrial plants, research on process of determining the priority of patients’ treatments has assumed an increasing importance in view of emergency management (De Felice et al., 2016). During an emergency, human judgment and decision-making is often negatively influenced by stressful conditions (Hammond, 2000). Recent studies confirm the effect of stress on cognitive process and on judgment (Farhadbeigi et al., 2012). Decisions that are made in the first minutes are critical to the successful management of emergencies. At the same time, emergency decision-makers are required to process massive amounts of information, which is sometimes incomplete. Definitively, the relationship of stress to judgment and decision-making in emergencies is an aspect of human behavior that remains relatively unexplored. This paper aims to develop a new management model to handle emergencies during an industrial disasters. The model is based on digitalization principles and innovative technologies such as: big data systems used for data storage and simulation software. Digitalization and the use of new intelligent tools for emergency management represents a key point since they provide a flow of digital information accessible real time to all emergency management stakeholders (Arora et al, 2010). Furthermore, the use of connected devices to each other makes allow to develop a network between different “players” involved in the emergency (De Mauro et al., 2015). The underlying motivation on which is based the present research is the awareness that worldwide health care enterprise has devoted relatively little technical talent, and intellectual effort to improve operations of health care emergency systems management (IOM, 2004). Our study outlines a model to address the process of determining the priority of patients’ treatments based on the severity of their condition in order to improve the quality of care. The research tries to cover the limitation of actual triage methods integrating new principles of health 4.0 in order to analyze, design, and control the patient treatment efficiently when resources are insufficient for all to be treated immediately. The model takes advantage of a GIS system for the facilities hospital selection where to hospitalize the injured. It is validated using Flexsim Software© to represent a real emergency scenario. The use of smart tools is proposed to promote the digital transformation of health care systems engineering. The paper is organized as follows: Section 2 presents a summary of the most used Triage models. Section 3 describes the rationale of the proposed model. Section 4 presents an experimental design of the proposed model concerning the emergency scenario occurs in a petrochemical plant. Finally, in section 5 conclusions are discussed.

2. Literature review on the most used Triage models
Communication and coordination among stakeholders are key elements in an industrial emergency disaster management (Haghighi et al., 2013). During an industrial emergency, it is essential to take decisions in very short time intervals in order to sort patients into those who need critical attention (Arbon, 2004; Burstein & Carlsson, 2008). In this context, triage is absolutely required for categorizing the casualties in accordance with medical care priorities (Craig et al., 2013; Eitel et al., 2003). Definitively, a proper triage process is a crucial element to manage the emergency situation in the best way. Different methods of triage have been applied worldwide (Iserson & Moskop, 2007). Following, some of the most used triage models in the world have been analyzed. A critical analysis of the most important triage models is developed. Australasian triage scale (ATS) is a triage model developed in Australia in the 1994. The model assesses patient’s severity in five minutes. The evaluation of the patient is
made subjectively by the triage officer. The symptoms considered for the analysis are: cardiac and respiratory arrest, respiratory rate, behavioral disorder, respiratory distress, chest pain, testicular torsion, major trauma and other. The scale of severity is developed in five levels of gravity (in descending order: red, orange, green, blue, white), it represents patient's severity. Each level is associated with a maximum time within which patient has to be cured (Considine et al., 2004).

*Canadian triage and acuity scale* (CTAS) is a triage model developed in 1990 in Canada. The evaluation of the patient is made by the nurse or medic and the time to assessment is about 15 minutes. This model uses a list of symptoms to assess the patient's condition. The symptoms considered for the analysis are: cardiac and pulmonary arrest, major trauma, shock states, unconscious, severe respiratory distress, head injury, altered mental state, pain, overdose, abdominal pain, dyspnea, vomiting and diarrhea, psychosis, agitation and other. This triage model defines a scale with five levels of severity (in descending order: red, orange, yellow, green and blue). CTAS model defines many more symptoms than the ATS model and it defines a relationship between patient's symptoms and the potential causes of illness (Bullard et al., 2008). On the other hand, CTAS assessment is slower than ATS.

*Manchester triage scale* (MTS) used in UK, defines a scale with five levels patients’ severity (in decreasing order: red, orange, yellow, green and blue). For each level, it defines a maximum time within which patient has to be cured. This model assesses patient through the use of 52 diagrams relating to symptoms (Martins et al., 2009). The symptoms considered for the analysis are: abdominal pain, abscesses, infection, allergy, pain, diarrhea, diabetes, eye problems, ear problems and other. Triage nurse applies the protocol to the patients. The MTS model differs from its predecessors because it also provides a telephone evaluation remotely if necessary.

*Emergency severity index* (ESI) is a triage model developed in the US in the '90s. Priority is defined considering patient’s condition and resources necessary to cure him. Even in this case, the model provides five levels of severity (Shelton, 2009). The propriety depends on the patient’s severity and the necessary resources. Initially nurse analyzes vital signs. If the patient is not critical (Level 1 or 2) the decision maker considers the expected resources necessary to determine triage level (level 3,4, or 5). The algorithm is based on four questions:

- Does this patient require immediate life-saving intervention?
- Is this a patient who shouldn’t wait?
- How many resources will this patient need?
- What are the patient's vital signs?

Using this question it is defined the triage acuity scale. This model is more methodical than the models previously described, as it follows a standard evaluation procedure. Again, there are no numerical evaluations, but the evaluation is very subjective.

Research indicates that traditional healthcare models, are subjective, qualitative and not based on communication and information flow (Christ et al., 2010). Also, they do not use technologically advanced tools in the healthcare process (Christian et al, 2006). The digital revolution imposed by the market drives the innovation of all processes, including healthcare. Thus, the goal of the present research is to overcome the limitations identified in literature, developing a new management model/algorithm, which digitizes emergency process using smart tools. In particular, the proposed model involves the development of a new algorithm triage “mathematical” that through the definition of scores allows to evaluate the condition of patients. Moreover, through digitization of the model, information flows are much faster and therefore the management of the emergency takes more control.

### 3. The rationale of the proposed model

Research methodological approach develops a management model based on an new algorithm to promote a digital transformation of health care systems engineering and to define the priority of patients' treatments. The proposed approach integrates GIS algorithm, big data and multi-criteria analysis. In detail, Medical staff defines the maximum time within which each patient has to be cured, considering triage level and using an integrated GIS system. A multi-criteria analysis is carried out in order to choose the best hospital in which to lead the patient. Information about hospital conditions (vacancies, departments, etc.) are acquired through big data systems. A data memory system updates in real time the status of emergency room. The numeric/quantitative model identifies patient’s severity and the most suitable hospital to his/her conditions, in the shortest possible time. All information is analyzed in real time through the use of “smart” tools in view of smart emergency management. A triage model is widely adopted and used, only if it ensure excellent reliability and validity. Thus, a specific rationale has been developed to implement the proposed model. The model is simulated through Flexsim Software®

Here below is a description of the main elements that characterize the proposed model.

#### 3.1 A new triage algorithm

Traditional triage models, are qualitative and they not use innovative tools during emergency management. Subjectivity patient's evaluation is assigned to the medical staff. The proposed triage model provides a quantitative assessment and it defines five evaluation levels (Table 1).

It is based on ESI model, colors assessment of MTS model and hospitalization time of ATS model.

<table>
<thead>
<tr>
<th>Level</th>
<th>Name</th>
<th>Hospitalization time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dying</td>
<td>Immediately</td>
</tr>
</tbody>
</table>
The patient’s evaluation model is shown in Table 2. During an emergency situation, the evaluation table is filled in on the tablet supplied to the medical staff. Table 2 describes patient’s symptoms and weights associated with each symptom. The triage algorithm is executed in field, where the disaster occurs.

### Table 2: Triage algorithm

<table>
<thead>
<tr>
<th>Symptoms</th>
<th>Severity</th>
<th>Weight factors</th>
<th>Index (SxW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart beat</td>
<td>1</td>
<td>0.263</td>
<td></td>
</tr>
<tr>
<td>Breathing</td>
<td>2</td>
<td>0.263</td>
<td></td>
</tr>
<tr>
<td>Injury</td>
<td>3</td>
<td>0.240</td>
<td></td>
</tr>
<tr>
<td>Level of consciousness</td>
<td></td>
<td>0.070</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td></td>
<td>0.070</td>
<td></td>
</tr>
<tr>
<td>Pressure level</td>
<td></td>
<td>0.070</td>
<td></td>
</tr>
<tr>
<td>Pain</td>
<td></td>
<td>0.008</td>
<td></td>
</tr>
<tr>
<td>Panic</td>
<td></td>
<td>0.008</td>
<td></td>
</tr>
<tr>
<td>Past medicals</td>
<td></td>
<td>0.008</td>
<td></td>
</tr>
</tbody>
</table>

### Resources

- Blood labs
- Urine labs
- Electrocardiogram
- X-rays
- Fluids hydration

\[
\sum \text{(weight factors)} = 1 \quad (1)
\]

Weights of symptoms are defined according to their importance for human health. Medical staff has to associate with each symptom a severity level between 1 and 3. According to the triage algorithm, Heart beat, Breathing and Injury are considered as critical vital functions. They have to be analysed prior to the others symptoms because they directly generate Level 1 assignment. Only vital functions (in bold) can be evaluated “critical”. If one vital function is considered critical, patient is dying and he is assessed “Level 1”. Otherwise, a severity value is associated with each symptom. After, symptom index is calculated with the following equation:

\[
\text{Index} = \text{Severity} \times \text{Weight} \quad (2)
\]

Then, it defines an overall index that describes patient's severity. The overall index is calculated by the following equation:

\[
\text{Overall index} = \sum \text{Index} \quad (3)
\]

The following scenarios may occur:
- If overall index is between 3 and 2.5 the patient is evaluated “Level 2”.
- If overall index is between 2.5 and 1.5 the patient is evaluated “Level 3”.
- If overall index is less than 1.5 is necessary to analyze necessary resources that will benefit the patient.
- If the patient needs more than 2 resources is evaluated “Level 4”, otherwise “Level 5”.

Figure 1 summarizes the triage diagram for proposed algorithm.

### 3.2 GIS model

GIS system is integrated in “smart” device of health rescuers. Smart device is equipped with GPS system that identifies the location of accident (“POI” point of interest). GIS simulator (Figure 2) identifies a set of hospitals near the accident site and calculates the optimal routes of ambulances during rescue.
3.3 Big data

Big data system, collects information about hospital conditions (Figure 3). First information is hospital location to identify the distance from the accident site. In addition, the big data system stores real time information about vacancies hospitals. Medical staff, after patients assessment, acquires necessary information through device and it defines multi-criteria approach to final decision. The emergency management system (internal or external emergency plan) is not considered in the system. Information are about hospital conditions. Information is transmitted to devices via internet (not Wi-Fi). The present paper does not cover issues related to the security of big data. The information is accessible only by external medical staff arriving at the accident site.

3.4 Multicriteria analysis

Multi-criteria analysis helps to choose hospital for each patient, considering patients’ condition (triage) and conditions of hospitals (big data). For each hospital it is necessary to define: (1) departments; (2) distance from accident site; and (3) vacancies in emergency room. Figure 4 shows multi-criteria approach for hospital choice considering patient’s condition (triage) and hospital characteristics (big data).

3.5 Simulation

Simulation is the last phase of research. It validates the model and it represents approximately a real case study. In this study, simulation software used is Flexsim©. Simulation develops a dashboard that describes the main KPIs of the process. The analysis of KPIs identifies strengths and weaknesses of the system. This analysis defines optimum strategies to improve emergency healthcare model.

4. Case study and experimental design

An emergency management in a petrochemical plant was analysed. Emergency was caused by the explosion of a furnace and consequently developing of a fire. Operator in the control room immediately alerted rescue and firefighters. Three ambulances arrived at the plant. Five operators were injured. Health emergency team assessed injured’ conditions using the new triage algorithm. Table 3 shows an example for operator’s 1 assessment.

<table>
<thead>
<tr>
<th>Symptoms</th>
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<th>Weight factors</th>
<th>Index (SxW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart beat</td>
<td>x</td>
<td>0.263</td>
<td></td>
</tr>
<tr>
<td>Breathing</td>
<td>x</td>
<td>0.263</td>
<td></td>
</tr>
<tr>
<td>Injury</td>
<td>x</td>
<td>0.24</td>
<td>0.48</td>
</tr>
<tr>
<td>Level of</td>
<td>x</td>
<td>0.07</td>
<td>0.14</td>
</tr>
<tr>
<td>consciousness</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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<table>
<thead>
<tr>
<th>Age</th>
<th>x</th>
<th>0.07</th>
<th>0.14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure level</td>
<td>x</td>
<td>0.07</td>
<td>0.14</td>
</tr>
<tr>
<td>Pain</td>
<td>x</td>
<td>0.008</td>
<td>0.016</td>
</tr>
<tr>
<td>Past medicals</td>
<td>x</td>
<td>0.008</td>
<td>0.016</td>
</tr>
<tr>
<td>Panic</td>
<td>x</td>
<td>0.008</td>
<td>0.016</td>
</tr>
</tbody>
</table>

Operator 1 manifested two critical elements (heartbeat and breathing). Triage level 1 was classified. Table 4 shows a summary of the triage assessment for five injured operators.

Table 4: Triage assessment (five operators)

<table>
<thead>
<tr>
<th>Operator</th>
<th>Triage Level</th>
<th>Hospitalization time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Level 1</td>
<td>Immediately</td>
</tr>
<tr>
<td>2</td>
<td>Level 1</td>
<td>Immediately</td>
</tr>
<tr>
<td>3</td>
<td>Level 3</td>
<td>30 min</td>
</tr>
<tr>
<td>4</td>
<td>Level 5</td>
<td>120 min</td>
</tr>
<tr>
<td>5</td>
<td>Level 5</td>
<td>120 min</td>
</tr>
</tbody>
</table>

Through GIS model two hospitals were identified near the accident site. Figure 5 shows the petrochemical plant (1) and two hospitals (2,3). First hospital was 6 minutes from the plant, while second hospital was 16 minutes from the plant. This time may vary according to local traffic during emergency.

![Figure 5: GIS simulator](image)

Big data system provided several information directly on medical staff's device (Figure 6). In particular, the most important information were:

- hospital distance from accident;
- hospital departments;
- vacancies in the emergency room classified for each triage level.

Data showed that hospital 1 was able to accept more “red codes”, while hospital 2 was able to accept more “yellow codes”. Furthermore, hospital 2 was not equipped with dermatology department.

A multi-criteria analysis identified allocation for each patient. Five injured needed immediate care. Thus, emergency department (ED) was needed. Big data analysis (Figure 6) showed that both hospitals were equipped with ED. Therefore, it was necessary consider patients’ hospitalization time. Operator 1 and operator 2 were hospitalized in the nearest hospital. Considering GIS system, hospital 1 was the nearest to accident site. Big data described vacancies. Then, the first two operators (red triage level) were conducted in hospital 1 with 2 ambulances. The simulator only considers the number of beds available for different triage levels. The two wounded can arrive simultaneously because at that moment there are two vacancies for red code. At the same time third ambulance conducted operator 3 (yellow triage level) in hospital 2. Operator 3 is conducted in the hospital 2, because he does not need of dermatological or surgical treatment. Finally, the first two ambulances, back on and they conduct operators 4 and 5 (blue triage level) in hospital 1.

Table 5 summarizes hospitalization strategy.

Table 5: Hospitalization strategy

<table>
<thead>
<tr>
<th>Operator</th>
<th>Triage Level</th>
<th>Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Level 1</td>
<td>Hospital 1</td>
</tr>
<tr>
<td>2</td>
<td>Level 1</td>
<td>Hospital 1</td>
</tr>
<tr>
<td>3</td>
<td>Level 3</td>
<td>Hospital 2</td>
</tr>
<tr>
<td>4</td>
<td>Level 5</td>
<td>Hospital 1</td>
</tr>
<tr>
<td>5</td>
<td>Level 5</td>
<td>Hospital 1</td>
</tr>
</tbody>
</table>

The model was validated using Flexsim©. Simulation model implemented real actions, described in emergency plans. Figure 7 shows emergency condition. Five injured workers are in the safe zone. The color of shirts describes their triage condition. Meanwhile, three ambulances were arriving in emergency area. Transport times included in the simulation, were those described by GIS simulator (Figure 5).
The period of the simulation is very short, about 30 seconds each simulation. This is because the Flexsim software allows to speed up the flow of time. Simulation assumptions were:

- ambulances speed: 80 km/h;
- patient evaluation time: 5 minutes;
- low level of traffic.

Italian Red Cross defines costs of emergency management. For each ambulance:

- fixed cost: 30 €;
- variable cost: 0.74 €/minute.
- These parameters are included in the simulation.

Figure 8 shows dashboard of KPIs obtained by the simulation. All injured were hospitalized after 40 minutes. Ambulances 1 and 2 traveled two trips, to transport a total of 4 patients in hospital 1, while ambulance 3 taken one trip to transport one patient (yellow code) in hospital 2. Ambulances 1 and 2 run 32 km each, while ambulance 3 runs 42 km. Time percentage of empty travel was about 40%. While time percentage for patient’s assessment was 18% for ambulances 1 and 2, while 14% for ambulance 3. The financial result shows a total cost of 176.30 €. The priority of the model is to save lives and hospitalize the wounded in the shortest possible time. Financial analysis takes on a secondary role. It only serves as an indication for emergency hospital transport costs. Cost analysis could serve as future development, starting from this emergency model, to limit management costs while maintaining a high level of service.

5. Conclusion

In the age of digitization and intelligent systems, all business processes are suffering significant changes. Safety elements have a fundamental role in this revolution. It is therefore necessary to deploy a new intelligent system for emergency management. Healthcare process assumes
considerable importance during emergency in industrial plants. Traditional healthcare methods are qualitative and not using intelligent systems. The research objective is to overcome limitations of literature, developing a quantitative algorithm which improves healthcare process. Key aspect of emergency management is information flow. The model developed allows to digitize healthcare process using intelligent tools (portable devices, GPS systems, big data systems) to transmit real time data. Simulation has to validate the model. Flexsim software© simulated emergency healthcare process. Results obtained allow us to identify the optimal strategy for healthcare specific emergency. This research highlights the importance of a digital transformation in the health care systems engineering. Digital technologies and applications have the potential to markedly enhance the quality of care. The model has been implemented in a real case study concerning an industrial plant. Of course, the model can be implemented in other scenarios and not only in industrial context. Future research will investigate how include internal or external emergency plan, emergency medical service in the model.

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References


