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A method of prioritizing victims of a mass casualty event for managing medical rescue operations

by

Łukasz Tomczyk* **and Zbigniew Kulesza****

*University of Warmia and Mazury in Olsztyn, Faculty of Technical Sciences, ul. Oczapowskiego 2, 10-719 Olsztyn, Poland

**Bialystok University of Technology, Faculty of Mechanical Engineering, ul. Wiejska 45C, 15-351 Bialystok

lukasz.tomczyk@uwm.edu.pl, z.kulesza@pb.edu.pl

Abstract: The paper discusses the concept of ICT-aided identification of mass casualty events and prioritization of victims of a mass casualty event for treatment in a Hospital Emergency Department (HED), which relies on a distributed network-centric Data Communications System for Managing Medical Rescue Operations (DCSMMRO). A method for triaging patients is presented and the functional architecture of a utility application for setting treatment priorities in DCSMMRO is designed. The proposed method and the developed application for the data communications system were verified on the example of a hypothetical event.

Keywords: mass casualty event, emergency medicine, managing medical rescue operations, prioritizing victims

1. Introduction

A mass casualty event, caused by a sudden accident, an epidemic or dangerous behavior may jeopardize the life or health of a large number of people, who will require direct medical assistance (see Holgersson and Björnstig, 2014, or Kosashvili, Loebenberg, Lin, Peleg, Zvi, Kluger and Blumenfeld, 2009, or Gautshci and Zellweger, 2007). The Provincial Emergency System (PES) has usually limited resources (see Leow, Brundage, Kushner, Kamara, Hanciles, Muana, Kamara, Daoh and Kingham, 2012), and therefore not all casualties can be provided with medical assistance which corresponds to the severity of their injuries.

Medical rescue operations which are initiated in response to a mass casualty event feature three main organizational tasks (see Zawadzki, 2007):

1. Triage or medical segregation of casualties (see Castle, 2006, or Cone and MacMillan, 2005).

2. Selection of Hospital Emergency Departments (HED), where victims will receive medical assistance and will be prepared for specialist treatment under hospital conditions to guarantee maximum treatment efficiency (Dean and Nair, 2014, or Einav, Aharonson-Daniel, Freund, Weissman and Peleg, 2004).
3. Allocation of medical means of transport for transporting casualties to the assigned HED (see Castle, 2006, or Rauner, Schaffhauser-Linzatti and Niessner, 2012).

Triaging involves the segregation of casualty groups into medical priority groups, which are coded with colors: red, yellow and green. Lethal victims are coded in black (see Ciećkiewicz, 2008). In this approach, every color-coded group may contain more than one person at any given moment. As a consequence of this classification, transport priority of each group has to be defined.

In previous studies (see Kołodziński and Tomczyk, 2012, or Kołodziński and Tomczyk, 2013), it was proposed to replace the process of medical segregation and HED selection in a mass casualty event with the following organizational tasks:

1. Identification of the post-emergency situation, including the determination of the number and the condition of victims who require medical assistance.
2. Prioritization of victims for transport to HED – without previous segregation.
3. Determination of the required number and the equipment standards of the HED, which will provide medical rescue services and will prepare casualties for specialist treatment under hospital conditions to guarantee maximum treatment efficiency.
4. Determination of the required number and the equipment standards of medical means of transport, which will transport casualties to a selected HED.
5. Selection of the HED, to which the victims will be transported, including the selection of the appropriate medical means of transport.

Successful decision-making in rescue operations initiated in response to a mass casualty event requires access to information about (see Zawadzki, 2007, or Artinger, Maier, Coskun, Nestler, Mahler, Yildirim-Krannig, Wucholt, Echtler and Klinker, 2012):

- the post-emergency situation, so as to determine the services required for rescue operations and the course of the rescue action,
- victims' health conditions,
- availability of rescue forces and resources,
- service ability of roads connecting the scene of accident with the HED, where casualties can receive medical assistance.

Officers who manage rescue operations:

- have to account for a high number of factors in the decision-making process relating to every rescue operation,

- work under time pressure and sense of extraordinary responsibility for the life and health of casualties; this pressure causes additional stress and has an adverse effect on decision quality,
- are faced with ethical dilemmas in the process of prioritizing patients for treatment,
- may overestimate the level to which an individual has experienced an illness or injury, thus delaying the treatment of other patients, who urgently require medical assistance, which, altogether, decreases the effectiveness of the rescue action,
- have to account for the fact that the condition of casualties may deteriorate significantly over time, and therefore patients may have to be classified into a different priority group.

In a mass casualty event, the effectiveness of rescue services is often determined by the moment when treatment becomes available. The timing of the rescue response can be controlled by improved data communications support for rescue operations. A distributed and net-centric system is developed to serve the above purpose, and in successive sections of this study, it will be referred to as the *Data Communications System for Managing Medical Rescue Operations* (DCSMMRO) (see Kołodziński and Tomczyk, 2012).

This article proposes the methods for:

1. Identifying a post-emergency situation.
2. Prioritizing casualties for treatment in HED with the use of DCSMMRO.

2. A concept of a data communications system for managing medical rescue operations in a mass casualty event

2.1. Contextual model of a DCSMMRO in a mass casualty event

At the *operational level*, the Provincial Emergency Notification Center (PENC) is represented by the Medical Rescue Coordinating Physician (MRCP). The coordinator allocates the forces and resources of the Provincial Emergency System (PES), which will participate in the emergency operations, initiated in response to a mass casualty event. Information needed for the decision-making process in an emergency, in particular – the data regarding Hospital Emergency Departments (HED) and Medical Rescue Teams (MRT), should be supplied by the Data Communications System of a Provincial Emergency System (DCSPES).

At the *tactical level*, the following personnel members manage rescue operations at the site of emergency (see Ciećkiewicz, 2008):

1. *Chief Emergency Officer* (CEO), usually a State Fire Service (SFS) officer who supervises the operations of all personnel members at the emergency site. His main tasks include:

- notifying ENC of the occurrence or suspected occurrence of a mass casualty event,
- indicating the precise location of the event and organizational requirements for the rescue action,

- diagnosing the demand for rescue equipment and personnel;

2. *Medical Emergency Supervisor* (MES) at the site of a mass casualty event. His main responsibilities are:

- managing rescue operations on behalf of CEO until CEO's arrival at the site of accident,
- estimating the number of casualties who require assistance and evaluating their health condition,
- determining the required number of HEDs with the necessary equipment and facilities,
- determining the demand for medical means of transport for transferring casualties to the HEDs,
- triaging patients for transport to the HEDs,
- allocating MRTs to successive victims in a mass casualty event.

At the *executive level*, rescue operations are performed by rescue officers, who are referred to as Segregation Officers. In the proposed solution for optimizing medical rescue operations, the above staff members will be termed as *Casualty Health Monitors* (CHM).

The health condition of victims is assessed to determine:

- the organization of medical rescue services at the scene of accident,
- priority of patients transported for treatment in the HEDs,
- HED to which casualties should be transported,
- the required type of medical means of transport.

The operating environment of a Data Communications System for Managing Medical Rescue Operations is presented in Fig. 1.

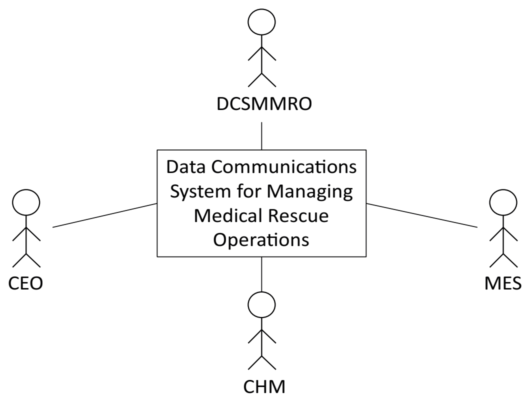

Figure 1. Context diagram of DCSMMRO supporting the organization of rescue operations in a mass casualty event (source: own elaboration)

2.2. Identification of a post-emergency situation with the use of DC-SMMRO

The use cases of DCSMMRO in the process of identifying a post-emergency situation are shown in Fig. 2.

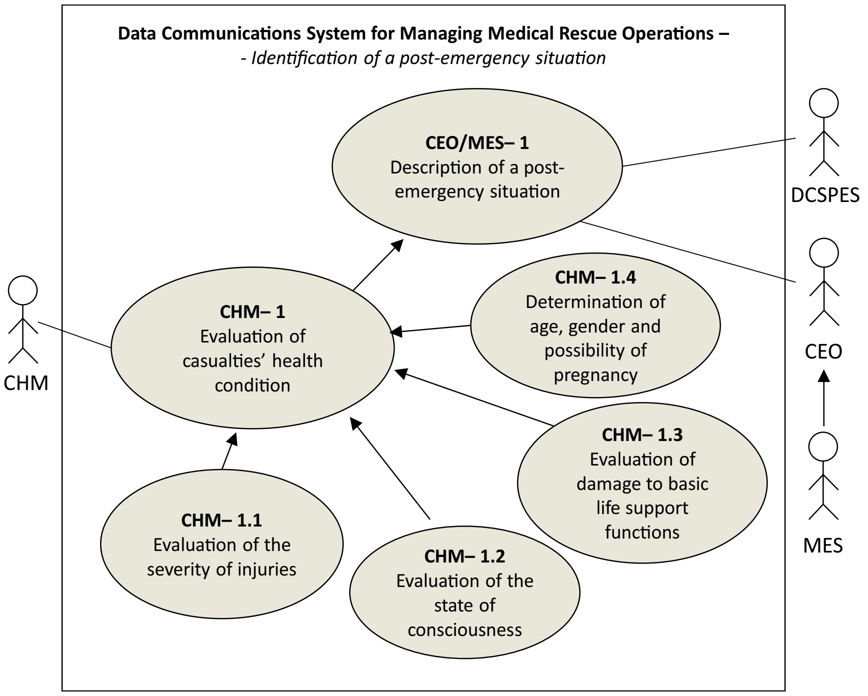

Figure 2. The use case diagram of DCSMMRO in the process of identifying a post-emergency situation (source: own elaboration)

We provide below the description of use cases of DCSMMRO presented in Fig. 2:

CEO/MES - 1. Description of a post-emergency situation

The process of identifying a post-emergency situation begins when a mass casualty event is reported to the ENC. The following information is verified at the site of accident, and the resulting data is entered into the DCSMMRO:

- geographic coordinates of the emergency site,
- time of event,
- type of event, i.e. type of threat that caused the event,
- estimated number of victims.

CHM – 1. Evaluation of casualties' health condition

The condition of the l^{th} ($l = \overline{1, L}$) victim in a mass casualty event is described by six variables (see Kołodziński and Tomczyk, 2012, or Kołodziński and Tomczyk, 2013):

$$s_l =< s_{l,1}, s_{l,2}, s_{l,3}, s_{l,4}, s_{l,5}, s_{l,6} > \ , \ \ l = \overline{1, L}, \tag{1}$$

where:
$l-$ victim's number;
$L-$ number of casualties in a mass event;
$s_{l,1}-$ extent of injuries;
$s_{l,2}-$ state of consciousness;
$s_{l,3}-$ degree of damage to basic life support functions;
$s_{l,4}-$ gender;
$s_{l,5}-$ pregnancy;
$s_{l,6}-$ age.

In (1), the variables $s_{l,2}$ and $s_{l,3}$ are the derivatives of the extent of injuries of the l^{th} victim, which is determined by variable $s_{l,1}$. The extent of injuries suffered by the l^{th} victim is described by a set of injuries assigned numbers $u \in \mathbf{U}_l^{pow}$.

A diagram of activities performed by CHM to produce partial assessments of the casualties' health condition and enter the resulting data in DCSMMRO is presented in Kołodziński and Tomczyk (2012).

2.3. Prioritizing victims for treatment in HED with the use of DCSMMRO in a mass casualty event

The existing procedure of triaging casualties into priority groups (coded with colors: red, yellow and green) is replaced with the process of assigning a unique number to every diagnosed patient. Information about casualties' health condition is collected by CHM and entered into DCSMMRO. The above data are used to prioritize patients for treatment in HED.

The use cases of DCSMMRO in the process of prioritizing victims of a mass casualty event for treatment in HED are presented in Fig. 3.

Victims of a mass casualty event are prioritized for treatment in HED in line with the procedure illustrated in Fig. 3.

MES–1. Determination of individual priority levels for each patient

Based on the rules of an expert knowledge base (see Kołodziński and Tomczyk, 2012), the DCSMMRO determines partial treatment priorities for every individual based on his/her health condition. An individual priority level is set in view of a partial assessment of the victim's condition which indicates:

- extent of injuries,
- state of consciousness,
- damage to basic life support functions,
- possibility of pregnancy,
- age and gender.

The above values are determined for every individual regardless of the remaining casualties' health status. The treatment priority for the l^{th} victim is determined

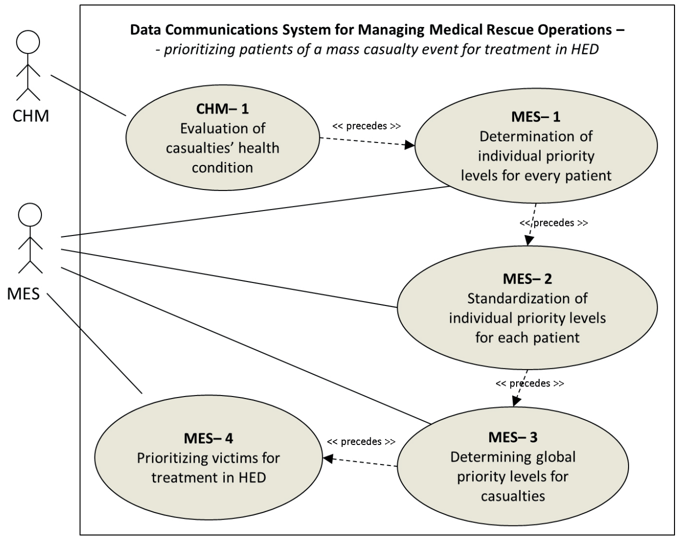

Figure 3. The use cases of DCSMMRO in the process of prioritizing victims of a mass casualty event for treatment in HED (source: own elaboration)

based on the rules presented in Kołodziński and Tomczyk (2012), or Kołodziński and Tomczyk (2013):

$$s'_{l,k} = d_k(s_{l,k}), k = \overline{1, K}, \quad l = \overline{1, L}, \tag{2}$$

where:

K – number of identified variables describing a patient's health condition,

L – number of victims in a mass casualty event,

$d_k(s_{l,k})$ – decision-making function whose argument is the k^{th} component describing the health condition of the l^{th} victim. The value of the k^{th} component is used to determine a partial treatment priority.

The only exception is the gender of the l^{th} victim ($s_{l,4}$) which has no separate influence on individual treatment priority

According to Kołodziński and Tomczyk (2012, 2013), gender is taken into account only when partial priorities are determined in view of the victim's age and pregnancy.

MES – 2. Standardization of individual priority levels for each patient

Partial priorities determined in the use case *MES–1* based on individual components describing the health condition of the l^{th} victim have different ranges of variability. The above prevents an objective comparison of casualties as regards the urgency of their treatment. To overcome this problem, partial priorities are standardized, and the results take on the following form:

$$\bar{s'}_{l,k} = \frac{s'_{l,k} - \min\limits_{l} s'_{l,k}}{\max\limits_{l} s'_{l,k} - \min\limits_{l} s'_{l,k}} k = \overline{1,K}, l = \overline{1,L}, \tag{3}$$

where:

K – number of identified variables describing a patient's health condition,

L – number of victims in a mass casualty event,

$s'_{l,k}$– treatment urgency of the l^{th} victim based on the k^{th} component describing the victim's health condition – the lower its value, the higher the treatment priority.

When all casualties are assigned the same partial priority in view of the k^{th} component describing their health condition, the standardized parameter takes the value of zero.

MES–3. Determining global priority levels for casualties

Standardized partial treatment priorities for casualties constitute a basis for determining the global level of treatment priority. The global level of treatment priority is determined with the use of the decision-making function which is expressed as:

$$s''_l = \sum_{k=1}^{K} w_k \, \bar{s'}_{l,k} \text{ for } \quad l = \overline{1,L} \ , \tag{4}$$

where:

$\bar{s'}_{l,k}$– standardized value of treatment priority level in view of the k^{th} component describing the health condition of the l^{th} victim,

w_k – weight of the k^{th} component describing a victim's health condition,

where: $\sum\limits_{k=1}^{K} w_k = 1$.

The lower the overall evaluation $s''_{l,k}$, the higher the individual level of treatment priority.

MES–4. Prioritizing victims for treatment in the HED

Victims are prioritized for treatment in the HED based on the overall evaluation performed in use case *MES-3.* Casualties with lower global scores are triaged to a higher priority group. Every time a CHM enters a victim's health status data in the system, DCSMMRO rearranges the priority list of casualties awaiting treatment in HED. Diagrams of operations performed by MES to prioritize casualties for treatment in HED with a detailed description of the relevant procedures are presented in Kołodziński and Tomczyk (2012).

2.4. Diagram of activities performed by medical rescue officers with the support of DCSMMRO in a mass casualty event

The tasks performed by medical rescue officers with the support of DCSMMRO in a mass casualty event are presented in an activity diagram in Fig. 4.

3. Functional architecture of a utility application for a data communications system for managing medical rescue operations in a mass casualty event

The functional architecture of a utility application for a Data Communications System for Managing Medical Rescue Operations, which supports the identification of the post-emergency situation and prioritization of patients for treatment in HED in a mass casualty event is presented in Fig. 5.

Functional characteristics of DCSMMRO components, which are presented in the use case diagram in Fig. 5, are shortly outlined below:

- DCSMMRO–1. Description of the post-emergency situation:
  - *Event description* – program component used by CEO and MES terminals. This component is used to enter data such as geographic coordinates of the emergency site, time of rescue action commencement, etc.;
  - *Client-server communication* – program component used by CEO and MES terminals. This component supports direct communication with MRCP, including forwarding information about the demand for medical rescue resources in a mass casualty event;
- DCSMMRO–2. Evaluation of casualties' health condition:
  - *Health evaluation*– enables CHM to enter information about the examined patient's health condition into the system;
  - *Client-server communication* – program component which enables CHM to communicate with MES via the network and retrieve system information about the health condition of patient (from the MES server) who need to be re-evaluated.
- DCSMMRO–3. Prioritizing patients for treatment in HED:
  - *Individual priority* – program component, which relies on the rules of the expert knowledge base to determine partial treatment priorities based on individual components describing casualties' health condition;
  - *Treatment priority* – program component which supports the prioritization of patients for treatment in HED;
  - *Client-server communication* – program component which enables MES to communicate with various CHMs in real time. This component receives and releases data about casualties' health condition to

enable CHM to update the relevant information when patients need to be re-evaluated.

The components of DCSMMRO, presented in Fig. 5 have been designed and programmed using Microsoft Visual C# 2010 and Microsoft Windows Phone Developer Tools 7.1 in the Microsoft Visual Studio 2010 Professional environment. The expert problems were solved with the involvement of the PC-SHELL 4.5.3 expert system shell from the AitechSphinx package.

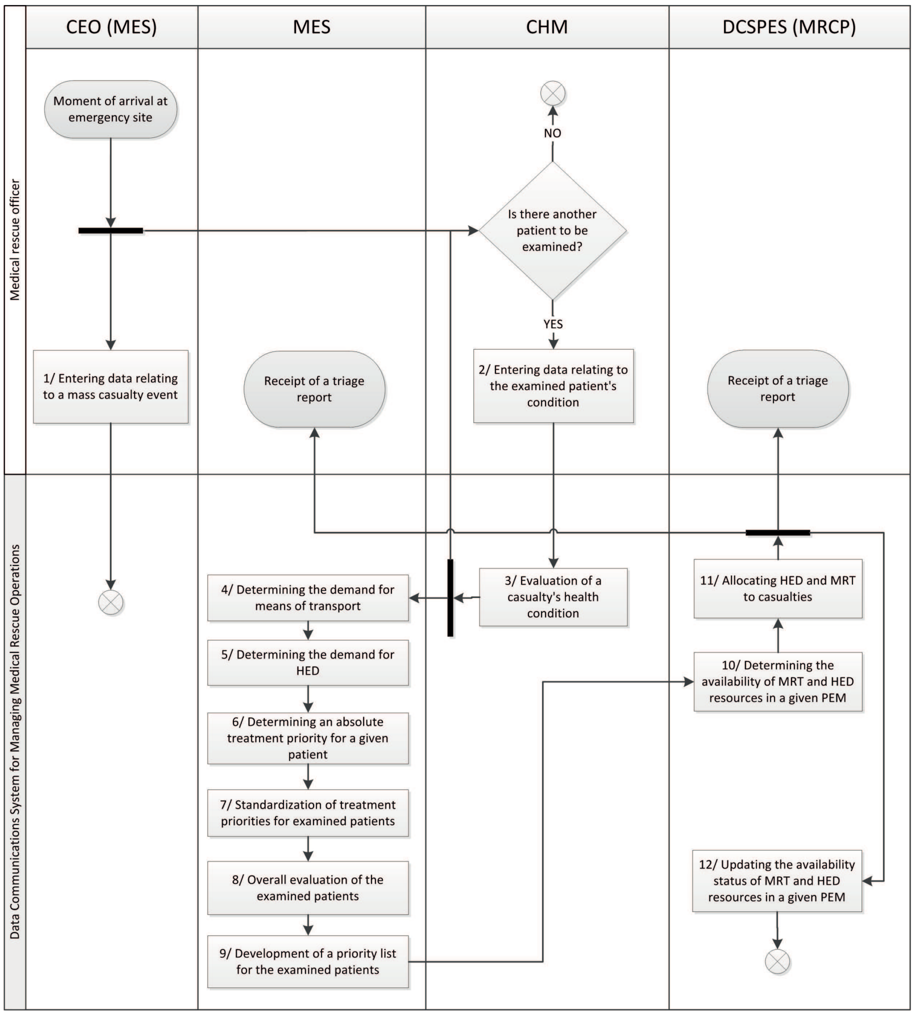

Figure 4. Diagram of activities performed by medical rescue officers with the support of distributed net-centric DCSMMRO in a mass casualty event (source: own elaboration)

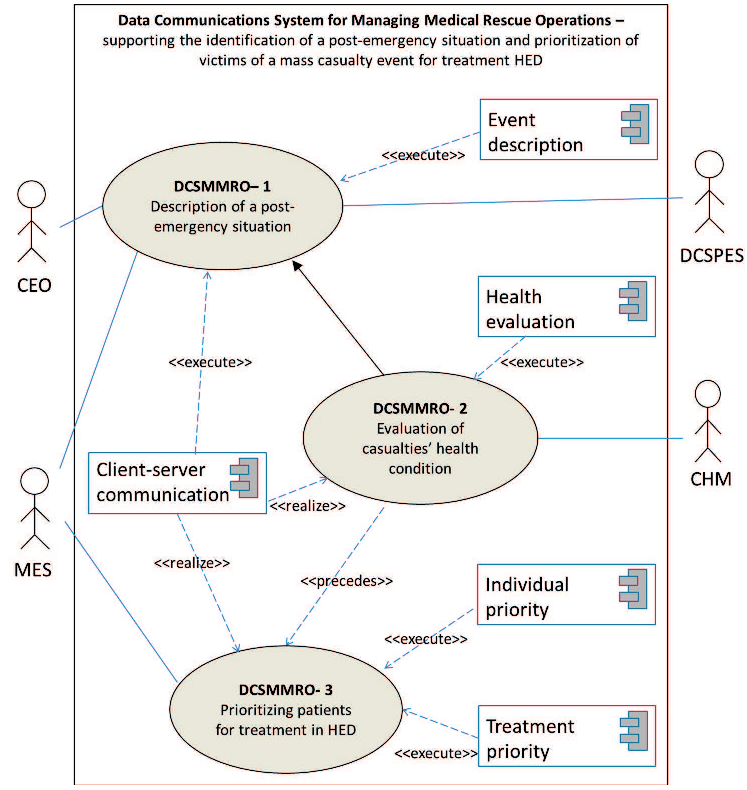

Figure 5. Diagram of use cases of DCSMMRO components for the identification of a post-emergency situation and prioritization of victims of a mass casualty event for treatment in HED (source: own elaboration)

The functional correctness of DCSMMRO software in the process of identifying patients' health condition and allocating medical rescue resources to victims of a mass casualty event has been verified with the help of the example, described in the following section.

4. Use case example of a data communications system for managing medical rescue operations in prioritizing victims of a mass casualty event for treatment in a hospital emergency department

In considering this example, we assume that:

1. The victims of a mass casualty event can sustain various types of injuries at different levels of severity, as illustrated in Table 1.
2. There are ten victims in a mass casualty event ($L = 10$).

3. CHM identified the health condition of every casualty and entered the relevant data into DCSMMRO with the use of a mobile device.

Table 1. List of possible injuries in a mass casualty event with the relevant levels of severity based on TRIAGE system

Injury number ($u \in \mathbf{U}_l^{pow}$)	**Level of severity (n)**	**Type of injury**
1	1	"Superficial wounds"
2	1	"Up to 10% body area affected by less than third-degree burns"
3	1	"Fracture of forearm bones"
4	1	"Foot fracture"
5	1	"Hand fracture"
6	2	"Spine injury"
7	2	"Hip injury"
8	2	"Shoulder injury"
9	3	"Isolated fracture of crus bones"
10	3	"Traumatic amputation of limb"
11	3	"Hypothermia"
12	3	"Head injury"
13	3	"Unstable chest wall injuries"
14	3	"Shock"
15	4	"Severe head injury"
16	4	"Traumatic brain injury"
17	4	"Extensive crush injuries"

Information about the health condition of victims in the analyzed mass casualty event is presented in Table 2.

The following priorities are determined based on the information entered into DCSMMRO via the expert system module which supports the *prioritization of victims of a mass casualty event for treatment in HED*:

- partial absolute treatment priorities based on the value of components (1) describing each casualty's health condition – *activity 6* in Fig. 4;
- standardized partial priorities – *activity 7* in Fig. 4;
- overall evaluation of victims based on standardized partial priorities in view of the weight of each component – *activity 8* in Fig. 4;
- priority of treatment in the HED, based on an overall evaluation of casualties' health condition – *activity 9* in Fig. 4.

The indirect results of the process of prioritizing patients for treatment in the HED and their transport are presented in Table 3.

Table 2. Description of the health condition of victims in a mass casualty event (source: own elaboration)

Victim's number (l)	**Values describing the health condition of the l^{th} victim**						
	U_l^{pow}	$s_{l,1}$	$s_{l,2}$	$s_{l,3}$	$s_{l,4}$	$s_{l,5}$	$s_{l,6}$
1	4, 5, 8	3	10	10	1	0	40
2	2, 10	1	9	12	1	0	14
3	8, 14	2	12	13	1	0	2
4	1, 8, 9	1	10	11	0	0	4
5	2	3	9	12	1	0	46
6	1, 9	3	6	8	1	0	24
7	7	2	14	13	0	0	60
8	2, 3	1	15	16	0	1	24
9	6	2	10	12	1	0	77
10	8	2	8	13	1	0	30

5. Conclusions

The use of a Data Communications System for Managing Medical Rescue Operations in the process of identifying a post-emergency situation and prioritizing victims of a mass casualty event for treatment in HED significantly increases the effectiveness of rescue action. The here discussed system:

- enables the medical rescue officers to identify the consequences of a mass casualty event and monitor the progress of rescue operations in real time,
- allows the medical rescue officers for directly communicating the health status information to HED and MRT which can, therefore, get promptly prepared for handling the casualties,
- supports communication of unique information about the victims' health condition to every medical rescue officer responsible for different stages of the chain of survival – in keeping with the "one-stretcher" principle,
- maximizes the safety of rescue operations by suggesting better solutions and eliminating errors when data is communicated by medical rescue officers,
- supports, with its open source expert knowledge base, the improvement of expert rules by relaxing or tightening the principles for determining partial priorities and/or modifying the weights of evaluation components,
- sets specific operating requirements for individual casualties, i.e. indicates the required type of transport and medical resources in HED,
- effectively caters to the demand for medical rescue services through access to a distributed data base of HED resources, MRT location and status,
- contributes to a more effective use of the HED and MRT resources of a Provincial Emergency System.

A data communications system, which supports the emergency officers in the process of organizing rescue operations should have the basic attributes of:

- *a dispersed system* – regardless of the computer terminal supporting the operations of a given officer, the system forms a logically connected whole. The data concerning casualties, rescue forces and HED resources are gathered and physically distributed to various locations, and access to data is not determined by their original source;
- *a net-centric system* – a distributed data communication system provides all emergency officers with simultaneous access to data needed at any given moment, thus contributing to real-time communication in a mass casualty event;
- *an expert system* – expert knowledge used by emergency officers is rule-based and available in knowledge bases of the data communications system,
- *mobile system* – facilities the operations of medical rescue officers at the emergency site and significantly shortens decision-making time.

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Table 3. Indirect results of prioritizing patients for treatment in HED (source: own elaboration)

Victim's number (l)	Values of transformed components describing casualties' health condition, absolute priorities and respective standardization results (values of $s_{\mathbf{li}}$ are provided in Table 2)												Overall evaluation (s''_l)	Level of treatment priority in HED
	$s'_{l,1}$	$s'{}_{l,1}$	$s'_{l,2}$	$s'{}_{l,2}$	$s'_{l,3}$	$s'{}_{l,3}$	$s'_{l,4}$	$s'{}_{l,4}$	$s'_{l,5}$	$s'{}_{l,5}$	$s'_{l,6}$	$s'{}_{l,6}$		
1	1	0	3	0.22	5	0.25	0	0	2	1	6	1	2.47	1
2	3	1	2	0.11	7	0.5	0	0	2	1	6	1	3.61	9
3	2	0.5	5	0.44	8	0.63	0	0	2	1	3	0	2.57	2
4	3	1	3	0.22	6	0.38	0	0	2	1	4	0.33	2.93	5
5	1	0	2	0.11	7	0.5	0	0	2	1	6	1	2.61	3
6	1	0	10	1	3	0	0	0	2	1	6	1	3	6
7	2	0.5	7	0.67	8	0.63	0	0	2	1	5	0.67	3.47	8
8	3	1	8	0.78	11	1	0	0	1	0	6	1	3.78	10
9	2	0.5	3	0.22	7	0.5	0	0	2	1	5	0.67	2.89	4
10	2	0.5	1	0	8	0.63	0	0	2	1	6	1	3.13	7