ESTIMATION OF THE NUMBER OF MEDICAL PERSONNEL NEEDED AT THE DISASTER SITE

By Medical Rescue Capacity (MRC) is meant the number of casualties per hour that can be adequately and efficiently offered lifesaving and limbsaving help at the disaster site. This number will depend on the following factors:

- In each phase of the chain of medical care the capacity is determined by PERSONNEL, by MATERIALS and by METHODS;
- In this case the personnel are doctors, nurses and first-aid providers. The extent of their training and experience in disaster medicine will largely determine their efficiency and thus the MRC. The MRC will also be determined by whether or not work is carried out on a (fixed) team basis;
- the MATERIALS required to carry out the lifesaving and limbsaving activities also determine the MRC, both qualitatively and quantitatively;
- the lifesaving and limbsaving actions constitute the principal METHODS at the disaster site. Doctors, nurses and first-aid providers must also learn how to carry out other duties at the disaster site, such as communication and registration;
- the MRC is further dependent on the type of injury concerned: mechanical, chemical, nuclear, biological, or combinations thereof. It should be noted, however, that whatever type of injury is involved, the lifesaving and limbsaving actions are (virtually) the same;
- finally, the MRC is determined by the severity factor (S). This factor represents the ratio between the number of injured who need to be admitted to hospital (T1 and T2) and the number of casualties who need not be hospitalized (T3).

  It is in particular the T1 and T2 casualties at the disaster site who determine the medical consumption, and to a lesser degree the T3 casualties. In short, the higher the S, the more T1 and T2 casualties there are compared to T3 casualties and the more MRC is needed.

Until recently the MRC for mechanical injuries could only be approximated on the basis of impressions gained during exercises. These have assumed that 12 (T1 + T2) casualties would be hospitalized per emergency team per hour.
A mobile medical team in the Netherlands comprises a surgeon, an anaesthesiologist and two specialized nurses. Because these emergency teams have considerable clinical experience but limited on-the-ground experience, four ambulance nurses - with less clinical experience but more on-the- ground emergency experience - might provide the same capacity.

MEDICAL, NURSING AND FIRST-AID TASKS AT THE DISASTER SITE

The medical actions to be carried out at the disaster site, as derived from the legal requirements, have been defined as followed:

- the three-fold airway manoeuvre; *
- mouth-to-mouth or mouth-to-nose resuscitation;
- external heart massage;
- application of stable side position; *
- oropharyngeal aspiration *
- oropharyngeal intubation; *
- orotracheal/endotracheal intubation; *
- balloon respiration; *
- oxygen administration; *
- chest tube placement; *
- pericardial puncture; *
- insertion of an intravenous cannula for infusion; *
- hemorrhage control; *
- insertion of a gastric tube; *
- immobilization of fractures; *
- insertion of a bladder catheter; *

In the absence of emergency team specialists, the following tasks are optional (though hardly ever indicated at disasters):

- coniotomy;
- mouth to mouth (nose) resuscitation;
- bladder puncture;
- external heart massage;
- insertion of a sternal screw;
- carrying out a phlebotomy.

The first-aid providers tasks at the disaster site are the following:

- unloading casualties;
- supervision of casualties upon their arrival at the casualty collection point;
- assistance with treatment;
- arranging internal transport;
- guarding casualties;
- presence at the loading of casualties;
- care for casualties during treatment;
- activities at the morgue;
- materials management.

Until now this number of casualties, 12, has been adopted for an emergency team, but is it realistic? Further analysis provides the following insights. Lifesaving and limbsaving activities might be further subdivided into a series of separate actions, such as infusion and intubation. By drawing up an inventory of these actions and assigning them an average duration, the MRC could be calculated for all kinds of T1/T2 ratios, taking into account which duties a first-aid provider, a nurse and a doctor can and is authorized to carry out. See table on medical, nursing and first-aid tasks.
To which actions can an average duration be assigned? These actions are presented in the same table and are indicated with an asterisk (*). In a separate table the average durations are added. These times were obtained partly from the literature and partly through our own research.

The T1/T2 ratio may vary from 1 : 2 to 1 : 4. For one T1 casualty and three T2 casualties, for instance, an experienced team consisting of a doctor/specialist and a nurse supplemented by one or two first-aid providers as the necessary support staff, would need (8 + 15) + (3 x 13) = 23 + 39 = 63 minutes. This means four (T1 + T2) casualties per hour. A mobile medical team, which comprises two such teams, (see above) would therefore be able to 'process' eight (T1 + T2) casualties. This is considerably fewer than had been originally estimated.

Assuming the fire brigade's rescue capacity (RC) to be 24 (T1 + T2 + T3) casualties (a value which requires verification), this means 8 (T1 + T2) casualties and 16 T3 casualties in the event of an S of 0.5.
The 8 (T1 + T2) casualties would therefore require one mobile medical team supplemented by four first-aid providers. A few ambulance crews and the remainder of the first-aiders would then be available for the 16 T3 casualties. The Medical Rescue Capacity would therefore be able to cope with an S of 0.5. In the event of an S of 2.0, however, two mobile medical teams would be needed.

The nurse's tasks at the disaster site are the following:

1 *Assisting the doctor*

The nurse assists the doctor in carrying out the necessary medical treatment. A nurse should be able to carry out the following medical and technical actions independently:

- three-fold airway manoeuvre;
- arranging stable side position;
- oropharyngeal aspiration;
- oropharyngeal intubation;
- mouth-to-mouth/mouth-to-nose resuscitation;
- external heart massage;
- oxygen administration;
- hemorrhage control;
- immobilization of fractures by means of splints;
- insertion of a gastric tube.

These actions all form part of the certified A-nurse training course. In emergency situations the nurse will also have to carry out certain medical actions independently, even if the conditions of 'assistance only' are not met; the legal obligation to assist those who need help (to which the nurse, as any citizen, is subject) forces him/her to do so. The nurse will nevertheless have to restrict himself/herself to those tasks for which he/she has acquired the necessary theoretical and practical skills. The nurse may only carry out elaborate medical actions if:

- he/she has completed a theoretical and practical training course for this purpose;
- communication with a competent doctor is possible at a certain stage in the care provision process;
- these actions are laid down in a protocol.

2 *Nursing care provision*

An essential condition for optimal care provision is efficient cooperation between the doctor and nurse.

3 *Safeguarding hygiene*

Although hygienic conditions are difficult or impossible to safeguard completely at the casualty collection point, hygiene must nevertheless be as good as possible in the circumstances.

4 Control and supervision of first-aid providers actions

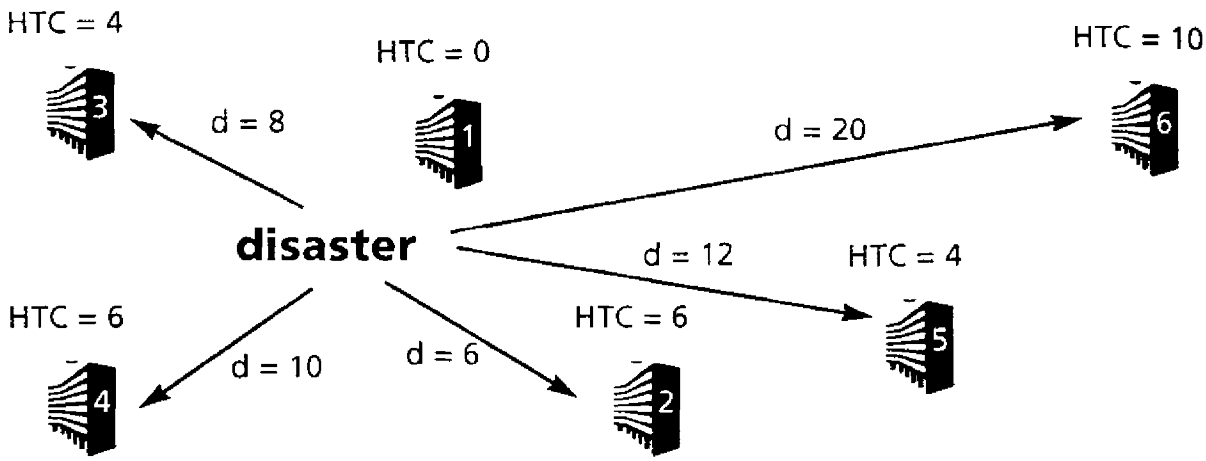
Medical acts and average length of time for doctors and nurses working as a team at the disaster site

T1	Disturbances of vital functions, breathing and circulation		
	. orientation & positioning	1	*
	. airway management	1	
	. orophargyngeal intubation	1	minimal 8'
	. oxygen administration	1	
	. intravenous line	3	
	. stable side position	1	
	. hemorrhage control	3	
	. fracture immobilization	5	
	. oropharyngeal aspiration	2	additional 15'
	. oroendotracheal intubation	5	
	. assisted ventilation with bag	p.m.	
	. nasogastric tube	3	
	. bladder catheterisation	4	
	. chest tube placement	6	optional 18'
	. pericardiocentesis	5	
T2	If no adequate first-aid measures are to be taken disturbances of vital functions are to be expected within 4-6 hours		
	. orientation & positioning	1	
	. hemorrhage control	3	
	. fracture immobilisation	5	maximal 13'
	. intravenous line	4	

* round off minutes

Estimation of the number of ambulances needed at disasters*
or
Calculation of the medical transport capacity (MTC)

* ADAPTED FROM AN ARTICLE IN THE JOURNAL OF PREHOSPITAL AND DISASTER MEDICINE (1996)



Hospital	**Distance**	**HTC**	**Total HTC/hour**
1	0	0	0
2	6	6	6
3	8	4	10
4	10	6	16
5	12	4	20
6	20	10	30

Based on a proper victim allocation plan.

N disaster victims have to be transported within a clearance time of *T* hours by *X* ambulances provided each ambulance carries n victims and needs *t* hours to overcome *d* (average).

There is a number of reasons why it is important that the ambulance capacity available in the event of a disaster should match the need for medical transport. First and foremost, the "normal" ambulance service must be continued for as long as possible. Apart from making financial sense, this also provides a balanced response to the demand for transport. After all, the personnel sent to a disaster is removed from the normal service, and sending too many not only depletes this service but also costs more money.
Secondly, the methodology could be applied in the preparedness phase utilizing the model of the chain of medical care for various scenarios in different areas (centres) and sites at risk (airports, stadiums, industrial)

METHODOLOGY

Since the number of ambulances needed at a disaster (X) is directly proportional to the number of victims requiring hospital treatment (N) and the average travelling time between the disaster site and the surrounding hospitals (t), and is inversely proportional to the number of victims who can be transported on each journey (n) and the total time (T) available for the transportation (clearencetime) of N, the following formula can be

applied: $X= \frac{N.t}{T.n}$

The example indicates that this formula is in principle mathematically "sound". The formula would appear to make it possible to calculate the number of ambulances needed to transfer victims to nearby hospitals.

We say "would appear" because it is very difficult to determine the number of victims requiring hospital treatment (N) and the average travelling time (t) to local hospitals. This is not the case with the other variables T and n. Since triage I victims must be stabilised within the "golden hour" and then - like the triage II victims - treated in hospital within four to six hours, T can be set at a maximum of six hours. The number of triage I and II patients requiring transport by ambulance on each journey (n) has been set at one in the Netherlands, although a triage III victim might be taken along as well. However, the calculation is based primarily on triage I and II victims (who require hospital treatment).

if	N = 100 victims requiring hospital treatment n = 1 victim per ambulance per journey T = 6 hours to transport 100 victims t = 1 hours' average travelling time	X=16

Sample calculation of number of ambulances required

However:

N and **t** are difficult to estimate,

while n and T are fixed!

The problem is thus to determine N and t. The number of victims (N) can only be estimated. It has been found in practice that this number is usually underestimated in the case of natural disasters, while it is generally overestimated in disasters resulting from human activity (= Rutherford's Rule). The first estimate in the event of a natural disaster usually refers to only a proportion of the affected area. Hours or days later it becomes clear that there are more victims than originally thought. The opposite applies to man-made disasters. Examples of the two include the floods in 1953 and the Bijlmer air crash in 1992.

However, we can do no more than bear this general rule in mind during the initial determination of the number of victims, and it cannot help to give a more precise estimate of N.

Determining the average travelling time (t) is also problematic. Several hospitals will be involved in any disaster. The distance from the site to the hospital differs from one disaster to another, so an average distance will have to be worked out and an average driving speed applied, while the time taken to embark and disembark will also have to be taken into account. At any rate, the victims will have to be divided among the hospitals in the area in such a way that the capacity to treat them is not exceeded. This is done on the basis of a victim distribution plan.

A more accurate estimate of N and t will ultimately also lead to a more accurate estimate of the number of ambulances required.

$$\pi R^2 = \frac{N \times 246}{T \times 12}; \quad R^2 = \frac{N \times 246}{T \times 12 \times \pi} = \frac{N \times 80}{T \times 12}; \quad R = 2{,}6 \frac{\sqrt{N}}{\sqrt{T}}$$

Calculation of the radius of the area comprising the hospitals needed to treat the number of victims (N) requiring hospitalization and based on an average hospital treatment capacity (HTC) of 12 T1 and T2 victims per hospital within a clearance time of T hours.

↓

$$t = 0.09 \frac{\sqrt{N}}{\sqrt{T}} \text{ hour}$$

Based on figures valid only for the Netherlands, however, each district, region, municipality, should introduce their own figures.

DETERMINING THE AVERAGE TRAVELLING TIME (t)

There are some 150 hospitals in the Netherlands unevenly spread over some 37,000 km^2. One hospital therefore serves an average area of 37,000/150 = 246 km^2, with a radius of approximately 9 km.

In total there are some 60,000 beds, with each hospital having around 400. In a disaster response plan the medical treatment capacity has been set at 3%* of the bed capacity per hour, so about 12 triage I and II victims per hour can be treated adequately and efficiently for a period of T hours. This means that an average hospital with 400 beds, situated in an area with a radius of some 9 km, can treat approximately T x 12 triage I and II victims adequately and efficiently, provided they have a well-rehearsed disaster response plan. If there are N victims, where N is taken to be multiple of 12 and T is given in hours, then N : T x 12 hospitals are needed to handle the triage I and II victims. These hospitals will be in an area of (N : T x 12) x 246 km^2. The radius of this area is calculated as shown.

The average distance between the disaster site and the surrounding hospitals is thus:

$$0.7 \times 2.6 \frac{\sqrt{N}}{\sqrt{T}} \text{ km}$$

which has to be covered twice (the figure 0.7 is a mathematical given).

If this distance is driven at an average speed of 40 km/h, the average travelling time is:

$$\frac{2 \times 0.7 \times 2.6 \sqrt{N}}{40 \times \sqrt{T}} = 0.09 \frac{\sqrt{N}}{\sqrt{T}} \text{ uur}$$

Thus, with 289 victims who must be ferried to hospital in six hours the average travelling time per ambulance will be:

$$\frac{0.09 \times 17}{2.5} = 0.6 \text{ hour} = 36 \text{ minutes}$$

* On the basis of a large number of exercises carried out at the time, although 3% is now regarded as too high.

Estimating numbers of disaster victims

Basic figures for contingency planning

		IMMOVABLES	range[1]
residential area[2]	per hectare	low-rise buildings	20-50
		high-rise buildings	50-200
business	per hectare		0-800
industrial area	per hectare		0-200
leisure area	per type	stadium	-[7]
		discotheque	-
		camp-site	-
shops	per type	department store	-[7]
		arcade	-

		MOBILE OBJECTS	
road transport	per 100 M (lenght)	multiple collision	5-50
	per type[3b]	coach	10-100
rail transport[4]	per type	single deck	5-400
		double deck	10-800
air transport[5]	per type	small	10-30
		large	150-500
inland shipping[6]	per type	ferry	10-1000
		cruise ship	200-300

1 depends on date and other local circumstances.
2 combination of number of residents per house (1.8-2.8) and number of houses per hectare (30-70)
3a per car: length 5m and 1.5-3 passengers (see 1)
3b (articulated) local bus or (articulated) double-decker bus
4 carriage of 3 or 4 wagons (see also 1)
5 seat occupancy 70%
6 seat occupancy 80%
7 awaiting further research

DETERMINING THE NUMBER OF VICTIMS REQUIRING HOSPITAL TREATMENT (N) (see also chapter on Rutherford's Rule)

Whereas the average travelling time between the disaster site and the hospital can be approximated by means of calculation, this is not the case when it comes to the number of victims (N). This requires an entirely different approach, which for the time being must be based on empirical information.
The population density in the affected area is the most important parameter. The population density in the Netherlands varies form 0 persons per km^2 in some parts of Drenthe and Gelderland to roughly 100,000 per km^2 at a packed football stadium or rock festival. The average density is just over 400 per km^2, giving each inhabitant an area of 50 x 50 metres (2500 m^2 or a quarter of a hectare).

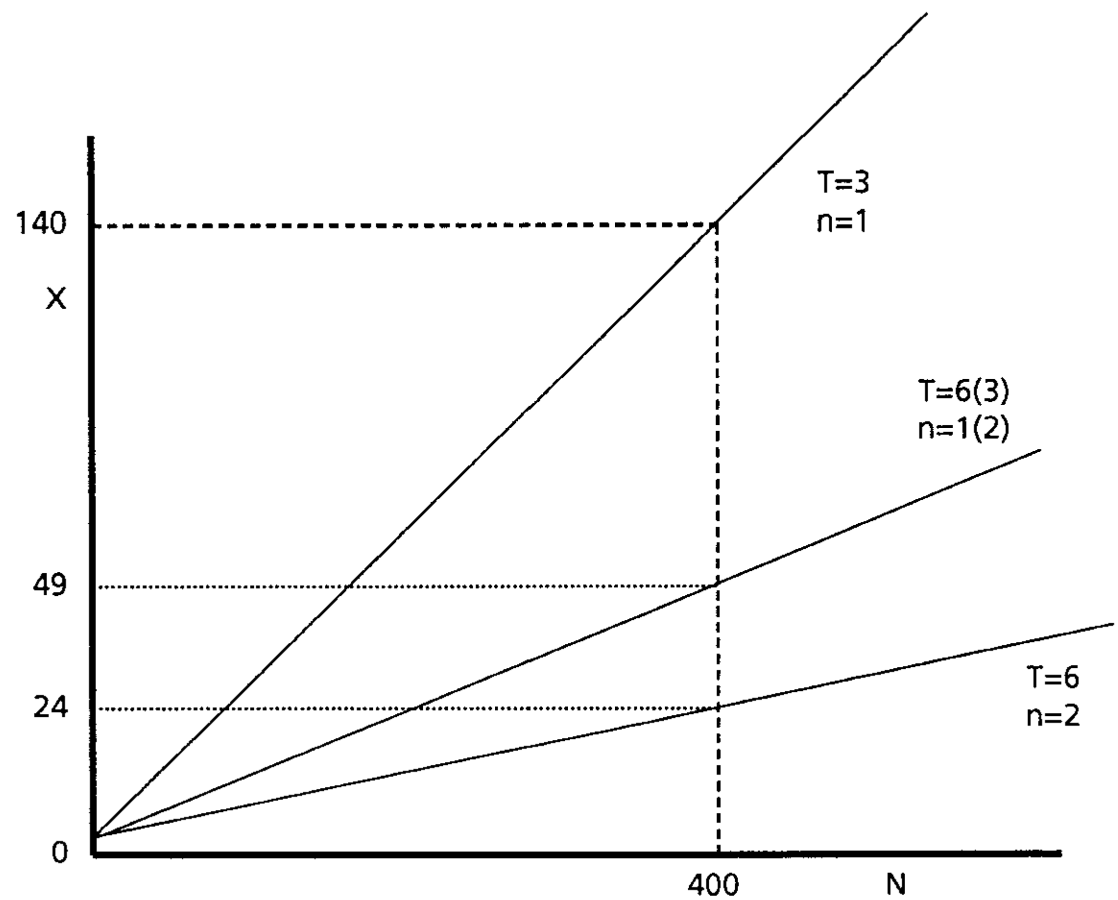
But this in itself tells us nothing about the density in a residential area, building, plane, train, on a motorway (in the event of a multiple pile-up) or industrial site, or the density within and outside working hours. This information has been gathered and is presented in the table. However, knowing the population density of a particular area does not tell us the number of victims requiring hospital treatment.
In road traffic accidents, the percentage distribution in terms of seriousness of injury is: 5-10% fatalities, 10% triage 1, 20% triage 2 and 60% triage 3 victims.
Of course there is a great deal of variation in this distribution. However, one can generally expect a higher proportion of deaths and serious injuries in the event of a fire or explosion; in contrast, civil unrest tends to lead to more minor injuries. (see chapter on Evaluation of disasters)
On the basis of the above data we can say that in the average disaster, 40% of the victims will require hospital treatment (10% triage I and 20% triage 2 victims). To be on the safe side, if we can estimate in the area where the victims are situated, the population density , the size of the disaster site and/or the number of units affected (cars, train, carriages, planes), we can assume that all the people present in the area have been affected and half of them will need hospital treatment. In the case of fire, explosions, plane crashes and collapsed buildings, the proportion could be as high as two-thirds; one-third would be an appropriate figure in the case of civil unrest.
On the other hand, we should point out that it takes a long time to rescue the victims of certain types of disaster (collapsed buildings, train crashes). This means that the victims will not all require transportation at once, so that fewer ambulances will be needed.
The formula can now be applied as shown in the table, and can be represented graphically as shown in the figure.

$t = 0{,}09\,\frac{\sqrt{N}}{\sqrt{T}}$; T = 6 uur; n = 1:

$$X = \frac{N \times t}{T \times n} = \frac{N \times 0{,}09\,\sqrt{N}}{T \times \sqrt{T}} = 0{,}09\,\frac{N\sqrt{N}}{T\sqrt{T}}$$

$$X = \frac{0{,}09 \times 289\,\sqrt{289}}{6\sqrt{6}} = \frac{0{,}09 \times 289 \times 17}{6 \times 2{,}5} = 29 \text{ ambulances}$$

The formula for determining the number of ambulances needed, on the basis of 289 victims requiring hospital treatment.



Relationships between the number of victims requiring hospital treatment and the number of ambulances needed with different values for T and n.

Discussion

In the worst-case scenario, several disasters might happen simultaneously or in succession, perhaps as a result of acts of terrorism or a chain reaction, leading to a shortage of ambulances. This can be prevented by more accurate prediction of the number of ambulances needed at a disaster. But before any disaster occurs, more accurate prediction can be used in the preparation stages of disaster response in the form of policy instruments. One might, for instance, focus on certain areas of high risk, such as airports, industrial sites, motorways etc. where N and t can be roughly determined in advance and, therefore, so can X. The graph clearly shows that, the shorter the "clearance time" (T), the greater the number of ambulances needed; conversely, the more victims taken to hospital in each ambulance (n), the lower the number of ambulances required.
We can also calculate that a disaster in NL involving more than 1,500 victims requiring hospital treatment cannot be cleared in six hours by civilian ambulances alone. The entire ambulance fleet of around 325 would have to be called in, and extra support from the military would be needed.

The general formula $X = \frac{N.t}{T.n}$ applies for numbers (X) of any kind of vehicle

(ambulances, lorries, busses) transporting a total amount (N) of "things"
(men, patients, material), where each vehicle is carrying a part of these things (n), taking an average transporttime (t) within a certain timelimit (T). Off course, T should be a multiple of t and N a multiple of n. One could immediately see that when N equals n the formula becomes X = T/t and when T equals t the formula will be X = N/n, while X = 1 for T = t and for N = n.
When we are dealing, however, with victims who should be treated within certain time limits, preferably, 1-2 hours for triage 1 and 4-6 hours for triage 2 victims, this general formula has to be modified.
In this respect and as mentioned before t and N are difficult to estimate, however, N could be obtained empirically, while t could be calculated in a certain area in terms of N and T, provided we are dealing with triage 1 and 2 vicitms to be treated in a certain number of hospitals with a given hospital treatment capacity, i.e. the number of victims that can be treated per hour during a certain period T. For The Netherlands t could be set

at $0{,}09 \cdot \frac{\sqrt{N}}{\sqrt{T}}$

For a remote area the size of The Netherlands with, say 3 hospitals of 100 beds each, where a plane crashed with 36 triage 1 and 2 victims, one can immediately see that t will be larger than T, which makes the formula worthless. Where will be the limits now for this formula? In order to answer this question further mathematical analysis of the formula is required, which will be the subject of a next study.

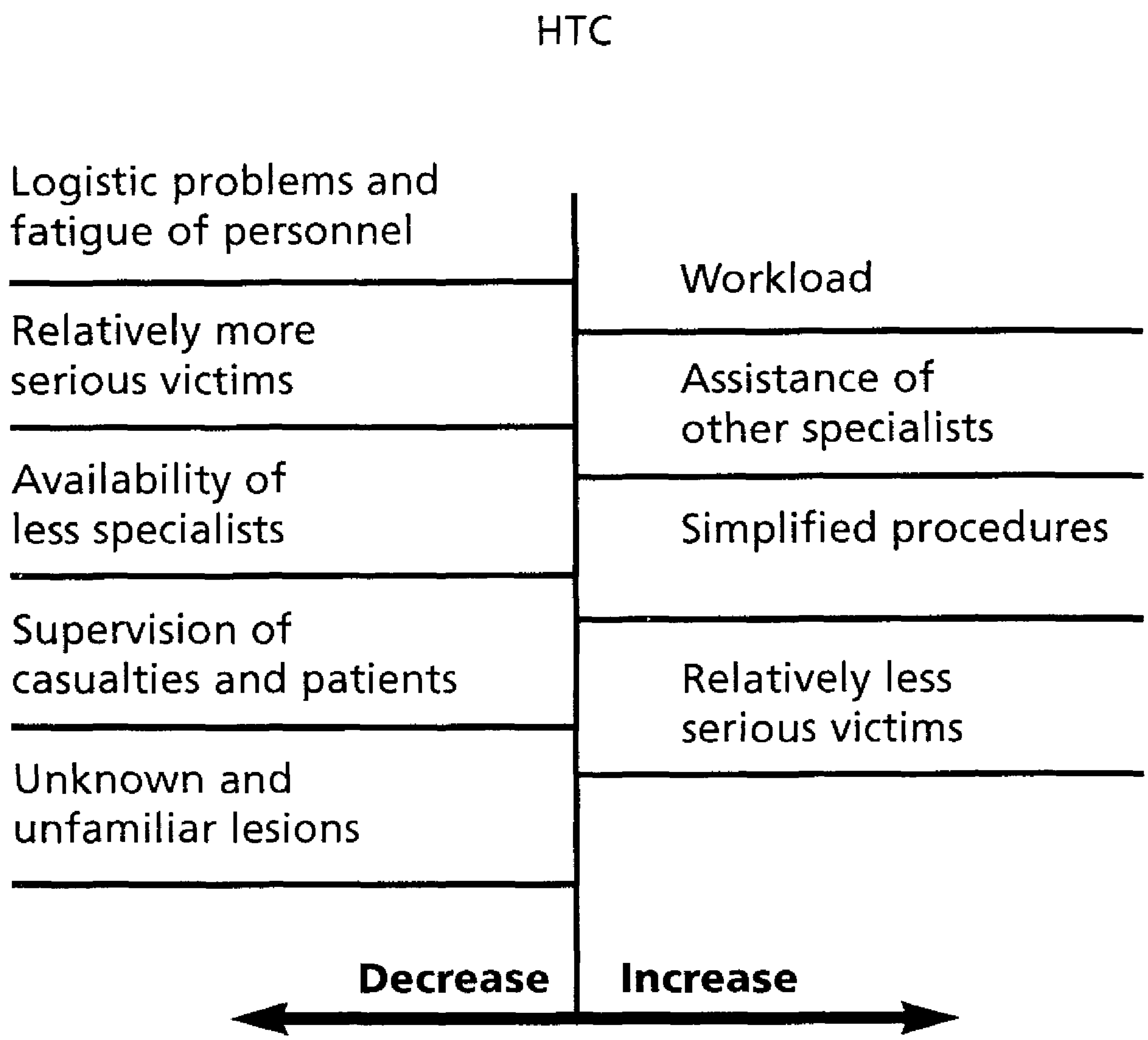
THE HOSPITAL TREATMENT CAPACITY (HTC)

How to calculate the hospital treatment capacity (HTC) for mechanical injuries for a given hospital.

		Number (N)	Weight(W)	N x W
1	Total number of beds		1/3000	
2	Number of surgical beds		1/250	
3	Number of intensive care beds		1/20	
4	Number of operating theaters		1/10	
5	Number of operations per year		1/20000	
6	Number of surgeons		1/5	
7	Number of anaesthesiologists		1/4	
8	Number of surgical residents		1/10	
9	Number of other surgical specialists		1/10	
10	Number of A & E patients per year		1/10000	
			Total	

The last phase in the chain of medical care is the hospital. In an average hospital, either large (1000 beds) or small (100 beds) doctors, nurses and paramedical pers-onnel are working. In these hospitals the basic specialists are usually available, like surgeons and internists. In a day-to-day situation these specialists can hand-le the majority of accidents and emergencies. Depending on the type of emer-gency, whether the patient has suffered a mechanical, chemical, nuclear or bio-logical lesion, the hospital treatment requires a certain period of time. The tre-atment of a patient with mechanical injuries, like fractures or damaged organs, requires more time than the treatment of a patient with an infectious disease, like cholera.

For mechanical injuries this time has been determined, for the other types of inju-ries (lesions) this time is unknown. This hospital treatment capacity (HTC) is the number of patients which can be treated per hour and per 100 beds, because this treatment is related to the number of beds in a general hospital. Only for patients with mechanical injuries this HTC is known for a normal day-to-day situ-ation and amounts 0.5-1.0 patients per hour, per 100 beds. However, with a well practiced disaster procedure (see the appropriate chapter) this HTC can be incre-ased to 2.0-3.0 patients per hour and per 100 beds. This figure has been obtained through many exercises and is mainly determined by the number of surgeons, anaesthesiologists specialised nurses, specific accomodation and some other features.


HTC
Logistic problems and fatigue of personnel
Relatively more serious victims
Availability of less specialists
Supervision of casualties and patients
Unknown and unfamiliar lesions
Workload
Assistance of other specialists
Simplified procedures
Relatively less serious victims
Decrease
Increase

Of course, this HTC for mechanical injuries is influenced by many factors. Under these circumstances hospital personnel work harder, which increases HTC. Eventually, however, fatique will decrease this capacity. Certain disasters, like explosions, may cause relatively more seriously injured victims, hampering HTC; on the other hand less severely wounded like civil disturbances, may lead to the reverse.

One of the measures to be taken in a hospital disaster procedure is the discharge of those patients who are supposed to be discharged one of the next days. This results in relatively more serious hospital patients. Together with those being rushed in following a disaster, this means that the supervision of operated casualties and hospital patients will be more timeconsuming, thus decreasing HTC. Instead of performing sophisticated reconstructive surgery the surgeon may decide, under the given circumstances, to utilize simplified procedures, which increases HTC. This increase may also be the result of the assistance of other "cutting" specialists, like gynaecologists and urologists.

Another approach for calculating the HTC for mechanical injuries, might be the one used for determining the medical rescue capacity, as described in the appropriate chapter.

As mentioned earlier the HTC for other types of injuries, chemical, nuclear and biological, is unknown. Research in this field is therefore imperative.