# An Attempt at More Accurate Estimation of the Number of Ambulances Needed at Disasters in The Netherlands

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**Abbreviations:**
n = number victims transported per journey
N – number of victims requiring hospital treatment
t = traveling time between disaster site and hospitals
T = total time available for transport
X = number of ambulances needed at disaster

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**Abstract**

*A more accurate estimate of the number of ambulances needed at disasters prevents vehicles from being withdrawn unnecessarily from their "normal" duties, thereby curtailing needless expense and helping to ensure that disaster sites are not overcrowded with emergency workers impeding each other's effectiveness. This article discusses a formula for determining the number of ambulances needed at a disaster.* **Prehospital and Disaster Medicine 1996;11(2):125–129.**

## Introduction

There are several reasons why it is important that the ambulance capacity available in the event of a disaster should match the needs for first aid and medical transport. First, "normal" ambulance service must be continued for as long as possible. This makes financial sense, and provides a balanced response to the demand for first aid and transport. The personnel sent to a disaster are removed from the normal service, and sending too many of them not only depletes this service, but costs more money.

## Methods

Because the number of ambulances needed at a disaster (X) is directly proportional to the number of victims requiring hospital treatment (N), and the average traveling 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 of N, the following formula can be applied:

$$X = \frac{Nt}{Tn} \qquad \text{(Equation 1)}$$

The example in Table 1 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. However, it is very difficult to determine the number of victims requiring hospital treatment (N) and the average traveling time (t) to local hospitals. This is not the case with the other variables, T and n. Because the condition of triage category I victims must be stabilized within the "golden hour," and then, like the triage category

| |
|---|
| If<br>N = 100 victims requiring hospital treatment<br>n = one victim per ambulance per journey<br>T = six hours to transport 100 victims<br>t = one hour average traveling time |



**Table 1**—Sample calculation of number of ambulances required

II victims, category I victims must receive treatment in a hospital within four to six hours; T can be set at a maximum of six hours.[1] The number of triage category I and II victims requiring transport by ambulance on each journey (n) has been set at one in The Netherlands, although a triage category III victim might be transported. However, the calculation is based primarily on triage category I and II victims (who require hospital treatment).

Thus, the problem is to determine the values of N and t. The number of victims (N) can only be estimated. Practice has shown that this number usually is underestimated in the case of natural disasters, whereas it generally is overestimated in disasters resulting from human activity. In the event of a natural disaster, the first estimate usually refers to only a proportion of the affected area. Hours or days later, it becomes clear that there are more victims than originally estimated. The opposite applies to manmade disasters. Examples of the two include the floods in 1953 and the Bijlmer air crash in 1992. This general rule can be used during the initial determination of the number of victims, but it cannot provide a more precise estimate of N.

Determining the average traveling time (t) also is problematic. Several hospitals are involved in any disaster response. The distance from the site to the hospital varies from one disaster to another; thus, an average distance must be calculated and an average driving speed applied, and the time taken to embark and disembark also must be considered. At any rate, the victims will be sent to 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 ultimately will lead to a more accurate estimate of the number of ambulances required.

*Determining Average Traveling Time (t)*

There are approximately 150 hospitals in The Netherlands unevenly spread over some 37,000 km². Therefore, one hospital serves an average area of 37,000/150 = 246 km², with a radius of approximately 9 km.

Approximately 60,000 beds are available, with each hospital having about 400. In a disaster-response plan,[2] the medical treatment capacity has been set at 3% of the bed capacity per hour,[1] so about 12 triage category 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

$$\pi R^2 = \frac{N \times 246}{T \times 12}$$

$$R^2 = \frac{N \times 246}{T \times 12 \times \pi}$$

$$= \frac{N \times 80}{T \times 12}$$

$$R = 2.6 \frac{\sqrt{N}}{\sqrt{T}}$$



**Table 2**—Calculation of the radius of the area containing the hospitals needed, on the basis of an average treatment capacity of 12 category I and II victims per hospital, where N is the total number of victims requiring hospital treatment

triage category I and II victims adequately and efficiently, if they have a well-rehearsed disaster-response plan. If there are N victims, where N is a multiple of 12 and T is given in hours, then N : T x 12 hospitals are needed to handle the triage category I and II victims. These hospitals will be in an area of (N : T x 12) x 246 km². The radius of this area is calculated in Table 2. Thus, the average distance between the disaster site and the surrounding hospitals is:

$$\text{Travel distance} = 0.7 \times 2.6 \frac{\sqrt{N}}{\sqrt{T}} \text{km} \qquad \text{(Equation 2)}$$

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 traveling time is:

$$\text{Average traveling time} = \frac{2 \times 0.7 \times 2.6\ N}{40 \times T} = 0.09 \frac{\sqrt{N}}{\sqrt{T}} \text{hour} \qquad \text{(Equation 3)}$$

Thus, with 289 victims who must be transported to hospitals within six hours, the average traveling time per ambulance will be:

$$t = \frac{0.09 \times 17}{2.5} = 0.6 \text{ hour} = 36 \text{ minutes} \qquad \text{(Equation 4)}$$

*Determining Number of Victims Requiring Hospital Treatment (N)*

Whereas the average traveling time between the disaster site and the hospital can be approximated by means of calculation, this is not the case in estimating the number of victims (N). This calculation requires an entirely different approach, which for the time being must be based on empirical information.

| | Working Hours 0800–1800 h | Outside Working Hours 1800–0800 h |
|---|---|---|
| Residential area (per ha*) | 20– 50 | 75–175 |
| Office buildings (per ha) | 400–800 | 0– 20 |
| Industrial sites (per ha) | 10–200 | 0– 10 |
| Highway crash (per 100 m)† | 25 | 75 |
| Passenger train (per car) | 140 | 70 |
| Passenger aircraft (each) | 100–400 | 100–400 |

*†Per 100 meters of pileup; car length approximately five meters and 1.5 passengers per car during working hours, three at other times*
**Combination of number of inhabitants per dwelling (2.5) and number of dwellings per hectare (30–70)*
*NOTE: The figures in this table could be calculated more precisely on the basis of detailed studies*



**Table 3**—Estimate of the average population density during working hours and at other times (ha = hectares)

$$t = 0.09 \frac{\sqrt{N}}{\sqrt{T}}, \quad T - 6 \text{ hour and } n = 1;$$

$$X = \frac{N \times t}{T \times n} = \frac{N \times 0.09 \sqrt{N}}{T \times \sqrt{T}} = 0.09 \frac{N \sqrt{N}}{T \sqrt{T}}$$

$$X = \frac{0.09 \times 289 \sqrt{289}}{6 \sqrt{6}} = \frac{0.09 \times 289 \times 17}{6 \times 2.5} = 29 \text{ ambulances}$$



**Table 4**—The formula for determining the number of ambulances needed, on the basis of 289 victims requiring hospital treatment

The population density in the affected area is naturally the most important parameter. The population density in The Netherlands varies from 0 people/km$^2$ in some parts of Drenthe and Gelderland to roughly 100,000/km$^2$ at a packed football stadium or rock festival. The average density is just over 400/km$^2$, giving each inhabitant an area of 50 x 50 meters (2,500 m$^2$ or a quarter of a hectare). However, this provides no information about the density in a residential area, building, plane, train, on a highway (in the event of a multiple-car pileup) or industrial site, or the density during and outside working hours. This information is presented in Table 3. However, knowing the population density of a particular area does not determine the number of victims requiring hospital treatment.

In road traffic accidents, the percentage distribution in terms of seriousness of injury is as follows: 10% fatalities, 10% triage category I, 30% triage category II, and 50% triage category III.[3]

There is a great deal of variation in this distribution. However, a higher proportion of deaths and serious injuries can be expected in fires or explosions; in contrast, civil unrest tends to lead to more minor injuries.

On the basis of the above data, in the average disaster, 40% of the victims will require hospital treatment (10% triage category I and 30% triage category II). To provide a margin of safety, if the population density, the size of the disaster site, and/or the number of units affected (cars, train, carriages, planes) can be estimated in the area where victims are situated, it can be assumed that *all* the people 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 of those requiring hospital treatment could be as high as two-thirds; one-third would be an appropriate figure in the case of civil unrest.

Conversely, it should be noted that it takes a long time to rescue the victims of certain types of disaster (collapsed buildings, train crashes). Thus, the victims will not all require transportation at once, and fewer ambulances will be needed. The formula now can be applied as shown in Table 4 and can be represented graphically as shown in Figure 1.

## Discussion

In a worst case, 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. However, before any disaster occurs, a more accurate prediction can be used in preparation for disaster response in the form of policy instruments. For example, attention might be focused on certain areas of high risk, such as airports, industrial sites, and highways, where N and t can be determined roughly in advance and, therefore, X. The graph (Figure 1) shows that, the shorter the

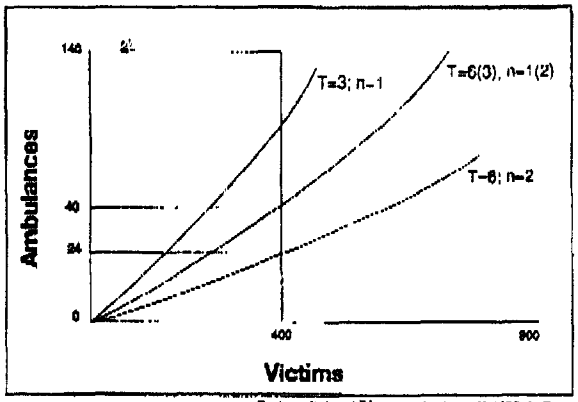


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**Figure 1**—Relationships between the number of victims requiring hospital treatment and the number of ambulances needed with different values for T and n

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.

When these formulas are used, a disaster in The Netherlands 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 summoned, and extra support from the military would be needed. The general formula:

$$X = \frac{Nt}{Tn} \qquad \text{(Equation 1)}$$

applies for numbers (X) of any kind of vehicle (ambulances, trucks, buses) transporting a total amount (N) of "things" (men, patients, materials), where each vehicle is carrying a part of these things (n), taking an average transport time (t) within a certain time limit (T). Of course, T should be a multiple of t and N a multiple of n. When N equals n, the formula becomes X = T/t and when T equals t the formula is X = N/n, whereas X = 1 for T = t and for N = n.

For victims who should be treated within certain time limits, preferably, one to two hours for triage category I and four to six hours for triage category II victims, this general formula has to be modified. In this respect, t and N are difficult to estimate; however, N could be obtained empirically, and t could be calculated in a certain area in terms of N and T, provided triage category I and II victims are 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:

$$t = 0.09 \frac{\sqrt{N}}{\sqrt{T}} \qquad \text{(Equation 6)}$$

For example, for a remote area the size of The Netherlands with three 100-bed hospitals, where a plane crashed with 36 triage category I and II victims, t will be larger than T, which makes the formula worthless. What are the limits for this formula? Further mathematical analysis of the formula is required, which will be the subject of another study.

## Summary

More accurate estimates of the number of ambulances needed to cope with a disaster are important not only when it comes to the actual response, but also in the preparation stage. The model presented should be used to develop scenarios for different areas (centers) and sites at risk (airports, stadiums, industrial sites, and so on), possibly with the aid of a computer.

## End Note

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

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## Editorial Comments

*Peter JF Baskett, MRCP, FRCA, Frenchay HealthCare NHS Trust, Frenchay Hospital, Consultant Anaesthetist, Bristol, UK*—In this article, Professor de Boer addresses the potential requirements for ambulances to attend critical incidents and disasters in the Netherlands. This is a valuable study, for we are all subject to financial constraints and conscious wastage of precious resources.

The parameters Professor de Boer uses in his calculations theoretically are correct, but all are subject to variation which will influence the results arrived at in any individual incident. For example, *N*—the number of victims frequently is a matter of confusion in the early stages of a major incident; *T*—the traveling time between the disaster site and the hospital is influenced by extrication and rescue time (which frequently involves ambulance crews), traffic congestion due to sightseers "the second threat" beloved by terrorists to maximize their impact, and of course weather conditions. Hand-over time between the ambulance crew and the hospital also will need to be included.

As Professor de Boer points out, the formula will require modification for different types of major incidents, and local geography and infrastructure will play a key modifying role. The proposals put forward in this paper however, will serve as a template for those involved in major incidents and disaster response planning at local level. Each of us must take into account modifying local factors and plan for the events that most likely will befall us. Murphy's Law, however, dictates that things don't always go according to plan, and flexibility is the key to successful planning and preparedness.

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*Paul Anderson, Rural EMS Institute, Lincoln, Nebraska USA*—Overall, this formula to estimate more accurately the number of ambulances needed at disasters in the Netherlands appears to be sound. It is suggested that, as an exercise, every area/regional emergency medical services (EMS) system use this formula in conjunction with hypothetical disaster situations of varying magnitudes, to try to predict how their EMS systems would be able to perform. Each EMS system, of course, may change certain parameters, such as the "T" factor to vary the total time to transport particular categories of patients to definitive care facilities, or the "n" factor for the number of patients by category transported on each journey.

Before discussing this further, it may be well to review the reason for having such a formula. The author states that "first and foremost" there is a need to maintain normal ambulance coverage for a geographical area, and 2) that it costs money to send more units than necessary. I would suggest that most EMS systems will not be able to maintain "normal" ambulance coverage during any large-scale disaster, and the dispatch center will have to give a very low priority to nonemergencies and certain transfer calls, deferring some of them for hours. I do not believe that saving money should be a major consideration as major disasters occur infrequently, and it can be argued that sending a few too many units to the disaster scene, as long as sufficient units remain available to respond to other emergencies, is better than sending too few. A reason for sending more than enough ambulances is that some EMS personnel will be needed to fill management roles at the scene, e.g., EMS command, triage, treatment, safety, and transportation. There also is a need to discuss briefly the fact that there are major differences in ambulance resource patterns in various localities. Using the information in this paper, it is calculated that there is one ambulance per 45 square kilometres in the Netherlands. In contrast, in the states west of the Mississippi River in the United States, the ambulance density is one ambulance per 400—600 square miles (650—1,000 km$^2$) or lower density in vast rural areas. My point is that some geographical areas immediately will see, if they use this formula for disaster response planning purposed, that there will be very long time periods before a sufficient number of ambulances get to the disaster site; whereas in the Netherlands, with a much higher density of ambulances, the wait should be much shorter. Also, most areas (outside of major urban areas) will not have the density of hospital facilities that exist in the Netherlands. In areas with a significantly lower density of hospitals, this markedly will affect transport times and the ability of any particular ambulance to make repeat trips back to the scene to transport additional causalities to definitive care.

In the Netherlands, because of the high density of resources (both ambulance and hospital), it can be expected that in many situations, category I and II patients will be transported within acceptable time frames. In contrast, in many areas of the world, use of this formula quickly will show that unless EMS systems incorporate plans to use the military, or delivery vans, or other substitute vehicles when ambulance resources are over extended, they will not be able to transport all category- I and -II patients within the time frames that are acceptable even in good weather conditions. As I am writing this review, it is now minus 20°F (-50°C) in some areas of the midwestern section of the United States. I would suggest that in such weather conditions, the time frames to get patients transported, at least short distances to facilities, such as school gymnasiums that can be set up as secondary triage and treatment sites, might well take precedence over waiting for sufficient ambulances to arrive to get the patients to definitive care facilities. This is just one reason for EMS systems, on a preplanned basis, to set-up disaster caches of hundreds of spine boards and other supplies at strategic locations so that substitute vehicles can be used to augment the number of available ambulances in disasters. In most EMS systems, if off-duty EMS personnel are called back into service during a disaster, there will be many more personnel available than ambulance vehicles to put them in. What I am suggesting is that this formula, if used by all EMS systems for disaster preparedness planning, will help them determine with some precision how well their system would perform. However, many EMS systems will want to alter the formula somewhat. While, in the Netherlands, he proposes to only transport one category-I or -II patient at a time, I would suggest that most EMS systems would not want to have only one category I per transport, they would feel quite comfortable in transporting two category-II patients per trip. In summary, this formula could be used easily by any EMS system by varying certain parameters to fit local/area resource patterns.