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ROAD INCIDENTS EMERGENCY SERVICE - A CASE STUDY FOR LOCATING AND EQUIPPING FIRE BRIGADES

ABSTRACT

This paper presents the application of MLCP location-allocation model in GIS environment to optimise the number and locations of fire brigade units, which would intervene in case of road incidents. There are 40 fire brigade units that are more or less equipped and trained to intervene in such cases. For simulation purposes, a potential demand for intervention of emergency squads was calculated, and the potential spatial accessibility was investigated.

KEY WORDS

Road accident, Emergency, Accessibility, GIS, Location-Allocation models, Fire brigade

1. INTRODUCTION

In the past few years, the average number of road accidents with the injured or dead persons in the Republic of Slovenia ranged around 6500 per year. Further, an average of six per cent of all accidents requires fire-brigade intervention. Fire-fighting, vehicle saving or extracting injured people, as well as hazardous materials emergencies represent the majority of all emergency calls. In order to increase the level of emergency service and minimise the equipment costs, the Administration of the Republic of Slovenia for Civil Protection and Disaster Relief at the Ministry of Defence called for a study, requiring also the evaluation and optimisation of the present state.

At the moment, 40 fire brigades are more or less equipped and trained to intervene in the case of road incidents. These were selected within a Decree on the Organization, Equipment and Training of Protection, Rescue and Relief Forces (Official Gazette of the Republic of Slovenia, 22/99).

Our work focuses on the evaluation of the present distribution of those fire brigades considering the calculated potential demand, and possibly optimisation of the number and the locations of fire brigades to reduce the costs. For this purpose the location-allocation model is used in the GIS environment. This paper presents the used model and the results of the number and location optimisation of fire brigades equipped and qualified for saving people and goods involved in road incidents.

2. THEORETICAL BACKGROUND

Availability of and access to emergency services are fundamental to the productivity, well–being and development of a society [1]. In case of road incidents, this is the most basic of all services, for it may depend on this service whether we survive the accident and, if we recover, whether we retain full use of essential faculties or suffer permanent handicap [1]. As well as in ambulance service, in case of road incident where rescue or extraction of the injured person from the vehicle is needed, the fire brigade rescue squad has the same importance. Moreover, the importance increases in case of the necessity to prevent or limit fire spreading, explosion, and hazard material spills and contamination.

The accessibility, distribution and utilisation of fire emergency services have great impact on the effectiveness, efficiency and equity of service delivery. Hence, one of the primary objectives of the provision of fire emergency services is to deploy a limited number of rescue vehicles in a way that maximises the number of people or calls that have emergency unit available to respond within a maximum time with stated reliability [2].

However, one of the fundamental problems in evaluating the accessibility in general is that it "can embody multiple dimensions and be influenced by many factors" [3]. This reality has made the concept of accessibility difficult to define and open to many debates, especially with respect to emergency respond units.

As for previous consideration, our research objective is to examine the potential spatial accessibility. Geographic or physical accessibility emphasises the importance of space or distance as a barrier to facilitating access to the emergency system.

The used method reduces the distance deterrence between fire brigade locations and incident locations. A location-allocation model is typically applied to emergency unit location planning where resources are available for a fixed number of emergency units.

2.1. The model used

The Maximal Covering Location Problem (MCLP) and the MCLP with a Mandatory Closeness Constraint are the two basic forms of location-allocation models designed to solve emergency service location problems. The objective of these models is to serve as many calls as possible within a specified time or distance. The first model locates a fixed number of facilities in order to maximise the population covered within distance or time threshold [2]. The constrained model is used to ensure that the target population, which is not covered by the distance or time objective, will be covered by a second threshold to ensure a reasonable degree of service.

$$Max\ Z = \sum_{i=1}^{n} w_i * z_i \qquad (1)$$

subject to:

$$\sum_{i=1}^{m} y_i = p \qquad (2)$$

$$\sum_{i \in N_i}^{m} y_j \geq z_i, \forall_i \qquad (3)$$

$$\sum_{i \in M_i}^{m} y_j \geq 1, \forall_i \qquad (4)$$

$$y_j = 0,1, \forall_j \qquad (5)$$

$$z_i = 0,1, \forall_i \qquad (6)$$

where:

i = demand location

j = candidate facility location

n = number of demand locations

m = number of candidate facility locations

p = number of facilities to locate

w_i = weight at demand node i

d_{ij} = shortest distance between demand location i and candidate j

S = the maximal service distance

T = the mandatory service distance

N_i = {j | d_{ij} <= S} the set of facilities j that can reach node i within the maximal service distance S

M_i = {j | d_{ij} <= T} the set of facilities j that can reach node i within the mandatory distance T. Since $T > S$, M_i contains the set N_i

y_j = 1, if a facility is located at site j
= 0, otherwise

z_i = 1, if demand node i is covered
= 0, otherwise

2.2. GIS approach

GIS technology is increasingly used and recognised as an important planning tool for the acquisition, organisation, manipulation, analysis and display of large volumes of spatially referenced data. The success of GIS implementation in the planning field has been particularly notable in areas of spatial data creation, task automation and enhanced map production [4].

The integration of model-based methods and GIS technology have substantial benefits for managing and analysing data to produce information relevant to decision-making and in simulating the effects of different planning decisions [5]. In this context, GIS technology is particularly significant in its potential to provide a unifying framework to facilitate the development of real-world applications of geographical models and to enhance the problem understanding through the visualisation of spatial, map-based data patterns not immediately evident in raw data.

In this research, the commercial GIS package ARC/INFO (Environmental Systems Research Institute) was used to locate fire stations for emergency service. The location-allocation function reads in a set of demand locations and a set of candidate station locations. When applied to solve the MCLP in ARC/INFO, the software determines the locations for a specified number of stations to serve demand most efficiently within one (MCLP unconstrained) or two (MCLP constrained) specified distance or time thresholds. Three output files are written to describe the global statistics for the location-allocation configuration, the statistics for each station, and the allocation of demand to each station. The location-allocation output files contain information such as total weighted distance, average weighted distance, and amount of demand served.

3. USED DATA AND POTENTIAL DEMAND FORMULATION

The data we used were mostly provided by the Administration of the Republic of Slovenia for Civil Protection and Disaster Relief.

The Republic of Slovenia has a non-uniform population distribution, which also affects accident location distribution. Almost all data used to formulate this model were collected as a spatial reference to settlement. Thus, the main area unit used for calculation of demand was a settlement-imposed boundary. Based on the available time series of road accidents in

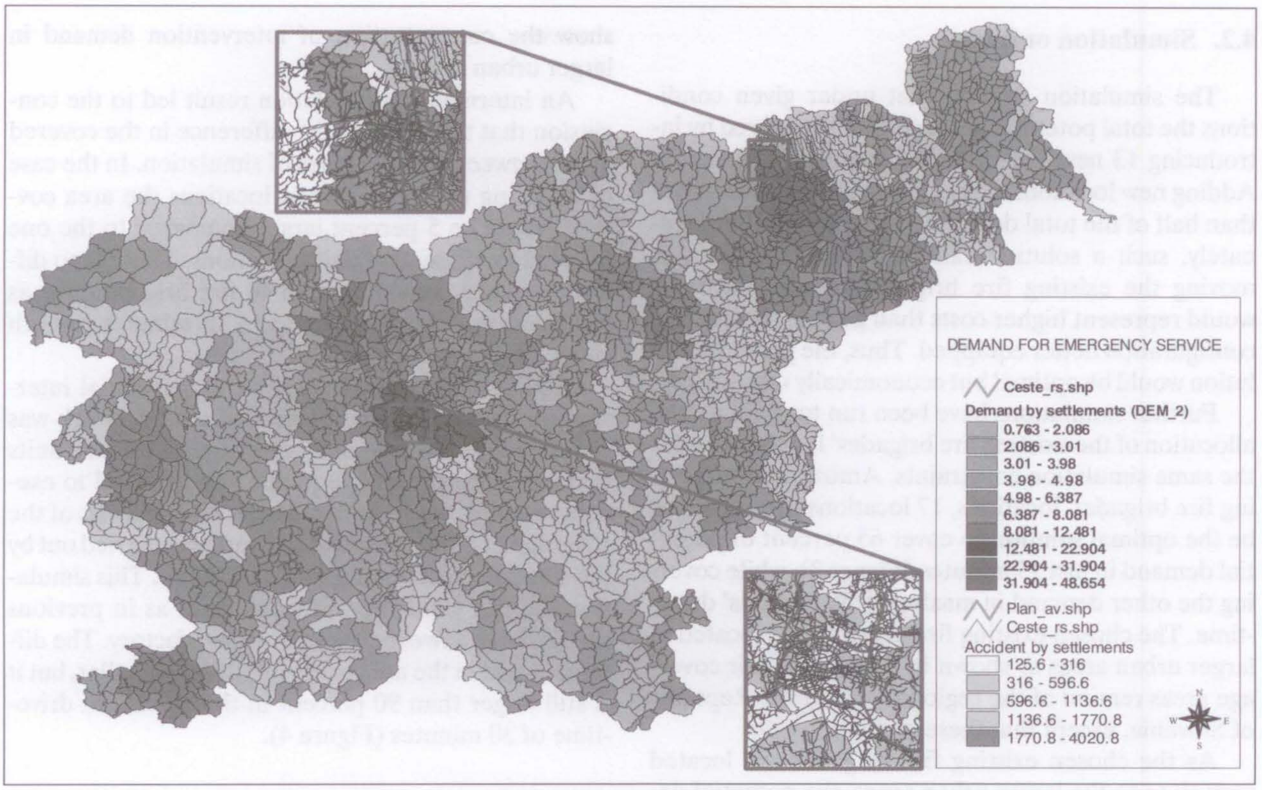

Figure 1 - Calculated potential demand for emergency service.

the past years and the estimated coefficients, the demand for emergency service was calculated as follows:

$$Dem\_2 = tras\_ac + 0{,}005 * p\_nes + 0{,}2 * (Nes\_c\_98 + Nes\_c\_00 + Nes\_c\_01) \qquad (7)$$

where:

Tras_ac = road laying out (value depending on road category),

P_nes = average number of all road accidents in the past 5 years

Nes_c_98 = number of fire brigade interventions in 1998 (road accident)

Nes_c_00 = number of fire brigade interventions in 2000 (road accident)

Nes_c_01 = number of fire brigade interventions in 2001 (road accident)

Figure 1 shows the calculated potential demand for emergency service.

As expected, the demand is not uniformly distributed but concentrated in major cities and along major roads.

4. SIMULATIONS

For the simulations, the commercial GIS package ARC/INFO® 7.1.0 was used. The build-in model has been run to test a variety of scenarios and generate a number of alternatives for comparison. Running the location-allocation model several times gives us an opportunity to assess potential spatial accessibility by enumerating the costs and benefits for each alternative configuration.

With respective constraint that no demand is outside 30-minutes drive time and that the demand covered in 15-minutes drive time is maximised, two types of simulations were performed:

- Simulations to optimise the fire brigades' number and locations;
- Simulations to optimise the existing fire brigades' number and locations.

In order to simplify the model and to reduce the number of simulations, we assumed that the emergency vehicle has a constant speed of 1 km/min.

4.1. Some limitations

One crucial limitation of the simulation is the limitation of implicated model (MCLP) that does not consider the possible situation in which no road accident intervention squad is available at the closest fire stations to respond to a call within the time or distance threshold. The second important limitation is that potential spatial accessibility is calculated, which does not consider other geographic factors, social–economic characteristics of target populations, and organisation characteristics of emergency service. These factors and characteristics may either increase or decrease accessibility.

4.2. Simulation outputs

The simulation showed that under given conditions the total potential demand can be covered by introducing 13 new fire brigades' locations (Figure 2). Adding new locations makes it possible to cover more than half of the total demand in 15 minutes. Unfortunately, such a solution cannot be implemented, as moving the existing fire brigades to new locations would represent higher costs than getting the existing configuration better equipped. Thus, the proposed solution would be optimal but economically unjustified.

Further simulations have been run to optimise the allocation of the existing fire brigades' locations under the same simulation constraints. Among all the existing fire brigades' locations, 17 locations turned out to be the optimal solution to cover 65 percent of potential demand in just 15 minutes (Figure 3), while covering the other demand in maximally 30 minutes' drive-time. The chosen existing fire brigades are located in larger urban areas as shown in Figure 3. Their coverage areas remind of the regional split in the Republic of Slovenia, except that these are less.

As the chosen existing fire brigades are located very close to the larger urban areas, the potential demand on fire brigade intervention can be covered in less than 15 minutes in most cases. The suburbs and more distant areas with less potential demand can be covered in maximally 30 minutes. Statistical time series of interventions carried out in the last few years show the concentration of intervention demand in larger urban areas.

An intermediate simulation result led to the conclusion that there is a slight difference in the covered areas between the two types of simulation. In the case of choosing new fire brigade locations the area covered would be 5 percent larger compared to the one covered by 17 existing units' locations. There is no difference when considering all 40 fire brigade units as total demand can be covered in 15 minutes in both simulation types.

Additionally, the coverage of the potential intervention demand on the Slovenian road network was simulated for the case of 17 existing fire brigade units that would be properly equipped and trained to execute rescue tasks in road incidents. The analysis of the coverage of Slovenian road network was carried out by the simulated constant speed of 60 km/h. This simulation did not yield the results as good as in previous simulations; however, these were satisfactory. The difference was in the area covered, which is smaller, but it is still larger than 90 percent in the maximum drive-time of 30 minutes (Figure 4).

5. CONCLUSION

This paper presents theoretical background and applies the MCLP model for solving the problems of equipping and allocating fire brigade units that inter-

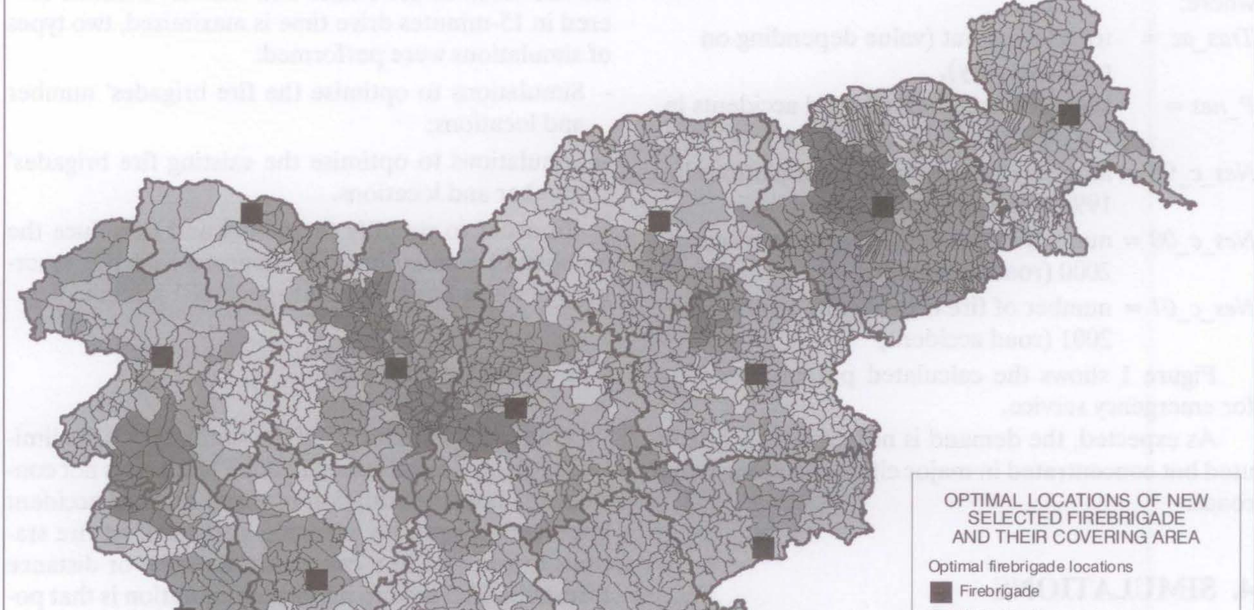

Figure 2 - Optimal simulation solution (new created units' locations).

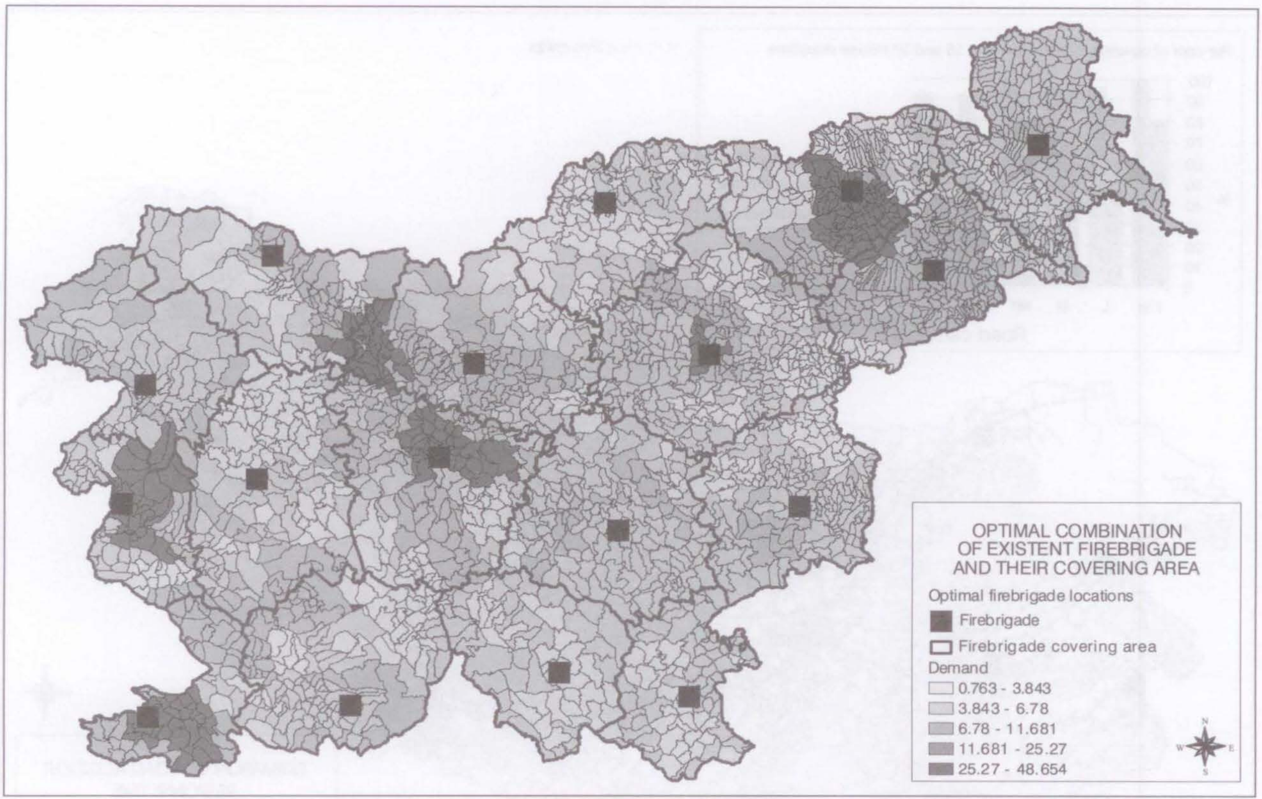

Figure 3 - Optimal simulation solution (existing units' locations).

vene in case of road incidents. As expected, the MCLP model has turned out to be very good and effective for solving such problems [2]. The use of GIS tools allows the results to be simulated and visualised.

After calculating the potential demand for fire brigade rescue squad intervention, an optimal number of fire brigade units that can intervene in case of road incidents, is analysed considering the given constraints. The recommended solution, which represents an optimal feasible equipment allocation, is 17 existing fire brigade units. These are already more or less equipped and trained for interventions in case of road incidents (Decree on the Organisation, Equipment and Training of Protection, Rescue and Relief Forces).

Following the simulation results, the existing configuration of 40 fire brigade units can cover a total potential demand for intervention in 15 minutes. This shows that the existing allocation in space is very good. However, the results also show that in order to reduce the costs, 17 better equipped and trained units for interventions in road incidents would be enough to cover the demand. In this way the response time in urban areas would be shorter, on the other hand, the accessibility to road incidents in rural areas would be worse. It should be noted that potential spatial accessibility was calculated without taking into account other geographic factors, social–economic characteristic of target populations, and organisation characteristics of emergency service, which may either increase or decrease accessibility.

The combination of 17 specially equipped and trained units, and 23 units with basic equipment for interventions in cases of road incidents is also possible. This would increase availability of squads and equipment in case when interventions are needed at several locations.

This model has set the basis for policy-makers when they decide about road safety on Slovenian road network. Further efforts invested in developing the model and simulations can bring to better solutions, especially by considering more factors and characteristics that affect the demand.

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POVZETEK

V članku predstavljamo aplikacijo MLCP modela v GIS okolju, s katerim optimiziramo število in lokacije gasilskih enot za tehnično posredovanje v primeru prometnih nesreč. Za take primere je v Sloveniji z uredbo določenih 40 gasilskih enot, ki so različno usposobljene in opremljene. Izračunali smo potencialno povpraševanje po intervenciji gasilskih enot in analizirali potencialno geografsko dostopnost pri različnih pogojih simuliranja.

KLJUČNE BESEDE

nesreče na cesti, reševanje, dostopnost, GIS, lokacijsko – alokacijski modeli, gasilske enote

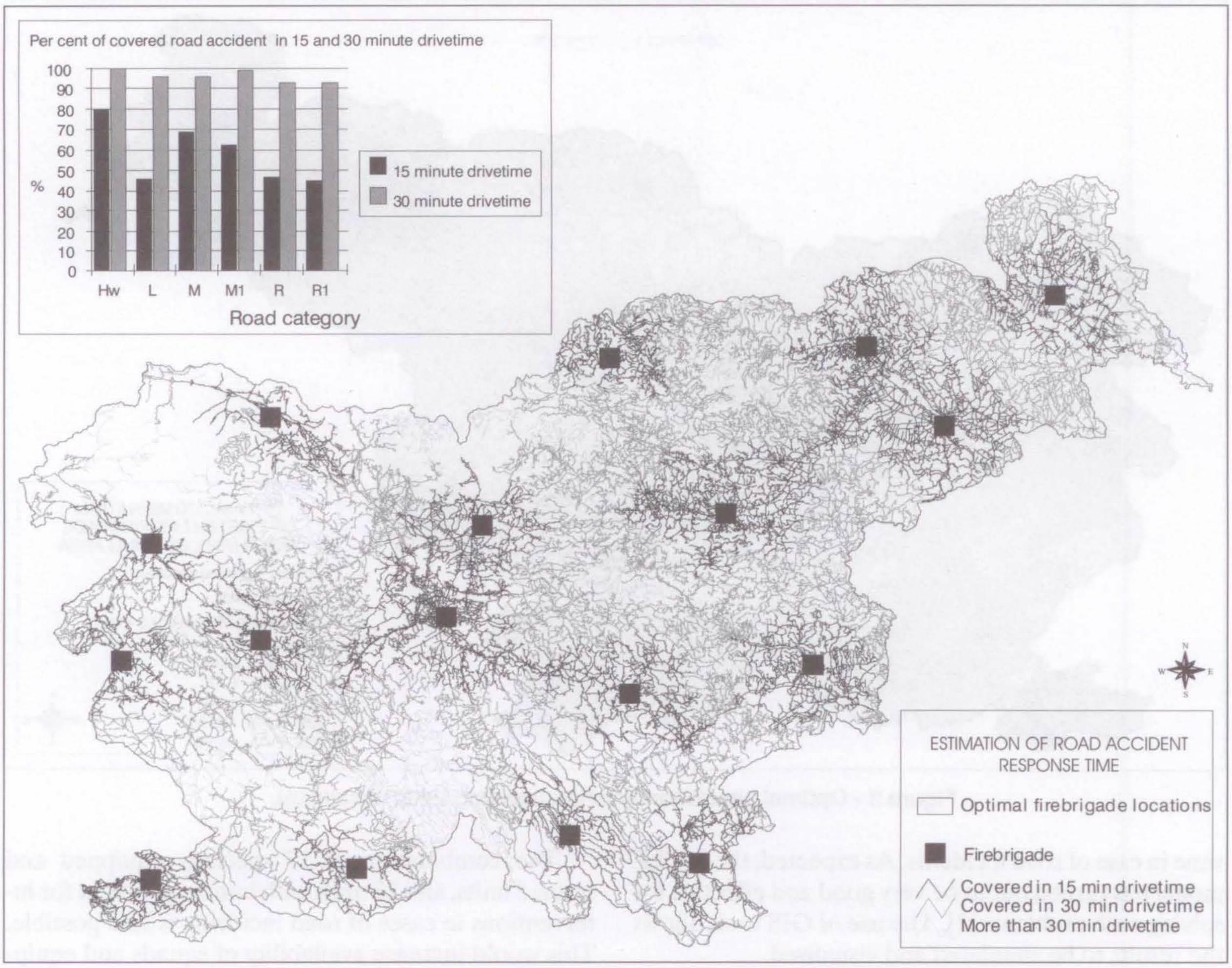

Figure 4 - Potential demand coverage on Slovenian road network.

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