Planning for emergency services using GIS-based geographic accessibility analysis

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Abstract

Municipalities and metropolitan structures are required by law to provide sufficient response to emergency situations. In order to respond efficiently to disasters such as fire and flooding, it is necessary to place facilities optimally. This case study presents and applies a methodology to determine the locations of additional fire stations, using accessibility analysis rather than incident data which is often incomplete or unavailable. The required response time is based on the SANS 10090:2003 standard for various risks. The case study recommends that in the longer term seven additional fire stations are needed in conjunction with the existing 19 fire stations in the eThekwini Metro in South Africa to offer a response to fire incidents as required by the standard.

BEPLANNING VAN NOODDIENSTE DEUR MIDDLE VAN GIS-GEBASEERDE TOEGANKLIKHEIDSANALISE

Munisipaliteite word wetlik verplig om gepaste nooddienste aan die bevolking binne hul grense te verskaf. Die optimale plasing van nooddiensfasiliteite stel nooddienste in staat om effektief binne 'n bepaalde tyd te reageer in noodgevalle soos brand- and vloedinsidente. Die betrokke studie maak gebruik van 'n GIS-gebaseerde toeganklikheidsanalise om die optimale ligging van addisionele brandweerstasies binne 'n munisipaliteit te bepaal. Die metode word voorgestel vir omgewings waar insidentdata nie bekombaar is nie, of waar die insidentdata onvolledig is. Die analise bepaal die ligging van nuwe fasiliteite deur die voorgeskrewe reaksietyd vir verskillende tipes risiko-areas soos aangedui deur SANS 10090:2003 in berekening te bring. Die gevallestudie wys hoe en waar hierdie metode sewe addisionele brandweerstasies, tot die huidige 19, vir die eThekwini-munisipaliteit voorstel om te sorg dat die nooddienste van die metro aan die SANS 10090:2003 standaard voldoen.

TSHEBEDISO YA GIS-BASED GEOGRAPHIC ACCESIBILITY ANALYSIS HO RERA DITSHEBELETSO TSE POTLAKILENG

Masepala le teropo tse kholo di tlangoa ke molao ho ba le ditshebeletso tse phethahetseng ho re ho be le ditshebeletso ts ephethahetsebg tsa nako ya dikotsi tse ka reng mollo le metsi a mangata ka baka la pula, ho bohlokoa ho beha ditshebeletso dibakeng tseo di tla khona ho fihla kotsing kapele le ha bobebo. Dipatlisiso tsa mosebetsi ona di bontsha, ebile di sebedisa mekhoa ya ho etsa diqeto tsa hore na dibaka tsa matlo a di tima mollo tsa ncha di be kae, ho sebedisoa accessibility analysis ntle le incident data eo ka mehla ee be e sa fella kappa e le sieo. Nako e hlokahalang ya ho araba dikopo tsa thuso di ahloloa ke SANS 10093:2003. Dipatliso tsa mosebetsi ona di eletsa hore matlo a di tima mollo a supa a macha a hlokahala ho sebedisanan mmoho le a leshome e metso e robong e se ntse e le teng eThekwini metro, Afrika Borwa, ho fana ka nako e phethahetseng hantle ya ho araba dikopo tsa thuso.

1. INTRODUCTION

Government and other stakeholders such as municipalities are required to provide for the rapid and effective response to disasters, as set out in the Disaster Management Act No. 57, 2002 (South Africa, 2002).

The application of customised accessibility analysis modelling to fire station location planning supports the effective provision of emergency services and can ensure effective city-wide reach when major disasters occur. This case study uses the example of location planning for fire stations. This approach would, however, also be applicable in terms of planning for the location of other services and personnel which may be used in responding to disasters. The location of fire stations is pertinent to disaster risk management as fire stations house the equipment and manpower used in the first response to disasters, and are ideally situated to be used as logistics centres and central management points. Local and national government authorities are faced with the daunting task of providing services to all communities within their jurisdiction in a fair, equitable and sustainable way. The Government Programme of Action (Outcome 12) requires government departments to develop geographic access norms for government services (The Presidency, 2012: online).

The accessibility analysis approach used, in this instance, has successfully assisted the

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fire departments of three major metropoles in testing and prioritising investment in new fire stations. Through applying the methodology, the emergency services departments can determine spatially where gaps currently occur in service delivery to best respond to fire, flooding and other emergency situations. The approach used is unbiased, as it is based on spatial data, which provides guidance on where to intervene in a spatially equitable manner to protect economic infrastructure and people's homes.

A case study from this work is used to illustrate the approach based primarily on the fire-response component of the emergency services and shows typical data outputs that can be provided to decision-makers. Some of this work was undertaken as part of a study for the Department of Public Service and Administration in 2012 while some additional analysis was undertaken for the specific purpose of this article. Owing to the lack of reliable geo-referenced incident data that can be used to evaluate demand for services, the methodology included the use of risk-potential maps based on land-use categories; similar maps would also be useful in supporting planning for, and providing first-response emergency services cover in cases of disasters. The South African Bureau of Standards has established norms for response time to fire incidents in the different land-use categories and these can be tested using the GIS tools available. This case study highlights the approach that has been used for over nine years to assist the local government of eThekwini to prioritise its investment in fire stations.

It must be recognised that, in most cities, there are insufficient funds to provide all the required facilities, particularly fire stations, and that choices are required as to which locations serve the greatest need and which should then be prioritized for investment. It is not possible to rely on the free market to successfully regulate the distribution and provision of social facilities in a developing country; thus a welfare approach to facility planning is more appropriate in South Africa (Smith, 1995: 1-5) in order to determine "who gets what, where and how". To enable such decisions, evidence and quantitative measurement are essential. Information is required about the land within reach of any current fire station, such as how much land of what type is in or out of reach of the station, how many people would be affected by potential incidences, the value of property, the number of jobs, which of the proposed new locations have the furthest reach based on the current road network, and how the different locations compare to each other.

2. BACKGROUND

Fire, flooding and other disasters that are anthropogenic or natural are a potential threat to humankind, property and the environment (Johnson, 2000). Disaster management consists of five phases, namely planning, mitigation, preparedness, response, and recovery. Geographic Information Systems (GIS) are used in each of these phases (Johnson, 2000). GIS is used in fire-fighting from both a planning (Murray, 2013) and a response perspective (Han, Potter, Bedkett, Pringle, Welch, Koo, Wickler, Usmani, Torero & Tate, 2010: 1128-1141; Abed, Hongxia & Hongyan, 2008: 2972-2976; Sauvagnargues-Lesage, L'Héritier & Boussardon, 2001: 307-318).

This article focuses on the planning phase and specifically on the availability of fire-response services in the eThekwini Metro, South Africa. Planning, in this context, is the optimal placing of additional fire stations to respond to fire incidents efficiently. Murray (2013: 64-71) states that, according to literature, spatial optimization models are optimally used in placing fire stations and that, over the past 40 years, various models have been utilized in placing fire stations optimally, using response-time standards. Murray (2013: 64-71) further indicates that models have been used to support current infrastructure to add new fire stations at optimal locations to provide response where existing stations cannot provide the required response in the time required to provide effective response. Fire protection and other disaster response time requirements in the South African context are provided in the Disaster Management Act 57 of 2002 (South Africa, 2002) and the SANS 10090:2003 from the South African Bureau of Standards (SSA, 2003). Murray (2013: 64-71) discusses three models that are used in placing fire stations optimally, namely the Maximal Covering Location Problem (MCLP), which maximises the total number of fire stations required to meet a demand based on certain restrictions such as funding and available resources; the Threshold Coverage Model (TCM), which considers the minimum number of fire stations at optimal locations to provide the required level of service, and the Complementary Threshold Coverage Model (CTCM), which minimizes the number of fire stations necessary, using the current or modelled number of fire stations as an input.

The approach used in placing additional fire stations in the eThekwini Metro utilizes the Flowmap software which provides a model similar to TCM. Flowmap also has a model that is similar to CTCM using the TCM-type results as an input. The Flowmap software and equivalent models will be discussed in the methodology section.

3. METHODOLOGY

3.1 Response targets, access norms and service demand

Murray (2013: 64-71) indicates that norms with regards to response times to incidents are the main criteria for placing fire stations. In the United States of America, the National Fire Protection Association (NFPA) provides the norms for response times, which indicate that 90% of the calls for assistance must be within nine minutes from a fire station in urban areas. Murray (2013: 64-71) further indicates that some municipalities may adjust their criteria slightly owing to the nature of the built environment. The South

African Bureau of Standards (SABS) provides guidelines in the SANS 10090:2003. This standard outlines the standards for response times for various land use or development types and thus establishes the principle or concept of demarcating and mapping risk categories for each area of a city (SSA, 2003).

Table 1 sets out five risk categories as defined by the SANS 10090:2003, together with the required response time and the types of land uses that fall into each category (SSA, 2003). Thus, to evaluate how well the fire services are located and to measure their potential reach and service gaps, it is necessary to analyse and compare the travel time via a road network from the closest station to all areas of the city and to compare this with the desired response time with respect to fire.[1]

Fire services in South Africa also provide first response to accidents, flooding and other disasters, which are not listed in the standard and, with the absence of standards for other disasters than fire, it was decided to treat these disasters as being similar to fire incidences.

The identification of comparable and benchmarked access norms and threshold guidelines are an essential ingredient for evaluating the sufficiency and accessibility of any facilities. The acceptance of norms such as those provided by SANS 10090:2003 within governance and delivery mechanisms is essential to enable auditable and defensible measurement of progress with respect to service delivery (Green, Breetzke & Mans, 2009). Since the intention of the accessibility analysis is to spatially identify service gaps, it is necessary to first map and geo-locate all the different land-use categories and identify any localised areas of risk that are associated with specific infrastructure such as oil pipelines, petroleum installations, hospitals, and schools. Spatially locating all levels of risks into a GIS-based 'risk map' creates a demand surface for the fire and emergency services which can be evaluated with respect to any set of response times.

3.2 Computing geographic access

GIS models vary significantly in their manner of computing geographic access. Murray (2013: 64-71) combines CTCM with ArcGIS. Park (2012: 13-21) uses a combination of ArcGIS's Network Analyst, Thiessen polygons and spatial autocorrelation to determine access to libraries. Mallick & Routray (2001) use GIS and buffers at selected distances from rural service centres to determine access to facilities. Mallick & Routray (2001) use buffers owing to the lack of proper road datasets for the study area in the Kendrapara District of Orrisa, India.

The model used in this case study incorporates the use of transport networks to establish the reach of services. The advantage of using a road network is that it takes into consideration the topography of the area in question, i.e. access over a river, cliff or rail line is only possible where there is a bridge, and gradients can be reflected by varying travelling speeds. The GIS data layers and road networks reflect the state of current urban development. By contrast, GIS-based software that uses only straight-line distance cannot take the aforementioned factors fully into account. The application of a road network with specific speed variables is critical when modelling the possible response times of call-outs to fire incidents and other emergencies.

The Flowmap software, used in the accessibility modelling, calculates the distance between all land parcels in the study area to the closest fire station. In this way, it is possible to evaluate the reach to all areas from the closest fire stations with all stations acting in competition with each other. The model simultaneously interrogates the supply of all service points in relation to the total study area/planning area/ city, thus enabling simultaneous evaluation of facility distribution with respect to the land use and population distribution subject to acceptable travel time limits (De Jong, 2004). Evaluation and auditing of the supply and demand of fire stations is performed within a fine-grained spatial context, thereby ensuring that results can be used at a detailed level to inform decisions on providing services and facilities in a spatially equitable manner to a specific target group.

3.3 Tools, data and analysis parameters

Certain tools, data and analysis parameters are needed to produce the required outputs of an accessibility analysis. The tools refer to the software and

Table 1: Risk categories and their response times

Risk categories and their response times		
Risk category	Broad land use/development type	Required response time
A – High	CBD; extensive commercial and industry	Within 8 minutes
B – Moderate	Limited CBD; smaller commercial or industry	Within 10 minutes
C – Low	Residential (of conventional type)	Within 13 minutes
D – Rural	Vegetation and limited buildings in remote areas	Within 23 minutes
E – Special	Various, including noxious industries, squatter areas, large shopping centres	Must be reached within time associated with development type, but are generally high risk – thus 8 minutes

Source: SSA, 2003

1 Note: For this analysis the emphasis was placed on travel response time to fire emergencies and was not related to the weight of response required (i.e. size of station or equipment) within each of the catchment areas. Although the latter is considered important, the operational aspect would be the next step in determining the equipping and staffing of fire stations in response to the number and severity of expected incidences. The geo-location of historical incidences is currently being undertaken to make this possible if required.

software functionality needed to do the analysis of key data sets. The analysis parameters refer to the facility norms regarding access distance or time to respond to an event, as outlined in SANS 10090:2003 for fire response. These norms define the constraints within which the fire services have to operate in order for the service to be defined as acceptable. Once the tools, data and analysis parameters have been set, the analysis can be conducted.

Within the Flowmap software, the catchment area analysis routine is used to audit the current service coverage of services, after which optimisation and expansion modelling is applied to discover where best to locate new stations and to support other decision-making. The catchment-based approach is specifically designed to assist planners of central place-type services and facilities to audit service accessibility from the perspective of existing and potential customers/events. The accessibility modelling outputs – together with planning inputs – can be used to explore and plan ways in which to achieve a better match between supply and demand, and to test the best trade-off between improved service availability, access distance, area, and people served per station.

The current lack of accurate historical GIS fire-incident data at a fine scale means that the modelling can only be undertaken based on land-use types and specific site evaluations rather than a combination of all three. A risk-coverage map is created for the evaluation of response time, which is based on land use and local fire inspection data, rather than on historical incident response data. The modelling allocation process assumes that the closest fire station has sufficient capacity and will respond to any incident irrespective of the time of day. Although this is not always realistically possible, this approach is suitable at a strategic level for the evaluation and planning of the strategic distribution of local facilities, including fire stations, to achieve sufficient coverage and reach for the majority of users.

3.4 Stepwise accessibility analysis and planning procedure

Table 2 shows the generic stepwise accessibility analysis process employed for most facility planning applications (Naudé, Green & Morojele, 2001: 32). The analysis process will be discussed later in the analysis section.

The table below is a summary of the generic five-step process followed when undertaking accessibility analysis for the purpose of providing strategic planning support for the location of new facilities. The first three steps comprise the auditing of current provision / supply of facilities versus the spatial distribution of the identified demand or target group. Steps 4 and 5 look to identify locations for new facilities and create a spatial balance between demand and supply. The five steps together constitute the complete planning process. See Section 4 for more detail.

Table 2: Stepwise accessibility analysis and planning procedure as implemented in the study

Stepwise accessibility analysis and planning procedure		
Step 1: Defining catchments based on access norms Step 2: User-side analysis/ classification Step 3: Service-side analysis/ facility classification	Steps 1, 2 & 3 = auditing	Steps 1 to 5 = entire planning process
Step 4: Spatial matching of supply and demand Step 5: Co-location and linking of multiple facilities		

3.5 Summary of the criteria and processes of eThekwini fire station analysis

The criteria and processes used in the eThekwini fire station analysis are summarised in Table 3. This table summarises all the input variables used as well as the supply scenarios tested and discussed later in the paper. From this it can be seen that the entire road network was used and that each link was ascribed a speed. Thus in the analysis the process would be to link each fire station to every analysis cell via this network. The time taken would then be compared to the travel time in Table 1 to evaluate compliance to risk category speed. Table 3 shows that the analysis used the entire city area and all its population as the demand while the supply points used were all the operational fire stations. ‘Analysis undertaken’ refers to two scenarios tested namely: evaluation of the status quo; and, testing of the re-opening of the moth-balled station at Cato Manor in combination with the development of up to six new stations over the long term.

Table 3: Summary of criteria and analysis process for fire stations

Facilities analysed	Fire stations
Travel network access time	Entire network with specific speeds per link and travel time according to risk category (See Table 1)
Demand	Entire area of metropolitan authority divided into risk category areas and inhabited by a population of 3 667 188 (2011 mid-year estimate Stats SA)
Supply	19 currently operational facilities and one mothballed station
Analysis undertaken	Assessment of current service coverage Testing impact of re-opening Cato Manor Testing impact of six other new locations.

3.6 Basic data sets used

Calculating the distances between stations and all areas of eThekwini is a key input for evaluating the coverage of the city with respect to emergency services. The capacity of stations and their ability to respond were not included in the analysis. It is acknowledged that, on the whole, this service experiences staff and equipment shortages. Accessibility analysis, as used in facility-based planning, is reliant on three basic data sets. In the case of the fire stations in eThekwini/Durban, these were as follows.

3.6.1 Fire-risk map

This map layer was created in consultation with the relevant emergency services personnel. The land area was tessellated into a detailed grid (in this instance, 20 ha hexagon units) and divided according to the five specified land-use risk categories. Population distribution within eThekwini for 2011, together with the risk category hexagon layer, formed the basic demand data for services. This data was supplemented with data on housing type. The latter was specifically directed to identify areas of informal dwelling structures which are categorised as Special Risk and require a shorter response time. The housing type and basic land-use layer as provided by eThekwini Municipality were used as a starting point for creating the risk-potential map, after which the emergency services personnel made specific corrections to the fine-grained hexagon layer based on fire inspection reports and local knowledge which allowed for the accommodation of areas of specific risk relating to hazardous industries, gas installations, pipe lines, and so on.

Figure 1 shows the resultant risk layer which formed the basis for the accessibility analysis and testing of response times. Statistics of the hectares of each land-risk type and the number of people living within each category were also developed.

3.6.2 Fire station locations

To undertake an accessibility audit, facility data is required; specifically, the geographical coordinates of facilities together with attribute data reflecting facility type and capacity, if relevant. The location of all existing fire stations with co-ordinates was provided by the City's Emergency Services Department. Stations were defined as a structure for storing fire-fighting equipment (vehicles and other equipment) and a place where firefighters are stationed. The locations of assembly points for stand-by crews were excluded.

3.6.3 The road network

The response time of a station to an incident is a major consideration for the location of fire stations. The network provides a travel distance and speed surface which is adjusted for topography and existing travel infrastructure, thus providing an accurate travel analysis layer. This data was developed in conjunction with eThekwini officials and was partially extracted from an earlier EMME2 transport modelling layer. Once complete, a workshop was held with both emergency services and transport planning staff to adjust the potential road speeds on all links.

The road speeds were adjusted for use by fire trucks based on achievable speeds on different classes of road. The national roads and freeways were assigned a speed of 90 km per hour, while all other main through roads (i.e. M and R routes) were assigned average EMME/2 speeds calculated using the high (peak traffic) and low (off-peak) EMME/2 speeds for each link, but with a minimum speed of 35 km per hour. Minor roads were assigned a speed of 25 km per hour. All roads in the CBD, regardless of road class, were also assigned speeds of 25 km per hour, according to perceived traffic conditions. Response times for each station included a three-minute turn-out time. The road network forms the link between each hexagon (demand/population, etc.) and the facilities (supply points). Thus, the hexagon set and network are related and are used to develop an origin-destination matrix for each specific facility or scenario.

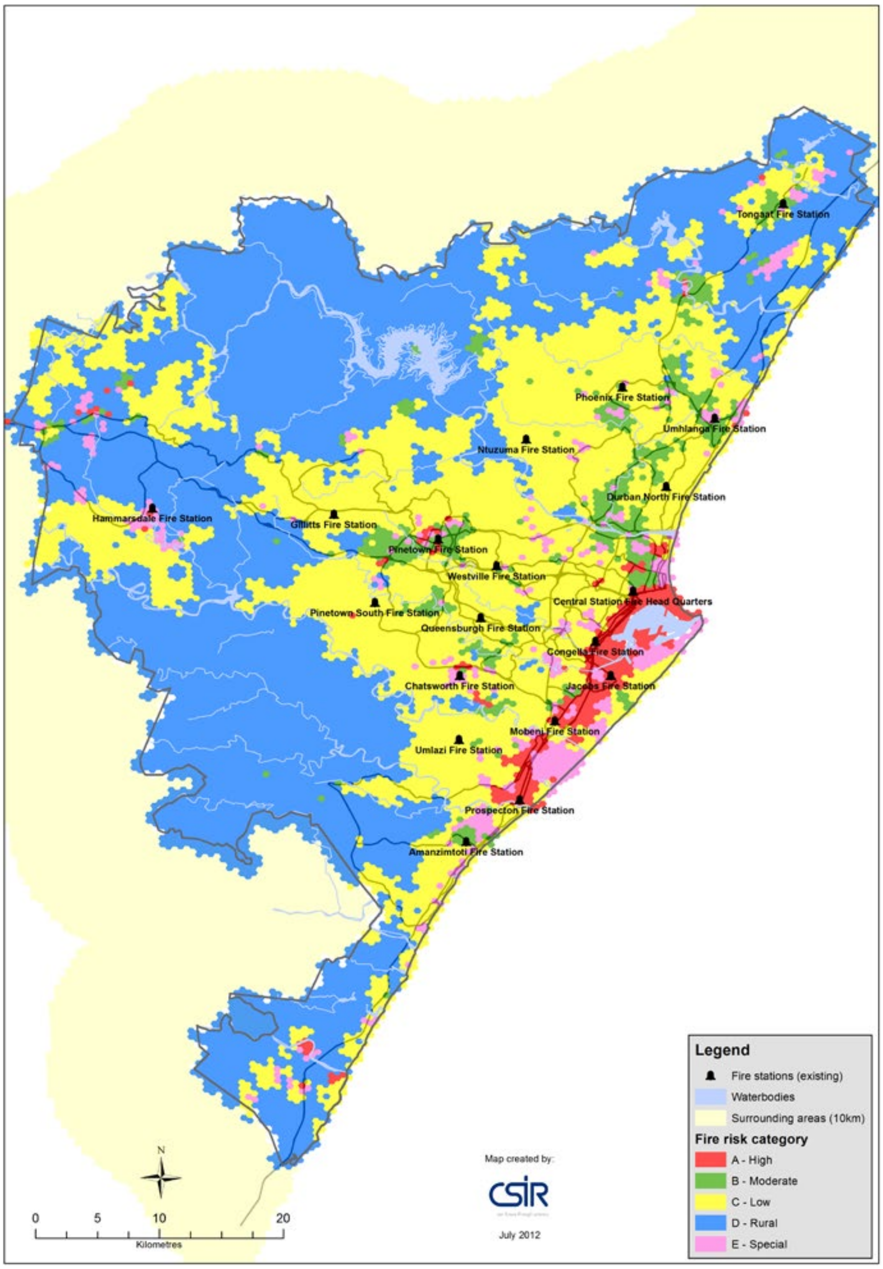

Figure 1: eThekwini: Fire risk areas and existing fire stations map

Source: Green, Mans, Le Roux, Schmitz, Mokgalaka, McKelly, Ngidi, Badenhorst, & Zietsman, 2012

4. ANALYSIS

The analysis process for fire response planning, as referred to in the methodology section, is based on the following five steps (Naudé *et al.*, 2001: 32).

4.1 Step 1: Audit the current service coverage

The first step in the analysis is to audit the current service coverage. An analysis is run to determine the current travel distance from stations to all parts of the community to establish the current coverage of each station. This audit is not of real-time 'call-out' times, but rather of potential expected response times. This seeks to establish if stations are well distributed across the metro areas, based on average travel speeds, the current and potential future footprint of the City, and its development pattern.

An unconstrained travel-time analysis is executed to evaluate the current travel distances to all areas of eThekwini using Flowmap. The travel time is measured using specifically defined 'emergency speeds' on the transport network and is used to simulate the vehicle response time from the fire station to all hexagons via the network. For emergency response, a further three minutes of turn-out time is added to the travel time to establish the actual reach of each fire station before comparing this to the risk category response requirements in Step 2.

4.2 Step 2: User-side analysis

Using the outputs of the above analysis, it is possible to undertake Steps 2 and 3 of the analysis process as listed in Table 2. The travel-time results are compared spatially to the risk category response requirements as well as their associated required response times to determine the regions that could be considered as served (those that fall within the standard) and those regions that are considered as unserved (those that fall outside of the defined standard). Results are mapped and statistics developed. Based on the classified risk category of areas, statistics of area coverage and population in each category is summarised.

4.3 Step 3: Service-side analysis

In this step, the data is reviewed at a station-by-station level, with the data indicating the potential facility demand of each of the current stations. This is based on the modelled number of hectares of land-area demand of each risk category within the acceptable response time. The number of people living within each served area by risk category is also calculated. This data can be used as input to calculate the operational size of each fire station. Before expansion is considered, this modelled demand should, if possible, be cross-checked with historical call data and the activity rates of the specific facility.

4.4 Step 4: Spatial matching of supply and demand

This step involves a detailed analysis of the under- or poorly-served areas and quantification of the likely backlog (areas of substandard response times) in a service area. This provides clues regarding the expansion process to be followed. The question of whether the distribution and location of facilities is matched to urban development and population distribution can then be answered. If there are gaps in the service areas, one can ask if there is sufficient or significant demand at any location within the unserved area where a new fire station is warranted. Consideration can also be given to road upgrades and building new link roads or bridges to expand the area coverage, or even if other service models should be considered to address demand.

4.5 Step 5: Co-location and linking of multiple facilities

The final step is to make recommendations for an expansion plan and, where possible, to integrate these with the delivery plan of other related services. The recommendations that are made are for generalized locations where services should preferably be provided together with an indication of the potential demand. The potential demand being the number of hectares of each risk type and the population potentially served. This can then be used to do detailed resource planning in conjunction with land availability.

5. DISCUSSION OF RESULTS

The previous section discussed the generic analysis process followed in fire-response planning. This section discusses the results obtained following the aforementioned steps.

5.1 eThekwini fire-risk areas

A review of the basic input data, that is the risk-potential map, shows that 78% of people live in low risk areas; the C Risk Category is defined as living in conventional suburban brick-and-mortar developments. The rural areas, which are, in general, classified as Category D, form the largest spatial extent, but the majority of the population live within Category C areas, which in total makes up only one third of the land area. Of the rural population, 12% live in brick-and-mortar developments. The areas of highest risk, namely A, B and E categories, which constitute the commercial, economic and industrial centres of the city where most jobs are located and where the largest and highest buildings are located and which, in general, are of highest value, constitute just over 10% of the land area. This 10% must, out of necessity, be a key focus area with respect to fire protection and these areas require response times within ten minutes or less to meet minimum response standards. The large rural area with a low population versus the small spatial extent of high-risk areas presents a specific problem with regard to the analysis of the statistics and how to plan to meet the demand effectively and equitably. Figure 1 gives the risk areas that were used in this case study.

5.2 Response times of eThekwini fire stations

In order to evaluate the response times to incidences of fire in the entire city, risk-category areas, as described earlier, were used as the basis of evaluation. In the evaluation of the results, all areas where the travel time is within the required risk-category limit are considered served, while those areas where the travel time exceeds the time required by the risk category are considered unserved.

Figure 2 shows the potential travel times from the fire stations to all areas within eThekwini from the closest stations. The figure legend in Figure 2 shows the travel time on the road as well as the total response time which includes the turn-out in brackets. For each scenario set of proposed facility locations analysed, the risk map, as illustrated in Figure 1, was compared to the travel-time map of the relevant set of fire-station locations under review. Figure 2 gives the travel or response times from the current fire stations.

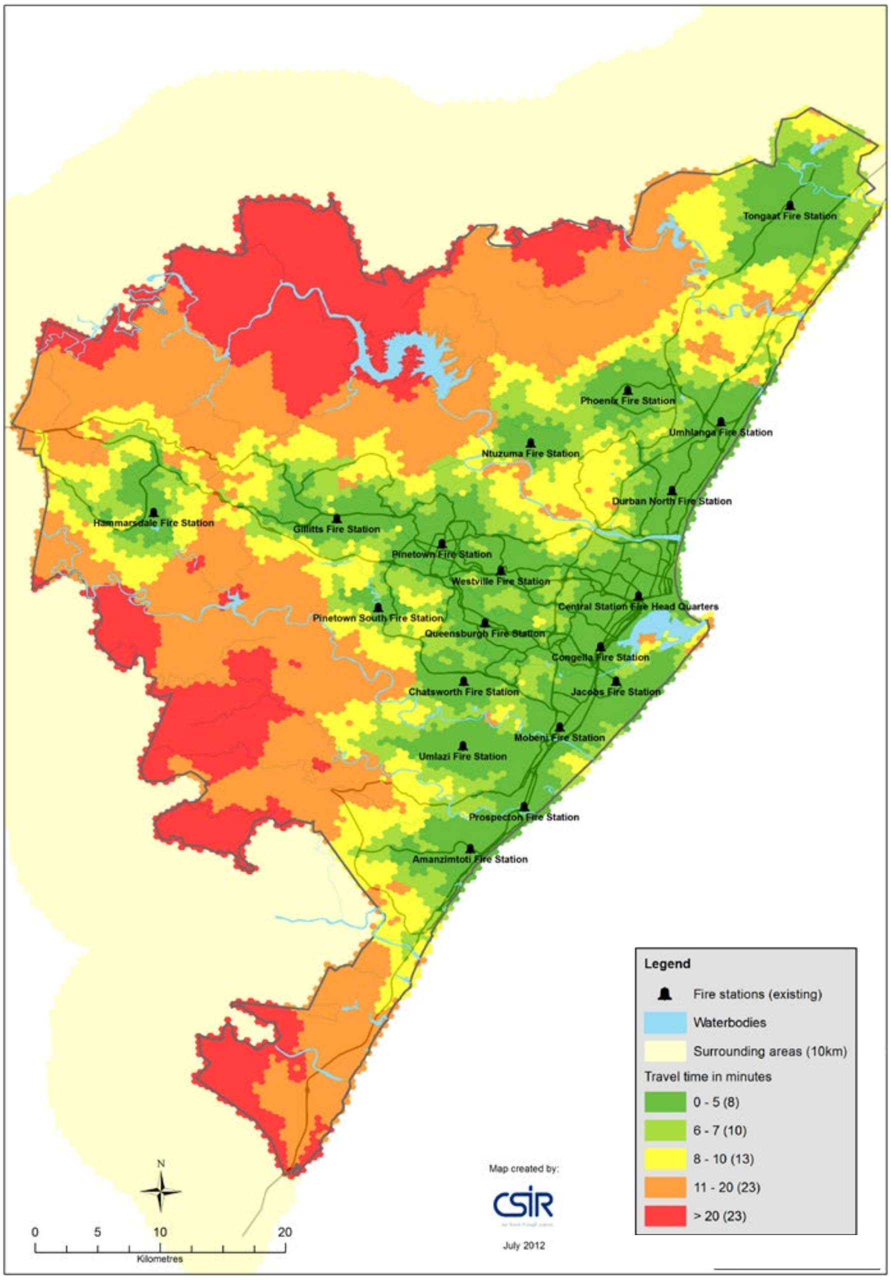

Figure 2: Travel or response time from existing fire stations in eThekwini

Source: Green, *et al.*, 2012

5.3 Service area of current eThekwini fire stations

Table 4 summarises the percentage population and land area served by each station. The development pattern and density variations in eThekwini mean that the demands on each station are very different, as reflected in Table 4. On average, the demand with respect to population served for each station is approximately 4.5%; however, this ranges from a high of 11.7% to a low of 0.98%. Each station also has a very different profile with respect to the number of hectares of each risk category which it serves.

Table 4: Coverage within access norms and demand on current stations with respect to population and land area within reach

Name of fire station	Percentage population served	Percentage land area served	A – High fire-risk area served (ha)	B – Moderate fire-risk area served (ha)
Amanzimtoti	3.56	2.63	-	360
Central Station Fire Headquarters	5.75	1.98	1 160	760
Chatsworth	3.93	1.81	100	160
Congella	1.28	0.98	520	-
Durban North	4.32	2.01	60	1 240
Gillitts	2.59	8.07	-	40
Hammarsdale	3.16	4.92	0	-
Jacobs	1.11	1.18	1 040	120
Mobeni	4.43	1.65	780	180
Ntuzuma	8.02	2.21	-	20
Phoenix	10.00	2.11	-	720
Pinetown	5.22	3.82	200	1 400
Pinetown South	3.27	1.43	-	20
Prospecton	2.30	1.18	840	20
Queensburgh	1.84	1.57	-	460
Tongaat	2.08	5.61	20	520
Umhlanga	0.98	1.90	40	980
Umlazi	11.70	3.34	20	80
Westville	1.45	1.73	-	160

The accessibility statistics show that 87% of the population are served by fire stations within the recommended travel times. A breakdown of the currently served population shows that 91% of people living in the urban areas are served. The National Fire Protection Association (NFPA) provides the norms for response times, which state that 90% of calls for assistance must be within nine minutes from a fire station in urban areas (Murray, 2013: 64-71). Accessibility to people in the rural and dense rural areas is below 60%.

5.4 Unserved areas in eThekwini

The travel time from current stations was compared to the risk-category requirements and the resultant map of areas where the travel time exceeds the prescribed time for the SABS risk categories for each hexagon is shown in Figure 3. The number of unserved/out-of-reach people for fire stations totals 509 731 or 13% of the total population. The statistics confirm that less than 9% of the population in the urban areas are poorly served.

Based on the analysis of the current supply and distribution of fire stations, the spatial coverage of the developed areas is good; however, most of the areas on the periphery of the municipal area are not being reached within an acceptable time. Of major concern is the large Category E risk area (special category) that is not adequately served, as well as the out-of-reach Category B areas, as shown in Figure 3 of unserved areas.

The 'poorly served areas' shown in Figure 3 formed the basis of the investigation into new locations for fire stations to best meet the needs of those areas not yet achieving the SABS required response times.

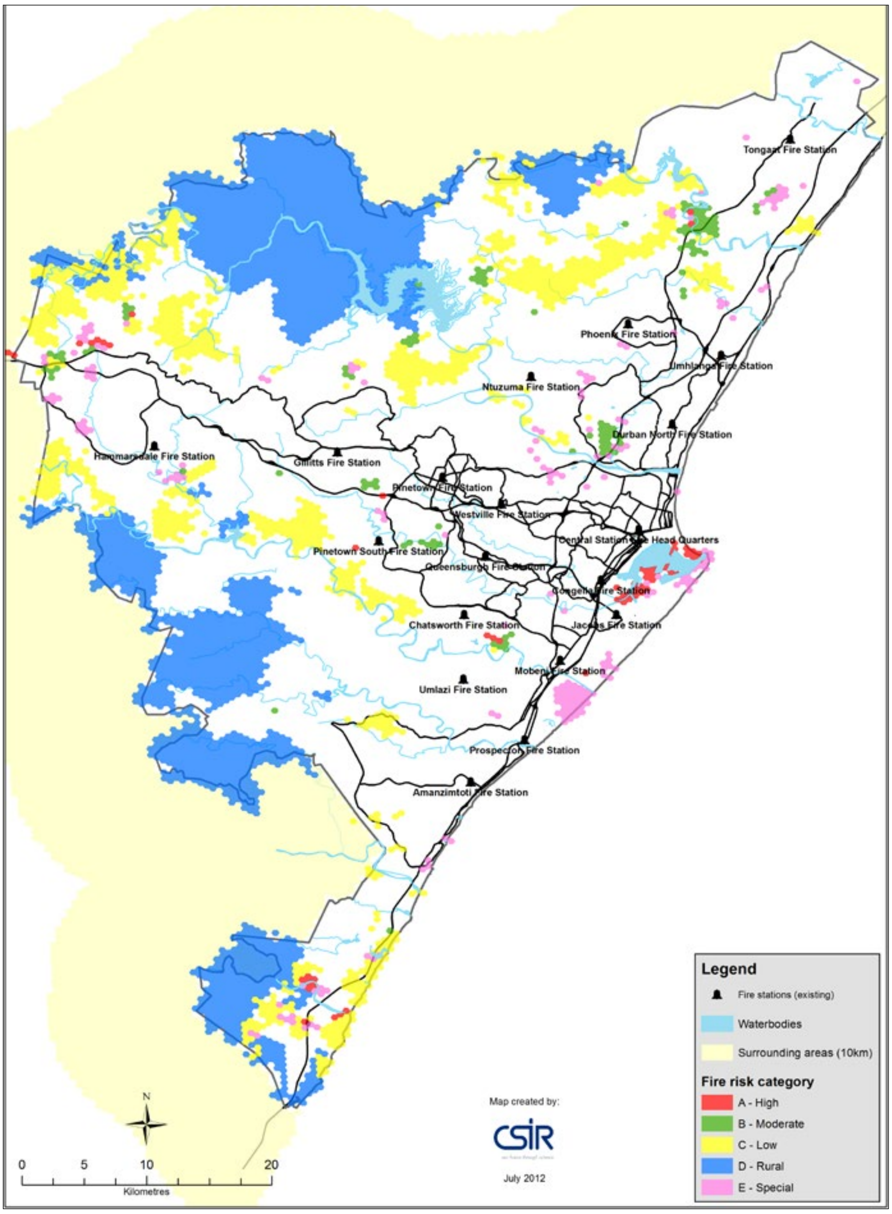

Figure 3: Areas that are not adequately covered by existing fire stations classified by fire-risk categories

Source: Green, *et al.*, 2012

6. INTERVENTION STRATEGY

6.1 Results

Solutions to improve the response to fire incidents in eThekwini, especially in the areas identified in Figure 3, were based on the analysis results. The finding that generally only 13% of the population is not served, but that there is a high percentage of those in the more rural areas who cannot currently be reached within an acceptable response time was important. Forty per cent of the population in the dense rural areas and 47% of those in rural areas are out of reach of existing fire stations; these populations are considered specifically vulnerable. If no alternative to conventional fire-station services can be used to provide these areas with services, the cost of providing services will be high, relative to the percentage population served. The area coverage is already high and thus, in areas of sparsely distributed population and smaller settlements, the potential service coverage of any new fire station will be limited, and each new station is likely to provide only 1% to 2% more coverage at most.

Decisions also need to be made regarding the protection of lives versus that of property and jobs. Unless sufficient funds are available to meet all needs, which is highly unlikely, compromises will be required and trade-offs will need to be made between the number of people served versus the requirements of protecting A- and B-risk areas, specifically, as well as the E-risk areas. The A- and B-risk areas not only have a higher property value and provide a large number of employment opportunities, but, due to the formal nature of these areas, the building materials used and the size of the structure, the fire services are more likely to have a higher success rate of salvaging value in these areas than at sites with smaller houses and informal dwellings which have higher burn rates.

6.2 Additional new facilities

A heuristic approach was used to select six new fire-station locations based mainly on higher risk areas currently not meeting requirements. These areas, although substantial with respect to the number of hectares, are fragmented and the cost to provide services per 1 000 residents will be much higher than in the more established higher density areas. These areas are home to only 14% of the metropolitan population and can potentially be identified as 'poorly served' with respect to coverage and services from existing fire stations. At this stage, a conventional approach of providing for new fire stations was tested; however, other service models such as the distribution of bakkie-pumps with stand-by crews that are located in selected locations have yet to be considered.

The spatial distribution of the 'poorly served' population highlighted six clear clusters which were then selected as the locations for testing the impact of new fire stations. These six extra locations, coupled with the inclusion of the mothballed Cato Ridge fire station, formed the basis of the next phase of analysis.

Using the seven identified sites, an unconstrained, that is unrestricted with respect to travel time or people allocated per station, catchment-area analysis was run and compared to the potential risk map to evaluate the impact of adding these extra fire stations to the current supply. Figure 4 shows the travel times from the existing and newly identified fire stations.

Accessibility statistics indicated that the addition of seven newly identified fire stations would potentially result in only a 6.5% increase in the overall service coverage to the population – an increase from 86.45% to 93.21%. The biggest single improvement was observed in the rural areas where coverage could potentially increase from 53% to 73%. In the densely settled rural areas, the potential increase is from 59% to 71%, while the urban areas also increased from serving 91% to 97% of the population, respectively. Due to the fragmented nature of development, a further 6.79% or 249 149 of the population would still remain without adequate cover.

Table 5 shows the likely individual coverage of the mothballed Cato Ridge station and the seven identified new stations. Although Table 5 shows that the population served by the new stations would number over 595 000, this includes some population (10%) previously served by other stations, but which is now better served by the new locations. Although 10% of the current population served would be better served by the newly identified locations, eThekwini is likely to prefer to first consider areas currently not meeting requirements with respect to access targets, rather than trying to improve an already acceptable service level. The unserved population is reduced from 509 731 to 249 149 with the re-opening/addition of the eight stations.

Statistics on hectares served by type for each station were also developed to support the decision-making process and the trade-off with respect to prioritising station investment. Even if seven additional stations become operational, some areas will remain unserved.

Figure 5 maps the areas that remain unserved, even after the addition of the newly identified stations. Table 5 summaries the areas served

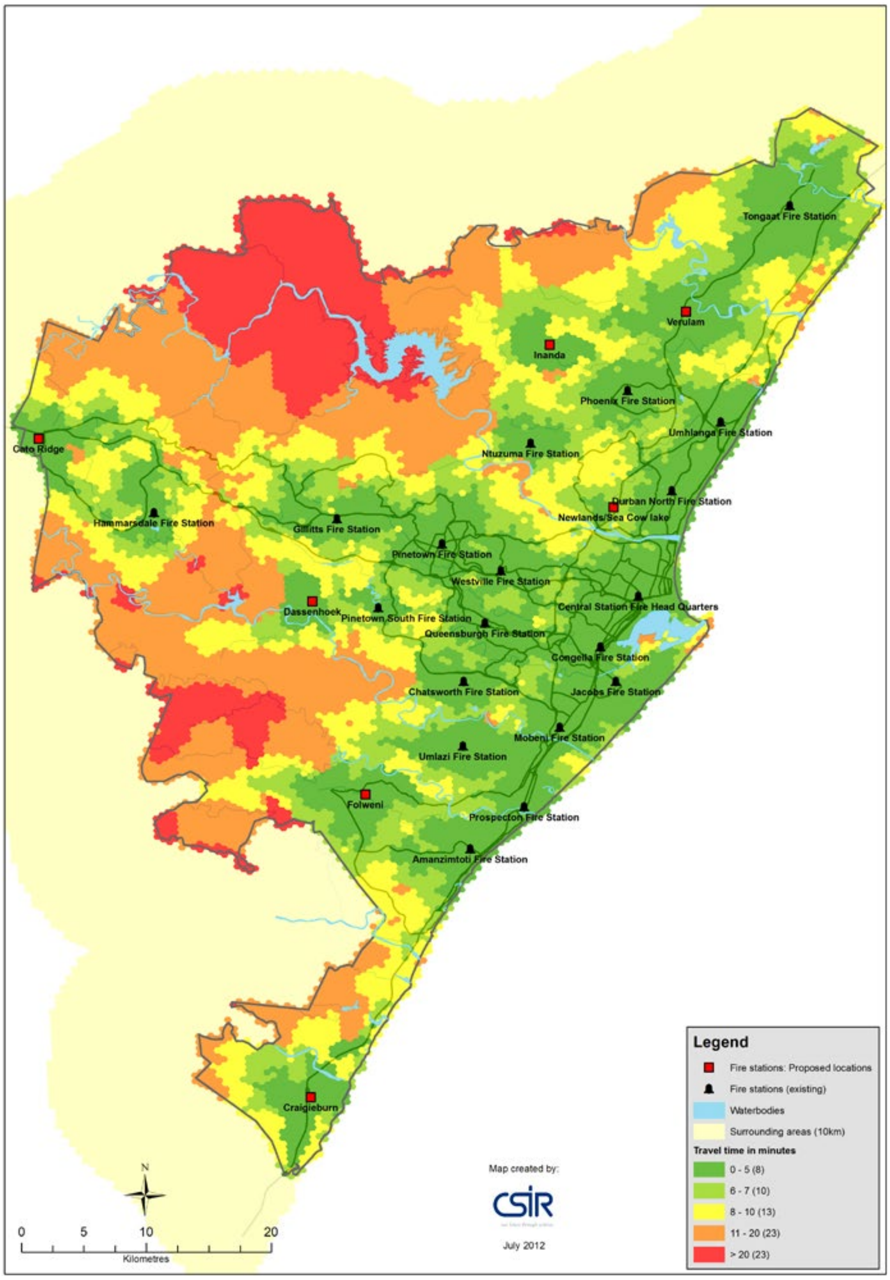

Figure 4: eThekwini: Travel time (response time) from the 19 existing and seven newly identified new fire stations

Source: Green, *et al.*, 2012

Table 5: Accessibility statistics of potential coverage for the previously unserved population and area by the seven newly identified fire-station locations in eThekwini

Proposed hexagon location	Newly identified location	Fire-risk category	Population		Area	
			Population served by existing and newly identified stations **	Population **newly** served by newly identified stations	Area served by existing and newly identified stations **	Area **newly** served by newly identified stations
16504	Folweni	B – Moderate	271	271	60	60
		C – Low	75 880	43 715	1300	580
		D – Rural	70 641	7 399	12560	3960
		Total	146 792	51 385	13 920	4 600
22871	Dassenhoek	C – Low	63 869	38 813	1480	1060
		D – Rural	11 935	1 526	8540	3120
		Total	75 804	40 339	10 020	4 180
25542	Newlands / Sea Cow lake	B – Moderate	3 469	2 804	500	340
		C – Low	59 481	3 106	1780	120
		D – Rural	1 918	-	220	0
		E – Special	185	185	20	20
		Total	65 053	6 094	2 520	480
28533	Cato Ridge	A – High	6	6	60	60
		B – Moderate	399	399	260	260
		C – Low	16 585	7 907	1140	780
		D – Rural	8 857	2 036	7420	800
		E – Special	45	45	140	140
		Total	25 891	10 394	9 020	2 040
30928	Inanda	C – Low	78 311	50 516	2760	2360
		D – Rural	26 299	4 204	8860	2640
		Total	104 610	54 720	11 620	5 000
31821	Verulam	A – High	199	199	40	40
		B – Moderate	5 494	5 253	800	680
		C – Low	90 193	40 882	4800	2380
		D – Rural	22 053	3 369	7820	620
		E – Special	1 210	1 210	60	60
		Total	119 149	50 914	13 520	3 780
6698	Craigieburn	A – High	1 411	1 411	160	160
		B – Moderate	177	177	20	20
		C – Low	28 254	22 437	2440	2180
		D – Rural	25 670	7 912	9720	4160
		E – Special	2 203	2 203	180	180
		Total	57 715	34 140	12 520	6 700
		Grand total	595 015	247 986	73 140	26 780

by the new proposed stations. Columns marked ** include land area and population that can already be considered served by existing stations, but are now better served by the new proposed locations.

6.3 Practical implications

The existing fire stations in the eThekwini area serve 87% of the current population, while only 13%, or 509 731 of the population, are poorly served by the existing stations.

The newly identified six locations and the addition of the Cato Ridge fire station will reduce the unserved population to 249 149, leaving 6.79% of the population still unserved. Given the high cost of capital and operations, an average 1% additional coverage per station is high. Even with seven new stations, 29% of the densely settled rural areas and 28% of the rural (low-density) population will still be poorly served and will require alternative means of service. The numbers of people in question is, however, very low in relation to the total city population.

The re-opening of the Cato Ridge fire station will reduce the unserved population by 10 394. It can potentially serve 0.71% of the total population, but will only serve an additional 0.28% of the population that is currently unserved. It will, however, provide valuable coverage for the unserved A- and B- and Special-risk areas next to the N3. The N3, which is the main freight route between the Durban harbour and Johannesburg and which has a high accident rate in the Cato Ridge area, can now be better served. A new station at Craigieburn will have a significant impact with respect to A-risk coverage, while stations in Inanda and Newlands will have a major impact on B-risk areas.

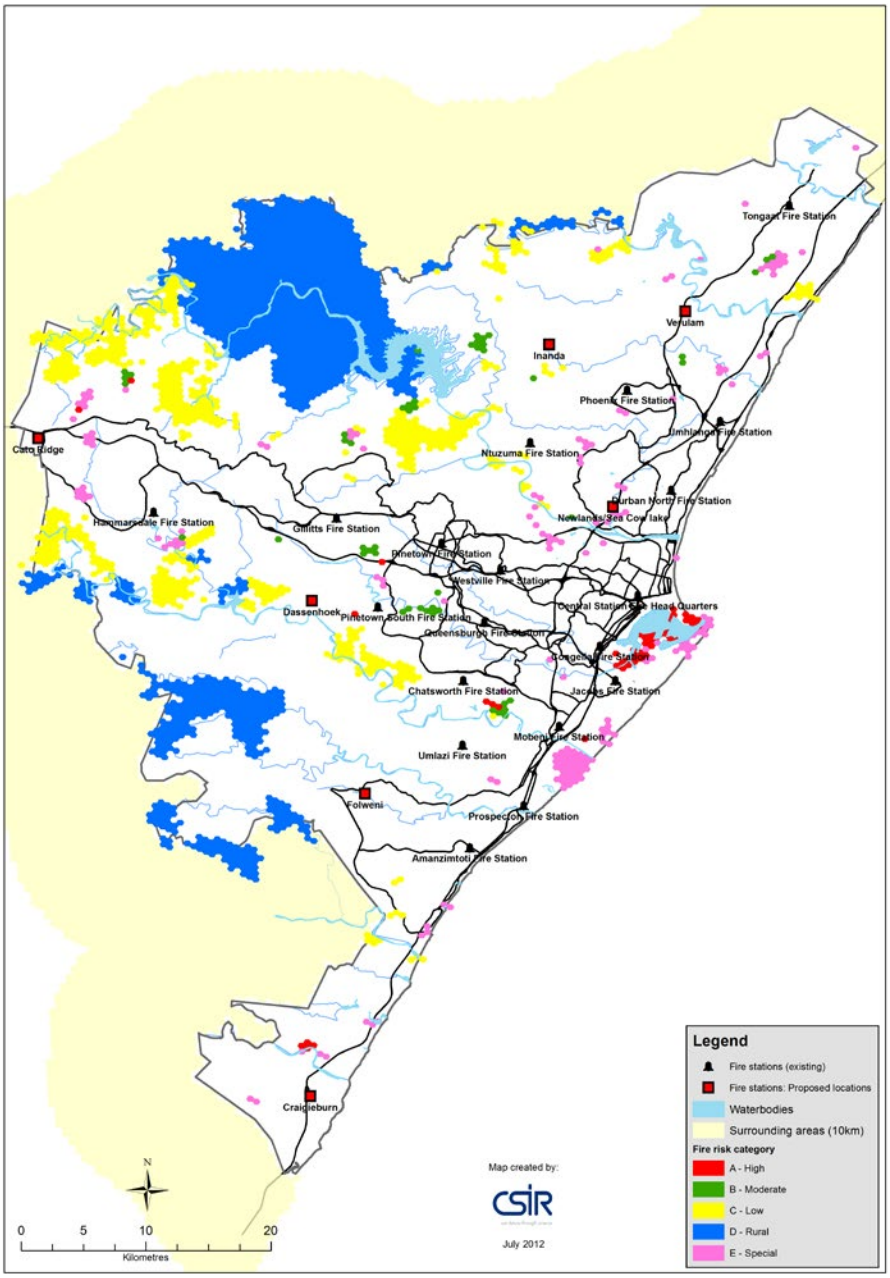

Figure 5: eThekwini: Fire-risk areas that are not adequately covered by the existing and seven new fire stations by risk category

Source: Green, *et al*., 2012

Stations at Verulam and Inanda have a similar impact on reducing backlog with respect to population coverage. However, unlike Verulam, Inanda will not make any impact on A- and B-risk coverage. In the final analysis, all the different benefits will need to be weighed up and the city elders will need to consider the growth paths of the city before capital budgets are approved. Significant additional data tables and maps were provided to the City to support decision-making.

Catchment areas are not static and will change over time. Specific shifts will occur as new facilities come on line and areas once served by an older station are more optimally served by a new station. The modelling of the new proposed stations in competition with the current stations showed the likely changes in catchment areas. The likely coverage of each station in competition, as well as the extent of areas that are likely to fall into the service area of another station after all seven new stations are operational, was made clear and indicated likely shifts in the extent of operational coverage. This is of use in potentially re-assigning resources such as staff. For example, Amanzimtoti station will need to provide less coverage of population (house fires) after Folweni and Craigieburn are operational, but A- and B-risk coverage remains the same. Mobeni Fire Station will not be impacted by any new fire station, while the demand on the Phoenix Station will be substantially reduced, if stations are built at Verulam and Inanda.

7. RECOMMENDATIONS AND CONCLUSIONS

To ensure a successful implementation of the newly identified fire stations, it is recommended that:

- The model outputs such as population and area served are used together with local knowledge, call out history, etc., to motivate future expansion programmes.
- Informal settlements and backyard shacks should be specifically mapped, if so required, to support spatial planning decisions.
- Local planners should be consulted with regard to future growth, and a future development scenario can be tested to ensure long-term sustainability of new facilities.

Since it is unlikely that sufficient capital and operating funding to build all six stations and re-open a seventh in the short term will be secured, a cost-benefit analysis or political decision will be required to weigh up the merits of each station and to prioritize investment. The ability to protect industrial property and, by implication, jobs in one area will need to be compared to the ability to respond effectively to house fires in others. Greater awareness and education, together with the implementation of additional safety measures, can also help reduce the incidents of fires in residential areas and reduce loss of life. Ultimately, the model provides very effective data to support decision-making, but authorities cannot rely on a model alone in identifying where new facilities should be located. The output simply provides the decision takers with a greater spectrum of information to assist in taking an informed decision when resources are limited.

In conclusion, by applying the access-analysis approach to facility-location planning, as discussed in this article, a number of outcomes are achieved. First, residential areas with the greatest imbalance in terms of facility provision are identified. The planning and optimisation phase of this project established where the facility need can be satisfied most efficiently with respect to risk categories, residential settlement density and transport networks.

The accessibility-planning approach provides evidence for making decisions on where to invest in facilities that best serve the people in the most equitable and unbiased manner and enables backlogs to be spatially quantified and communicated visually to communities and decision-makers.

In the absence of GIS-based data that tracks the number, location and severity of incidences to which the fire and emergency services respond, the use of the risk-potential map and the accessibility-analysis approach provide a robust alternative to evaluate fire station and emergency response coverage at a strategic level. This approach has proved of significant value to support investment decisions in eThekwini over a number of years for both fire stations and a range of other social facilities. The model has successfully identified areas with facility backlogs to support the planning of new facilities where they are most needed and this was done in an integrated way for a selection of key facilities – irrespective of ward boundaries and political processes.

This accessibility analysis may be extended to consider all strategic assessments of identified potential disaster sites, with respect to sea-level rise and other disasters, to provide the most effective distribution of emergency facilities and manpower to be deployed in the management of disasters and the provision of quick response times when disasters strike.

REFERENCES LIST

ABED, F.H., HONGXIA, Z. & HONGYAN, Z. 2008. Open source web-based GIS and database tools for emergency response. In: *Proceedings of the IEEE International Conference on Automation and Logistics*, 1-3 September 2008, Qingdao, China, pp. 2972-2976.

DE JONG, T. 2004. Practical guide: Accessibility modelling and service location planning. Course material for Course GS-MBIM: Accessibility analysis and interaction modelling, presented by the Faculty of Geosciences, Utrecht University, The Netherlands.

GREEN, C.A., BREETZKE, K. & MANS, G. 2009. GIS-based evaluation of public facility provision to achieve improved governance and equitable service delivery. In: Schrenk, M., Popovich, V.V., Engelke, D. & Elisei, E. (eds.). REAL CORP 2009 Proceedings of the 14th International Conference on urban planning, regional development and information society. Cities 3.0. Strategies, concepts, technologies, 22-25 April, Catalonia, Spain, pp. 167-175.

GREEN, C.A., MANS, G., LE ROUX, A., SCHMITZ, P., MOKGALAKA, M., MCKELLY, D., NGIDI, M., BADENHORST, W. & ZIETSMAN, H.L. 2012. Geographic accessibility study of social facility and government service points for the metropolitan cities of Johannesburg and eThekwini 2011/12. Pretoria: CSIR Built Environment.

HAN, L., POTTER, S., BEDKETT, G., PRINGLE, G., WELCH, S., KOO, S.H., WICKLER, G., USMANI, A., TORERO, J.L. & TATE, A. 2010. FireGrid: An e-infrastructure for next-generation emergency response support. *Journal* of *Parallel* and *Distributed Computing*, 70(11), pp. 1128-1141.

JOHNSON, R. 2000. *GIS technology for disasters and emergency management*. An ESRI White Paper. Redlands, CA: Environmental Systems Research Institute, Inc (ESRI).

MALLICK, R.K. & ROUTRAY, J.K. 2001. Identification and accessibility analysis of rural service centers in Kendrapara District, Orissa, India: A GIS-based application. *JAG,* 3(1) pp. 99-105.

MURRAY, A.T. 2013. Optimising the spatial location of urban fire stations. *Fire Safety Journal*, 62(2013), pp. 64-71.

NAUDÉ, A.H., GREEN, C.A. & MOROJELE, N. 2001. Multi-criteria spatial profiling and catchment area analysis. AccessPSG-2. DP-2001/2 (Final Draft), CSIR Transportek, Pretoria.

PARK, S.J. 2012. Measuring public library accessibility: A case study using GIS. *Library & Information Science Research*, 34(1), pp. 13-21.

SAUVAGNARGUES-LESAGE, S., L'HÉRITIER, B. & BOUSSARDON, T. 2001. Implementation of a GIS application for French fire fighters in the Mediterranean area. *Computers, Environment and Urban Systems*, 25(2001), pp. 307-318.

SMITH, D.M. 1995. Geography, social justice and the new South Africa. *South African Geographical Journal*, 77(1), pp. 1-5.

SOUTH AFRICA. 2002. Disaster Management Act, Act 57 of 2002. Pretoria: Government Printer.

STANDARDS SOUTH AFRICA (SSA). 2003. *SANS 10090:2003 Community protection against fire*. *South African National Standard.* Pretoria: Standards South Africa.

THE PRESIDENCY. 2012. *Government's Programme of Action (2012)*. Available from: <http://www.thepresidency.gov.za/pebble.asp?relid=738> [Accessed: 2 August 2012].