A system dynamics model of the fire department EMS in Taiwan

Lan, C-H. , Chuang, L-L. and Chen, Y-F.

Published version deposited in CURVE May 2012

Original citation & hyperlink:
Lan, C-H. , Chuang, L-L. and Chen, Y-F. (2010) A system dynamics model of the fire department EMS in Taiwan. International Journal of Emergency Management, volume 7 (3/4): 323-343.
http://dx.doi.org/10.1504/IJEM.2010.037015

Publisher statement: This document is the published PDF of the journal article made available in CURVE with the Publisher's permission.

Copyright © and Moral Rights are retained by the author(s) and/ or other copyright owners. A copy can be downloaded for personal non-commercial research or study, without prior permission or charge. This item cannot be reproduced or quoted extensively from without first obtaining permission in writing from the copyright holder(s). The content must not be changed in any way or sold commercially in any format or medium without the formal permission of the copyright holders.

CURVE is the Institutional Repository for Coventry University
http://curve.coventry.ac.uk/open

A system dynamics model of the fire department EMS in Taiwan

Chun-Hsiung Lan

Department of Business Administration,
Nanhua University,
No. 32, Chung keng Li, Dalin,
Chiayi 62248, Taiwan
Email: chlan@mail.nhu.edu.tw

Liang-Lun Chuang*

Management Sciences, Department of Business Administration,
Nanhua University,
No.380, Sansing Street, Sinying City,
Tainan County 73051, Taiwan
Email: pb35kimo@yahoo.com.tw
*Corresponding author

Yung-Fang Chen

Department of Geography,
Environment and Disaster Management,
Coventry University, Priory Street,
Coventry, GE514, CV1 5LW, UK
Email: aa4106@coventry.ac.uk

Abstract: Allocation of pre-hospital EMS (Emergency Medical Service) resources and effectiveness of emergency medical training are critical to patients. The demands for EMS are expected to increase in the future. By analysing the relationship between emergency response and the survival rates, the effectiveness of EMS resources and competence of personnel were evaluated. In other words, the current EMS resources will be insufficient, and the ratio of busy ambulances will increase. Patients may need to wait for an ambulance. In this paper, indicates that three more ambulances should be added and the priorities of resources to be allocated to suffice future demands are simulated. Through arrangement of extra hours of training, ROSC of patients within the system can be enhanced. Besides, by accelerating the travel speed of ambulances and shortening the average response time to 6.5 minutes, survival rate of patients could be increased and allow the EMS teams to take another 2.6 cases.

Keywords: SD; system dynamics; pre-hospital emergency medical service; resource allocation; EMT; emergency medical technician; OHCA; out-of-hospital cardiopulmonary arrest; response time.

Reference to this paper should be made as follows: Lan, C-H., Chuang, L-L. and Chen, Y-F (2010) ‘A system dynamics model of the fire department EMS in Taiwan’, *Int. J. Emergency Management*, Vol. 7, Nos. 3/4, pp.323–343.

Copyright © 2010 Inderscience Enterprises Ltd.

Biographical notes: Chun-Hsiung Lan is a Professor and Chairman of Graduate Institute of Management Sciences in Nanhua University, Taiwan. His research interests include efficiency management, resource strategy, advanced manufacturing technology, modelling and computational intelligence, operations research and calculus of variations.

Liang-Lun Chuang is Director of Emergency and Rescue Command Center in Tainan County Fire Bureau, Taiwan. He received his PhD degree from the Management Sciences of Business Administration at Nanhua University (Taiwan) in 2010, and then he completed his Master's degree from the Nanhua University (Taiwan) in 2004. His research interests lie in the fields of efficiency management and forest fire rescue.

Yung-Fang Chen is a Senior Lecturer in Disaster Management and Emergency Planning at Coventry University, England. The focus of her research is on strategies for crisis and emergency response management, particularly in the context of using training exercises to facilitate risk communication. Her research interests also include emergency management organisations and serious games for emergency response.

1 Introduction

The effectiveness of the Emergency Medical Service (EMS) procedure is crucial to a patient's life and long-term effect. The demands for the pre-hospital EMS have significantly increased in the past few years in Taiwan. The average number of EMS services has increased by 5–10% annually (NFA ROC, 2007). The higher dependence of citizens on the services of Emergency Medical Service System (EMSS) suggests that the fire departments investigate an optimum and effective resource allocation model.

Pre-hospital EMS is one of the key responsibilities of the fire department in Taiwan, according to the Emergency Medical Service Act in 1989. Although the system has been developed and improved in the past 20 years, due to the limit of budget, there is still lack of equipment and competent personnel which prevents a higher patient survival rate in the pre-hospital EMS.

Regarding survival rate of patients with OHCA (Out-of-Hospital Cardiopulmonary Arrest), despite the fact that all EMS teams of Tainan County Fire Bureau have been equipped with an Automatic External Defibrillator (AED) since 2006, the Return of Spontaneous Circulation (ROSC) in patients treated by these EMS teams is 12%. While compared to the average survival rate in Australia (3–22%) (Finn et al., 2001; Leung et al., 2001) and the USA (2–21%) (Casner et al., 2005), there is much needed to be done to improve the effectiveness of the service, in particular, the number of firefighters and ambulances to cope with the higher demands and the emergency medical training regarding the improvement of ROSC in OHCA patients.

Traditionally, mathematical methodologies are used to estimate the resource and personnel needed in the system. However, it is argued that the mathematical methodologies used in the science of management, such as linear methods, queuing theory and Monte Carlo simulation, cannot effectively explain the dynamics in real problems, because these linear and static methods cannot be applied to high-order and non-linear problems of dynamic systems (Forrester, 1992). Hence, the research proposed to adopt the Forrester's

(1961) system dynamics approach, using differential equations to compute the variation of complex systems over time to explore the instantaneous rate of change of the system. Table functions and delay functions are employed to address problems involving dynamics, delays and a non-linear relationship.

In practice, performance of an emergency medical system is mainly determined by dynamics, complexity, medical information and delay effect (Lan et al., 2009). Among these variables, there are also non-linear and close causal relationships. System dynamics is an approach to understanding the structure and characteristics of a complex system.

Roberts (1978) argued that the cause-and-effect feedback loops in system dynamics are suitable for analysing complex structures. Through the use of feedback loops, the causal relationship between variables and the impact of external environment on the system can be better investigated. The system dynamics approach adopted in the research overcomes the problems of traditional dynamic analyses because it takes many variables into consideration. It also uses computing processes to simulate complex procedures. An EMSS involves a broad range of external and internal factors: population, service coverage distance, severity of injury and traffic conditions are external factors; while fire manpower allocation, scale of ambulances, response time, budget for training and effectiveness of training are internal factors.

The research simulated the system dynamics of the EMSS to analyse the operational structure and system behaviours and thereafter the phenomena and problems observed within the system could be explained. As mentioned earlier, the fundamental mission of EMS is to transport the patients to the nearest hospital as soon as possible. Al-Ghamdi (2002) mentioned that response time[1] of an EMS team is an effective measurement of the accessibility of EMS; it is the fundamental factor to impact on the patient survival and recovery rate. The National Fire Protection Association (NFPA) also emphasised that the response time is the most decisive factor in the appraisal of the quality of an EMS system. Baker et al. (1987) found that the mortality rate of patients is higher in areas with lower population density, and this is due to longer response time of EMS teams. Brodsky (1990) also agreed that the quality of EMS is related to timing.

Through the simulation of the system dynamics, the effects of service coverage distance, ambulance travel speed and emergency medical training on the response time of EMS teams and survival rate in patients treated within the system can be investigated.

The results of the analysis can be used to determine an optimum scale of resource allocation, for example the number of ambulances needed and a more effective method to dispatch ambulances. In addition, the results of the simulation also propose an ideal interval of emergency medical training on improvement of patient survival rate.

2 Background of Tainan EMSS

The missions of EMSS are to provide pre-hospital and in-hospital emergency medical care to reduce mortality and morbidity of patients in need during normal and emergency situations. As the demands for the pre-hospital EMS have significantly increased in the past few years in Taiwan, it has become important for the EMSS to allocate sufficient resources and utilise existing competent personnel effectively. This section provides background of the case study: EMSS in Tainan, Taiwan. By comparing the response time in several cities and areas, the paper uses 6.5 minutes as acceptable response time for Tainan County.

The EMSS in Taiwan consists of the Fire Department and the hospital systems. The fire department is responsible for the pre-hospital EMS (including EMT-1 and EMT-2), while doctors and nurses at hospitals are responsible for in-hospital emergency medical care. Pre-hospital EMS includes activating the emergency call and dispatch, EMS response, triage and transporting of the patient to a hospital.

The population of Tainan County is just above 1,000,000. The county consists of 31 administrative districts, and it is the second ranking of all cities/counties in Taiwan regarding the number of administrative districts. The county contains both rural and urban lifestyles.

Owing to the increasing number of ageing population in the county, and the change of the concept of using ambulance service, the demand for EMS has significantly increased in recent years. The annual growth of the number of EMSS service cases is 5~10%. It is necessary for the government to be proactive to plan for future EMS resources.

In Taiwan, 10,645 firefighters and 973 ambulances were available in 2007. On average, 46 firefighters and 4.2 ambulances were allocated to cover each 100,000 of population. In the same year, 720,797 EMS cases were recorded, which is on average 8.6 cases for every 100,000 of population per day (Table 1). The demand for the service is lower in Tainan County when compared to other regions or counties; however, the percentage of ambulance and fire manpower allocated is much lower in Taiwan, too.

Table 1 A comparison of the average EMS resources and service cases between EMSS of Tainan county and other cities

Nation region	*Total population (100,000)*	*Number of ambulances for every 100,000 people*	*Number of EMS staff for every 100,000 people*	*Number of rescue services demanded by 100,000 people per day*
USA Tidewater Region	100	19.3	280	20
Canada BC	390	11.5	81	28
Australia New South Wales	630	12.7	52	28
UK London	800	14.5	33	19
Germany Hamburg	250	16.4	92	25
Japan Tokyo	1200	1.9	150	16
SP Singapore	420	1.3	38	7
China Hong Kong	680	3.9	129	27
Taiwan Tainan County	2300 (110)	4.2 (3.44)	46 (39.6)	8.6 (8.5)

Source: Adapted from Wang et al. (2008) and Yang (2005)

In general, it is widely accepted that the response time in the urban areas is 8 minutes 59 seconds (Jay, 2005), though the acceptable response time in urban areas is 6 minutes in the USA. Table 2 illustrates the standard of ambulance response time and patient survival rates in different cities and countries. In major cities in Taiwan, 75% of the cases are under 8 minutes. In Tainan, the average response time is 7.2 minutes. Most of the cases (76%) are dealt with under 8 minutes; however, in over 10% of the cases the response time was over 9 minutes. In order to investigate an optimum and effective resource allocation model the target value of response time is set as 6.5 minutes for Tainan County.

Table 2 The standard of ambulance response time in different cities and countries

City area	*Standard*
London, England	50% under 8 min
England, UK	75% under 8 min
Denver, USA	90% under 8 min
Edmonton, Canada	90% under 9 min
Urban Areas, Brazil	75% under 8 min
Sydney, Australia	50% under 10 min
Hong Kong, China	92% under 12 min
Major Area, Taiwan	75% under 8 min
Tainan, Taiwan	Average 7.2 min

Source: Adapted from Singer and Donoso (2007)

3 Model construction

In order to simulate the EMSS, key elements and systems that are involved in the EMSS: the fire manpower dispatching (system), pre-hospital EMS and emergency medical training systems are examined in order to provide the simulation model with a fundamental background knowledge and variables.

3.1 Fire manpower system

The Emergency and Rescue Command Centre (ERCC) is set up to be responsible to receive emergency calls. Once a witness to an accident or a person in need of EMS makes a 119 emergency phone call to the ERCC for help, the dispatchers at ERCC notify the fire department nearest to the accident scene to send an EMS team to provide triage and necessary treatment. If necessary, the patient will be transported to an emergency room or a hospital within the shortest time. The task-dispatching quality of the ERCC affects the quality of EMS to be provided. In a good EMSS, dispatchers' professional knowledge and communication skills are strongly emphasised, because experienced dispatchers can avoid the waste of the EMS resources.

In Taiwan, the coverage of the fire service and the quota of staff to be employed by a fire department are determined by the population size and the jurisdiction of an area. However, this does not necessarily reflect the practical demands, for example there might be more accidents in the mountain areas which have a lower population; while in highly urbanised areas, the demand for search and rescue team is much higher than in normal cities. In addition, the demand for emergency rescue service increases by 5–10% annually. By this measure, the growth of fire manpower among all counties in Taiwan is generally insufficient.

The demand on the emergency service is expected to increase in the future; therefore, more personnel and ambulances would be required to be deployed. Owing to the limitation on the number of fire manpower and ambulances to be recruited, it is suggested that the improvement of dispatching skills and human resource management would result in a better and more effective EMSS. Based on the system dynamics approach, the research established a quantitative model and simulated the EMSS. The research used the two auxiliary variables and attempted to obtain a balance within the system. The results can be references for decision makers to determine the number of new staff to recruit. The advantage of combining system dynamics and computer simulation is that this compensates for the limitation of variances of variables; in addition, it reduces the complication of calculation procedures.

3.2 Pre-hospital EMS system

Pre-hospital emergency medical care is crucial as delays in receiving care could cause long-term damage to the health and life of a patient. In order to provide essential physical, physiological and psychological treatments to the patient, an EMS team needs to arrive at the scene in as short a time as possible, provide essential emergency triage at the scene, cooperate with an ER physician to ensure medical quality, transport the patient to a hospital and optimise the utilisation of the EMS resources (Clawson, 1989). The quality and quantity of training that the firefighter received directly determines the effectiveness of the treatment that they provide.

As explained in the previous section, the EMSS in Taiwan consists of the fire department and the hospital systems. The fire department is responsible for the pre-hospital EMS, while hospitals are responsible for in-hospital emergency medical care. In order to propose a cost effective method to minimise the time for an ambulance to arrive at the scene and transport the patience to a hospital under limited resources, the research assumed that the service coverage of a fire department is in a ‘circle area’, and an effective coverage leads to minimise the average transport time. The ambulance service rate, attendance rate and the scale of ambulance were included as auxiliary variable. However, the research is aware of the climate contributing to the variance of the average attendance rate of an ambulance. One of the variables of the research is the percentage of false emergency calls – although it has been decreasing, there is still an abuse of using ambulance service by the public (NFA ROC, 2007). The simulation found that during peak hours, decision makers should increase the number of standby ambulances which will reduce the time for an ambulance to attend a scene; therefore, the effectiveness of ambulance service and ambulance operations would be improved. The results of the simulation can be a reference for appropriate allocation and effective management of resources.

3.3 Emergency medical training system

The networks in the chain of survival are interdependent. The survival rate of patients cannot be increased if the network is not sufficiently developed or an element is missing (Cummins et al., 1991). Pre-hospital EMS plays an important role in reducing mortality and morbidity of patients. The emergency medical technician’s skills and knowledge in emergency medical techniques is crucial to pre-hospital treatment of trauma patients. Effective emergency medical training should be conducted consistently over time.

According to the Management Guidelines for Emergency Medical Technicians in Taiwan, Emergency Medical Technicians 2 (EMT-2) are required to take continuing 'intermediate-level education' on emergency medical care 'for 24 hours', so as to ensure constant improvement of their knowledge, techniques and the total EMS quality. Training is a way to convert cost of training into resources that contribute to organisational performance. Activities that can 'facilitate' transfer of training are considered as a cost-effective investment.

However, Baldwin and Ford (1988) investigated the retention rate of the training and argued that the effectiveness of training decreases over time. Only 40% of the learning outcomes of the training could be applied directly to real-life situations; only 25% of the knowledge and skills are retained after 6 months. After 12 months, the personnel who received training retained 15% of the knowledge and skills.

As budget, time, personnel and logistic limits, the balance between the training and patient survival rate of EMSS should be calculated carefully, with consideration of budget for emergency medical training, hours of training and time-variant effectiveness, a reasonable model for predicting the survival rate in patients treated within an EMSS will be constructed in this paper.

In addition, strengthening the various techniques of EMT is an important key to improving EMS quality. Thorndike (2004) pointed out that learning is a progressive process and the time needed to solve a problem decreases as practice increases. A National Fire Administration (NFA ROC, 2007) survey indicated that the majority of staff in emergency rooms in Taiwan agree that EMTs of fire departments have fulfilled their responsibility to provide pre-hospital EMS and demonstrated progress in their service quality. People are also more satisfied with and reliant on their services. The presence of EMTs at accident scenes and during their treatments is much more accepted now. Although ambulances in the fire departments have been equipped with an AED, the survival rate in patients treated within the domestic EMSS is still lower than those in other countries. This is due to the lower rate of implementation of early CPR.

According to the results derived from the simulation, the hours of training to be provided can be determined, and the methods to shorten the response time can be explored, too. The research simulated the effectiveness of training regarding the types, learning outcomes and continuity of training. The relationship between training effectiveness and OHCA ROSC improvement can be explored. The results of the simulation also serve as a reference when providing recurrent training to EMT-2 for the Fire Bureau.

3.4 Critical variables in the simulation model

From the above discussion, it is possible to extract critical variables in order to construct a model of system dynamics and use it to optimise allocation of EMS resources and response time of Tainan County EMS teams in the face of a growing demand for rescue services and the requirement of recurrent training. In this model, various dynamic processes are integrated.

Five level variables (total number of firefighters, total number of rescue cases, perceived number of rescue cases, total hours of emergency medical training and accumulated effect of emergency medical training). Eight rate variables (number of staff to be employed, number of staff to be retired, number of accepted cases, number of services, information update, total hours of training input, training output and training effectiveness depletion). Fourteen auxiliary variables (number of cases that can be served, difference, average number of service cases, number of 119 dispatchers, online completion rate, number of cases reported, scale of ambulances, ambulance travel speed, average ambulance service rate, ratio of busy ambulances, scale of ambulances to be adjusted, number of staff added to suffice deployment of ambulance, budget for training and training effectiveness). Seven table functions and five constants are included in the model.

4 Simulation results and analysis of resource allocation

4.1 Results of simulation

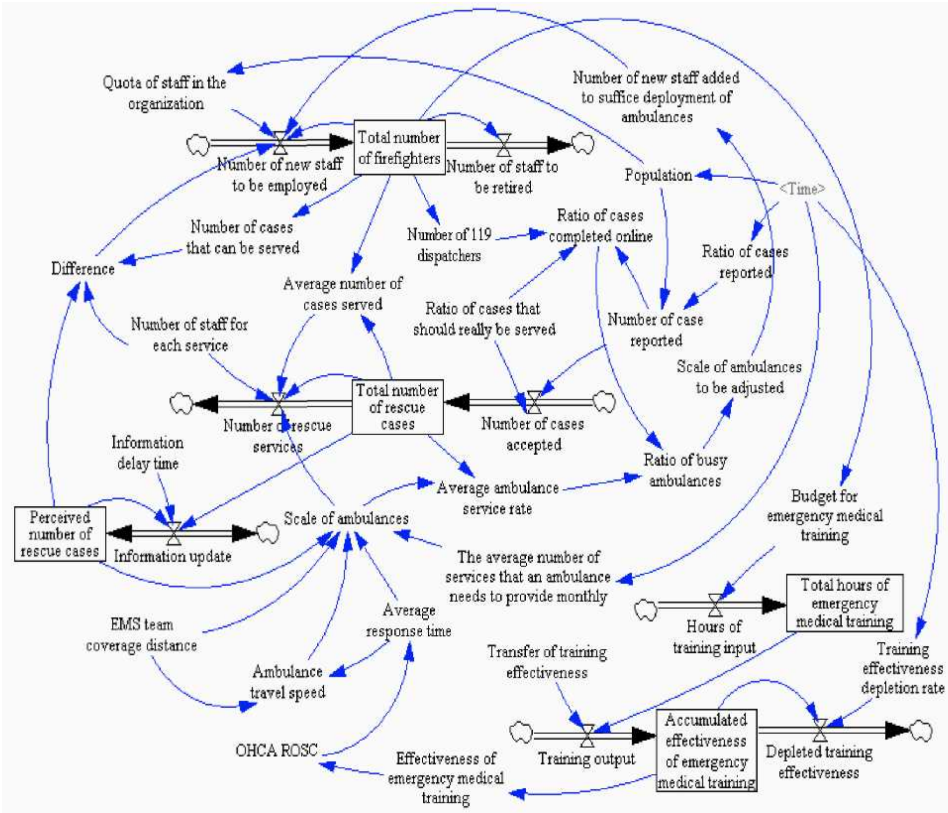
After the EMS model is constructed, simulation of Tainan County Fire Bureau's EMSS can be conducted. The current population in Tainan County is approximately 1,107,000. The quota of staff to be employed varies yearly with population in the county. An ERCC has been set up as the central agency responsible for processing 119 calls (emergency calls). In 2008, Tainan County has 38 EMS teams, and each team is equipped with one ambulance. There were 436 EMTs (including 40 EMT-1, 356 EMT-2 and 40 EMT-P). In total, there were 150,000 emergency calls in Tainan County. Approximately four calls would be received by the EMS (report call, repeated report, waiting for query and urging call). The number of rescue cases in Tainan County of the year has been increased from 17,972 (2001) to 35,529 (2008), the growth rate is about 5–10%. There are 8.9 rescue cases among 100,000 people each day, and each EMT has to run an average of 0.24 duties a day. The number of services that each ambulance provides varies in different seasons.

The average coverage distance of each EMS team is 6.5 km, and the average distance between EMS teams is 13 km. Twenty-nine out of the 38 EMS teams could respond to emergency calls within 8 minutes. The average time of all EMS teams to arrive at the scene (response time) is 7.2 minutes and the average total service time (from response to arrival at hospital) is 25.53 minutes, while the world standard (SD) is 20.85 minutes (Al-Ghamdi, 2002). In order to retain the skills and knowledge relating to EMS, the EMTs in Tainan County Fire Bureau are required to take 24 hours of continuing professional education per year (including 8 hours of disciplinary training and 16 hours of field learning). The performance during the training is evaluated by the ER physicians of emergency responsible hospitals. The annual budget for each EMT's training is NT $400 (only).

Figure 1 demonstrates the stock and flow diagram constructed by Vensim according to the variables determined by the research. The diagram illustrates the structure and operating procedures of EMS provided by Tainan County Fire Bureau. A complete list of dynamic equations is provided in the Appendix A.

The model provides decision makers at the Incident Command Centre and Human Resources Department with much information relating to real-time situations to make flexible decisions. Decision makers at fire departments could also use the information obtained to analyse and improve the effectiveness of resource allocation. The research applied the data obtained from the EMS to the simulation of the system dynamics model. The following section discusses the effectiveness of level, rate, endogenous and exogenous variables from the management perspective.

Figure 1 Dynamics of Tainan County EMS system (see online version for colours)



4.2 Number of new staff to be employed

How resources are allocated would influence the effectiveness, efficiency and productivity of an organisation. Improper allocation of resources may have significant impact on organisational operations. Improving the scale of fire resources is an important issue to improve the service of the fire department. The demand for EMS has been gradually increasing, and this has resulted in a higher ratio of 'busy' ambulances. The number of new staff to be employed is proposed to be determined by calculating the minimum value between the number of ambulances being deployed and the number of staff distributed to an ambulance. The calculation allows decision makers to employ an optimum number of staff. This analysis allows decision makers to make a reasonable investment of human resources under the demand for more manpower.

Table 3 demonstrates the results of the simulation. Comparing the difference between the perceived and actual rescue cases and the number of the ambulances deployed, the number of staff to be employed is suggested. For example, 14 new persons should be employed in the third month. In this month, the total number of firefighters is 442 persons. The number of firefighters is sufficient to deal with emergencies and rescue cases in the month.

Table 3 Number of new staff to be employed at different intervals

Operation interval (month)	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*
Difference	12	5	14	27	43	60	87	100	120	134	143	147	147	148	152	152
Number of new staff added to suffice deployment of ambulances	6	13	20	21	21	17	18	13	11	9	7	8	13	8	8	9
Number of new staff to be employed	6	5	14	21	21	0	18	0	0	0	0	0	0	8	0	9
Total number of firefighters	436	440	442	453	472	490	488	503	500	498	495	493	491	488	493	490
Operation interval (month)	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*	*30*	*31*	*32*
Difference	148	150	153	152	155	155	153	151	152	153	153	151	153	163	169	172
Number of new staff added to suffice deployment of ambulances	10	10	9	8	7	9	9	8	10	7	8	14	16	12	11	9
Number of new staff to be employed	0	0	9	0	0	0	9	0	0	7	0	0	0	12	0	0
Total number of firefighters	497	494	492	498	496	493	491	496	494	491	495	493	491	488	497	494
Operation interval (month)	*33*	*34*	*35*	*36*	*37*	*38*	*39*	*40*	*41*	*42*	*43*	*44*	*45*	*46*	*47*	*48*
Difference	175	174	170	170	163	163	166	162	170	176	181	184	189	194	194	194
Number of new staff added to suffice deployment of ambulances	7	9	8	9	11	11	14	13	13	12	18	15	11	11	9	9
Number of new staff to be employed	0	0	0	9	0	0	14	0	0	0	0	15	0	0	0	0
Total number of firefighters	492	489	487	485	491	488	486	497	495	492	490	487	499	497	494	492

In the 19th month, nine extra new staffers should be employed. This number is derived from the number of new staff to be employed to suffice all ambulances (nine persons) rather than from the number of staff computed on the basis of the difference between perceived and actual rescue cases (153 persons), because only 1.285 ambulances should be added to satisfy the need for EMS during this period of time. However, in the 45th month, the department will not recruit any new member of staff. This is because the number of firefighters at the time (499 persons) has reached the quota of staff for the population in the area. The number of appropriate personnel should be increased from 436 to 506; the 70 vacancies could be recruited in stages to meet the demand of EMS.

4.3 Scale of ambulances to be adjusted

The EMS provides an optimum number of ambulances to be deployed according to practical needs. Distribution of demands for Advanced Life Support (ALS) during a 12-month span should not be significantly different from that during a 7-day span (Sorensen et al., 1996). A higher ratio of the usage of ambulances can quickly raise the probability of waiting for the ambulance, but increasing the number of ambulances in service may reduce the economic effects of scale (Singer and Donoso, 2007).

Although downsizing the scale of ambulances can decrease spare capacity, it increases the probability of waiting time (Singer and Donoso, 2007). The demand for ambulance service is contingent. The scale of ambulance should be calculated properly, as previous decisions cannot be immediately rectified when the system has reached a stable state.

As shown in Table 4, the average ambulance service rate is simulated to be in a stable state, meaning there is no significant difference in the number of ambulance journeys across different seasons. The ratio of busy ambulances fluctuates between 2~4. If it is greater than 1, the current scale of ambulances is insufficient. For instance, in the 43rd month of operation, the system estimates that 3.56 ambulances should be deployed to prevent increase of waiting time. This indicates that 2.56 more ambulances should be added (from 38 to 41 ambulances) to meet the demand for EMS during the period. The three additional ambulances can be recruited from backup ambulances. Besides, it can be discovered that two more ambulances should be added in 35 months, three in 8 months and one in 5 months.

Based on the population and the number of ambulances to prioritise the resources allocation, three EMS teams were identified and each team should be increased by one more ambulance:

1 Sinying EMS team (with population of 78,110 persons, 2174 rescue cases in 2008 and only one ambulance in service)

2 Yongkan EMS team (with population of 201,776 persons, 7062 cases in 2008, 2114 rescue cases by Yongkan branch and four ambulances in service)

3 Rende EMS team (with population of 64,471 persons, 2850 cases in 2008, 1588 rescue cases by Rende branch and two ambulances in service).

Table 4 Variation of ambulance service at different intervals

Operation interval (month)	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*
Average ambulance service rate	0.539	0.342	0.257	0.256	0.251	0.256	0.268	0.313	0.342	0.36	0.381	0.384	0.38	0.404	0.432	0.438
Ratio of busy ambulances	1.773	2.805	3.792	3.951	3.944	3.364	3.516	2.817	2.537	2.186	1.991	2.028	2.784	2.031	2.039	2.218
Scale of ambulances to be adjusted	0.773	1.805	2.792	2.951	2.944	2.364	2.516	1.817	1.537	1.186	0.951	1.028	1.784	1.031	1.039	1.218

Operation interval (month)	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*	*30*	*31*	*32*
Average ambulance service rate	0.404	0.392	0.417	0.439	0.463	0.447	0.425	0.405	0.387	0.414	0.429	0.427	0.334	0.344	0.377	0.42
Ratio of busy ambulances	2.316	2.333	2.285	2.057	1.929	2.18	2.165	2.053	2.317	1.931	2.143	2.928	3.245	2.589	2.434	2.194
Scale of ambulances to be adjusted	1.316	1.333	1.285	1.057	0.929	1.18	1.165	1.053	1.317	0.931	1.143	1.928	2.245	1.589	1.434	1,194

Operation interval (month)	*33*	*34*	*35*	*36*	*37*	*38*	*39*	*40*	*41*	*42*	*43*	*44*	*45*	*46*	*47*	*48*
Average ambulance service rate	0.44	0.432	0.416	0.41	0.39	0.376	0.368	0.36	0.359	0.383	0.391	0.34	0.4	0.418	0.414	0.418
Ratio of busy ambulances	1.986	2.173	2.05	2.226	2.448	2.457	2.995	2.801	2.757	2.573	1563	3.053	2.451	2.48	2.265	2.196
Scale of ambulances to be adjusted	0.986	1.173	1.05	1.226	1.448	1.457	1.955	1.801	1.757	1.573	2.563	2.053	1.451	1.48	1.265	1.195

4.4 Variation of survival rate

The purpose of validating the training is to evaluate whether the purpose(s) of the training has been achieved. What is most important is to transfer the learning outcomes to the real-life practice (Goldstein, 1993). EMTs are required to respond to emergencies quickly with special rescue techniques. Skills and knowledge are gained by learning from similar tasks in training. If EMTs are able to receive sufficient training in normal time, they can apply their rescue techniques in emergency conditions better.

Figure 2 and Table 5 present the variation of OHCA ROSC at different intervals of training. EMTs in Tainan County Fire Bureau are required to receive 24-hour training per year. Based on the maximum number of firefighters (503 persons) shown in Table 3, 12,072 hours of training are provided each year (503*24 = 12,072), which is close to the total hours of training estimated for the 4th month in Table 5, where the effectiveness of training is 2,884.45 and OHCA ROSC is 1.44%. After 4 years of training, the total hours of training are 48,288 hours. This figure is closer to the estimate for the 13th month in Table 5. The effectiveness of training is 21,425.2 and OHCA ROSC is 7.43%. The average OHCA ROSC within the EMS system of Tainan County Fire Bureau is 12%, which is closer to the estimate for the 22nd month. It can be inferred that in order to obtain this performance, each EMT has to receive 6.7 years of training (81110.8/12072 = 6.7).

ROSC in patients with OHCA allows no delay of EMS. The world standard of ROSC is 20% (Jay, 2005). To achieve this goal, the total hours of training in a year should exceed 116,536 hours. That is to say every EMT has to receive another 19.3 [(116,536 – 24)/503/12 = 19.3] hours of training every month or 4.8 hours of extra training every week. Fire branch can arrange training on topics such as ‘emergency rescue techniques’, ‘study of rescue cases’ and ‘operation of emergency medical equipment’ to fill up this gap. Taking the ROSC (44%) in the EMSS of Seattle in Washington as a goal (Rober, 2006), Tainan County Fire Bureau has to provide a total of 183,356 hours of training a year. In other words, each EMT has to take 30.37 [(183,356 – 24)/503/12 = 30.37] extra hours of emergency medical training so as to have a better command of response techniques and provide a proper treatment to patients.

The results demonstrated that each fire branch should increase 30.37 training hours per person per month, or 7.59 hours per person per week, to increase the emergency response capacity. Training should include the operation of emergency equipment, techniques of recording and documentation, and lesson learned from EMS cases.

Figure 2 Variation of OHCA ROSC and effectiveness of emergency medical training (see online version for colours)

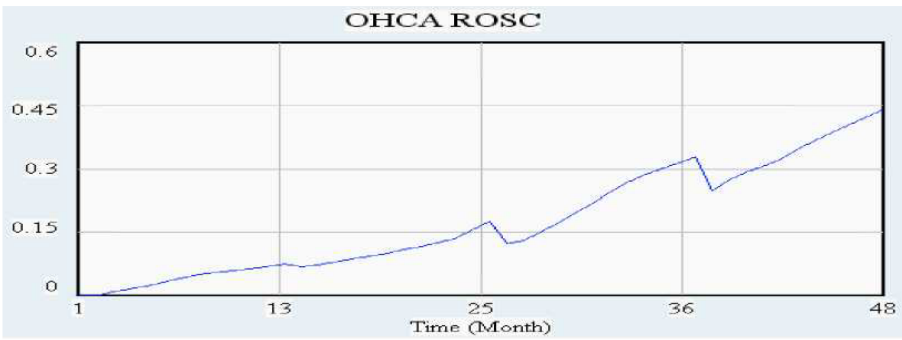


Table 5 Variation of effectiveness of training at different intervals

Training interval (month)	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
Total hours of training	0	3488	7001.85	10532.9	14155.7	17927.9	21846.1	25744.7	29764.6	33764.5	37744.4	41704.4
Training output	0	1395.2	2800.74	4213.15	5652.27	7171.15	8738.43	10297.9	11905.9	13505.8	15057.8	16581.8
Depleted training effectiveness	0	0	1311.49	2624.85	3936.02	5259.15	6750.84	8239.02	9717.95	11229.4	12735.7	14230.4
Effectiveness of training	0	0	1395.2	2884.45	4472.75	6195	8101	10088.6	12147.4	14335.3	16611.8	18973.9
OHCAROSC	0	0	0.006976	0.0144223	0.0223637	0.030995	0.040505	0.0501772	0.0542949	0.0586707	0.0632236	0.0679477
Training interval (month)	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*
Total hours of training	45644.6	49565.1	53466	57405.1	61324.5	65292.5	69240.7	73169.2	77149.9	81110.8	85051.8	88973.2
Training Output	18257.8	19826	21386.4	22962	24529.8	26117	27696.3	29267.7	30860	32444.3	34020.7	35589.3
Depleted training effectiveness	21425.2	17710.1	19151.3	20574	21997.2	23400	25205.4	25735.5	28215.6	29699.2	31171.9	32630.9
Effectiveness of training	21425.2	18257.8	20373.8	22608.8	24996.8	27529.4	30246.4	32737.4	35259.5	37913.9	40659	43507.8
OHCAROSC	0.0742757	0.0665157	0.0711213	0.0778264	0.0849905	0.0925883	0.100739	0.108212	0.115809	0.123742	0.134613	0.154555
Training interval (month)	*25*	*26*	*27*	*28*	*29*	*30*	*31*	*32*	*33*	*34*	*35*	*36*
Total hours of training	92940.2	96887.4	100815	104775	108715	112635	116536	120507	124457	128388	132299	136190
Training Output	37176.1	38755	40325.9	41909.9	43486	45054.2	46614.5	48202.6	49782.8	51355.1	52919.5	54476.1
Depleted training effectiveness	46466.2	36060.8	37478	38873.5	40264	41630	43667.2	45200.8	46679.8	48138	49580.2	51006.8
Effectiveness of training	46466.2	37176.1	39870.2	42718.2	45754.6	48976.5	52400.6	55347.9	58349.7	61452.7	64669.8	68009.1
OHCAROSC	0.175264	0.121528	0.129611	0.149027	0.170282	0.192836	0.219205	0.242783	0.266798	0.285811	0.298679	0.312036
Training interval (month)	*37*	*38*	*39*	*40*	*41*	*42*	*43*	*44*	*45*	*46*	*47*	*48*
Total hours of training	140062	143984	147885	151767	155742	159697	163631	167547	171442	175433	179404	183356
Training output	56024.9	57593.4	59154.1	60707	62296.8	63878.6	65452.6	67018.6	68576.9	70173.3	71761.8	73342.3
Depleted training effectiveness	71478.3	54344.1	55717.7	57056.6	58388.8	59720.1	62014.6	63582	65033.7	66454.3	67891.6	69318.3
Effectiveness of training	71478.3	56024.9	59274.2	62710.6	65350.9	70258.9	74417.5	77855.5	81292.2	84835.3	88554.3	92424.4
OHCAROSC	0.32887	0.248199	0.274193	0.290842	0.305404	0.321553	0.346505	0.367133	0.386461	0.404177	0.422772	0.439698

4.5 Variation of response time

The key to increase the ROSC in patients with Sudden Cardiac Arrest (SCA) is to reduce the interval between an emergency call and the pre-hospital treatment. Every 1 minute saved can increase the ROSC in patients with SCA by 57% (Jay, 2005). The statistics of response time can also be used to find an optimum location to deploy an EMS team or re-assign an ambulance to the emergency scene. As Tainan County Fire Bureau is not planning to redeploy their base, it can only improve its response time by enhancing its service quality.

As shown in Table 6, the average response time of Tainan County Fire Bureau EMS teams is 7.2 minutes and the average travel speed of ambulances is 899 m/min (0.899 km/min). To reduce the current response time to 6.5 minutes, the average ambulance travel speed has to increase to 1000 m/min (1 km/min). In peak time, each journey can be reduced by 40 seconds. Given 100 rescue cases a day, 66.67 minutes can be saved (100 calls * 0.67 min). The time saved can increase the survival rate of 66 patients by 57% and allow the EMS teams to take another 2.6 cases (66.67/25.53 min = 2.6). Moreover, the average total service time (from response to arrival at hospital) in the present (25.53 minutes) (world standard SD = 20.86 minutes) can be reduced to 23.78 minutes by 1.75 minutes.

Table 6 Variation of response time at different intervals

Operation interval (month)	*1*	*2*	*3*	*4*	*5*	*6*
Average response time	20	20	18.3	17.12	14.53	12.95
Ambulance travel speed	0.325	0.325	0.355	0.38	0.447	0.502
Operation interval (month)	*7*	*8*	*9*	*10*	*11*	*12*
Average response time	12.48	11.99	11.86	11.71	11.56	11.4
Ambulance travel speed	0.521	0.542	0.548	0.555	0.562	0.57
Operation interval (month)	*13*	*14*	*15*	*16*	*17*	*18*
Average response time	11.19	11.45	11.3	11.07	10.93	10.82
Ambulance travel speed	0.581	0.568	0.575	0.587	0.595	0.601
Operation interval (month)	*19*	*20*	*21*	*22*	*23*	*24*
Average response time	10.7	10.6	10.49	10.38	10.22	9.94
Ambulance travel speed	0.607	0.613	0.62	0.627	0.636	0.654
Operation interval (month)	*25*	*26*	*27*	*28*	*29*	*30*
Average response time	9.64	10.41	10.29	10.01	9.71	9.39
Ambulance travel speed	0.674	0.625	0.632	0.649	0.669	0.692
Operation interval (month)	*31*	*32*	*33*	*34*	*35*	*36*
Average response time	9.01	8.68	8.33	8.06	7.91	7.78
Ambulance travel speed	0.721	0.749	0.78	0.807	0.821	0.836
Operation interval (month)	*37*	*38*	*39*	*40*	*41*	*42*
Average response time	7.61	8.6	8.23	7.99	7.85	7.69
Ambulance travel speed	0.854	0.756	0.79	0.813	0.829	0.846
Operation interval (month)	*43*	*44*	*45*	*46*	*47*	*48*
Average response time	7.44	7.23	7.04	6.86	6.67	65
Ambulance travel speed	0.874	0.895	0.924	0.948	0.974	1

5 Conclusions and suggestions

The purpose of EMSS is to provide effective medical care and appropriate assistance through a well-organised process. When an emergency incident occurs, trauma patients are able to get access to immediate medical assistance and receive pre-hospital care through EMSS. EMS teams will transport the patients to the hospital quickly to reduce the possibility of mortality and morbidity. Taiwanese EMSS has gradually expanded in the past 20 years after the launch of the Emergency Medical Service System Plan. With the increasing number of the pre-hospital emergency rescue cases, it is difficult for decision makers to appreciate the development and the causes of problems in the EMSS. The paper explored and simulated the causal relationships among variables that affect an EMSS and the impact of the external environment in the system through the use of the feedback loops in System Dynamics (SD). SD is proposed to be an ideal approach to constructing a model of dynamics in an EMSS. Based on system behaviours, the model could further predict future development of the system. Resource allocation is influential on the effectiveness, efficiency and productivity of any organisation. Without a reasonable allocation of resources, operations of any organisation will be seriously affected.

The research uses the number of perceived rescue demands or the scale of ambulances as criteria to determine the number of new staff to be employed. This method provides decision makers with a formula to solve the complicated issues in the future. In addition, in the discussion of future demand for EMS, it is discovered that the probability of a patient waiting for the ambulance has significant relation to the ratio of the usage of ambulances. The impact of scale of ambulances on the services of Tainan County EMS teams can be validated through the priorities in adjusting the scale of ambulances and allocation of resources among regional EMS teams. The research also verified the correlation between the length and effectiveness of emergency medical training and the first aid survival rates.

The results of the simulation showed that Tainan County Fire Department should introduce three more ambulances to meet the increasing demand of EMS. It is also suggested that the resource allocation can be prioritised based on the population and the number of EMS.

Through our simulation, it is proposed that more training should be allocated to EMS staff in order to enhance their response capabilities and provide proper treatment to trauma patients. 76.32% of the EMS teams of Tainan County Fire Bureau arrive at emergency scene within 8 minutes. The purpose of measuring the response time is to evaluate the effectiveness of EMSS and improve ambulance travel speed while safety is ensured. The more the arrival time is decreased, the more time the services can be provided, and therefore the survival rate of patients will be enhanced.

The aim of measuring response time is to evaluate the effectiveness of EMSS. The research showed that patient survival rates could be increased if the maximum travel speed permitted for ambulances is raised from 53.94 km/h to 60 km/h as the emergency, the maximum response time of 6.5 minutes can be achieved. In this case, 2.6 more cases can be treated per day. The survival rates for 66 patients can be increased by up to 57%. The total EMS response time can be reduced by 1.75 minutes to 23.78 minutes. This also narrowed the gap with the international standard response duration (20.86 minutes). There is a need to increase the training as the OHCA of the Fire Department has not met the requirements of the international standard in 20% of cases. Relevant case studies and operational procedures should be included in the training programme to enhance the capacity of EMS.

The simulation provides decision makers with structural and quantitative solutions to improve the effectiveness and efficiency of EMSS. With sufficient resources, the fire department will be able to maintain social and public safety more effectively. Without substantial evaluation and monitoring of EMS, the quality of EMS cannot be ensured. The quality of EMS can be ensured by monitoring and evaluation of the scale of fire response resources and on-site execution of EMS. As the population in Tainan County has continued to grow, the scale of the EMS should be extended to respond to the future demands. In addition to regular retraining, additional courses on emergency care should be provided to EMTs to improve their techniques. Moreover, evaluating the training outcomes should be conducted to ensure the skills and knowledge of EMS team members. In sum, a structural and numerical method for allocating fire resources is presented in this paper to improve EMS quality and also effectively avoid waste of resources.

References

Al-Ghamdi, A.S. (2002) 'Emergency medical service rescue times in Riyadh', *Accident Analysis and Prevention*, Vol. 34, pp.499–505.

Baker, S.P., Whitfield, R.A. and O'Neill, B. (1987) 'Geographical variations in mortality from motor vehicle crashes', *New England Journal of Medicine*, Vol. 316, pp.1384–1386.

Baldwin, T.T. and Ford, J.K. (1988) 'Transfer of training: a review and directions for future research', *Personnel Psychology*, Vol. 41, pp.63–105.

Brodsky, H. (1990) *Emergency Medical Service Time in Fatal Road Accidents*, Transportation Research Record 1270, T.R.B., National Research Council, Washington, DC.

Casner, M., Andersen, D. and Isaacs, S. (2005) 'The impact of a new CPR assist device on rate of return of spontaneous circulation in out-of-hospital cardiac arrest', *Prehospital Emergency Care*, Vol. 9, pp.61–67.

Clawson, J.J. (1989) 'Quality assurance: a priority for medical dispatch', *Emergency Medical Services (EMS)*, Vol. 18, No. 7, pp.53–58.

Cummins, R.O., Ornato, J.P., Thies, W.H. and Pepe, P.E. (1991) 'Improving survival from sudden cardiac arrest: the 'chain of survival' concept, *Circulation*, Vol. 83, No.5, pp.1832–1847.

Department of Health, Executive Yuan R.O.C. (Taiwan) (1989) *Emergency Medical Service Act*. Available online at: http://law.moj.gov.tw/Eng/LawClass/LawContent.aspx?PCODE=L0020045

Finn, J.C., Jacobs, I.F., D'Arcy, J., Holman, C. and Oxer, H.F. (2001) 'Outcomes of out-of-hospital cardiac arrest patients in Perth, Western Australia, 1996–1999', *Resuscitation*, Vol. 51, pp.247–255.

Forrester, J.W. (1961) *Industry Dynamics*, Productivity press 464, Cambridge, MA.

Forrester, J.W. (1992) *System Dynamics and Learner-Centered-Learning in Kindergarten through 12th Grade Education*, Paper D-4337, Sloan School of Management, MIT.

Goldstein, I.L. (1993) *Training in Organization: Needs Assessment, Development and Evaluation*, Brooks/Cole Pub. Co., Pacific Grove, CA, p.147.

Jay, F. (2005, September) 'Response times: myths, measurement & management', *Journal of Emergency Medical Service*, Vol. 30, No. 9, pp.46–56.

Lan, C-H., Chuang, L-L. and Chen, Y-F. (2009) 'Performance efficiency and resource allocation strategy for fire department with the stochastic consideration', *International Journal Technology, Policy and Management*, Vol. 9, No. 3, pp.296–315.

Leung, L.P., Wong, T.W., Tong, H.K., Lo, C.B. and Kan, P.G. (2001) 'Out-of-hospital cardiac arrest in Hong Kong', *Prehospital Emergency Care*, Vol. 5, No. 3, pp.308–311.

Rober, D. (2006) 'The method: measure how many victims leave the hospital alive', *USA Today*. Available online at: www.usatoday.com (accessed 25 May 2006).

Roberts, E.B. (1978) 'System dynamics: an introduction', in Roberts, E.B. (Ed.): *Managerial Applications of System Dynamics*, Productivity Press, Cambridge, MA, pp.293–314.

Singer, M. and Donoso, P. (2007) 'Assessing an ambulance service with queuing theory', *Computers & Operations Research*, Vol. 35, No. 8, pp.2549–2560.

Sorensen, M.B., Hogskillde, S. and Oberg, B., Reich, H. and Crawford, M.E. (1996, June) 'Pre-hospital advanced life support (ALS) demands in the City of Copenhagen', *Resuscitation*, Vol. 31, No. 3, p.S9.

Thorndike, R.M. (2004) *Measurement and Evaluation in Psychology and Education*, 7th ed., Prentice Hall, New Jersey, pp.30–50.

Wang, Z.X., Wang, Y.Z. and Huang, J.H. (2008) *Whether it is necessary to increase the number of EMS teams?* Available online at: http://www.tfd.gov.tw/cht/index.php?code=list&flag=detail&ids=151&article_id=2886

Yang, P.C. (2005) *Emergency Medical Care System in Taiwan*, Master dissertation, Institute of Hospital and Health Care Administration, National Yang-Ming University, p.57.

Note

1 The paper defines the period between receiving an emergency call and the team dispatched to arrive at the accident scene as the 'response time'.

Appendix A: Vensim dynamic equations

(01) FINAL TIME = 48 The final time for the simulation.

(02) INITIAL TIME = 1 The initial time for the simulation.

(03) SAVEPER = TIME STEP The frequency with which output is stored.

(04) TIME STEP = 1 The time step for the simulation.

(05) Total number of firefighters = number of new staff to be employed – number of staff to be retired

(06) Number of staff to be retired = total number of firefighters * 0.005

(07) Number of new staff to be employed = IF THEN ELSE ((Quota of staff in the organization – total number of firefighters) > 0, MIN (Difference, number of new staff added to suffice deployment of ambulances), 0)

(08) Quota of staff in the organisation = WITH LOOKUP (Population)

([(1.1e + 006,0) – (1.12e + 006,600)], (1.1e + 006,446), (1.101e + 006,454), (1.102e + 006,462), (1.103e + 006,469), (1.104e + 006,476), (1.105e + 006,482), (1.106e + 006,489), (1.107e + 006,495), (1.1075e + 006,501), (1.108e + 006,513), (1.1085e + 006,525), (1.109e + 006,537), (1.1095e + 006,548), (1.11e + 006,550), (1.1105e + 006,553), (1.111e + 006,556))

(09) Number of cases that can be served = total number of firefighters * (0.24 * 30)

(10) Difference = IF THEN ELSE ((perceived total number of rescue cases – number of cases that can be served) > 0, (perceived total number of rescue cases – number of cases that can be served)/(number of staff for each service * (0.24 * 30)), 0

(11) Number of staff for each service = 2

(12) Average number of cases served = total number of cases/(total number of firefighters * 2/3)

(13) Number of 119 dispatchers = total number of firefighters * 0.035

(14) Ratio of cases completed online = (number of cases reported * ratio of cases that should really be served) (number of 119 dispatchers * 15 * 12)

(15) Ratio of cases that should really be served = 0.24

(16) Population = WITH LOOKUP (Time)

([(0,1.1e + 006) – (48,1.12e + 006)], (0,1.105e + 006), (3,1.10567e + 006), (6,1.10577e + 006), (9,1.10589e + 006), (12,1.10606e + 006), (15,1.10622e + 006), (18,1.10637e + 006), (21,1.10653e + 006), (24,1.10669e + 006), (27,1.10637e + 006), (30,1.10605e + 006), (33,1.10572e + 006), (36,1.1054e + 006), (39,1.10557e + 006), (42,1.10573e + 006), (45,1.1059e + 006), (48,1.10606e + 006))

(17) Ratio of cases reported = WITH LOOKUP (Time)

([(0,0) – (48,0.02)], (0,0.0099), (1,0.0099), (2,0.01), (3,0.0102), (4,0.011), (5,0.0111), (6,0.01), (7,0.0109), (8,0.0105), (9,0.0103), (10,0.0093), (11,0.0089), (12,0.0091), (13,0.0123), (14,0.0095), (15,0.0103), (16,0.0113), (17,0.011), (18,0.0107), (19,0.0111), (20,0.0107), (21,0.0105), (22,0.0114), (23,0.0107), (24,0.01), (25,0.0105), (26,0.0093), (27,0.0108), (28,0.0146), (29,0.0126), (30,0.0103), (31,0.0108), (32,0.0108), (33,0.0102), (34 ,0.0109), (35,0.0099), (36,0.0105), (37,0.0111), (38,0.0107), (39,0.0127), (40,0.0119), (41,0.0116), (42,0.0115), (43,0.0162), (44,0.012), (45,0.0116), (46,0.0122), (47,0.011), (48,0.0107))

(18) Number of case reported = population * ratio of cases reported

(19) Total number of rescue cases = INTEG (+number of cases accepted – number of rescue services, 2700)

(20) Number of cases accepted = number of cases reported * ratio of cases that should really be served

(21) Number of rescue services = MIN (scale of ambulances * number of staff for each service * average number of cases served, total number of rescue cases)

(22) Perceived number of rescue cases = INTEG (information update, 3300)

(23) Information update = IF THEN ELSE((Perceived total number of rescue cases – total number of rescue cases) <= 0, (total number of rescue cases – perceived total number of rescue cases)/information delay time, (total number of rescue cases – perceived total number of rescue cases)/information delay time)

(24) Information delay time = 8

(25) Scale of ambulances = (perceived total number of rescue cases * (EMS team coverage distance/average response time)/(travel speed * average number of services that an ambulance needs to provide monthly)

(26) Average ambulance service rate = scale of ambulances * 30/total number of rescue cases

(27) Ratio of busy ambulances = ratio of cases completed online/average ambulance service rate

(28) Scale of ambulances to be adjusted = IF THEN ELSE(ratio of busy ambulances >= 1, ratio of busy ambulances – 1, 0)

(29) Number of new staff added to suffice deployment of ambulances = scale of ambulances to be adjusted * 7

(30) The average number of services that an ambulance needs to provide monthly = WITH LOOKUP (Time)

([(0,0) – (48,100)], (0,60), (1,68), (2,64), (3,71), (4,66), (5,68), (6,70), (7,74), (8,67), (9,69), (10,72), (11,75), (12,79), (13,80), (14,65), (15,72), (16,70), (17,73), (18,73), (19,69), (20,67), (21,66), (22,71), (23,70), (24,74), (25,78), (26,70), (27,74), (28,70), (29,76), (30,73), (31,76), (32,70), (33,71), (34,76), (35,75), (36,78), (37,79), (38,77), (39,79), (40,74), (41,76), (42,73), (43,75), (44,73), (45,70), (46,74), (47,74), (48,77))

(31) Ambulance travel speed = EMS team coverage distance/average response time

(32) EMS team coverage distance = 6.5

(33) Average response time = WITH LOOKUP (OHCA ROSC)

([(0,0) –(1,20)], (0,20), (0,19), (0.01,18), (0.015,17), (0.018,16), (0.02,15), (0.025,14), (0.03,13), (0.05,12), (0.08,11), (0.15,10), (0.22,9), (0.29,8), (0.39,7), (0.49,6), (0.55,5), (0.6,4), (0.61,3), (0.62,2), (0.63,1), (0.64,0.5), (0.65,0))

(34) Budget for emergency medical training = total number of firefighters * 400

(35) Total hours of emergency medical training = INTEG (hours of training input, 0)

(36) Hours of training input = budget for continuing emergency medical training/50

(37) Accumulated effectiveness of emergency medical training = INTEG (+training output – depleted training effectiveness, 0)

(38) Training output = transfer of training effectiveness * total hours of emergency medical training

(39) Depleted training effectiveness = training effectiveness depletion rate * accumulated effectiveness of emergency medical training

(40) Training effectiveness depletion rate = WITH LOOKUP (Time)

([(0,0) – (48,2)], (0,1), (1,1), (6,0.85), (12,0.75), (13,1), (18,0.85), (24,0.75), (25,1), (30,0.85), (36,0.75), (37,1), (42,0.85), (48,0.75))

(41) Transfer of training effectiveness = 0.4

(42) Effectiveness of emergency medical training = accumulated effectiveness of emergency medical training

(43) OHCA ROSC = WITH LOOKUP (Effectiveness of emergency medical training)

([(0,0) – (200000,1)], (0,0), (10000,0.05), (20000,0.07), (30000,0.1), (40000,0.13), (50000,0.2), (60000,0.28), (70000,0.32), (80000,0.38), (90000,0.43), (100000,0.47), (110000,0.5), (120000,0.51), (130000,0.53), (140000,0.55), (150000,0.55))