A Lean Transportation Approach for Improving Emergency Medical Operations

Bernardo Villarreal
Departamento de Ingeniería
Universidad de Monterrey, Ave. Ignacio Morones Prieto 4500 Pte.
San Pedro Garza Garcia, NL 66238, Mexico
E-mail: bernardo.villarreal@udem.edu

Jose Arturo Garza-Reyes*
Centre for Supply Chain Improvement
The University of Derby
Kedleston Road Campus, Derby, UK, DE22 1GB
E-mail: J.Reyes@derby.ac.uk
Tel. +44(0)1332593281

Edgar Granda-Gutiérrez
Departamento de Ingeniería
Universidad de Monterrey, Ave. Ignacio Morones Prieto 4500 Pte.
San Pedro Garza Garcia, NL 66238, Mexico
E-mail: edgar.granda@udem.edu

Vikas Kumar
Bristol Business School
University of the West of England
Coldharbour Ln, Bristol, UK, BS16 1QY
E-mail: Vikas.Kumar@uwe.ac.uk
Tel. +44(0)1173283466

Samantha Lankenau-Delgado
Departamento de Ingeniería
Universidad de Monterrey, Ave. Ignacio Morones Prieto 4500 Pte.
San Pedro Garza Garcia, NL 66238, Mexico
E-mail: salanken@microsoft.com

** Corresponding author*

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This paper extends the approach of Lean Transportation to improve the performance of Emergency Medical Processes (EMP), adapting the main concepts of the approach to incorporate the main characteristics of the EMP environment. The paper is based on an inductive theory-building process initiated from a case study in the field of Emergency Medical Services. The development of the suggested performance improvement approach was triggered from an exhaustive analysis of the process involved and an exploratory review of the existing improvement approaches available. The process of concern can be described as a specialized transportation process where human lives are at risk. Its characteristics led to a natural application of Lean Transportation. The results include a novel approach for improving the agility and efficiency of EMS processes. This is validated with an application for improving ambulance response times and turnaround times of the Red Cross operations located in Monterrey, Mexico. The approach proved to be an integrated scheme for identifying waste opportunities at a systems level. This characteristic is important to let operations management prioritize improvement efforts in a limited budget situation. This work suggests the application of the emerging Lean Transportation approach for increasing the agility performance of EMS processes.

Keywords: Emergency medical service, lean transportation; transportation waste.

Paper Type: Case Study

1. Introduction

The fundamental responsibilities of Emergency Medical Service (EMS) systems are to provide urgent medical care, such as pre-hospital care, and to transport the patient to the hospital if needed. The efficiency of EMS systems is a major public concern.

Over the past three decades, a significant amount of research studies have been conducted to improve the operational performance of EMS systems. The major focus of these studies has been on reducing response time (i.e. time between the receipt of a call at the dispatch center and the arrival of the first emergency response vehicle at the scene) by placing the ambulances in optimal locations. Problems, such as where to locate ambulances and how to dispatch ambulances, must be solved by EMS planners to provide effective and efficient service to the public. The emphasis on response time has been due to EMS systems are designed to rapidly provide advance medical care to critical patients such as cardiac arrest or trauma. Ambulance response time represents a high-profile target for potential process improvement. It remains self-evident that response time represents an important performance indicator, but taken alone, it does not completely predict the outcome of disease severity or mortality. In addition to the ambulance response time, other performance measures such as average unit hour utilization (i.e. number of services divided by the ambulance hours used), operational cost, ambulance turnaround time (i.e. time of ambulance arrival to the hospital until it is available to respond to other emergency) and ambulance cycle time (i.e. total time from the emergency call until the ambulance is available to service another call) are also relevant to determine the level of performance of EMS operations.

Mexican EMS institutions emerged since the beginning of the previous century. Since then, Mexican emergency medicine providers have evolved to date with many opportunities for performance improvement. The unique and excellent work developed by Roudsari et al., (2007) provide an ample and complete comparison of patient and injury related characteristics of pre-hospital trauma care systems among eleven developed and developing countries, including Mexico**.** Considering the level of care provided by an EMS, Roudsari et al., (2007) suggests four categories of delivery of pre-hospital care; an unorganized pre-hospital care, present in most of the developing countries, where there is no formal system providing care in the field; a Basic Life Support (BLS) Emergency Medical System where Emergency Medical Technicians (EMTs) provide non-invasive care to trauma patients; Advanced Life Support (ALS) EMS systems that provide more sophisticated and invasive therapy; and finally, (Doc-ALS EMS systems) where physicians attend patients on the scene of the injury providing advanced care. According to Roudsari et al., (2007), (BLS) EMS systems are focused on guaranteeing a rapid transport of patients to a medical facility or institution. As presented in Roudsari et al., (2007), Mexican EMS providers are classified as (BLS) EMS systems as shown in Table 1 (adapted from Roudsari et al., 2007).

Table 1. International comparison of type of EMS systems (adapted from Roudsari et al., 2007)

Country	**Type of EMS**	**Number of Personnel per Ambulance**
Iran (Tehran)	BLS	2 EMT-basic
Mexico (Monterrey)	BLS	2 EMT-basic
Australia (Victoria)	ALS	2 EMT-advanced
New Zealand (Auckland)	ALS	2 EMT-advanced
The Netherlands	ALS	1 EMT-basic, 1 EMT-advanced
The UK (Manchester, Yorkshire, Mensey and Trent)	ALS	2 EMT-advanced
The US (King County)	ALS	2 EMT-advanced
Austria	Doc-ALS	1 EMT-basic, 1 physician
Canada (Montreal)	Doc-ALS	1 EMT-basic, 1 physician
Germany	Doc-ALS	1 EMT-basic, 1 physician
Greece (Athens, Volos, Corfu)	Doc-ALS	1 EMT-basic, 1 physician
The UK (London)	Doc-ALS	1 EMT-basic, 1 physician

According to Fraga-Sastrias et al. (2010), 33% of the institutions that offer emergency medical services in Mexico are private organizations; 31% are non-governmental organizations financed through donations; and 26% of the institutions receive government financing. The main providers of emergency medical services in Mexico are the government funded Mexican Institute of Social Services (IMSS), the State Worker´s Institute for Security and Social Services (ISSSTE) and various private organizations such as the Mexican Red Cross. As stated in Pinet-Peralta (2006), Mexican institutions and organizations that offer prehospital services are not being overseen in terms of coordination, regulation and performance evaluation. One of the main private institutions that provide emergency medical services is the Mexican Red Cross, which was founded in 1910. This institution has a presence in every state of the country.

(https://www.cruzrojamexicana.org.mx/delegaciones?estado=GN) and its operation is heavily dependent on private donations.

1.1 Description of the methodology

The need for the work described in this document was indeed started from the requirement of the Red Cross institution, located in Monterrey, Mexico, to improve its ambulance response times to satisfy international standards. This request triggered the need to form a team of experts that consisted of the research team (the authors and a group of students) and an internal team from the institution. This last team included the General Director, the Director of operations and the general manager in charge of all the activities from the emergency call reception until the ambulance assignment. Then, the study proceeded with an exhaustive analysis of the institution´s operations including its operating system (activities, procedures, resources and infrastructure) and the full emergency call database gathered for the period of January to October of 2016. The previous study was accompanied by an exploratory review of approaches and methodologies used to improve performance of the overall EMS system (from the reception of emergency calls until the ambulance becomes available again, after handing over the patient in a health institution). The research team was involved in the project during the second semester of 2016.

Two important approaches that have been traditionally applied to achieve better performance levels, including ambulance response time reduction, emerged from the literature research; the mathematical modelling approach (Brotcorne et al., 2003; Saghafian et al., 2015) and; the incremental improvement lean approach (Murrel et al., 2011; White et al., 2015; Bedgood 2017). Additionally, the improvement of such process has been approached focusing on solving individual issues such as the re-location of facilities, identifying shortest routes from the ambulance sites to the emergency scenes, defining ambulance dispatching rules and the development of lean initiatives in triage operations. Most of these efforts have been independent and uncoordinated efforts.

The detailed analysis of the Red Cross institution was based on data obtained from field observation and the operational management information systems (OMIS). The use of OMIS insured the analysis of all the historical data related to each emergency call serviced from January to June of 2016, and of every new emergency call considered from July to October of 2016. Each and every call serviced or not by ambulances was considered. It should be mentioned that all these calls were geo-referenced by the research team for enabling spatial analysis and as an input for the application of modelling and mathematical procedures. Field observations consisted on observing samples of statistically significant number of observations of the activities executed to receive emergency calls, assigning and dispatching ambulances to service them. Also, members of the research team were allowed to accompany the driving crews in a significant number of ambulances serving emergency calls. These tasks were carried out during the period of July and August of year 2016, including time studies, value stream maps for various activities, and the identification of wastes and areas for improvement.

After the detailed analysis of the activities, resources and purpose of the EMS process, and supported by the experience of the research team in the field of lean transportation, it was decided to consider it as a specialized transportation process. One in which the "product transported" and the driving crew have important characteristics. The new driving crew include people with specialized medical knowledge and the products transported correspond to patients injured or sick whose life of is at great risk, and where the agility of transporting them is of great concern. The nature of the operations process led the research team to consider an emerging improvement approach, namely, lean transportation as an alternative option for

EMS process performance improvement. Lean transportation is an improvement approach for truck transportation operations that focuses on the identification of waste related to truck efficiency as defined by Villarreal (2012) and Simmons et al. (2004). As stated in Villarreal et al., (2016b) it is a systematic method that can help the studied organization to establish an integrated standardized routine to improve its transport operations. It provides the operations management with a holistic view of the EMS process and its areas for potential improvement. However, despite the vast acceptance of lean as 'best operational practice' by organizations around the world (Forrester et al., 2010) and its deployment in a wide variety of industrial sectors such as manufacturing, healthcare, telecommunications, education, fast food restaurants, among others (Garza-Reyes et al., 2012), evidence of its application in road transportation is still limited but with important results that validate its usefulness (Villarreal et al., 2016a, 2016b, 2016c, Garza-Reyes et al., 2016, Sternberg et al., 2017, Sternberg et al., 2013, Simmons et al., 2004). The next step consisted on adapting the waste concepts, measures and tools to satisfy the new conditions and characteristics of the EMS process as described in section 2.2. The previous proposition was then presented to the internal team of the institution for final approval on its implementation.

After the higher management of the institution decided that Lean Transportation was a feasible and adequate approach, the proposed scheme was finally applied for the first time to validate its usefulness. The objective of the intervention was to improve the level of agility (ambulance response time) of the Mexican Red Cross operations in the Monterrey's metropolitan area. The organization felt that the current level of agility of the organization was below international standards and its operating cost presented opportunities for reduction.

Thus, this paper contributes to the operations management theory by documenting the application of lean transportation, specifically, to improve emergency medical operations, and hence complement and support the very narrow body of knowledge on lean road transportation. Besides this theoretical contribution, the paper can also be used as a guiding reference for Medical Services to undertake improvement projects similar to the one presented in this paper. This is considered the main practical contribution of this work.

This paper consists of five sections. Section one offers an introduction to the problem and context around it. Section two provides a brief review of the literature on lean healthcare and transportation, and gives a description of the scheme utilized to decrease waste. This section also suggests an adaptation of the lean transport approach to improve EMS operations performance. The application of this scheme is undertaken in section three and section four where conclusions and future recommendations are presented.

2. Review of Lean Transportation and EMS Literature

Waste elimination is a fundamental aspect in Lean literature (Schonberger 1982; Ohno 1988). A process can be separated into value adding and non-value adding steps, also called waste, according to market's needs. Toyota was the first to contribute in the waste identification process. Toyota defined seven major types of waste in manufacturing and business processes (Ohno 1988; Shingo 1989). These include overproduction, waiting, unnecessary transport, incorrect processing, excess inventory, unnecessary movement and defects. It has been shown by Tapping and Shuker (2003) and Keyte and Locher (2004) that a great deal of waste has yet to be identified and eliminated in the administrative processes that support shop floor operations. In order to facilitate it, they adapt the seven wastes previously described for manufacturing operations to administrative processes, adding a new waste of underutilized people. As the focus of the value stream includes the complete value adding (and non-value adding) process, from conception of customer requirements to the consumer's receipt of product, there is a clear need to extend this internal waste removal to the complete supply chain. The seven wastes previously mentioned required an adaptation to the supply chain environment. A process mapping tool called Value Stream Map (VSM) was developed by Womack and Jones (2003) for the extended enterprise, looking to identify waste between facilities and installations in a supply chain. Mapping at the supply chain level, unnecessary inventories and transportation become important wastes to identify and eliminate. At this level, transportation waste is related to location decisions that seek to optimize performance at individual points of the supply chain. Therefore, the solutions suggested for its elimination are concerned with the relocation and consolidation of facilities, a change of transportation mode or the implementation of milk runs.

2.1 The pre-hospital process

Lean healthcare seems to be an effective way of improving healthcare organizations and the growing number of implementations and reports found in the literature reinforce this view. An initial consideration about the use of lean concepts is given by Heinbuch (1995), in the particular case of just-in-time. Some later publications that describe further applications are (Chalice 2005; Chalice 2007; Zidel 2006; Joint Commission on Accreditation of Healthcare Organizations 2006; Brandao 2009).

As it was the case for the manufacturing and administrative processes, it is necessary to define what is considered waste or value. Value adding activities related to good medical quality, accessibility and patient satisfaction can be identified from the point the patient makes the first contact until the treatment is completed. Thus, in order to identify the value stream one may begin with process mapping all activities. In addition, value is primarily created when the patient meets the health care staff during diagnostic and/or treatment activities. According to Gronroos (2000), the core service is the reason for a company being on the market. Additional services such as facilitating and supporting services are required in order to facilitate the use of the core service or to increase the value of the service. Translated to health care services the value-creating diagnostic and treatment activities may be seen as core services while, e.g. x-ray is a facilitating service to the diagnosing physician.

A framework of three types of waste is suggested in Bentley et al., (2008). These are; administrative; operational; and clinical. Both administrative and operational wastes are components of inefficient production, and clinical waste is a form of allocative waste. Administrative waste is the excess administrative overhead that stems primarily from the complexity of the U.S. insurance and provider payment systems, and operational waste refers to other aspects of inefficient production processes. Clinical waste is waste created by the production of low-value outputs. An extension of the seven Toyota manufacturing wastes to the healthcare area is proposed by Graban (2016) and illustrated in Table 2. This waste classification is more suitable for process improvement inside the health institution. They are more associated to hospital operations.

Table 2. Description of the Eight Healthcare Extended Wastes

Type of Waste	Brief Description
Defects	Time spent doing something incorrectly, inspecting for errors, or fixing errors
Overproduction	Doing more than what is needed by the customer or doing it sooner than needed
Transportation	Unnecessary movement of the “product(patients, specimens, materials) in a system
Waiting	Waiting for the next event to occur or next work activity
Inventory	Excess inventory cost through financial costs, storage and movement costs, spoilage, wastage
Motion	Unnecessary movement by employees in the system
Overprocessing	Doing work that is not valued by the customer or caused by definitions of quality that are not aligned with patient needs
Human potential	Waste and loss due to not engaging employees, listening to their ideas, or supporting their careers

According to Pons et al., (2005), EMS systems are to provide urgent medical care, such as pre-hospital care, and to transport the patient to the hospital if needed. The activities involved are:

- Receive emergency call and an ambulance is assigned.
- Ambulance preparation.
- Transporting the ambulance to the emergency scene.
- Serving the injured or sick person until he is stabilized.
- Transfer the customer to a health institution.
- Delivering the customer to the health institution.
- Transportation back to ambulance base.

The activities previously described are part of the ambulance cycle. According to Fitch et al., (2015), the provision of optimal emergency medical services care in the pre-hospital environment requires a high level of coordination and integration of multiple operational and clinical resources utilized by many people located at different places. Activities such as call taking and dispatching, scene response, on-scene patient care, triage and hospital destination decisions, continuing care during transport, and transfer to definitive care are all subject to online and off-line medical direction and guidance. The level of performance of this process is determined by the adequate management of all these elements.

Two of the most important performance indicators for EMS institutions; the agility required to execute the process; and its operations cost. The level of agility is measured by various time indicators; Paramedic response time; ambulance turnaround time; ambulance cycle time; patient stabilizing time at scene among others. Paramedic response time to the scene of a call for emergency medical assistance has become a benchmark measure of the quality of the service provided by EMS operations (Blackwell et al., 2009). As suggested by the authors, a target response time of ≤ 8 minutes for at least 90% of emergent responses has evolved into a guideline that has been incorporated into operating agreements for many EMS providers. The International Guidelines 2000 Conference on Cardiopulmonary Resucitation and Emergency Cardiovascular Care recommended a response time of 8 to 10 minutes to insure a successful cardiac and cerebral resuscitation (Blackwell et al., 2009). The time taken by paramedics to stabilize the patient at the scene is critical for achieving a service of quality. A standard established for a high quality service is a time less than or equal to ten minutes. This has been called as the Platinum Ten (Watson 2001). Other important performance indicator is related to the first 60 minutes after traumatic injury. This has been called the golden hour (Rogers and Rittenhouse 2014; Newgard et al., 2010).This concept states that definitive trauma care must be initiated within this 60-minute time window. The belief is that injury outcomes improve with a reduction in time to definitive care, and it is a basic premise of trauma systems and emergency medical services (EMS) systems. Ambulance Turnaround time is defined as the time taken by the ambulance starting from its arrival to a hospital until it is ready again and available to respond to other emergency call. Finally, the ambulance cycle time represents the total time taken by the ambulance from responding to an emergency call until it becomes available to respond to a new emergency call. All the previous time performance indicators, with the exception of cycle time, are important at the operational level. Ambulance cycle time could be related at the operational and the strategic level. This indicator is very well related to the ambulance installed capacity of the process and to the unit hour utilization indicator. Lower cycle times imply higher unit hour utilization and ambulance capacity. Furthermore, the level of these indicators impacts the level of the organization´s operating cost.

2.2 A lean pre-hospital process

The improvement of the time taken to execute the pre-hospital process described earlier has been approached mainly by utilizing a re-location of facilities, identifying shortest routes from the ambulance sites to the emergency scenes, defining ambulance dispatching rules and the development of lean initiatives in triage operations. Most of these efforts have been independent and uncoordinated efforts. It is important to point out that the EMS process described earlier can be considered as the basic transportation process described in Villarreal (2012). Furthermore, According to Simmons et al., (2004), improving transport operations performance can also be achieved increasing its efficiency through waste elimination.

Transport efficiency was originally suggested by Simmons et al., (2004). They made the measurement with the Overall Vehicle Effectiveness (OVE). Similar to the estimation of OEE, it is required to calculate the availability, performance and quality efficiency factors. The product of the three efficiency factors would yield an overall OVE percentage rate. This measure converted the OEE losses from manufacturing to transport operations. The result was the definition of five transport losses or wastes. These are driver breaks, excess load time, fill loss, speed loss and quality delays. The previous measure has also been modified by Villarreal (2012). In this case, the OVE measure is adapted to consider total calendar time as suggested by Jeong and Phillips (2001). Figure 1 illustrates the concepts and losses involved in the proposed measure that is called Total Operational Vehicle Effectiveness and represented by the term TOVE. In summary, four components for the new efficiency measure are suggested; Administrative or strategic availability, operating availability, performance and quality. The new measure would be obtained from the product of administrative availability, operating availability, performance and quality efficiency factors. In addition to the types of waste given by Simmons et al., (2004), additional types of waste are given by Villarreal (2012) and shown in Figure 1.

The TOVE index and related wastes is adapted to the EMS operations in this work. The new index is called the Ambulance TOVE and will be represented by A-TOVE hereafter. The associated wastes are illustrated in Figure 1. The wastes related to the Administrative Availability efficiency factor are similar to those of the Transportation Value Stream Map (TVSM) described in Villarreal (2012). The wastes considered in the operating availability efficiency factor are ambulance waiting to be assisted by a resource, ambulance time taken in excess to execute operation procedures, and corrective maintenance. These could happen before the ambulance departs to the point where it is required according to the call, during transportation of patients, triage and delivery of the patient to the hospital. The wastes considered in the performance efficiency are; speed loss; fill loss; and distance traveled in excess. Distance traveled in excess is a result of a deficient ambulance transport planning; wrong ambulance site definition; deficient route planning; and inadequate ambulance assignment and dispatching policies. Fill loss is related to the number of injured or sick persons that do not use the ambulance to transport them to the medical institution, either because it is not required or they use other means of transportation. Finally, speed loss is an important waste because it determines the time at which the ambulance will reach the emergency scene or the hospital at which the patient will be delivered.

Quality efficiency wastes are related to the percentage of times that international standard times are not met putting the patient´s health in risk; time in excess of response time; golden hour and platinum ten are considered. The value of A – TOVE is estimated by the product of the four efficiency factors. For our case, the Quality factor must represent more precisely the percentage of emergency calls that were serviced in less than ten minutes (%RT), the patient(s) was (were) stabilized in less than ten minutes (%PT), and finally, he (they) was (were) handed over a health institution in less than one hour (%GH). These quality indicators measure the level of agility of the EMS operations. In this document, we calculate the Quality efficiency by the product of %RT, %PT and %GH.

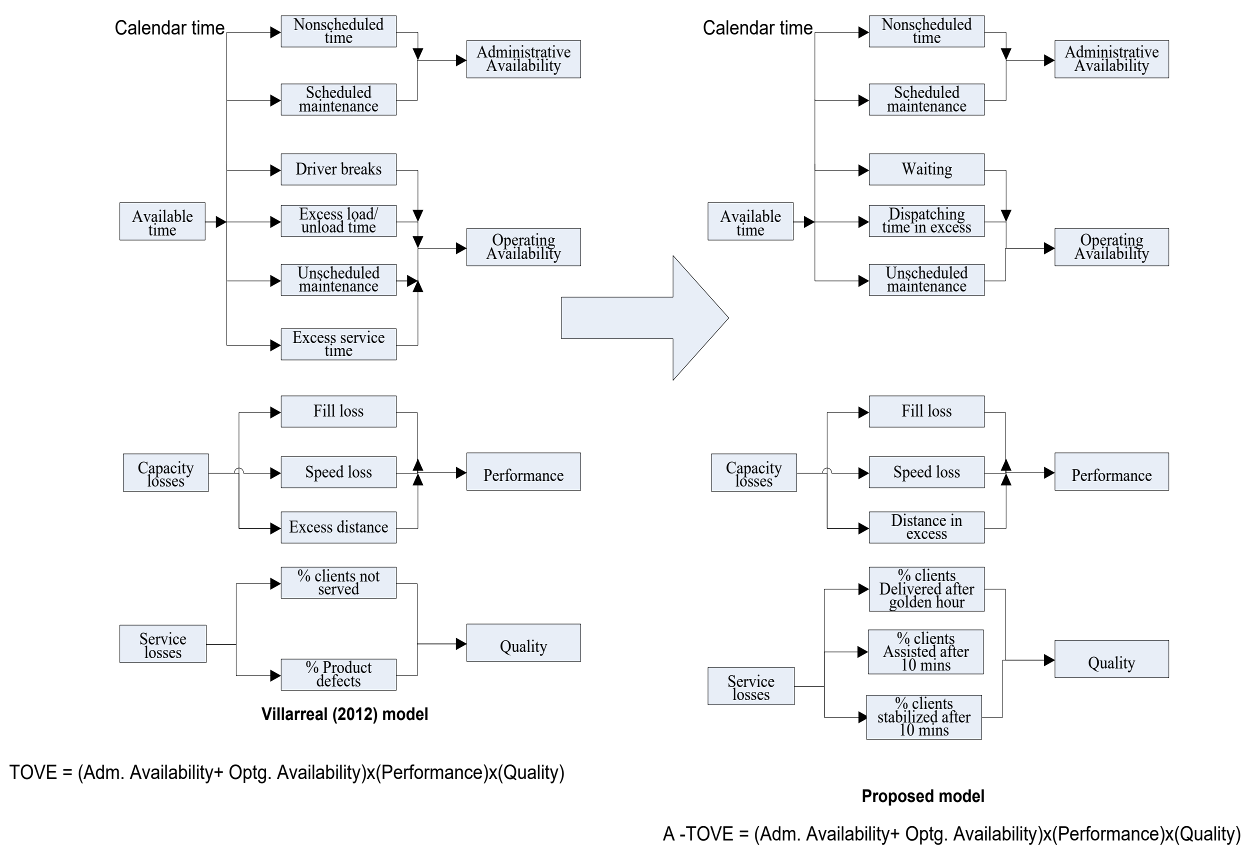

Figure 1. Description of TOVE and A-TOVE measures

The Value Stream Map (VSM) utilized in this work is a modified version of the one provided by Villarreal (2012) and will be denoted as the Ambulance VSM (A-VSM) hereafter. This A-VSM is obtained from following the Ambulance. Certain concepts are required to define the scheme. According to the author, routing activities can be classified as In-Tansit (IT), that is, while the transportation service is in process and Non-In-Transit (NIT) otherwise; i.e. setting up the service at an ambulance site. A transportation journey (TJ), is defined as the time specified for the transportation activity carried out by the ambulance crew. This may be a fixed period such as a shift of eight hours, or variable. It is considered that there always be 24 hours per day available for the service. Therefore, several services could be executed during a journey. An activity is defined as Internal if it is carried out during the TJ by the team of operators with the ambulance. If it is carried out off the TJ or by another organisational entity, the activity is called External. The ideal would be that NIT activities are also external, and IT activities are always internal.

2.3 Description of the Waste Reduction Scheme

This section considers the scheme provided by Villarreal (2012), and illustrated in Figure 2, to guide waste elimination generate projects for improving EMS operations performance. The scheme consists of five general stages: The first stage sets the direction of the strategy by determining the competitive factor that the organization is willing to achieve; agility or cost. The second stage concerns the mapping of the EMS services as detailed as possible.

Figure 2. Description of the Waste Elimination Scheme

The waste identification phase is the second stage. This phase should be exhaustive to set a strong foundation for defining an effective strategy for waste elimination. It should also be alienated to the strategic intention of the institution of interest. The third phase consists on the determination of waste elimination strategies. Efficiency waste reduction strategies as well as the strategies for different ambulance dispatching rules, facility relocation and transportation mode change could be used to eliminate waste. Finally, the implementation stage is suggested to assess and select the improvement initiatives.

3. Implementation and Results

This work proposes a scheme to improve the level of agility of the Mexican Red Cross′ operations in the Monterrey metropolitan area that serve 5.1 million in-habitants (https://www.eleconomista.com.mx/estados/Aumenta-en-NL-mancha-urbana-del-area-metropolitana-20170611-0017.html). The operations count with ten fixed locations and seven mobile locations from which ambulances are sent to service pre-hospital events. The organization has 34 ambulances but the financial resources to operate 50% of them during any day. Three types of emergency calls accounted for 93% of all calls; those related to people with a sickness total 40%; vehicular accident related calls account for 31%; calls of other type of accidents are 22%; and finally 7% of the calls are due to various other causes. The organization felt that the current level of agility needed to be improved significantly to satisfy international standards. On the other hand, the management of the institution was also willing to look for opportunities for reducing its operating cost.

3.1. Mapping the ambulance cycle process

The first step of the methodology is the mapping of the operations. In this case, an A - VSM for the cycle process of interest is elaborated. Figure 3 presents the Ambulance VSM of the Monterrey metro area operations. This A-VSM presents the big picture of improvement opportunities for the institution. This information can be used to develop an integrated improvement strategy for the Red Cross operations in metropolitan Monterrey.

The operations management of the Red Cross Monterrey decided to improve overall agility performance by reducing ambulance cycle time in two phases; the first phase consisted on increasing the level of ambulance response time. The institution was decided to achieve international standards in the following two years. The second phase focused on developing initiatives to decrease ambulance turnaround time. Improving ambulance cycle time would increase the EMS process throughput to achieve a reduction of operating cost. This document will describe the efforts of the institution for the first phase and present a description of the principal initiative undertaken to improve ambulance turnaround time as part of the second phase.

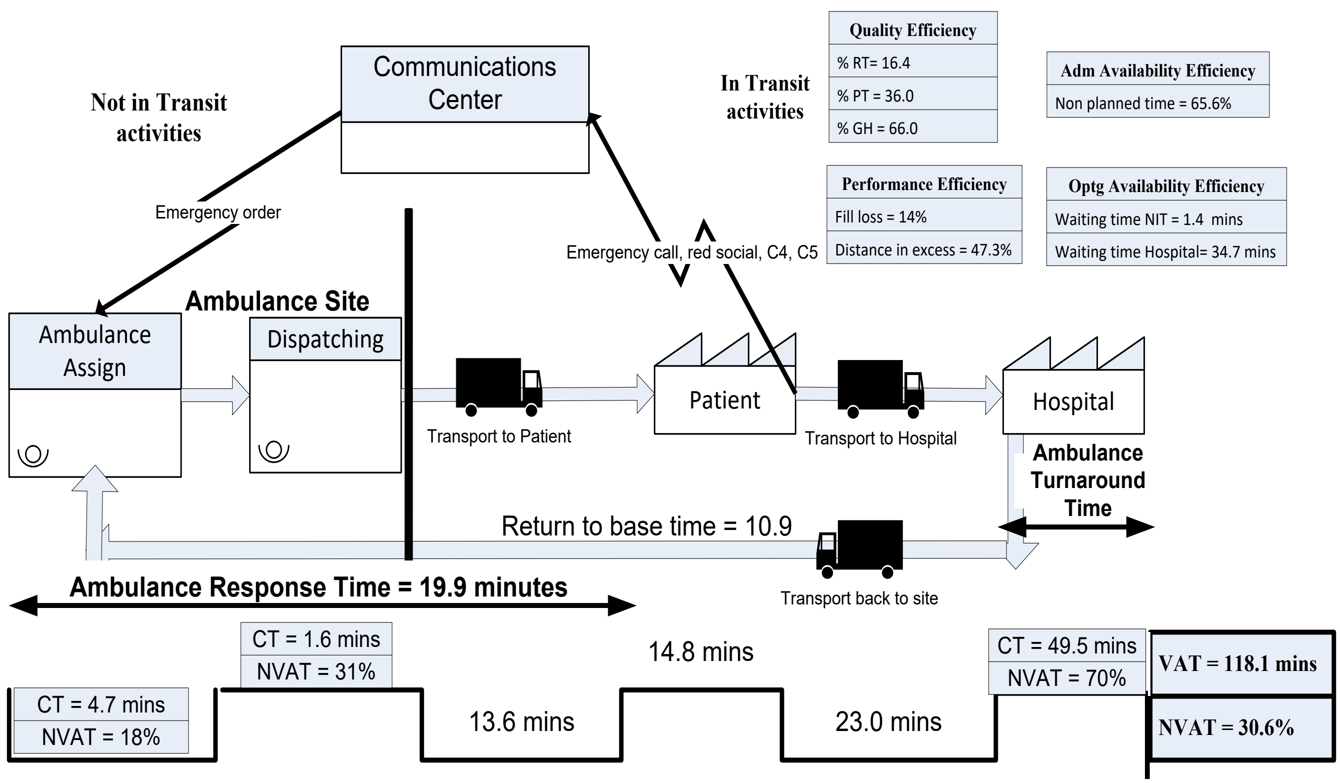

Figure 3. Description of the A-VSM for the Monterrey Metro operations

The results obtained in the A-VSM can be compared to those presented by Roudsari et al., (2007). Table 3 illustrates a modified version of Table 1 provided by Roudsari et al., (2007) including those results. Ambulance response time and transportation time to the hospital are situated among the highest values of the sample of countries. Scene time to stabilize the patient is the lowest of the sample.

Table 3. Summary of international comparison of Pre-hospital times

Country	Mode of Arrival (%)		Pre-hospital times (minutes)		
	Ground	Air	Response mean (median)	Scene mean (median)	Transportation to hospital mean (median)
Mexico (Monterrey)	100	0	4.5 (5.0)	15.8 (10.1)	8.0 (5.0)
Mexico (Monterrey)*	100	0	19.9	14.8	23.0
Australia (Victoria)	58	30	18.7 (12.0)	28.0 (22.0)	22.9 (18.0)
The UK (Manchester, Yorkshire, Mensey and Trent)	70	2	7.8 (7.0)	22,2 (20.0)	15.8 (13.0)
The US (King County)	85	15	10.0 (8.0)	21.2 (19.0)	23.3 (20.0)
Austria	49	51	26.2 (20.0)	28.7 (26.0)	20.6 (16.0)
Canada (Montreal)	100	0	9.8 (8.0)	17.9 (16.0)	10.8 (9.0)
Germany	59	41	20.9 (15.0)	32.6 (30.0)	19.9 (15.0)
The UK (London)	81	13	11.8 (11.0)	38.8 (37.0)	14.2 (14.0)

* Current study.

3.2 Identification of efficiency wastes

The level of Quality Efficiency is estimated in 3.8%. This a result of an average ambulance response time of 19.9 minutes, about 1.9 times the international standard. Under this service level, only 16.4% of the emergency services satisfy the international standards. Also, the average time recorded to stabilize the patient´s health is 48% over the Platinum Ten. As a result, only 36% of the patients were stabilized in less than ten minutes. Finally, taken into account the time from the emergency call until the time at which the patient is delivered into a health institution, the average estimated time is 78% above the golden hour. It is estimated that 66% of the patients were handed over a health institution within the golden hour. Turnaround time is estimated in 49.5 minutes and total Ambulance cycle time averaged 118.1 minutes. Therefore, given these results, the institution considered that it has a great challenge for improving its agility capability.

The available ambulance-hours of the institution are estimated in 860 per day. However, due to budgetary constraints, 50% of that service capacity is not used (408 ambulance-hours). According to data from operations during the period of January to June of 2016, the institution used only 11.69 ambulances per shift every day. Thus, the ambulance administrative availability efficiency is estimated in 34.4%.

After an exhaustive analysis of the activities carried out before the ambulance departs its base and at the hospital during the triage, it was found that 21% of the time taken before the ambulance leaves towards the patient is identified as non-value added. Similarly, about 70% of the time utilized to execute the triage activities is identified as non-value added. Therefore, the operating availability efficiency is estimated in 69.4%.

Fill loss of the process is estimated in 14% of the emergency calls. The distance and time in transit in excess are due to the initial status of the ambulance transportation planning. The assignment of ambulances to emergency services, the dispatching rules, the route design, and the location of the ambulance sites are executed manually without any updating or improvement during the last ten years.

3.3 Improving the level of agility of the process

As previously stated in section 3.1, the Red Cross decided to decrease ambulance cycle time in two phases. The first one consisted on the reduction of ambulance response time. For the second phase, the organization was focused primarily on reducing ambulance turnaround time identified as the bottleneck of the EMS process.

Improving ambulance response time

As mentioned previously, ambulance (Paramedic) response time to the scene of a call has become a benchmark measure of the quality of the service provided by EMS operations Blackwell et al., (2009). For this reason, there is a great amount of academic work published related to its reduction (Nogueira et al., 2016; Dibene et al., 2015; Peleg and Pliskin 2004; Wei et al., 2014; Ong et al., 2010. Previous studies developed in Mexico with the same objective of reducing ambulance response time are described in Dibene, et al., (2016), Fraga-Sastrias et al., (2004), Arreola-Risa et al., (1995) and Arreola-Risa et al., (2000). Ambulance response time includes the ambulance assigning and dispatching times and the one required to get to the scene of the emergency call. From Figure 3, the average time observed before the ambulance departs to service an emergency call is 6.3 minutes. Therefore, the required international standard of 10 minutes is practically reached without the ambulance being used at all. In addition, the average time taken by the ambulance to reach the call scene is 13.6 minutes. Table 4 presents a summary of the values of the transport times for the ambulance response times presented in all the studies carried out in Mexico applying mathematical models for relocating ambulance depots to improve them.

Table 4. Summary of ambulance response time of studies in Mexico

Study	City	Average Response Time (minutes)
Villarreal, 2018 (current study)	Monterrey, Mexico	19.9
Dibene, 2015	Tijuana, B.C.	14.0
Fraga-Sastrias, 2004	Mexico, D.F.	47% in ≤ 30.0
Arreola-Risa, 2000	Monterrey, Mexico	15.5
Arreola-Risa, 1995	Monterrey, Mexico	34.7

Improving time from call reception to ambulance dispatch

As previously stated, if the institution would like to achieve international standards this time must be reduced drastically. After observing the procedures and technology utilized to execute the activities the authors identified the following findings: Deficient coordination between the personnel in charge of carrying out the activities; non-standardized operating procedures; lack of communication between operating information systems with obsolete technology. The previous findings resulted in waiting wastes in the order of 22% without considering a significant waste of over-processing due to computational information systems that required redundant data feeding. After a discussion of the available initiatives for improving the process associated, the management decided to implement a two-step effort; The first step focuses on eliminating wasteful activities in the short term achieving a reduction of 1.4 minutes approximately; and the second step concentrates on replacing the current communication and computing infrastructure for a new integrated system that would reduce 80% of the time currently spent to execute all the activities before leaving the ambulance the bases. This second step would require an important investment that will be considered in the organization´s budget in year 2017.

Improving ambulance transportation time to patient scene

The time spent by the ambulance to reach the scene of the call is a result of several causes such as traffic congestion, ambulance base locations, the application of inefficient routing procedures, an inadequate assignment of ambulance to the emergency call. The last three conditions originate ambulance travelling distance in excess and the time required to do it. This is an important waste that determines the performance efficiency level. The description of the initiatives chosen to reduce the previous waste is provided in the following sections.

Re-location of ambulance depots

The location of ambulance depots depends upon the behavior of service density and its dynamics throughout the day and the ambulance desired response time. Current depot locations have not been adjusted in the last decade regardless of the service demand growth and dynamics. Considering daily service demand requirements behavior, described in Figure 4, two different patterns are identified; a low demand level in the range of two to three services per hour occurring from the 23:01 hrs of a day to 7: 59 A.M. of the following day and; a high demand level with a range of four to five services per hour occurring the rest of the following day. Therefore, two daily ambulance deployment strategies were developed for each day. A high-demand and a low-demand strategy for all days of the week.

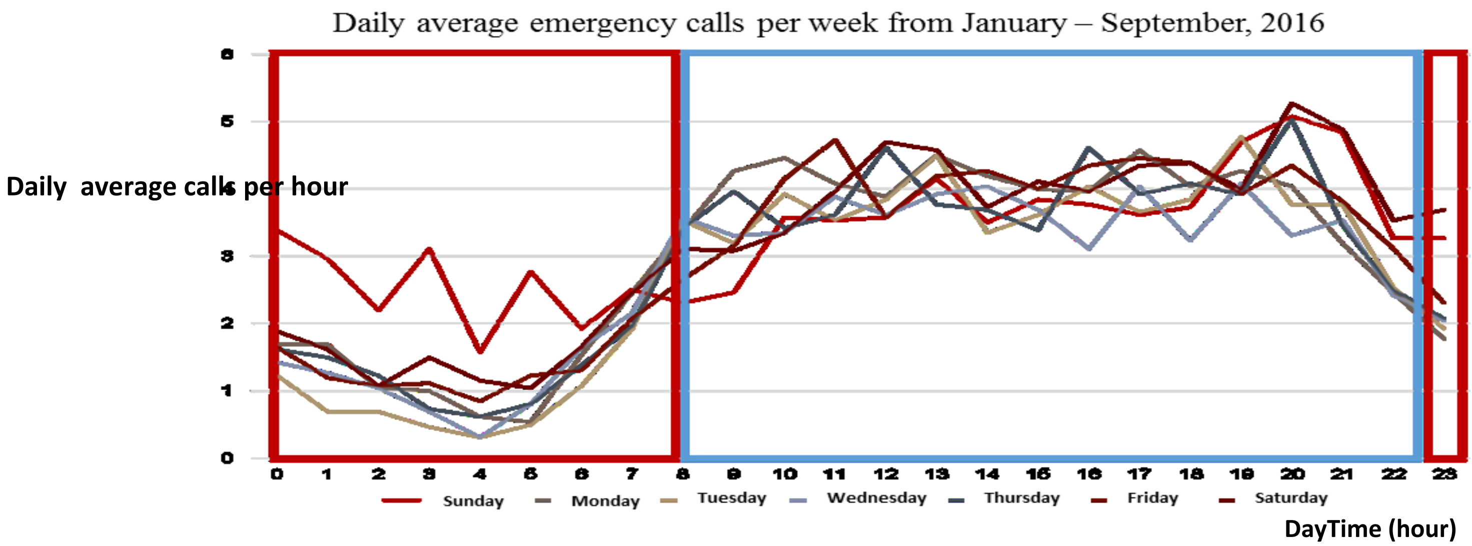

Figure 4. Description of service demand behavior for all days in a week

Emergency service demand presents a particular locational behavior shown in Figure 5. According to the Kernel density maps (Anderson 2016), emergency service needs are concentrated on specific places of the Monterrey metropolitan suburban area. The most concentrated place includes Monterrey downtown and a corridor that extends towards the northwest of the city close to the Garcia city. The other areas with concentrations of emergency services are Santa Catarina city, the frontier between Escobedo and San Nicolas cities, downtown Guadalupe city and Apodaca city.

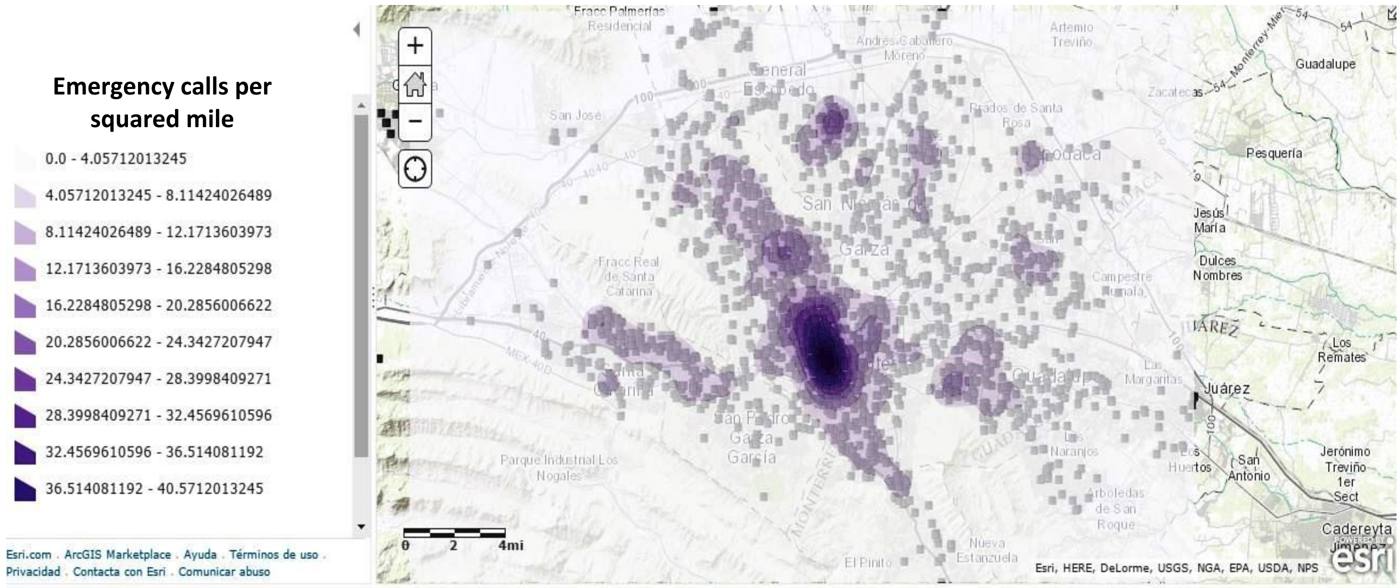

Figure 5. Kernel density map for high emergency call demand periods

The previously described information sets the general context required to guide the determination of ambulance capacity and location. The ambulance location problem has been exhaustively treated in the Operations Research area. An excellent review of ambulance location and relocation models is presented by Brotcorne et al., (2003). Leigh et al., (2016) illustrates a scheme in which a variation of the double standard model used for ambulance dispatching by Gendreau et al., (1997). However, in this work, a similar scheme to the ones suggested by Peleg and Pliskin (2004) and Leigh et al., (2016) is used to derive such strategies. An ambulance deployment scheme with the support geospatial analyses and the use of the ESRI Software System was performed during this study. The ESRI system contains the option for determining the optimal number and location of ambulance bases to cover certain percentage of emergency calls with a transport time from the bases to the patients in less than a certain time level.

Scenario analysis for two daily demand levels (low-demand and high-demand levels) is recommended. The initial structure for the Red Cross operations considered 10 fixed ambulance bases during the day. These were complemented by seven mobile ambulance locations for the high-demand level of the day, and three mobile bases for the low-demand level of the day. This will be called scenario I hereafter. Two additional ambulance location structure scenarios are evaluated with the consent of the institution´s operations management; scenario II considers keeping the initial fixed bases and determining the number and location of the additional mobile bases and; scenario III considers the definition of the optimal number and location of ambulance bases. Table 5 illustrates the results of running the predetermined scenarios. In summary, ten additional ambulances are required to achieve the required international standard of service level. These must be operating during the high demand period of every day in any of the proposed scenarios. However, for satisfying the goal under the low demand period, we need to relocate the necessary number of ambulances for 23 ambulances (scenario III). Figure 6 shows the recommended locations for the proposed scenario III.

Table 5. Summary of results for the initial and proposed ambulance structure scenarios

Demand Scenario	**Scenario I**		**Scenario II**		**Scenario III**	
	No. ambulances	% calls ≤ 10 minutes*	No. ambulances	% calls ≤ 10 minutes*	No. ambulances	% calls ≤ 10 minutes*
Low-demand	17	16.2	23	86.8	23	90.5
High-demand	17	16.6	27	91.2	27	93.9

*transport time from ambulance base to the scene of the patient

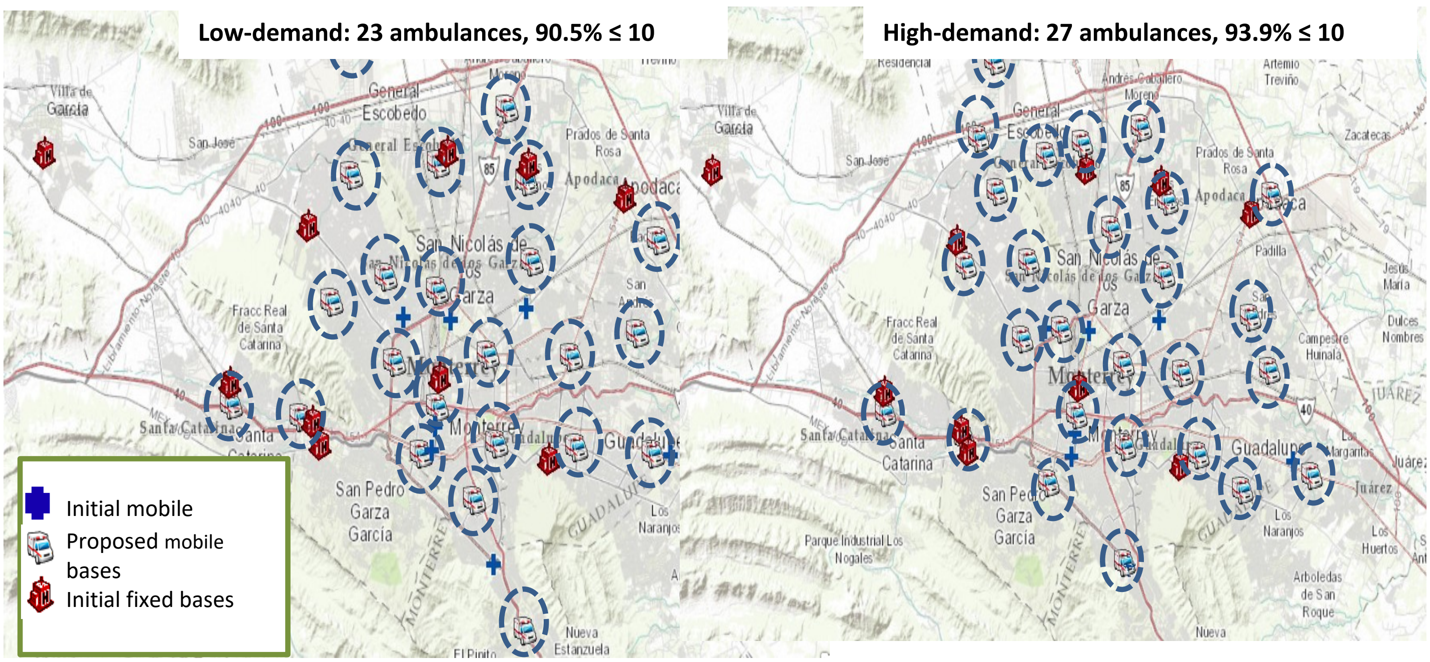

Figure 6. ESRI recommendation of number and location of ambulance bases for scenario with all bases optimized (III)

Defining shortest path ambulance routes

The determination of the shortest path between two points in real road networks is a challenging task. This is due to the existence of various parameters that interact in a dynamic manner; traffic congestion; random accidents, etc. Thus, the algorithms chosen to obtain the shortest path must consider the stochastic nature of these parameters.

Car navigation systems have become the most applied solutions to deal with the previously described environment. These systems work together with Global Positioning Systems (GPS) and digital road maps (Kanoh 2007). These integrated systems take into account the mentioned parameters to recommend shortest path routes. A review of the algorithms used for defining shortest path routes in a real time environment is provided by Ngoket al., (2012). A dynamic routing system to guide ambulances in real time traffic conditions is proposed by Shekar et al., (2012). This system includes as a component the Dijkstra´s algorithm to estimate the shortest paths. An interesting analysis of the capabilities of personal navigation devices and traffic phone applications is carried out in Belzowski and Ekstrom (2014), such as waze and garmin, under traffic jam conditions. For our case, the navigator device Garmin 670 was selected for running an initial pilot test.

3.4 Description of Results

Before, embarking to full implementation of the initiatives previously described, the management of operations of the Red Cross Monterrey, decided to carry out pilot programs. As an initial step towards the implementation of the optimal number and location of ambulances, the management of the institution determined to deploy a one-month pilot project with 11 ambulances for the low-demand daily period and 21 ambulances for the high-demand daily period. The amount of ambulances in the pilot project was limited by the shortage of well-trained crew members available at that moment and budgetary constraints. In order to support this pilot program, it was necessary to determine new optimal locations for both options. Based on this information, feasible locations were identified using Google maps and physical observation. The theoretical percentage of emergency calls to be satisfied with transport times under a ten-minute transport time from the base to the patient is estimated in 77%. A new base location structure for the high-demand option was also obtained. It is estimated that 92% of the emergency calls could have a transport time from the base to the scene of the emergency under 10 minutes with the suggested structure of locations.

The results of the pilot program are presented in Table 6. After a month of operating the new base location structure, the percentage of emergency calls served with transport times less than ten minutes increased from 16.4% to 58.0%. It is expected that this measure will increase to 92% in the following months and continue around that level in the long run.

Table 6. Summary of results from the pilot programs

	Initial Status		**Pilot ESRI**		**Pilot Real**		**Projected ESRI**	
	Ambulances	% ≤ 10 minutes	Ambulances	% ≤ 10 minutes	Ambulances	% ≤ 10 minutes	Ambulances	% ≤ 10 minutes
Low-demand	**17**	16.2	11	77	11	**58**	23	91
High-demand	**17**	16.6	21	92	21	**58**	27	94

With respect to the reduction of time required to travel the shortest route, the management of the institution authorized a pilot test consisting in installing GARMIN 670 devices in two ambulances. Therefore, this pilot test was setup in ambulances; NL 154 and NL 156, assigned to Monterrey and Apodaca. The test started on September 5th. Up to date, the benefits of this test are an average of 5 minutes per call for the ambulance of Apodaca, and of one minute per call in Monterrey. Even though this initiative is mainly oriented to reduce response time, it will also help to arrive quicker from the emergency scene to the health institution. These results provide important insight to decide if the investment required to install navigator devices in all ambulances is justified. The total impact of this initiative is presented in Table 5. Given that the benefits of having a navigator in ambulances located in Monterrey downtown were not significant, it is recommended to complement the operation with motorcycles. The utilization of motorcycles has provided with important benefits in various other operations (Lin et al., 1998; Soares-Oliveira et al., 2007). These vehicles are sent first to the scene of the emergency to start patient stabilization and assess if there is a need for an ambulance. This scheme of operation has been also tested in Mexican operations of the Red Cross such as the one in Tijuana city. According to Planeacion y Gestion

Estrategica (2014), in this pilot test, only in 13% of the cases that were assisted by motorcycle, there was a need for an ambulance to transport the patient to a health institution. The time taken to respond was reduced an average of 6 minutes with respect to the time required by an ambulance. Additionally, the labor and fuel costs of operating motorcycles instead of ambulances are reduced significantly. The projected impact of using motorcycles is shown in Table 7.

Finally, there is also the opportunity of decreasing the time to execute the activities required to prepare the ambulance to satisfy the emergency calls. Here again, the short term solution was to improve and standardize operating procedures under the given limitations set by the current computational and communication systems. However, the management was aware that it was necessary to practically eliminate these activities to achieve the international standard for ambulance response time. In order to obtain these results, it was absolutely necessary to implement an integrated system such as the Interact Computer Aided Dispatch System (http://www.interact.mx/productos/interact-cad/). The investment estimated for the system is about 275 thousand US dollars with an estimated implementation time of three months. Table 7 illustrates the projected impact of implementing this definitive initiative. The initial average response time has been reduced 13.5% and the percentage of calls served in with a transport time less than ten minutes is 58%, after one month of partial pilot tests. It is expected that after the full deployment of the total number of ambulances (given by scenario III) equipped with navigator devices, and the implementation of motorcycles and the Interact system, the international average response time benchmark can be achieved.

Table 7. Summary of impact of implementing initiatives

Phase description	Average time for assigning ambulance (minutes)	Average time for dispatching (minutes)	Average time for transport to patient (minutes)	Average response time (minutes)
Initial status	4.8	1.6	13.6	19.9
After pilot programs	4.0	1.2	11.9	17.1
Navigator projection	4.0	1.1	9.0	14.1
InterAct projection	0.8	0.5	9.0	10.4
Motorcycle projection	0.8	0.5	8.0	9.4

3.3.2 Reducing Ambulance Turnaround Time

This initiative is part of the second phase of the improvement strategy. For this study, it was required to map and analyze the activities involved with the arrival of the ambulance to the emergency department of a health institution and handing over the patient. The time required for executing these activities corresponds to the ambulance turnaround time. Several health institutions are the main recipients of patients. From these, five institutions accounted for about 77% of the emergency arrivals of the Red Cross ambulances. These were Hospital de Zona 21 (HZ) with 27%, Hospital Metropolitano (HM) with 20%, Hospital Universitario (HU) with 19%, Clinica 6 del IMSS (IMSS 6) with 7% and Clinica 17 del IMSS (IMSS 17) with 4%. Emergency calls where serviced by the fleet of ambulances available. The daily behaviour of average arrivals to the health institutions presents two general patterns; a high level of emergency arrivals occurring from 7 to 22 hrs and a low level load pattern during the rest of the day (at night).

In order to identify the most important causes for long ambulance turnaround times, a sample of 850 observations were taken during the months of February and March of year 2017 from the previously mentioned institutions. This sample of observations was used to develop value stream maps for each institution and identify the most important wastes (Graban 2016) in their handover processes. For all of them the most constrained activity corresponded to stretch liberation. The most significant wastes encountered were waiting for doctors and the stretch and over-processing. The New South Wales Ministry of Health (2012) suggests that EMS operations should terminate after the triage, when the patient's responsibility is transferred to the health institution. Nevertheless, paramedics in the Monterrey Red Cross branch rarely finished their participation at the ideal suggested stage. Due to the lack of stretches available in the health institutions, they were forced to continue "their participation" in the process until there was a way to release the patient safely.

As indicated by Figure 7, for the process for HZ, the total average turnaround time of the sample was estimated in 41.7 minutes. The highest element of the ambulance turnaround corresponded to stretch liberation with 38.8%. This value was significantly higher than the recommended international standard range of 15–30 minutes.

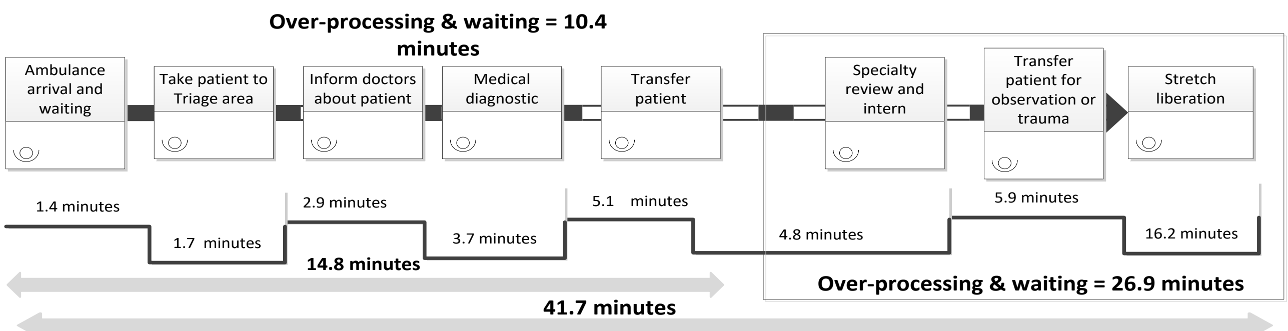

Figure 7. VSM for the EMS operations of the Monterrey Red Cross branch with HZ

For HZ, the ambulance turnaround time increased from an average of 14.8 minutes to an average of 41.7 minutes. Thus, the main sources of wastes were waiting for doctors and stretches, excess of movement, and over-processing. Figure 7 illustrates the location of occurrence of these wastes. In summary, the study indicated that paramedics took an average of 26.9 minutes working for the health institution performing tasks that did not correspond to their duty. Additionally, it was observed that the rest of the activities contained a 70% of waste time due to over-processing information, waiting for doctors, nurses and medical students, and excess movements of the patients.

After the step of information analysis, a brainstorming session was planned and carried out to obtain suitable improvement strategies applicable to this project (Garza-Reyes et al., 2016b). As recommended by Fortune (1992), key stakeholders and experts of the EMS process were involved in the formulation of the improvement strategies, these included paramedics, doctors, operations managers and administrative staff. Two main improvement initiatives generated from the brainstorming session were considered the most appropriate to tackle the excessive ambulance turnaround time, namely: (1) incorporating an ambulance decoupling team and; (2) negotiating with the institutions the Red Cross responsibility in the patient handover process. If the last initiative were to be implemented, it would automatically imply the liberation of the ambulance immediately after the patient triage.

Incorporating an ambulance decoupling team

The initiative of the ambulance decoupling team consisted in putting together a crew formed by a paramedic and an assistant per shift and hospital. This team would be responsible for booking the patient from the ambulance crew and proceed with the rest of the activities. The impact of implementing this initiative may be significant if implemented. For instance, total average turnaround time could be reduced to an average of 14.8 minutes approximately. Before making a full implementation of this initiative a pilot project was carried out to ensure the feasibility of the modification in practice. The implementation of the pilot project was undertaken during the months of April and May of 2017 for HZ. Thus, the results described hereafter are based on the information gathered during this period. The real average turnaround time for HZ, during the pilot project period, was estimated in 16.4 minutes, a 61% reduction from the original.

4. Conclusions

The improvement of the EMS operations has been of great concern in the healthcare sector. Two important approaches have been applied to achieve this objective; the mathematical modelling approach and; the incremental improvement lean approach.

A survey provided by Rais and Viana (2010) selected research work in Operations Research (OR) applied exclusively to the problems in Healthcare. As established by Royston (2009), OR is utilized much more now to address daily hospital management, resource-constrained operations or treatment planning aspects in Healthcare. Key healthcare optimization issues include service planning, resource scheduling, logistics, medical therapeutics, disease diagnosis and preventive care. An excellent review of OR contributions for optimizing patient flow in emergency operations is provided by Saghafian et al., (2015). The authors identify ambulance location as an important issue for the improvement of flow into part of the operations. The ambulance location problem has been exhaustively treated in the Operations Research area. An excellent review of ambulance location and relocation models is provided by Brotcorne et al., (2003). As previously stated in section 2.1, lean healthcare has proven to be an important approach of improving healthcare organizations performance. This fact is supported by the increasing number of applications and research found in the literature, particularly in triage activities (Murrel et al., 2001). Waste elimination is the fundamental core of the lean approach. Therefore the definition of waste is key to make it operational. Two important waste frameworks have been suggested by Bentley et al., (2008) and Graban (2016). Both frameworks are ad-hoc for process improvement inside the health institution.

This work has two main contributions; It proposes a new conceptual approach for improving EMS operations by adapting the lean transportation concepts and methodology (Simmons et al., (2004); Villarreal (2012); Sternberg et al., 2013) for this purpose and; it provides the first application of this approach to improve the level of agility for the Mexican Red Cross operations located in the Monterrey metro area. Lean transportation is an emerging improvement approach for truck transportation operations. The approach has been validated with applications in several companies with important operational and economic results (Sternberg et al., 2013; Garza–Reyes et al., 2017; Garza-Reyes et al., 2016; Villarreal et al., 2016a; Villarreal et al 2016b; Villarreal et al 2016c. It focuses on the identification of waste related to the truck efficiency as defined by Villarreal (2012) and Simmons et al., (2004). Since the EMS process is a specialized health - related transportation process, it seemed natural to apply the approach to this environment. For this, several wastes and the TVSM tool were adapted to satisfy the conditions of the process. The results and experience gained with the application of this approach to improve the agility of the EMS operations of the Red Cross operations in Monterrey, Mexico metro area are very promising. The application of the approach was originally intended to decrease ambulance response time. However, the management decided to extend it to consider the ambulance cycle time as the target. Therefore, the full strategy included two phases. The first one was focused on improving ambulance response time. The second phase concentrated on breaking the bottleneck of the cycle process, namely the ambulance turnaround time. Based on the results of the pilot programs and the projected results of other initiatives the operations management of the Red Cross in Monterrey expects a reduction of 34% of the average ambulance cycle time. This expected improvement can increase the number of services per ambulance from four to six, in an eight-hour shift.

The management of the institution considered the approach of great value to provide order and guidance in their efforts for improving operations performance. After proving the results with pilot programs, they will proceed with the definitive implementation of initiatives including the required investments in the 2017 year budget. Even though, the truck transportation scheme has been applied with favorable operating and economic results, future additional applied research is recommended to enrich and validate the concepts and methodology of the proposed improvement approach in the EMS operations.

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