Reduce Turnaround Time Through Waste Elimination

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Abstract

According to the NHS Confederation (2012), "It's not good to be a patient stuck on an ambulance trolley in a corridor, but the patients at risk are the road traffic accidents or heart attacks still waiting for the ambulance service to respond". Ambulance Turnaround time is a measure of particular interest in the performance of Emergency Medical Systems (EMS). It determines the degree of coordination and communication with the health institutions where each patient will receive his final treatment. Its value is key in the determination of the ambulance capacity of the operations system of an EMS institution. Long turnaround times decreases the availability of ambulances for future services and furthermore, it increases ambulance response times and patient´s health risk. This work is about applying an improvement approach based on Lean Thinking for reducing ambulance turnaround time in the EMS operations of the Red Cross located in metropolitan Monterrey, Mexico. Results of the application are provided.

Keywords
Ambulance turnaround time; bottleneck, waste reduction; emergency operations

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.

According to Fitch et al., (2015), 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:

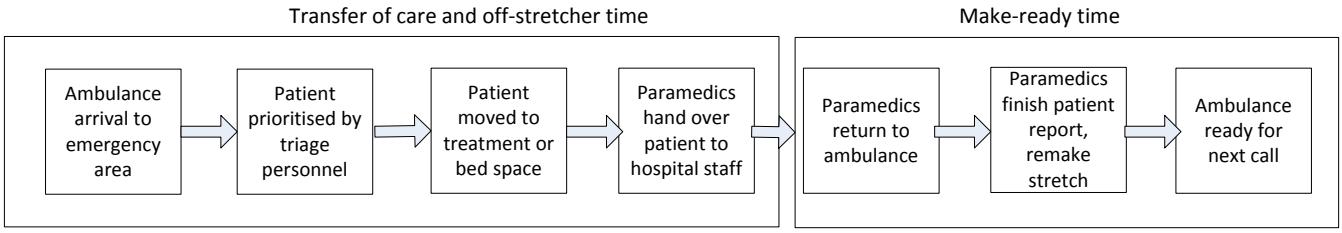
- Receive emergency call and an ambulance is assigned.
- Ambulance preparation.
- Transporting the ambulance to the emergency scene.
- Serving the injured or sick person until he is stabilized.
- Transfer the customer to a health institution.
- Delivering the customer to the health institution.
- Transportation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

The activities previously described are part of the ambulance cycle. According to Blackwell et al., (2009), 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.

1.1 Delivering the customer to the health institution

Our main concern in this work is the time taken to deliver the patient to a health institution after being transported by the ambulance. This is called Turnaround time, and it is defined as the time spent by paramedics at hospital emergency departments. It is measured from the time an ambulance arrives at a hospital to when it is ready to respond to other incidents. As illustrated in Figure 1, There are two main components of turnaround time: off-stretcher time and make-ready time. The New South Wales (NSW) Ministry of Health introduced transfer of care in April 2012. It replaced off-stretcher time as the key measure of hospital performance in reducing ambulance delays. It places the pressure on hospitals, not paramedics, to record when a patient has been moved to a hospital bed and handover has occurred. Both measures are reported against a 30 minute benchmark. The target for NSW hospitals is for 90 per cent of ambulance patients to be transferred into hospital care within 30 minutes. For the National Emergency Medicine Programme Report, the target is established such that 95% of all patients should be handed over within 20 minutes. Further, according to the NHS Confederation (2012) the time standard should be 15 minutes.



Source: Audit Office research and discussions with Ambulance Service and Ministry of Health

Figure 1 Illustration of ideal patient handover process

Independently of the targeted standard, the idea would be to insure a turnaround time as short as possible. This would mean that ambulances can respond more quickly to other emergency calls in the community. If ambulances are delayed at hospitals, sometimes called trolley block, there are less ambulances in the community to respond to incidents. This may place the public at risk, especially those in need of urgent care and transportation. In addition, its value determines the ambulance capacity of the operations system of an EMS institution. For a given number of ambulances in operation, as the value of the average ambulance turnaround time increases, total ambulance capacity for the system is reduced. Additional impacts resulting from this situation are; an increase on the average ambulance response time and patient´s health risk due to the unavailability of ambulances; and a greater need of ambulance replacement investment requirements and operating cost.

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 turnaround time improvement lean initiatives. Section three gives a description of the recommended scheme. The application of this scheme is undertaken in section four and section five where conclusions and future recommendations are presented.

2. Review of Relevant Literature on Turnaround Time Improvement

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 et al., (2003) and Keyte et al., (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 Jones et al., (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.

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. Heinbuch (1995) offers an initial consideration about the use of lean concepts, in the particular case of just-in-time. Some later publications that describe further applications are: Chalice (2005) and (2007), Zidel (2006), and Brandao (2009).

As it was the case for the manufacturing and administrative processes, it is necessary to define what is considered waste or value. Bentley, T.G.K., et al., (2008) suggest a framework of three types of waste—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. Graban (2016) proposes an extension of the seven Toyota manufacturing wastes to the healthcare area as illustrated in Table 1. This waste classification is more suitable for process improvement inside the health institution. They are more associated to hospital operations.

Table 1 Description of the Eight Healthcare Extended Wastes

Type of Waste	*Brief Description*	*Hospital Examples*
Defects	Time spent doing something incorrectly, inspecting for errors, or fixing errors	Surgical case cart missing an item; wrong medicine or wrong dose administered to patient
Overproduction	Doing more than what is needed by the customer or doing it sooner than needed	Doing unnecessary diagnostic procedures
Transportation	Unnecessary movement of the "product" (patients, specimens, materials) in a system	Poor layout, such as the catheter lab being located a long distance from the ED
Waiting	Waiting for the next event to occur or next work activity	Employees waiting because workloads are not level; patients waiting for an appointment
Inventory	Excess inventory cost through financial costs, storage and movement costs, spoilage, wastage	Expired supplies that must be disposed of, such as out-of-date medications
Motion	Unnecessary movement by employees in the system	Lab employees walking miles per day due to poor layout
Overprocessing	Doing work that is not valued by the customer or caused by definitions of quality that are not aligned with patient needs	Time/date stamps put onto forms, but the data are never used
Human potential	Waste and loss due to not engaging employees, listening to their ideas, or supporting their careers	Employees get burned out and quit giving suggestions for improvement

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 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 et al., (2001). 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. The TOVE index and related wastes are adapted to the EMS operations by Villarreal et al., (2017). The new index is called the Ambulance TOVE and will be represented by A-TOVE hereafter. The wastes related to the Administrative and Operating Availability efficiency factors are similar to those of the Transportation Value Stream Map (TVSM) described in Villarreal (2012). The Value Stream Map (VSM) recommended by Villarreal et al., (2017) 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.

An important activity of the EMS process corresponds to the patient handover to a health institution. This activity occurs in emergency departments (EDs) of the. These areas face problems with crowding, delays, cost containment, and patient safety. EDs are increasingly implementing an approach based on Lean thinking to resolve these problems. Holden (2011) presents an analytic review of 18 articles describing the implementation of Lean in 15 EDs in the United States, Australia, and Canada. An analytic framework based on human factors engineering and occupational research generated 6 core questions about the effects of Lean on ED work structures and processes, patient care, and employees, as well as the factors on which Lean's success is contingent. The review revealed numerous ED process changes, often involving separate patient streams, accompanied by structural changes such as new technologies, communication systems, staffing changes, and the reorganization of physical space. Patient care usually improved after implementation of Lean, with many EDs reporting decreases in length of stay, waiting times, and proportion of patients leaving the ED without being seen. Success factors included employee involvement, management support, and preparedness for change. Despite some methodological, practical, and theoretic concerns, Lean appears to offer significant improvement opportunities. Other papers that treat the application of lean initiatives for improving patient flow and turnaround time in EDs are Rutman, T., et al., (2015), Chan, et al., (2014), Murrel, K.L., et al., (2011), Decker, et al., (2008), Dickson et al., (2009), Hagg et al., (2007), Sullivan et al., (2013), and White et al., (2015).

3. Description of the Waste Reduction Scheme

The waste elimination procedure considered in this work is part of a wider approach based on Theory of Constraints (TOC). As Goldratt, et al., (2012) suggest, the productivity of the manufacturing system is determined by a bottleneck or the most constrained capacity resource. Huang et al., (2002) state that this type of resource is the one with the highest Operational Equipment Effectiveness (OEE) value. Thus, the procedure they develop is fit into the five-step improvement cycle designed by Goldratt et al., (2012). The first two phases are designed to estimate the OEE values for each production resource. The third phase consists of the identification of the bottleneck or most constrained resource. This is done by identifying the resource with the highest OEE value. Once this is carried out, the identification of wastes or losses is the next task. These are associated with the availability, performance and quality efficiency factors of the bottleneck. The final phase of the procedure includes the definition of projects or actions with the purpose of eliminating the wastes found. This is done until the constraint is broken. The process is repeated if a new constraint is identified and it is desirable to continue improving the productivity of the manufacturing system. The previous procedure is constructed such that it is required to have all the OEE values for each capacity resource of the operations system. This is so because the identification of the bottleneck is done with this information.

The procedure suggested in this paper is very similar. However, it does not require all the OEE values for each capacity resource. The determination of the bottleneck or capacity constrained resource is carried out through a load analysis and the elaboration of a value stream map. This alternate procedure is described as follows:

(1) Elaborate the Ambulance Value Stream Map and a capacity load analysis for the process of interest.
(2) Identify the bottleneck or more restrictive resource.
(3) Exploit and elevate the bottleneck by identifying and implementing waste elimination initiatives. For our case, the average turnaround time of the EMS operations of the Red Cross is the highest of the process, becoming the bottleneck.
(4) The previous step continues until a new bottleneck is found or management decides to stop. If a new bottleneck is found, continue to step 2. Otherwise, the process ends.

It is important to point out that the waste classification applied in the study correspond to the given by Graban (2016).

4. Implementation and Results

This work applies a waste elimination scheme to improve the level of the Ambulance Turnaround time of the Mexican Red Cross´ operations in the Monterrey metropolitan area. The operations count with seven (7) fixed locations and three (3) 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.

4.1 Analysis of emergency call demand

The number of emergency calls considered in the analysis carried out in this work total 30,600 and occurred during the period of November of 2016 and June of 2017. 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 Turnaround time needed to be reduced significantly to satisfy international standards and satisfy the new upsurge of 16% in demand due to the project of centralization of emergency calls implemented by the government of the state of Nuevo Leon. This new situation put a great pressure on the level of operations cost and the requirements for more ambulance investment. Figure 1 illustrates the behaviour of daily call demand per hour and day of the week. Two characteristics are to point out; every day has the same pattern, with the exception of Sunday at night and; two demand levels are present every day, a high level of emergency calls of about six calls per hour occurring from 7 to 22 hrs and a low level of demand of 3three calls per hour during the night shift.

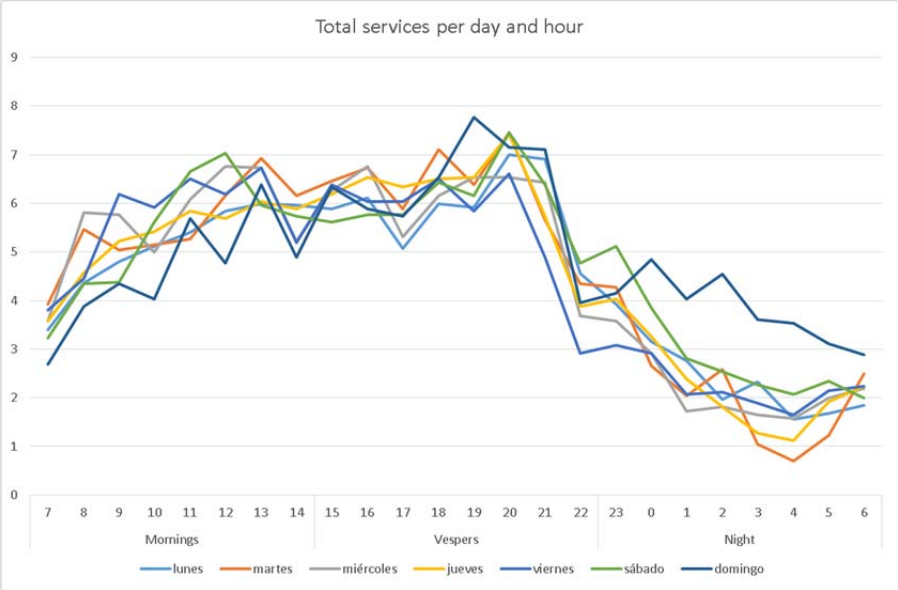


Figure 1 Description of emergency call demand pattern per day and hour of each day

The previous demand pattern of emergency calls was serviced by the fleet of ambulances available. However, not all of them required the transportation of the patient to a health institution. On average, the hourly level of calls that needed transferring the patient to a health institution decreased significantly. The daily behavior of average arrivals to the health institutions is presented in Figure 2. The general pattern of this behavior is similar to the one just described for the total emergency call demand. As shown, three health institutions receive most of these services; Hospital de Zona (HZ), Hospital Universitario (HU) and Hospital Metropolitano (HM).

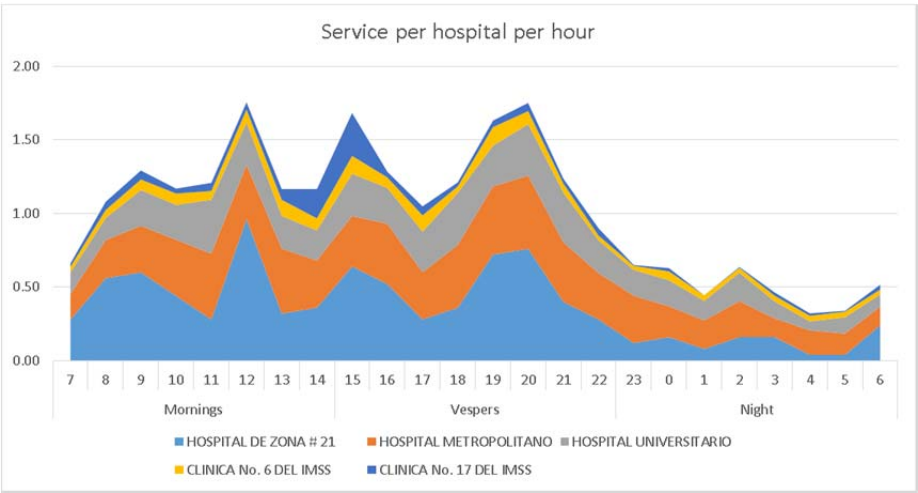


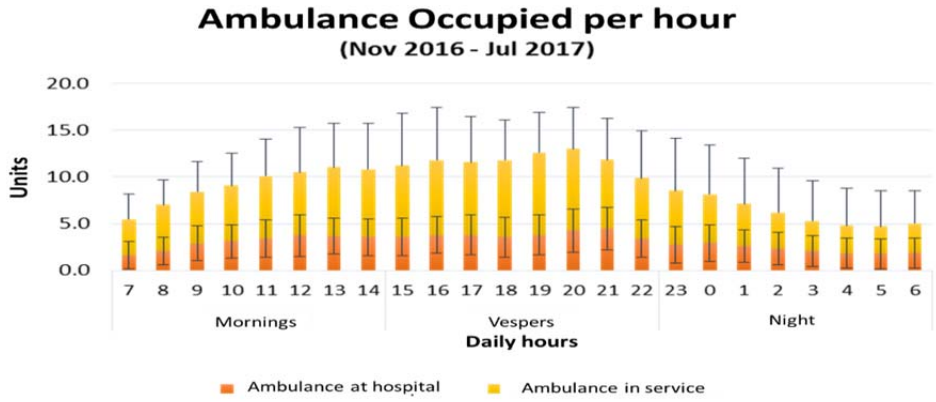
Figure 2 Behavior of the emergency arrivals to each health institution

Five institutions account for about 77% of the emergency arrivals of the Cruz Roja ambulances. These are Hospital de Zona 21 (HZ) with 26%, Hospital Metropolitano (HM) with 23%, Hospital Universitario (HU) with 18%, Clínica 6 del IMSS (IMSS 6) with 6% and Clinica 17 del IMSS (IMSS 17) with 4%. Furthermore, Table 2 illustrates the type of emergency arriving to each institution. Three institutions; HU, HM and HZ, take all types of emergencies considered such as physical aggressions, traffic and other accidents and illness. On the other hand, IMSS 6 and IMSS 17 receive mainly illness.

Table 2 Description of the Percentage per Type of Emergency Arrivals per institution

	Health Institution				
	HU	**HZ**	**HM**	**IMMS 17**	**IMSS 6**
Physical agression	35	33.5	29.4	0.4	1.8
Traffic accidents	18.6	59.2	20.7	0	1.4
Illness	23.6	5.6	44	12.8	14
Other accidents	17	58.4	22	0.8	1.9

As previously mentioned, ambulance turnaround time is important because it impacts on the availability of ambulances to service new emergency calls. Figure 3 illustrates the number of ambulances busy per hour of a day. This fluctuates from 5 to a high of 12 during the day. Of these, 40% of the ambulances are busy during the turnaround time at hospitals. Hospitals HU, HZ and HM are the ones that account for about 90% of the busy ambulances. Total busy ambulances present an increasing pattern from 7.00 A.M. until 20:00 hrs, time at which it reaches the highest level of about five ambulances. This pattern turns decreasing during the rest of the day.



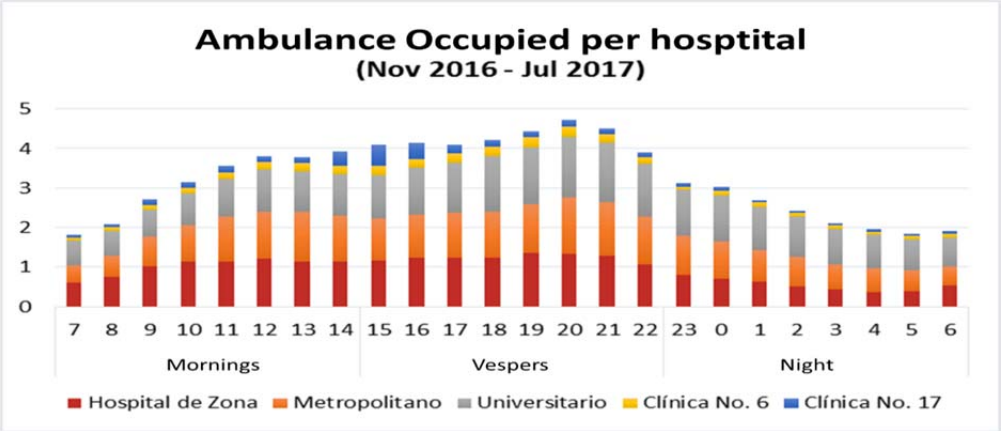
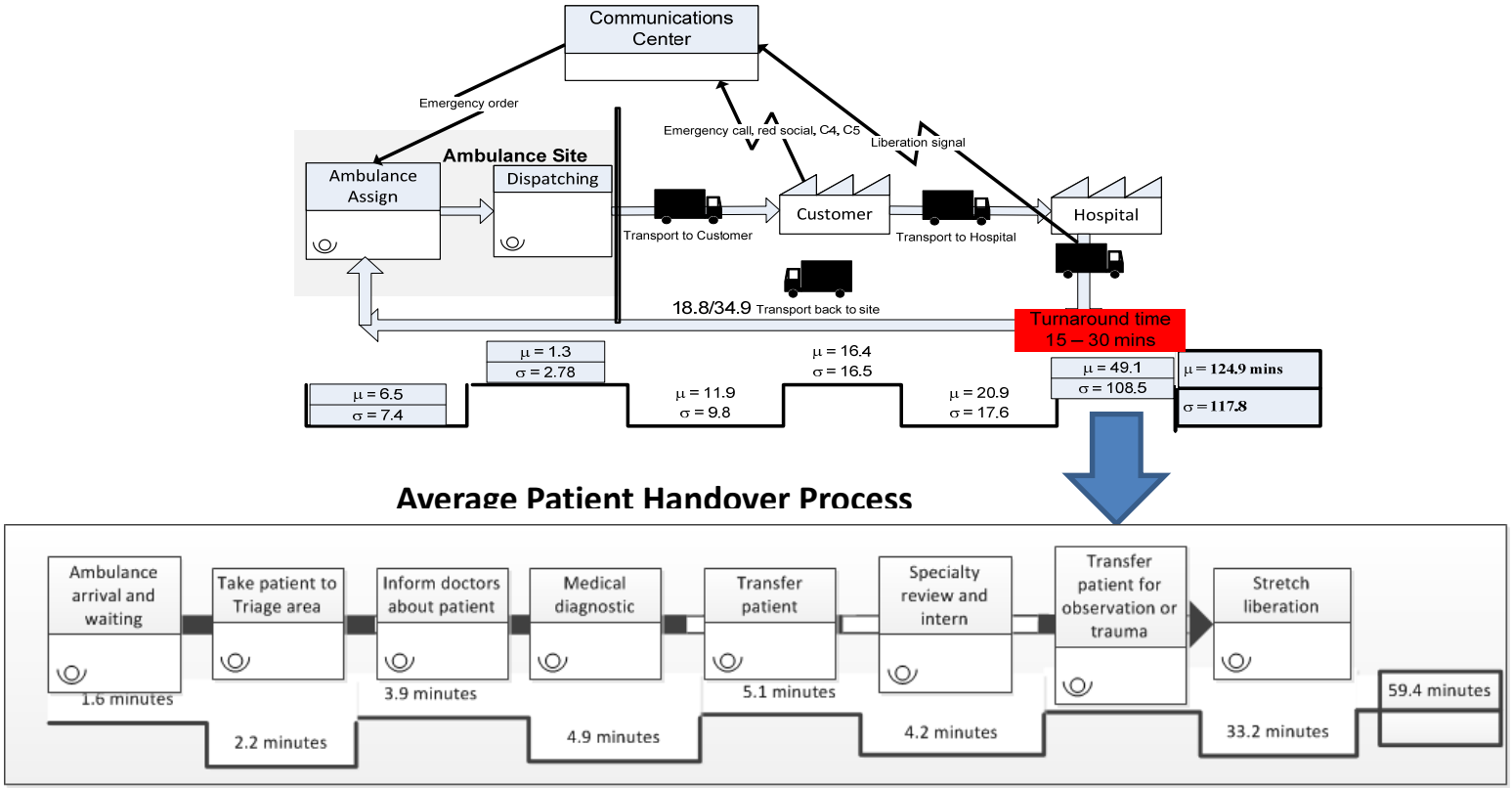


Figure 3 Number of ambulances busy in the system and at each health institution

4.2. Mapping the ambulance cycle and patient handover processes

The first step of the methodology is the mapping of the operations. Figure 4 presents a two-level Value Stream Map (VSM) containing the Ambulance VSM of the Monterrey metro area operations. According to the A - VSM, the average ambulance response time is estimated in 17.26 minutes, about 73% the international standard. Also, the average time recorded to stabilize the patient´s health is 34% over the Platinum Ten. 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 84% above the golden hour. Turnaround time is estimated in 46.7 minutes and total Ambulance cycle time averaged 115 minutes with a standard deviation of 114.3 minutes. The value of ambulance cycle time implies a patient throughput per ambulance of 0.51 per hour. Ambulance turnaround time is 48.3% of the cycle time and it is its greatest element. The bottleneck of the process would be the one related to the turnaround time.

In order to find out the most important causes for long turnaround times, a sample of 850 observations were taken during the period of August 15 to September 10 of 2017. These were gathered in the first five health institutions mentioned previously; HU, HM, HZ, IMSS 6 and IMSS 17. As shown in Figure 4, total average turnaround time is estimated in 59.36 minutes. The highest element of the turnaround corresponds to stretch liberation with 55.9%. This value is significantly higher than the recommended standard range of 15 – 30 minutes. HU and IMSS 17 have the highest turnaround times with 90.4 and 83.5 minutes respectively.



Health Institution	Amb arrival & Waiting	Patient to Triage	Interact with doctors	Medical diagnostic	Transfer patient	Specialty review & intern	Transfer to trauma or observation	Stetch liberation	Total time
HU	1.4	2.7	3.9	7.4	5.1	5.5	5.7	58.7	90.4
HM	1.8	1.9	5.5	7.7	7.1	4.3	4.3	18.7	51.3
HZ	1.4	1.7	2.9	3.7	5.1	4.8	5.9	16.2	41.7
IMSS 17	1.5	2.0	3.0	6.0	4.5	2.4	2.3	61.8	83.5
IMSS 6	1.2	4.0	2.4	4.0	1.4	6.6	4.2	16.0	39.8

Figure 4 Description of the VSM for the Patient Handover Process of the Red Cross

Comparing the patient handover process for the Red Cross with the ideal process shown in Figure 1, one can realize that it differs significantly in its activities. Ideally, the process should terminate after the triage with the transfer of the patient to the health institution responsibility. However, Red Cross paramedics rarely finish their participation at the ideal suggested stage. Due to the lack of stretches available at each health institution, they are forced to continue "their participation" in the process until there is a way to release the patient safely. Hence, what should be an average of 17.7 minutes of participation in the process, ends up being an average of 59.4 minutes of collaboration.

4.3 Description of areas of opportunity

The main wastes are due to waiting for doctors and stretch mainly, excess of movement and over-processing. Figure 5 illustrates the location of occurrence of these wastes. In summary, paramedics take an average of 41.8 minutes working for the health institution performing tasks that are not their duty. In addition, it was observed that the rest of the activities contain a 70 % of waste time due to over-processing information, waiting for doctors, nurses and medical students, and excess movements of the patients.

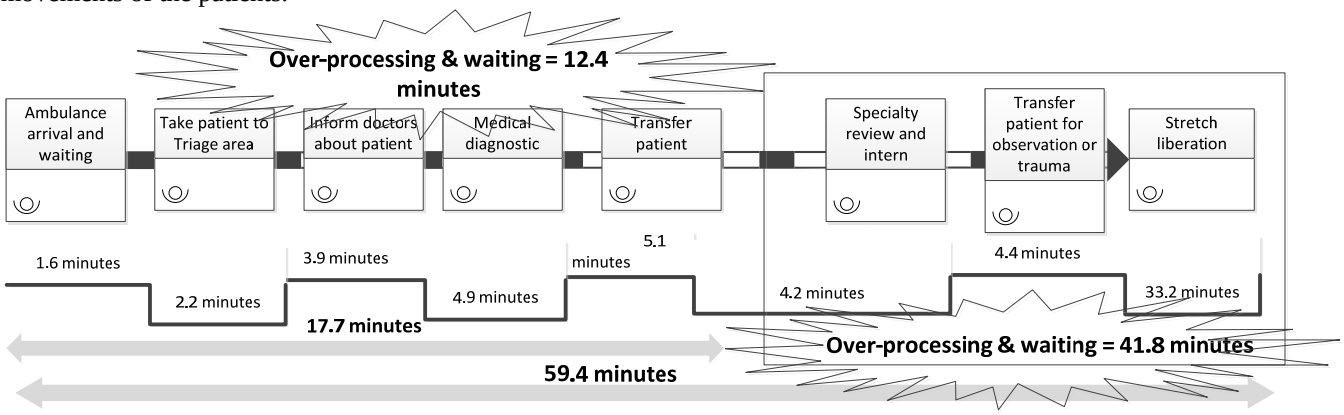


Figure 5 Description of the areas of opportunity for improving the patient handover process

4.4 Defining and implementing the improvement strategy

The strategy for improving performance consists of three initiatives: incorporate an ambulance decoupling team; define internet based tools to communicate patient information during his transfer to the hospital and the status of stretches in the hospital and; negotiate with the hospitals the Red Cross responsibility in the patient handover process. It is important to point out that if the last initiative is implemented, it will automatically imply the liberation of the ambulance immediately after the patient triage.

Incorporate ambulance decoupling team

This initiative consists of putting together a crew formed by a paramedic and an assistant per shift and hospital. This team will be responsible of receiving the patient from the ambulance crew and proceed with the rest of the activities. The potential decoupling points can be located right after the arrival of the ambulance to the hospital or after the execution of the patient triage, as shown in Figure 6. The impact of implementing this initiative may be very important if it is implemented. Total average turnaround time could be reduced to a range of 2 to 18 minutes approximately.

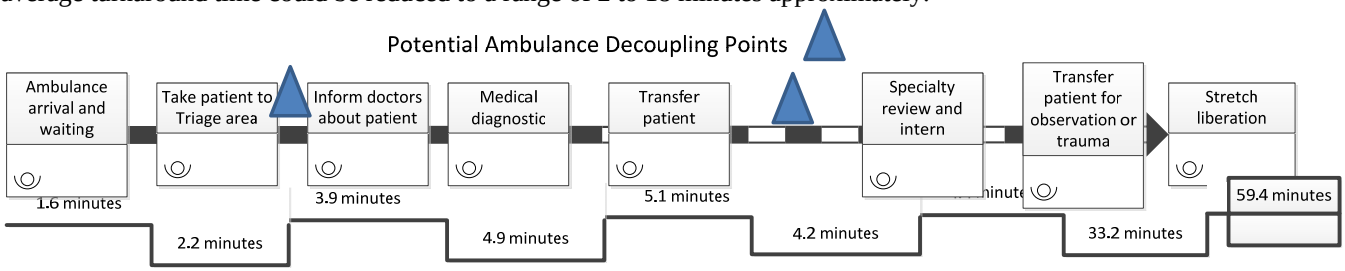


Figure 6 Illustration of potential decoupling points

The initiative of concern was tested in a two-stage pilot project at HU. The initial stage will consider the location of the decoupling point immediately after executing the patient triage. Then the team will be responsible to continue performing the rest of the activities including the stretch recuperation. The second stage of the project would be implemented simultaneously

with an internet based tool that will enable to transfer patient information from the ambulance to the team while transporting the patient. This information will make it possible for the team to receive the patient immediately after arriving to the hospital. The team will then be in charge of taking the patient through the triage and the rest of the activities of the handover process.

The implementation of the pilot project, in its first stage, of the ambulance decoupling point team was undertaken starting October 15 and at the HU. Thus, the results described hereafter are based on information gathered during about 15 days. The total number of observations is 108. The real average turnaround time for HU, during the pilot project period, is estimated in 19 minutes, a 79% reduction from the original.

Negotiation with hospitals of responsibility in handover process
This initiative considers the definition of the responsibility boundaries of the Red Cross, and the associated hospital, with respect to their participation in the patient handover process. Ideally, the collaboration of the Red Cross must be until the patient passes the triage activity, leaving the patient under the hospital´s responsibility. If this is carried out, the ambulance turnaround time would result in a significant reduction.

The implementation of this initiative was undertaken for HU and HM with different results up to date. The negotiation with HM was successfully completed and the one with HU was dependent on the results obtained from the implementation of the ambulance liberation team. The project with HM started on October 17. Therefore, the results so far of about 13 days with about 67 observations are important. Ambulance average turnaround time is estimated in 23.6 minutes during the pilot project period. This new level represents a 54% decrease versus the original value.

Implementing internet based tools
The internet based tools considered are destined to improve the communication between the ambulance and the hospital during its transport to the institution and to increase the level of control of stretches inside the hospitals. The impact of the first tool is expected to be at the triage activity reducing the time taken in about four minutes. The tools identified to monitor the stretches status would improve their recovery on time. The implementation of this initiative was actually postponed for the first semester of year 2018 once the operating budget for the institution is approved.

The following steps of the implementation of the first two initiatives in the following two months, will be to consider; the implementation of the ambulance decoupling team after the arrival of the ambulance at each hospital HU and HM and; to finish the negotiations to reconsider the responsibility of the Red Cross in the patient handover process in the HU.

5. Conclusions
This work describes the application of a lean based approach for decreasing the turnaround time of the Red Cross operations located in Monterrey Mexico. These operations serve a population of around 5 million people. The emergency demand is mainly clustered in Monterrey downtown and the surroundings of Apodaca and Escobedo cities. Most of the emergency calls that required a transfer to a hospital end up at the Hospital Universitario, Hospital de Zona and Hospital Metropolitano. The average level of ambulance turnaround time is estimated in 59.4 minutes, significantly higher than the international benchmark range of 15 – 30 minutes.

The situation previously described triggered the realization of the current study. The management of the Red Cross decided that the adequate approach to improve ambulance turnaround time was one of waste elimination. The classification of waste provided by Graban (2016) was selected for being a part of the scheme. The study included the analysis of 30,600 emergency calls occurring during the period of November of 2016 to June of 2017. Five health institutions received 77% of the calls. Therefore, the patient handover process for all of them was mapped and analyzed. However, the study and further implementation measures focused on 3 hospitals, HU, HM and HZ.

The delineated improvement strategy consisted of three initiatives: incorporate an ambulance decoupling team; define internet based tools to communicate patient information during his transfer to the hospital and the status of stretches in the hospital and; negotiate with the hospitals the Red Cross responsibility in the patient handover process. The first and third initiatives were implemented in pilot efforts in HU and HM with very successful results. The initiative of utilizing internet based tools was postponed until a new operating budget is approved. The impact of the implementation of the initiatives on turnaround time is very important. Initial results in HU report a decrease of 79%, and in HM, the reduction in ambulance

turnaround time is in the order of 54%. These new time levels provide an increase on ambulance service capacity from four services per day to almost six, about 50% increase in ambulance capacity.

References

Bentley, T.G.K., Effros, R.M., Palar, K. and Keeler, E.B., Waste in the U.S. Health Care System: A Conceptual Framework, *The Milbank Quarterly*, Vol. 86, No. 4, pp. 629 – 659, 2008.

Blackwell, T.H., Kline, J.A., Willis, J.J. and Hicks, G.M., Lack of Association Between Prehospital Response Times and Patient Outcomes, *Prehospital Emergency Care*, Vol. 13, pp. 444–450, 2009.

Brandao, D.S.L., Trends and approaches in lean healthcare, *Leadership in Health Services*, Vol. 22, No. 2, pp.121–139, 2009.

Chalice, R., *Stop rising healthcare costs using Toyota lean production methods: 38 steps for improvement*, Quality Press, Milwaukee, WI, 2005.

Chalice, R., *Improving Healthcare Quality using Toyota lean Production Methods: 46 Steps for Improvement*, 2nd ed., Quality Press, Milwaukee, WI, 2007.

Chan, H.Y., Lo, S.M., Lee, L.L.Y., Yu, W.C., Wu, Y.F., Ho, S.T., Yeund, R.S.D. and Chan, J.T.S., Lean Techniques for the Improvement of Patient´s Flow in Emergency Department, *World Journal of Emergency Medicine*, Vol. 5, No. 1, pp.24-28, 2014.

Decker, W.W. and Stead, L.G., Application of Lean Thinking in Health Care: A Role in Emergency Departments Globally, *International Journal of Emergency Medicine*, Vol. 1, pp. 161-162, 2008.

Dickson, E.W. and Singh, S., Cheung, D.S., Wyatt, C.C. and Nugent, A.S., Application of Lean Manufacturing Techniques in the Emergency Department,, *Journal of Emergency Medicine*, Vol. 37, pp. 177-182, 2009.

Fitch, J.J., Knight, S., Griffiths, K. and Gerber, M., The new EMS imperative: Demonstrating value, Infocus, *ICMA Publishing*, Vol. 47, No. 1. pp. 1 – 19, 2015.

Graban, M., *Lean Hospitals: Improving Quality, Patient Safety and Employee Engagement*, 3rd Edition, CRC Press, 2016.

Goldratt, E.M., Cox, J. and Whitford, D., *The Goal: A Process of Ongoing Improvement*, Third Edition, North River Pr., 2012.

Hagg, H.W., Mapa, L. and Vanni, C., Application of Lean Six Sigma Techniques to Optimize Hospital Laboratory Emergency Department Turnaround Time Across a Multi-hospital System, *Engineering Education*, Vol. 30, 2007.

Heinbuch, S.E., A case of successful technology transfer to health care: total quality materials managements and just-in-time, *Journal of Management in Medicine*, Vol. 9 No. 2, pp.48–56, 1995.

Holden, R.J., Lean Thinking in Emergency Departments: A Critical Review, *YMEM 2011*, Vol. 57, pp. 265-277, 2011.

Hwang, S.H., Dismukes, J.P., Shi, J. & Robinson, D.E., (2003), Manufacturing Productivity Improvement Using Effectiveness Metrics and Simulation Analysis, International Journal of Production Research, Vol. 41, No. 3, pp. 513-527, 2003.

Jeong, K. and Phillips, D.T., Operational efficiency and effectiveness measurement, *International Journal of Operations and Production Management*, Vol. 21, No. 11, pp.1404– 1416, 2001.

Keyte, B. and Locher, D., *The Complete Lean Enterprise: Value Stream Mapping for Administrative and Office Processes*, Productivity Press, 2004.

Murrel, K.L., Offerman, S.R. & Kauffman, M.B., Applying Lean: Implementation of a Rapid Triage and Treatment System, *Western Journal of Emergency Medicine*, Vol. XII, No. 2, 2011.

NHS Confederation, *Zero Tolerance*, London, UK, 2012.

Ohno, T., *Toyota Production System: Beyond Large-Scale Production*, Productivity Press, Cambridge, MA, 1988.

Schonberger, R.J., *Japanese Manufacturing Techniques: Nine Hidden Lessons in Simplicity*, Macmillan, New York, NY., 1982.

Rutman, L., Stone, K., Reid, J., Woodward, G.A. & Migita, R., Improving Patient Flow Using Lean Methodology: An Emergency Medicine Experience, *Current Treatment Options Peds*, Vol. 1, pp. 359-371, 2015.

Shingo, S., *A Study of the Toyota Production System from an Industrial Engineering Viewpoint*, Productivity Press, Cambridge, MA.,1989.

Simmons, D., Mason, R. and Gardner, B., Overall Vehicle Effectiveness, International journal of Logistics: Research and Applications, Vol. 7, No. 2, pp. 119-34, 2004.

Sternberg, H., Stefansson, G., Westernberg, E., Boije af Gennas, R., Allenstrom, E., Nauska, M.L., Applying a Lean Approach to Identify Waste in Motor Carrier Operations, *International Journal of Productivity and Performance Management*, Vol. 62 No. 1, 2013, pp. 47-65, 2013.

Sullivan, P., Cruise, K. and Callaghan, C.D., Lean Six Sigma Methods Reduce and Sustain Troponin Turnaround Time (TAT) for Emergency Department Patients, *American Journal of Clinical Pathology*, Vol. 140: A237, 2013.

Tapping, D. and Shuker, T., *Value Stream Management for the Lean Office-Eight Steps to Planning, Mapping and Sustaining Lean Improvements in Administrative Areas*, Productivity Press, 2003.

Thirion, A., *Modeles de localisation et de reallocation d'ambulances. Application aux communes en provinces de Namur et Brabant Wallon*, PhD thesis, Facultes Universitaires Notre-Dame de la Paix, Namur, Belgium, 2006.

Villarreal, B., Granda-Gutierrez, E.A., Lankenau, S., Bastidas, A.C. & Montalvo, A., Decreasing Ambulance Response Time Through an Optimal Base Location, *Proceedings of the 2017 International Symposium on Industrial Engineering and Operations Management (IEOM)*, Bristol, UK, July 24-25, 2017.

Villarreal, B., The Transportation Value Stream Map (TVSM), *European Journal of Industrial Engineering*, Vol. 6, No. 2, pp. 216-233, 2012.

White, B.A., Baron, J.M., Dighe, A.S., Camargo, C.A. and Brown, D.F.M., Applying Lean Methodologies Reduces ED Laboratory Turnaround Times, *American Journal of Emergency Medicine*, Vol. 33, pp. 1572-1576, 2015.

Womack, J.P. and Jones, D.T., *Lean Thinking – Banish Waste and Create Wealth in Your Corporation*, Free Press, Simon Schuster Inc, New York, NY., 2003.

Zidel, T., *A Lean Guide to Transforming Healthcare: How to Implement Lean Principles in Hospitals, Medical Offices, Clinics, and other Healthcare Organizations*, Quality Press, Milwaukee, WI., 2006.

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