

Lean Emergency Medical Operations

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Abstract

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 agility and efficiency of EMS systems are major public concerns. Since the EMS process involved is fundamentally a transportation process, the Lean Transportation approach is a viable option for improving Emergency Medical Service (EMS) operations performance. The identification of waste during the ambulance cycle time is the basis for designing an operations improvement strategy. The scheme utilized uses modified versions of the Transportation Value Stream Map (TVSM) and The Operational Vehicle Effectiveness (TOVE) Index. Thus, availability, performance and quality wastes are identified to define the improvement strategy. Results of the application for the Monterrey metropolitan operations of the Mexican Red Cross are provided.

Keywords:

Emergency medical service; waste elimination; platinum ten; golden hour; transportation waste.

1. Introduction

Over the past decades, a significant amount of research studies have been conducted to improve the performance of EMS systems. The major focus of these models is to reduce response time (the 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. The focus has been on response time because EMS systems are designed to rapidly provide advance medical care to critical patients such as cardiac arrest or trauma. Therefore, the system has to be extremely agile (Christopher, et al., 2001) to provide such a service. In addition to the ambulance response time, other agility performance measures are the ambulance turnaround time (time of ambulance arrival to the hospital until it is available to respond to other emergency) and the ambulance cycle time (total time from the emergency call until the ambulance is available to service another call) are also relevant to determine the level of agility performance of EMS operations.

On the other hand, the management of these systems must consider their level of efficiency. It is important to determine the level of utilization and consumption of the available resources required to attain certain degree of agility. The system must be agile, but with an adequate degree of efficiency. One important measure of efficiency considered in the literature is the average unit hour utilization (number of services divided by the ambulance hours used).

This work proposes a scheme based on transportation waste elimination to improve the level of agility and/or efficiency of EMS systems. The benefits of such a scheme are illustrated with its application on the Mexican Red Cross operations in the Monterrey metropolitan area. 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. The number of services carried out in year 2015 was 35,400. The organization felt that the current level of agility of the organization was below international standards and its operating cost presented opportunities for reduction.

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

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 and; 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.

Two of the most important performance indicators for EMS institutions; the agility required to execute the process; and its efficiency. 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 (Pons et al., 2005). As suggested by Pons et al., (2005) 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 Resuscitation 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 in Watson (2001). Other important performance indicator is related to the first 60 minutes after traumatic injury. This has been called the golden hour (Rogers et al., 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.

2.1 A lean pre-hospital process

The improvement of the time taken to execute the pre-hospital process described earlier has been approached mainly by re-locating 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. 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).

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 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, the patient(s) was (were) stabilized in less than ten minutes, and finally, he (they) was (were) handed over a health institution in less than one hour. These quality indicators measure the level of agility of the EMS operation.

2.2 Description of the waste reduction scheme

This work considers the scheme provided by Villarreal (2012) to guide waste elimination to 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. 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.

The waste identification phase is the third 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. 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. The number of services carried out in year 2015 was 35,400. 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.

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 1 presents the Ambulance VSM of the Monterrey metro area operations. According to the A - VSM, the Quality Efficiency is estimated in 3.8%. Ambulance cycle time is 1.95 hours implying a patient throughput per ambulance of 0.51 per hour. It is estimated that 37.4% of this time is non-value added. Ambulance turnaround time is 48.3% of the cycle time and it is the greatest element of it. The second greatest component of the cycle time is the ambulance response time which accounts for 20.3%. The bottleneck of the process would be the one related to the turnaround time. Therefore, if the institution is willing to decrease operating costs, the level of throughput per ambulance should be increased by breaking this bottleneck. The operations management of the Red Cross Monterrey decided to improve performance in two phases; the first phase consisted on increasing the level of agility in terms of ambulance response time. The institution was decided to achieve international standards in the following two years. The second phase included the goals of improving the total EMS operation agility in terms of the ambulance cycle time and the reduction of operating cost. This document will describe the efforts of

the institution for the first phase. Therefore, we will focus hereafter on the initiatives undertaken to improve the activities required from the reception of the emergency call until the arrival of the ambulance at the scene of the incident.

3.2 Identification of efficiency wastes

As previously indicated, Quality Efficiency is estimated in 3.8%. This a result of an average ambulance response time of 19.3 minutes, about 1.9 times the international standard. Under this service level, only 16.4% of the emergency services satisfy the international standards.

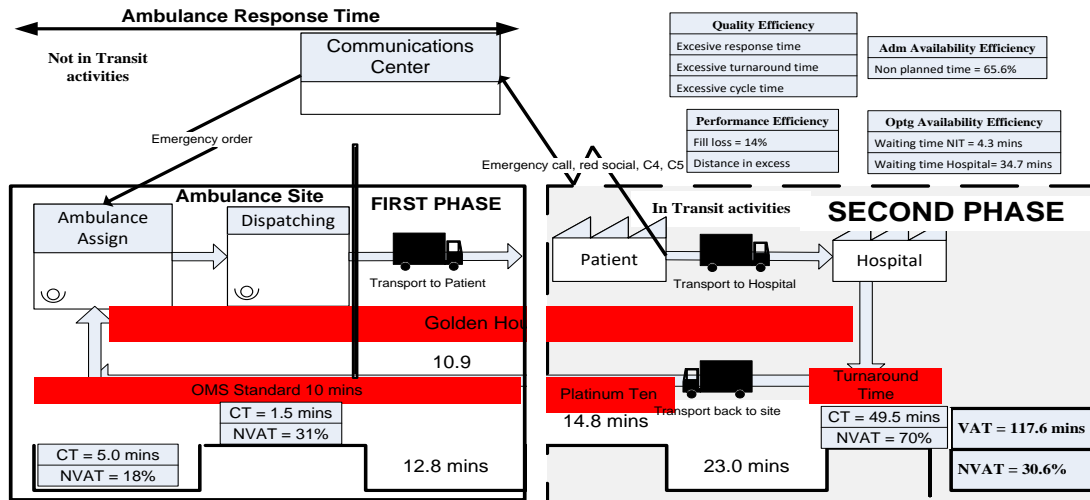


Figure 1 Description of the A-VSM for the Monterrey Metro operations

Also, the average time recorded to stabilize the patient’s health is 48% 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 78% above the golden hour. Turnaround time is estimated in 49.5 minutes and total Ambulance cycle time averaged 117.6 minutes. Therefore, given these results, the institution considered that it has a great challenge for improving its agility capability.

Other important wastes identified are; Not assigned ambulance time that determines an administrative availability efficiency of 34.4%; time in excess taken to execute activities for preparing ambulances before their dispatch and during triage, making the operating availability efficiency to be estimated at 69.4%; Fill loss of 14% and distance in excess traveled by the ambulance of 31% yielding a performance efficiency of 52%.

3.3 Improving the level of agility of the process

For our study, the level of agility will be determined mainly by the ambulance time response (phase I). 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 (Pons et al., 2005). For this reason, there is a great amount of academic work published related to its reduction (Nogueira et al., 2016; Peleg et al., 2004; Wei et al., 2014; Ong et al., 2010).

3.3.1 Improving ambulance response time

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 1, the average time observed before the ambulance departs to service an emergency call is 6.5 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 12.8 minutes.

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. After a discussion of the available

initiatives for improving the process associated, the management decided to implement a two-phase effort; eliminate wasteful activities in the short term achieving a reduction of 1.4 minutes approximately; and replace 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 phase 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, 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.

Emergency service demand presents a particular locational behavior. According to the Kernel density maps (Anderson 2006), 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.

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 et al., (2004) and Ong et al., (2010) 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 (<http://desktop.arcgis.com/en/arcmap/latest/extensions/network-analyst/location-allocation.htm>).

Scenario analysis starting from the current ambulance location structure for two demand levels per day (low-demand and high-demand levels) are evaluated. 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. 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 required 23 ambulances (scenario 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 (Kano 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 Ngoc et al., (2012). An interesting analysis of the capabilities of personal navigation devices and traffic phone applications is carried out in Belzowski et al., (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. In order to support this pilot program, it was necessary to determine new optimal locations for both options using ESRI. Based on this information, feasible locations were identified using Google maps and physical observation. The theoretical percentage of emergency calls to be satisfied under a ten-minute transport time from the base to the patient is estimated in 77%. The results of the pilot program are presented in Table 1.

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. The total impact of this initiative is presented in Table 1. 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 including the Mexican operations of the Red Cross 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. The projected impact of using motorcycles is shown in Table 1.

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 five million pesos with an estimated implementation time of three months. Table 1 illustrates the projected impact of implementing this definitive initiative.

Table 1 Summary of impact of implementing initiatives

Phase	Assign time (minutes)	Dispatch time (minutes)	Transport time (minutes)	Response time (minutes)
Initial status	5.0	1.5	12.8	19.3
After pilot programs	4.1	1.0	11.6	16.7
Navigator projection	4.1	0.9	8.9	13.9
Motorcycle projection	4.1	0.9	7.9	12.9
InterAct projection	0.8	0.5	7.9	9.2

As shown in Table 1, 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.

4. Conclusions

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; provides the first application of this approach to improve the level of response time for the Mexican Red Cross operations located in the Monterrey metro area. Additional applications of the approach are required to enhance concepts and methodology.

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Biographies

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Jose Arturo Garza-Reyes is a reader in Operations Management and Business Excellence at the Centre for Supply Chain Improvement, Derby Business School, the University of Derby, UK. He has published a number of articles in leading international journals and conferences, including *International Journal of Production Research*, *International Journal of Production Economics*, *Production Planning & Control*, *Journal of Cleaner Production*, *Robotics and Computer Integrated Manufacturing*, *Journal of Manufacturing Technology Management*, *International Journal of Quality and Reliability Management*, *TQM & Business Excellence*, *International Journal of Productivity and Performance Management*, among others. Dr Garza-Reyes has also written two books in the areas of quality management systems and manufacturing performance measurement systems. He has participated as guest editor for special issues in the *Supply Chain Management: An International Journal*, *International Journal of Lean Six Sigma*, *International Journal of Lean Enterprise Research*, *International Journal of Engineering Management and Economics* and *International Journal of Engineering and Technology Innovation*. Dr Garza-Reyes is co-founder and current Editor of the *International Journal of Supply Chain and Operations Resilience (Inderscience)*. He is currently serving in the editorial board of several international journals as well as has contributed as member of the scientific and organising committees of several international conferences. His research interests include general aspects of operations and manufacturing management, operations and quality improvement and performance measurement.

Edgar Aurelio Marco Granda is a full professor of the Department of Engineering of the Universidad de Monterrey. He holds a PhD of Industrial Engineering from ITESM. He has 18 years of professional experience in logistics, operations and supply chain in several Mexican companies. He has taught for 5 years courses on industrial engineering and logistics in the Universidad de Monterrey, ITESM, UMIN and Universidad Autónoma de Nuevo León. As a consultant, he has carried out projects on logistics and supply chain for different company in México.

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