



Universidad Popular Autónoma del Estado de Puebla
Vicerrectoría de Posgrados e Investigación
Posgrados en Ingeniería y Negocios
Doctorado en Logística y Dirección de la Cadena de Suministro

Asignación de vehículos tomando en cuenta tiempo entre fallos

Tesis para obtener el Grado de Doctor
en Logística y Dirección de la Cadena de Suministro

Presenta
Marcos Salazar Medina

Director
Dr. José Luis Martínez Flores

Puebla, México.

Agosto de 2020



UPAEP – Secretaría General

Dirección General de Apoyos Académicos

Dirección del Centro de Recursos para el Aprendizaje y la Investigación.

Biblioteca Central - **Karol Wojtyla**

Tesis Digitales Restricciones de uso:

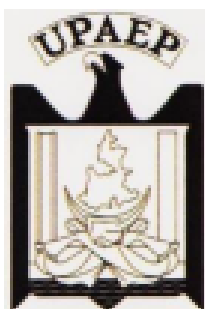
DERECHOS RESERVADOS ©

PROHIBIDA SU REPRODUCCIÓN TOTAL O PARCIAL

Todo el material contenido en esta tesis está protegido por la Ley Federal del Derecho de Autor (LFDA) de los Estados Unidos Mexicanos (México).

El uso de textos, imágenes, gráficas, fragmentos de videos, y demás material que sea objeto de protección de los derechos de autor, será exclusivamente para fines educativos e informativos y deberá citar la fuente de donde la obtuvo mencionando el autor o autores involucrados en el documento.

Cualquier uso distinto como el lucro, reproducción, edición o modificación, será perseguido y sancionado por el respectivo titular de los Derechos de Autor.



Universidad Popular Autónoma del Estado de Puebla

Vicerrectoría de Posgrados e Investigación

Posgrados en Ingeniería y Negocios

Doctorado en Logística y Dirección de la Cadena de Suministro

Se aprueba la Tesis titulada

Asignación de vehículos tomando en cuenta tiempo entre fallos

Presenta

Marcos Salazar Medina

Comité de revisión

A handwritten signature in black ink, likely belonging to Dr. José Luis Martínez Flores, is positioned above a horizontal line.

Dr. José Luis Martínez Flores

Director

A handwritten signature in blue ink, likely belonging to Dra. Diana Sánchez Partida, is positioned above a horizontal line.

Dra. Diana Sánchez Partida
Sinodal

A handwritten signature in black ink, likely belonging to Dra. Patricia Cano Olivos, is positioned above a horizontal line.

Dra. Patricia Cano Olivos
Sinodal

Puebla, Pue.

Agosto 2020

Agradecimientos

A mi familia por la motivación para terminar este proceso.

Al Dr. José Luis Martínez Flores, por las facilidades y la oportunidad de finalizar este trabajo.

A los revisores del trabajo por los comentarios emitidos para finalizar el proyecto.

A los profesores del doctorado por los conocimientos y guía para la conclusión del proyecto.

A la UPAEP por las facilidades prestadas.

Al Tecnológico Nacional de México por las facilidades dadas para llevar a cabo el proyecto.

Al Instituto Tecnológico de Orizaba por la oportunidad de llevar a cabo esta etapa profesional.

Al CONACYT por la ayuda y facilidades otorgadas para complementar esta etapa profesional.

Resumen

El transporte es un elemento fundamental para el desarrollo de la economía mexicana, permitiendo el acceso físico a los mercados y una distribución más rápida y eficaz de los productos que ofrecen las empresas a los puntos que quieren llegar

La transportación es un negocio intensivo en capital y los propietarios de flotillas desean mantener sus tractocamiones en servicio las 24 horas del día, los 7 días de la semana, los 365 días del año. Pero para lograrlo se necesita equilibrar el servicio de entrega a clientes y los pedidos con conductores y tractocamiones disponibles, así como con tiempos de carga.

El mantenimiento de los tractocamiones es parte fundamental para la correcta operación de las empresas dedicadas al autotransporte de materiales e insumos, en estos tiempos, adaptarse al constante dinamismo del mercado, se ha convertido ya en una necesidad para cubrir los requerimientos de los clientes.

El presente trabajo busca aumentar la eficiencia de las operaciones de las empresas de transporte terrestre, buscando el balance correcto entre costo y calidad en el servicio, tomando en cuenta restricciones de disponibilidad de tractocamiones y contenedores, así como, el mantenimiento de dichos tractocamiones.

En el capítulo 1, se presentan las generalidades del trabajo de investigación.

En el capítulo 2, se presenta la metodología para obtener los índices de confiabilidad de los tractocamiones. Se establece el sistema y los subsistemas del tractocamión. Se recolectan los datos para llevar a cabo las pruebas estadísticas y establecer las distribuciones probabilísticas adecuadas. Se establecen los parámetros para los cálculos de los indicadores de confiabilidad y se calcula la probabilidad de fallo del sistema.

En el capítulo 3, se presenta el modelo de asignación para los tractocamiones considerando la probabilidad de fallo. Calcula la proporción de tiempo antes del mantenimiento preventivo programado y basado en ello, asigna los tractocamiones a los diferentes destinos.

Palabras clave: Confiabilidad, probabilidad de fallo, indicadores de confiabilidad, asignación.

Abstract

Transport is a fundamental element for Mexican economic development, allowing physical access to all markets and a fast, overall effective, distribution of goods offered by companies to retailers in different locations.

Transportation is a capital intensive business, and transport fleet owners yearn to have their vehicles in service 24 hours a day, 7 days a week, 365 days a year, but to achieve this is necessary to balance delivery service to clients and collecting service to producers considering the number of available vehicles, along with loading times.

Maintenance of vehicles of the fleet is core for the correct operation of companies dedicated to the transportation of goods and supplies in times where adaptation to an ever-changing market has become a necessity to accomplish client's requirements.

The present work seeks to increase the efficiency of the operations performed by land transportation companies, looking for the fine quality-cost balance, having into account availability restrictions of the vehicles and containers, and maintenance of said vehicles.

In chapter 1, all generalities of the research work are presented.

Chapter 2 deals with the methodology to obtain reliability indexes of the vehicles of the fleet, establishing the system and subsystems of the vehicle. Data is collected for statistical analysis to establish proper probabilistic distributions. Lastly, the necessary parameters to calculate the reliability indexes are set in order to calculate the system's probability of failure.

In chapter 3, the model for assigning tasks to vehicles of the fleet according to the probability of failure is presented. Furthermore, time proportion before programmed preventive maintenance is calculated and, based on the results, vehicles are assigned to different routes.

Key words: Reliability, probability of failure, reliability indexers, assignation.

Índice

Agradecimientos	IV
Resumen.....	V
Abstract	VII
Capítulo 1. Introducción	12
1.1 Justificación.....	12
1.2 Objetivo general y específicos	15
1.3 Pregunta de investigación.....	16
1.4 Alcances y limitaciones.....	17
1.5 Estructura	17
Capítulo 2. Motor equipment reliability analysis.....	18
Abstract	18
Introduction	18
State of the art: Reliability concepts.....	20
<i>Reliability method</i>	21
<i>System Reliability</i>	21
<i>Failure</i>	22
<i>Availability</i>	22
<i>Exponential distribution</i>	23
<i>Normal distribution</i>	23
<i>Lognormal distribution</i>	23
<i>Weibull distribution</i>	23
<i>Rate of failure</i>	23
<i>Mean Time Between Failures</i>	24
Methodology.....	24
1. Selecting the equipment.	25
2. Sorting the equipment as sub-systems.	25
3. Acquiring failure time data.	25
4. Find the probability distribution.	29
5. Parameter distribution.....	35
6. Calculate the system's probability.....	36
Results.....	38

Conclusion	40
Acknowledgements	41
Referencias.....	41
Capítulo 3. Assignment of trailers with constraints of hours for maintenance	43
1. Introduction	43
2. The Linear Assignment Problem (LAP)	44
2.1 Linaer Assignment Problem (LAP).....	44
2.2 The Generalised Assignment Problem.....	45
2.3 Model considering time of maintenance.....	46
3. Example	47
3.The developed model	48
3.1 Interpretation of results	49
4. Conclusions.....	49
5. References.....	50
Conclusiones y trabajos futuros.....	51
Trabajos futuros.....	52
Referencias.....	53
Apéndice A. Evidence of publication on Advances and Aplications in Statistics.....	55
Apéndice B. Evidence of participation in 15th Annual International Conference on Industrial Engineering, Theory, Applications & Practice	56

Índice de Figuras

Capítulo 2

Figure 2 1. Maintenance classification (European Committee for Standardization, 2001)	20
Figure 2 2. Representation of two systems, each formed by three components: A, B and C.	21
Figure 2 3. Methodology	25
Figure 2 4. Fit Chart for Exponential distribution.....	30
Figure 2 5. Fit Chart for Normal distribution.....	31
Figure 2 6. Fit Chart for Log-Normal distribution.....	32
Figure 2 7. Fit Chart for Weibull distribution.....	33
Figure 2 8. Graphic representation of unit 133 components.	38

Capítulo 3

Figure 3. 1 Maintenance types according to EN 13306(2001)	44
Figure 3. 2 Results of the model.....	49

Índice de Tablas

Capítulo 2

Table 2. 1 Maintenance binnacle. (Author's original)	26
Table 2. 2 Units under mechanical system maintenance.....	27
Table 2. 3 Units under electrical system maintenance.....	27
Table 2. 4 Units under braking system maintenance	28
Table 2. 5 TBF for the mechanical system of one unit.....	28
Table 2. 6 TBF for the electrical system of one unit.....	29
Table 2. 7 TBF for the braking system of one unit.....	29
Table 2. 8 TBF fit for vehicle unit's mechanical system	35
Table 2. 9 TBF fit for vehicle unit's electrical system	35
Table 2. 10. TBF fit for vehicle unit's braking system.....	35
Table 2. 11 Total probability for delivery vehicle units	40

Capítulo 3

Table 3. 1 Kms traversed by trailer.....	47
Table 3. 2 Distance between cities.....	48
Table 3. 3 F_{ij} Factor.....	48

Capítulo 1. Introducción

La transportación es un negocio intensivo en capital y los propietarios de flotillas desean mantener sus camiones y tráilers en servicio las 24 horas del día, los 7 días de la semana, los 365 días del año. Pero para lograrlo se necesita equilibrar el servicio de entrega a clientes y los pedidos con conductores, tractores y tráilers disponibles, así como con tiempos de carga.

Las empresas dedicadas a prestar servicios de transporte terrestre para el movimiento de mercancías, se enfrentan a los retos de satisfacer a sus clientes en cuanto a costo, entrega en tiempo y forma. Esto hace que dichas empresas busquen la forma de bajar sus costos y que la programación y ruteo de sus vehículos sea el adecuado.

CANACAR [17] menciona que el autotransporte fue una de las actividades económicas más golpeadas por la crisis económica en México. La contracción de la demanda disminuyó de manera directa los volúmenes de carga que mueven las compañías y por tanto su nivel de ingreso. Además, aumentó el número de camiones parados por la escasez de carga: los niveles inflacionarios crecieron, en particular los insumos directos (diésel), el tipo de cambio afectó el costo de mantenimiento.

El aumento a los combustibles, peajes e impuestos, perjudica el desarrollo de la actividad de transporte que mueve el mayor porcentaje del flete hacia el extranjero y del cual dependen decenas de miles de empleos directos e indirectos.

El presente trabajo aumenta la eficiencia de las operaciones de las empresas de transporte terrestre, buscando el balance correcto entre costo y calidad en el servicio, tomando en cuenta restricciones de costo de la ruta, disponibilidad de tractocamiones y contenedores, así como, el mantenimiento de dichos tractocamiones.

1.1 Justificación

El tractocamión, según la definición dada en la Norma Oficial Mexicana 012-SCT-2-2008 [18], es el vehículo automotor destinado a soportar y arrastrar remolques y semirremolques, es decir, es el medio de transporte terrestre de carga más importante y el más utilizado por el sector productivo del país, ya que es la forma en que se transportan y distribuyen por toda la república, la mayoría de los contenedores que llegan al país vía marítima; además, de esta forma se transporta a Estados Unidos la mayor parte de las mercancías que se comercian con ese país.

Cuando se solicita un servicio de transporte para carga, la empresa de transporte se hace responsable de que la mercancía llegue a su destino en tiempo y forma. Incluyendo el nivel de servicio como los costos que el cliente debe pagar. En la relación con los clientes, no hay nada peor que informar que su mercancía se ha quedado en el camino. De ahí la importancia de que los tractores sean fiables. El mantenimiento adecuado de los tractocamiones es de vital importancia para las empresas de transporte porque de esa manera asegura que los clientes siempre cuenten con la disponibilidad de vehículos para transportar sus cargas. De igual manera el cliente, tiene la certeza de que su carga llegará en el tiempo solicitado y no tendrá problemas de producción.

La empresa debe equilibrar las necesidades de mantenimiento correctivo, que son inmediatas, con la programación del mantenimiento preventivo, que pueden ser programadas y coordinadas para asegurar la disponibilidad de su parque vehicular. El adecuado manejo del mantenimiento con la programación de los tractores presenta grandes beneficios para una empresa de transportista:

- La capacidad de utilizar mejor los equipos de transporte.
- Aumentar la rentabilidad global.
- Que el cliente se sienta seguro al contratar a una empresa de transporte con buen mantenimiento a sus vehículos.
- Se reducen las posibilidades de fallos en los tractores al realizar un servicio

En un ambiente competitivo donde la satisfacción del cliente es de vital importancia para adquirir una ventaja competitiva, las rutas de distribución se convierten en un elemento crítico. La empresa transportista debe encontrar balance entre costos y nivel de servicio, tomando en consideración todas las opciones al momento de crear las rutas de entrega y

recolección de productos o manejar las especificaciones de entrega de los clientes.

Al finalizar el trabajo, la empresa de autotransportes aumentará la eficiencia de sus operaciones en cuanto a la programación del mantenimiento preventivo de los tractocamiones y tanques. Así mismo, la programación y asignación de carga que incremente el nivel de servicio al cliente.

1.2 Objetivo general y específicos

1.2.1 Objetivo

Programación y asignación de tractocamiones, que minimice riesgo de fallo en carretera para una empresa dedicada a la transportación de material vía terrestre, utilizando mantenimiento basado en confiabilidad

1.2.2 Objetivos específicos

- Establecer indicadores de probabilidad de fallo utilizando análisis de confiabilidad
- Programación y asignación de las unidades de transporte al servicio de los clientes considerando el mantenimiento preventivo de dichas unidades.
- Mejorar las políticas de mantenimiento preventivo en cuanto a kilometraje recorrido, programación de mantenimiento preventivo, asignación de carga.

1.3 Pregunta de investigación

- ¿Se considera el mantenimiento preventivo de las unidades para una adecuada programación de las unidades?
- ¿Es posible mejorar las políticas de mantenimiento con una adecuada programación de los vehículos?

1.4 Alcances y limitaciones

1.4.1 Alcances

El estudio considerará solo los tractocamiones que no están rentados a clientes específicos.

1.4.2 Limitaciones

Algunas instancias de prueba deberán ser estimadas considerando datos históricos al no haber registros de ellos.

1.5 Estructura

El presente trabajo está dividido en los siguientes capítulos:

- Capítulo 2. Análisis de confiabilidad.
- Capítulo 3. Modelo de asignación.
- Capítulo 4. Conclusiones y trabajos futuros.

Capítulo 2. Motor equipment reliability analysis

Published in Advances and Applications in Statistics. Volume 63, Number 2, 2020, Pages 151-174: Marcos Salazar Medina, José Luis Martínez Flores, Diana Sánchez Partida and Patricia Cano Olivo

Abstract

In this paper, a methodology to establish the reliability of a delivery vehicle fleet, calculate its probability of failure and setting proper maintenance service time by means of the implementation of better practices and methodologies based on reliability studies is presented, proving their utmost importance for its entire operative and lucrative development.

Keywords: Reliability, Maintenance, Probability, Failure

Introduction

The creation of logistic diary that includes planification and maintenance programming for delivery vehicle fleet can be a daily challenge to keep up at due time and proper form.

The reliability test presented in this paper studies the process of the different maintenance activities (corrective and preventive) for a vehicle fleet from a delivery company, then uses the information acquired to calculate the probability of failure of each of them to establish the best strategy to suppress and avoid security threads, warehouse overstock (assuring availability in vehicle park) and sudden rises on maintenance costs, allowing better decision-making and action-taking for schedule all the necessary tasks for the sake of the delivery vehicle fleet, thus obtaining benefits in life cycles, economic parameters and the risk-profit balance.

It is curious to see that throughout time, authors have not deviate in what makes up for the term *maintenance* to its whole. Dounce (Dounce, 1992) defines it as “the human activity that preserves the quality in services provided by machines, installations and buildings in safe, efficient and low-cost conditions”. In another conceptual definition “it is the set of operations and cares needed by installations, buildings, industries, etc., to retain their full work capabilities”.

Maintenance comes from the verb *maintain*, meaning that it is the action of

retaining functionality of an object or good for it accomplish its intended functions (Mora, 2009), such an act can be done once a fault is present in a certain item, service or equipment, or foreseeing a possible fault by acknowledge of certain warning patterns. The first one is named *corrective maintenance*, and the latter *preventive maintenance*.

Preventive maintenance, which is defined as the combination of actions to restore or retain an equipment to or in a state required to provide a service (Mora, 2009) is vital for terrestrial delivery vehicles, since it is the one done, in pre-defined intervals of time or under certain criteria, to any equipment to reduce the probability of malfunctioning or degradation of any of its parts, whose would lead to a defective delivery service. As such, Daneshkhah (Daneshkhah A, 2017) states that early preventive intervention adds no meaningful reliance to the system and can lead to unnecessary costs, that's why important maintenance activities use not only corrective but preventive tasks. The challenge for well-informed decision-making is establishing the right moment for inspection, intervention and replacement of equipment, coming from the parameters of the associated anti-failure model. The cost function of preventive maintenance policy is influenced by the deterioration model as much as the parameters of the reparation model. Thus, the calculus of a mean rate of costs for a particular preventive maintenance policy is not robust enough, obtaining inefficient results.

With recurrent situations of theft to delivery vehicles, failure probability of the units must be minimized since they can add to the already high-risk factor for the goods in transit and the company by not disposing the required materials for their productive process (De la Torre, 2014). But again, according to the European Norm (AENOR: UNE-EN 13306:2011) preventive maintenance can differ in time and manner: It can be performed once certain conditions have been met or following a default schedule, so the key factor relies in differentiating between both of them. For further understanding, the maintenance terminology classification can be seen in figure 1.

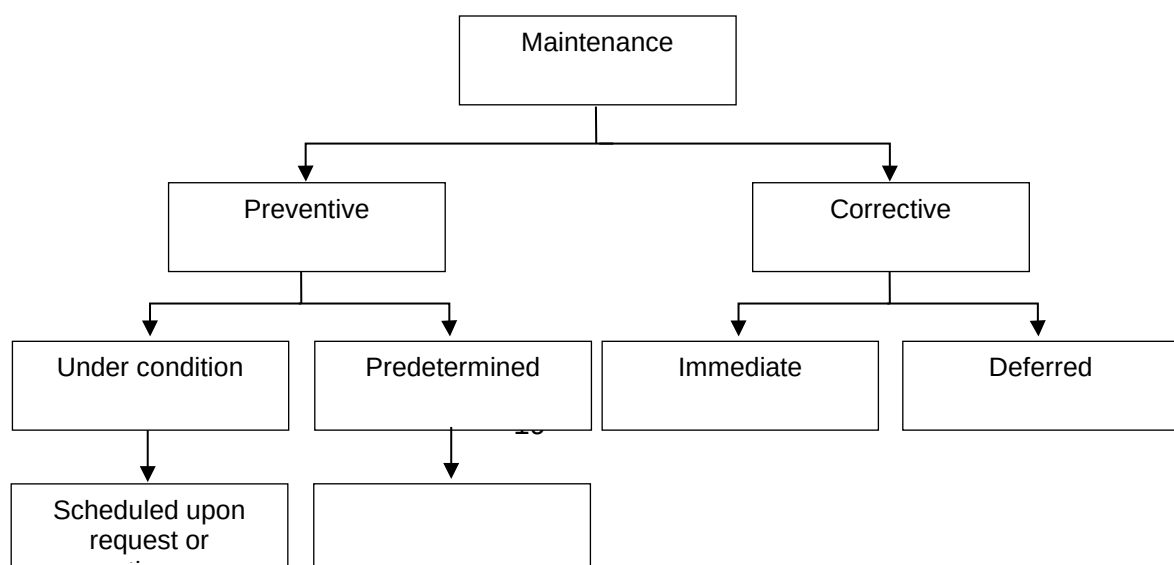


Figure 2 1. Maintenance classification (European Committee for Standardization, 2001)

State of the art: Reliability concepts

Postnikov (Postnikov I, 2017) establishes reliability as a methodology to determine the failure rates and restoration parameters, that gives the heat supply reliability a low cost and guarantees that each parameter and technical restriction can be calculated.

In his work, Bernstein (Joseph B. Bernstein, 2017) says reliability shows how to make accelerated test to predict the reliability of devices that present multiple failure mechanisms. He demonstrates how by calculating reliability one can bring up information about the proportional effect of each failure mechanism, allowing the extrapolation of the reliability forsaken by the device taking into account different conditions.

Reliability, according to Okoh (Okoh C, 2017) proposes a decision rule to inspect the system condition based on remaining time until failure evaluation. By this rule, general expressions are obtained to calculate the probability of correct or incorrect decisions. The efficiency of preventive maintenance is evaluated by means of indicators such as mean availability and average inactivity time per unit of time.

Reliability-Centered Maintenance (RCM) is, according to Sacristán (Sacristán, 2001), the set of disposures, techniques, means and actions which guarantee that all the machines, facilities and organization that makes a “basic process” or production line can develop the job forsaken in a constant production plan in constant evolution by Continual Improvement Process (CIP).

RCM is an optimum combination of strategies such as interval-based reaction time, condition-based reactions and proactiveness, used to increase the performance of the equipment, thus increasing its life cycle while reducing the costs (B. Suthep, 2015). Thus, it is profitable strategy where the cost and reliability requirements are technologically and economically compromised by the efforts of maintenance (Pourahmadi, 2017).

Reliability of a system can be evaluated based on the reliability of the equipment and its configuration, and can be improved by the adoption of a proper maintenance

policy. Particularly, there are 3 general policies:

1. Corrective maintenance
2. Backup items
3. Maintenance before failure

Reliability method

It is defined as the probability of doing a work action under certain conditions during a stablished period of time (Naresky, 1970). In contrast, unreliability method is classified in 3 levels (Skrzypczak I, 2017): *Level 1* being the sum of the semi-probabilistic method and the semi-probabilistic security concept, using partial security factors and characteristic values for materials and actions to ensure the required reliability level. There are no distribution formulae and lineal limit state functions are assumed. In *Level 2* are the processes defined by First and Second Order Reliability Methods (FORM and SORM respectively), which are employed for code calibration in Level 1. *Level 3* includes probabilistic methods such as numeric integration, stochastic simulation and Monte Carlo simulation.

System Reliability

Systems of every machine, vehicle or computer are made of a huge quantity of components, which can be mechanical, electrical or a combination of both, and which can be joint to create even smaller sub-systems. These components are classified in reliability by upper case letters and can be graphically represented, as in figure 2, by blocks.

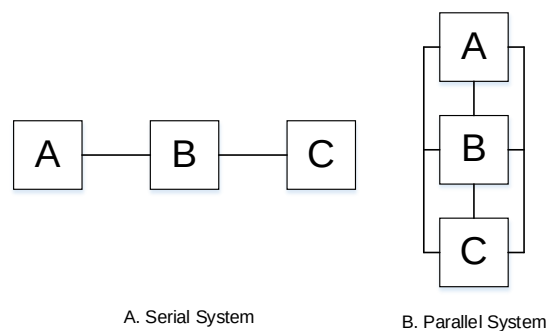


Figure 2 2. Representation of two systems, each formed by three components: A, B and C.

Mathematically, the structural function of a serial system is:

$$\varphi(x) = \prod_{i=1}^k x_i \quad (1)$$

While the structural function of a parallel system is:

$$\varphi(x) = 1 - \prod_{i=1}^k (1 - x_i) \quad (2)$$

Failure

Failure is defined as a mechanical fault, wear beyond an alarm limit, certain defects in system functionality or decrease of performance below acceptable levels (Gertbakh, 2000).

Skrzypczak (Skrzypczak, 2017) mentions that reliability is often understood as the probability of not losing the item's intended function. The term *equipment failure* doesn't always imply a catastrophic event, just that something is not working as it is supposed to. In structural reliability calculus, failure probability is the quantitative measure of a structural security. By the norm ISO-2394, unreliability is considered as the structural performance along the designed life cycle.

Availability

The probability that an equipment could perform during the tolerances of a certain time is called availability (Hosford, 1960). The commonly used probability distributions to represent reliability states are: Exponential, Normal, Logarithmic-normal and Weibull (Kapur, 1997).

Assuming a non-negative random variable $X(X \geq 0)$, stated in an equipment failure time, it has an accumulative probabilistic distribution $F(t) = \Pr\{X \leq t\}$ continuous from the right, and a probabilistic density function $f(t)(0 \leq t \leq \infty)$. These are called *failure time distribution* $F(t)$ and *failure density function* $f(t)$ in reliability theory (Pham, 2003).

Survival function of X is:

$$R(t) \equiv \Pr\{X > t\} = 1 - F(t) = \int_t^{\infty} f(u)du \equiv \bar{F} \quad (3)$$

Which is called reliability function with mean:

$$\mu \equiv E\{X\} = \int_0^{\infty} tf(t)dt = \int_0^{\infty} R(t)dt \quad (4)$$

Exponential distribution

Exponential distribution is commonly used in reliability analysis because it is well fitted to represent the unreliability phenomena, which tends to be high at life cycle beginnings, low at mid-term, and increasing up until the end (Seung-Kyum, 2007).

Normal distribution

It is known in many scientific and engineering fields thanks to its ease and commodity, especially in the central limit theorem theory, which establishes that the sum of all asymptotic variables with arbitrary distribution still has a normal distribution as the sample size increases (Seung-Kyum, 2007). This distribution is employed for coefficient variance cases, such as Young's modulus, Poisson index and other material properties.

Lognormal distribution

It is the distribution of a random variable whose logarithm follows a normal distribution. This rises as the combination of random values by a multiplication process. This technique has been used to describe *failure time* in reliability engineering, and *maintenance time* in maintenance engineering (Montgomery, 2005).

Weibull distribution

Also known as type-III distribution or extreme values distribution, can be useful for describing the weakest link phenomena, or a situation in which defects that lead to failure are analyzed (Seung-Kyum, 2007). It is commonly employed to describe strain, stress and fracture in brittle materials.

Rate of failure

Rate of failure represents a product trend to failure as a function of its age or time under operation. It is a measurement of the remaining items *mortality*. Also called risk rate, is the fraction of probable failures between the proportion of survivors at time t (Seung-Kyum, 2007). When the probability distribution of t is known, it is calculated from $h(t) = f(t)/R(t)$ that is the fraction of failure probabilities and the proportional survivors at time t .

Mean Time Between Failures

Mean Time Between Failures (MTBF) refers to the average time between failures (TBF), or the median value of the life cycle.

Exponential:

$$MTBF = \frac{1}{\lambda} \quad (5)$$

Normal:

$$MTBF = \mu \quad (6)$$

Lognormal:

$$MTBF = e^{\left[\mu_y + \frac{\sigma_y^2}{2}\right]} \quad (7)$$

Weibull:

$$MTBF = \eta \Gamma \left[\frac{1}{\beta} + 1 \right] \quad (8)$$

Methodology

The following steps are performed to calculate the reliability of a delivery unit:

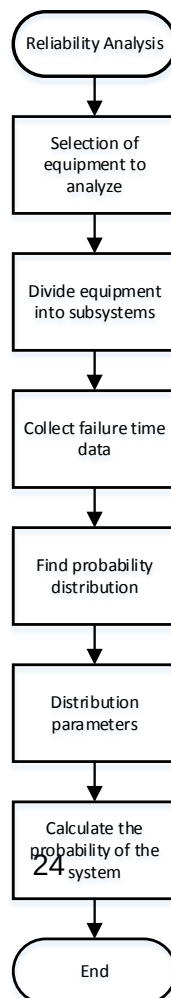


Figure 2 3. Methodology

1. Selecting the equipment.

Consider the equipment that possess a high content of preventive maintenance tasks and high-cost maintenance, or all of whom represent a high number of corrective maintenance actions during previous years.

2. Sorting the equipment as sub-systems.

It is a part of a system that can be studied by its own and can be considered as a system by itself.

3. Acquiring failure time data.

It is necessary to know the time that goes in-between faults of a delivery unit. For the process managed in the present article, 34 vehicles were considered, which had gone through corrective maintenance during this year. A binnacle of vehicle unit maintenance is shown in table 1.

Maint. N.	Unit	Entrance	Time	Exit	Days in Maint.	Delay
1	431	02/01	9:00	02/01	0.00	
1	405	02/01	9:00	02/01	0.00	
1	461	02/01	7:50	02/01	0.00	
1	413	02/01	8:20	02/01	0.00	
1	315	02/01	10:00	02/01	0.00	
+1	319	02/01	9:00	02/01	0.00	

Table 2. 1 Maintenance binnacle. (Author's original)

Once having acquired the entrance information of all the fleet units, the attended service is sorted by which system was affected in each fault. Table 2 shows the vehicle units that went through corrective maintenance due their mechanical system.

Maint. N.	Unit	Entrance	Time	Exit	Days in Maint.	Delay
1	333	06/01	9:00	06/01	1.00	
1	441	06/01	9:15	06/01	1.00	
1	363	06/01	9:50	06/01	1.00	

1	387	06/01	12:00	06/01	1.00	
1	119	06/01	15:20	06/01	0.00	
1	353	02/01	9:00	07/01	6.00	

Table 2. 2 Units under mechanical system maintenance

Table 3 shows the units that went through maintenance due their electrical system.

Maint. N.	Unit	Entrance	Time	Exit	Days in Maint.	Delay
1	455	08/01	9:00	08/01	1.00	1
1	243	08/01	12:15	08/01	0.00	1
1	389	10/01	17:00	11/01	2.00	1
1	123	11/01	21:50	12/01	1.00	1
1	427	12/01	10:50	13/01	2.00	1
1	351	13/01	14:40	14/01	1.00	1

Table 2. 3 Units under electrical system maintenance

Table 4 show the units that went through maintenance due the braking system.

Maint. N.	Unit	Entrance	Time	Exit	Days in maint.	Delay
1	431	02/01	9:00	02/01	0.00	

1	405	02/01	9:00	02/01	0.00	
1	461	02/01	7:00	02/01	0.00	
1	413	02/01	8:00	02/01	0.00	
1	315	02/01	10:00	02/01	0.00	
1	319	02/01	9:00	02/01	0.00	

Table 2. 4 Units under braking system maintenance

With all the previous information one can obtain the TBF for each vehicle unit in each of its systems. Table 5 shows the TBF for the mechanical system of one unit.

Unit	Date	Date	TBF
133	06/02	08/02	2
133	08/02	06/03	27
133	06/03	06/03	0
133	06/03	19/03	13
133	19/03	26/06	99
133	26/06	28/08	63

Table 2. 5 TBF for the mechanical system of one unit

Table 6 shows TBF for the electrical system of one unit.

Unit	Date	Date	TBF
243	02/02	15/02	13
243	15/02	30/03	44

243	30/03	08/05	39
243	08/05	30/06	53
243	30/06	08/08	39
243	08/08	28/09	51

Table 2. 6 TBF for the electrical system of one unit.

Table 7 shows TBF for the braking system of one unit.

Unit	Date	Date	TBF
303	02/02	15/03	42
303	15/03	30/04	46
303	30/04	08/07	69
303	08/07	30/09	84
303	30/09	08/11	39

Table 2. 7 TBF for the braking system of one unit

Tables 5 through 7 should be obtained for each and every vehicle unit from the fleet.

4. Find the probability distribution.

It is mandatory to know the probabilistic distribution to which all the data is fit.

Goodness of fit tests are done using the information acquired from the previous tables. Figure 3 shows an example using unit 303.

Exponential distribution fitting

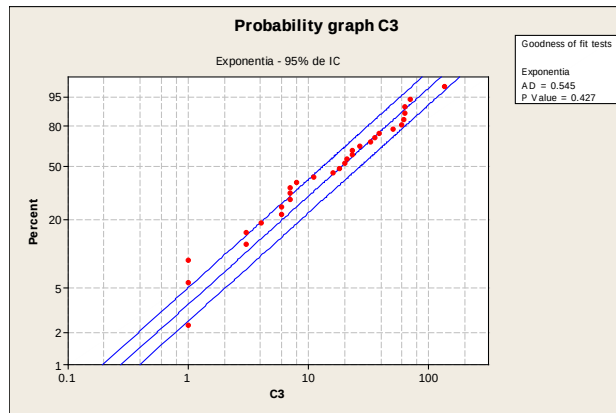


Figure 2 4. Fit Chart for Exponential distribution.

Descriptive Statistics:

		Standard		Minimu	Asymmetr		
N	N*	Mean	Deviation	m	Maximum	y	Kurtosis
30	0	27.5	29.933	1	135	1.84722	4.40984

Goodness of fit

test:

Distribution	AD	P
Exponential	0.545	0.427

ML estimations for distribution parameters:

				Skewnes
Distribution	Location	Shape	Scale	s
Exponential			27.5	

Normal distribution fitting:

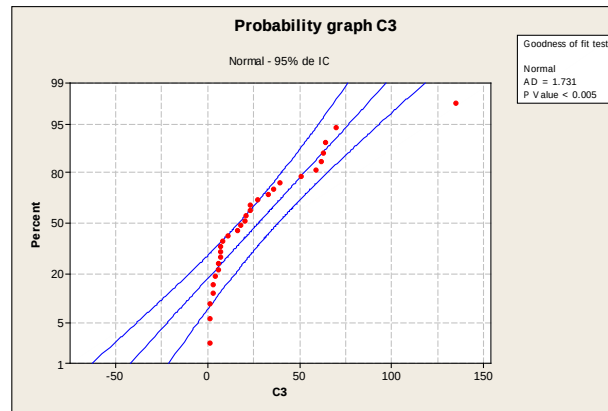


Figure 2 5. Fit Chart for Normal distribution

Descriptive Statistics:

N	N*	Mean	Standard Deviation	Minimum	Maximum	Asymmetry	Kurtosis
30	0	27.5	29.933	1	135	1.84722	4.40984

Goodness of fit

test:

Distribution	AD	P
Normal	1.731	<0.005

ML estimations for distribution parameters:

Distribution	Location	Shape	Scale	Skewness
Normal	27.5			29.93297

Log-Normal distribution fitting:

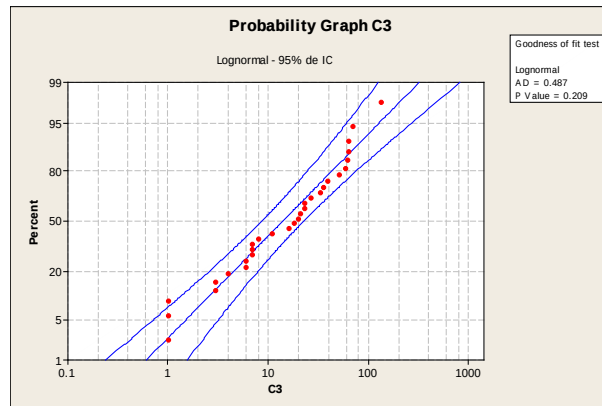


Figure 2 6. Fit Chart for Log-Normal distribution

Descriptive Statistics:

N	N*	Mean	Standard Deviation	Minimum	Maximum	Asymmetry	Kurtosis
30	0	29.933	19	1	135	1.84722	4.40984

Goodness of fit

test:

Distribution	AD	P
Log-Normal	0.487	0.209

ML estimations for distribution parameters:

Distribution	Location	Shape	Scale	Skewness
Normal	2.63267		1.34785	

Weibull distribution fitting:

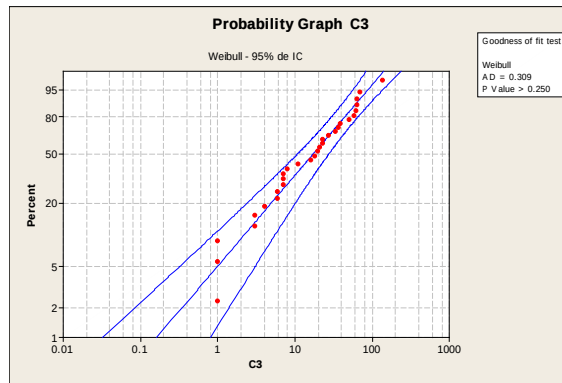


Figure 2 7. Fit Chart for Weibull distribution

Descriptive Statistics:

N	N*	Mean	Standard Deviation	Minimum	Maximum	Asymmetry	Kurtosis
30	0	27.5	29.933	1	135	1.84722	4.40984

Goodness of fit

test:

Distribution	AD	P
Weibull	0.309	>0.250

ML estimations for distribution parameters:

Distribution	Location	Shape	Scale	Skewness
Weibull		0.90583	26.21405	

To choose the data probabilistic distribution, a hypothesis test for the obtained results is ran in Minitab.

Hypothesis test for exponential distribution

1. Parameter: Non-parametric test

2. H_0 : Data fits to exponential distribution
3. H_a : Data doesn't fit to exponential distribution
4. $\alpha = 0.05$
5. Anderson Darling statistic
6. If calculated statistic is greater than the chart statistic or p is lower than α H_0 is rejected
7. $p = .0005$, since p is lower than α ($0.005 < 0.05$), H_0 is rejected
8. Conclusion: there is not enough statistical evidence to accept H_0 , thus, data doesn't fit to a normal distribution with a significance level of 5%

Hypothesis test for lognormal distribution

1. Parameter: Non-parametric test
2. H_0 : Data fits to lognormal distribution
3. H_a : Data doesn't fit to lognormal distribution
4. $\alpha = 0.05$
5. Anderson Darling statistic
6. If calculated statistic is greater than the chart statistic or p is lower than α H_0 is rejected
7. $p = 0.209$, since p is greater than α ($0.209 > 0.05$) H_0 is accepted
8. Conclusion: there is not enough statistical evidence to reject H_0 , thus, data fits to a lognormal distribution with a significance level of 5%

Hypothesis test for Weibull distribution

1. Parameter: Non-parametric test
2. H_0 : Data fits to Weibull distribution
3. H_a : Data doesn't fit to Weibull distribution
4. $\alpha = 0.05$
5. Anderson Darling statistic
6. If calculated statistic is greater than the chart statistic or p is lower than α H_0 is rejected
7. $p = 0.250$, since p is greater than α ($0.205 > 0.05$) H_0 is accepted
8. Conclusion: there is not enough statistical evidence to reject H_0 , thus, data fits to a Weibull distribution with a significance level of 5%

In table 8, probabilistic distribution results for various vehicle unit's mechanical system faults are allocated.

Unit	Exponential	Normal	Lognormal	Weibull	Result
133	Fits	Doesn't fit	Fits	Fits	Weibull
243	Fits	Doesn't fit	Doesn't fit	Fits	Weibull
303	Fits	Doesn't fit	Doesn't fit	Fits	Weibull

Table 2. 8 TBF fit for vehicle unit's mechanical system

As can be seen in table 8, unit 133 belongs to a Weibull distribution due to theory mentioning that it is the best one to represent material fatigue, fracture in brittle materials and material strength.

In table 9, probabilistic distribution results for various vehicle unit's electrical system faults are allocated.

Unit	Exponential	Normal	Lognormal	Weibull	Result
133	Fits	Doesn't fit	Fits	Fits	Weibull
243	Fits	Doesn't fit	Doesn't fit	Fits	Weibull
303	Fits	Doesn't fit	Doesn't fit	Fits	Weibull

Table 2. 9 TBF fit for vehicle unit's electrical system

In table 10, probabilistic distribution results for various vehicle unit's braking system faults are allocated.

Unit	Exponential	Normal	Lognormal	Weibull	Result
133	Fits	Doesn't fit	Fits	Fits	Weibull
243	Fits	Doesn't fit	Doesn't fit	Fits	Weibull
303	Fits	Doesn't fit	Doesn't fit	Fits	Weibull

Table 2. 10. TBF fit for vehicle unit's braking system

5. Parameter distribution.

Once the best fitting probabilistic distribution is chosen, distribution parameters are

set to use the equation to calculate the vehicle units' probability of failure.

Probability Function

Probability function for unit 133 in mechanical system belongs to a Weibull distribution, which has the following calculus equations:

$$f(t) = \lambda e^{-\lambda t} \quad (8)$$

$$F(t) = 1 - e^{-\lambda t} \quad (9)$$

$$R(t) = e^{-\lambda t} \quad (10)$$

$$h(t) = \lambda \quad (11)$$

6. Calculate the system's probability.

Probability of failure is calculated for each of the systems of the vehicle unit, with the resulting values, total system probability of failure can be calculated.

Distribution Characteristics are obtained through Minitab software:

Estimation Method: Least Squares (Failure time (X) on rank (Y))

Distribution: Weibull

Parameter Estimates

	Standard	Standard	95 % normal C I	
Parameter	Mean	Error	Lower	Upper
Shape	1.30528	0.440852	0.673306	2.53042
Scale	52.4814	10.7622	35.1117	78.4439

Log-likelihood = -75.110

Goodness of fit

Anderson-Darling (Adjusted) = 1.348

Correlation Coefficients = 0.937

Characteristics Of Distribution

	Estimate	Standard Error	95% normal CI	
			Lower	Upper
Mean (MTTF)	48.4313	10.6	31.5375	74.3747
Standard Deviation	37.4261	16.6482	15.6508	89.4982
Median	39.6331	8.78791	25.6637	61.2063
1st Cuartile	20.2054	7.54896	9.71512	42.0229
3rd Cuartile	67.4037	15.2029	43.3206	104.875
Intercuartile range	47.1983	15.9442	24.3434	91.5109

Table of percentiles

Percent	Percentile	Standard Error	95% normal CI	
			Lower	Upper
1	1.5468	1.8531	0.147799	16.1881
2	2.64085	2.69496	0.357357	19.5158
3	3.61701	3.31558	0.59991	21.8079
4	4.5267	3.8159	0.86744	23.6224
5	5.39207	4.23706	1.15581	25.155
6	6.22532	4.60081	1.46246	26.4997
7	7.03413	4.92039	1.78564	27.7094
8	7.82374	5.20457	2.12408	28.8176
9	8.59794	5.45954	2.47683	29.8464
10	9.35962	5.68987	2.84314	30.8118
20	16.6319	7.15337	7.15881	38.6405

30	23.8227	7.82602	12.5131	45.3545
40	31.3694	8.22899	18.7592	52.4564
50	39.6331	8.78791	25.6637	61.2063
60	49.0815	10.0725	32.8272	73.3841
70	60.5017	12.8789	39.8634	91.825
80	75.5688	18.4578	46.8204	121.969
90	99.4275	30.3064	54.7082	180.701
91	102.895	32.2553	55.662	190.207
92	106.729	34.4665	56.6761	200.985
93	111.026	37.0102	57.7667	213.388
94	115.924	39.9899	58.957	227.934
95	121.637	43.5667	60.2821	245.437
96	128.519	48.0112	61.7992	267.272
97	137.23	53.8333	63.6117	296.049
98	149.23	62.1832	65.9427	337.712
99	169.095	76.7567	69.4624	411.637

For this system, it is determined that the components behave as a serial system, since if a unit would present a fault in any of its components, it is wrong to assign it to a delivery, it must be programmed for maintenance.

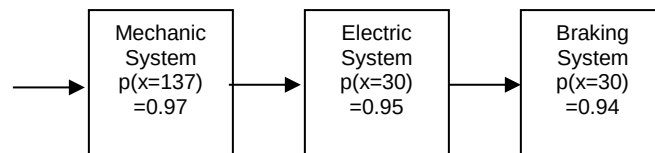


Figure 2 8. Graphic representation of unit 133 components.

$$\text{Systems probability} = 0.97 * 0.95 * 0.94 = 0.86621$$

(12)

Results

Once the probability of failure of a vehicle unit as a system is obtained,

programming shipping and delivery considering in-transit faults is possible. Moreover, the preventive maintenance routine would be done according to a sustained schedule, and corrective maintenance cost would reduce along with the in-transit faults. Table 11 shows the results for the total probability for delivery vehicle units.

Unit	Probability of failure
133	0.86621
243	0.76171
303	0.68722
119	0.69670
114	0.82196
147	0.91827
178	0.25659
180	0.05335
139	0.53616
181	0.79220
146	0.72594
174	0.95513
144	0.27563
168	0.17329
160	0.27135
151	0.30993
163	0.77344
152	0.30272
199	0.22888

137	0.00372
167	0.35391
147	0.19763
120	0.92132
145	0.89564
189	0.95358
121	0.03922
132	0.01913
154	0.39841
167	0.25914
195	0.54998
146	0.53996
156	0.81835
158	0.66590

Table 2. 11 Total probability for delivery vehicle units

This information allows the maintenance department chief to program preventive maintenance for units with higher probability of failure, such as the units 174 and 198. Furthermore, the personnel in charge of the assignment of the delivery units to each route, will chose the right vehicle based on the lower probability of failure, like unit 121.

Conclusion

Probability of failure calculus represents a tremendous tool for delivery companies,

being responsible for a better maintenance service program that could easily be seen in an overall customer service experience improvement.

To have a well-established preventive and corrective maintenance binnacle becomes an essential task for companies since that data becomes a factor to calculate the units' probability of failure. To do so, vehicle unit operators must be compromised to report any problem to the maintenance chief.

Acknowledgements

The authors would like to thank the Instituto Tecnológico de Orizaba and Consejo Nacional de Ciencia y Tecnología (CONACyT) for all the financial and technical support.

Referencias

- Daneshkhah A, S. N. (2017). Probabilistic sensitivity analysis of optimised preventive maintenance strategies for deteriorating infrastructure assets. *Reliability Engineering & System Safety*, 33-45.
- De la Torre, E. M. (2014). Herramienta para la evaluación del riesgo de robo en el autotransporte de carga. *Revista Electrónica Nova Scientia*, 438-469.
- Dounce, E. V. (1992). *Administración en el Mantenimiento*. México: CECSA.
- Gertbakh, I. (2000). *Reliability Theory with Applications to Preventive Maintenance*. New York: Springer.
- Hosford, J. (1960). Reliability Theory with Applications to Preventive Maintenance. *Operations Research*, 53-64.
- Joseph B. Bernstein, A. B. (2017). Reliability prediction with MTOL. *Microelectronics Reliability*, 91-97.
- Kapur, K. (1997). *Reliability in Engineering Design*. New York: John Wiley.
- Montgomery, H. (2005). *Probability and Statistic in Engeneering*. CECSA.

- Mora, L. A. (2009). *Mantenimiento: Planeación, ejecución y control*. Valencia, España: AlfaOmega.
- Naresky, J. (1970). Reliability definitions. *IEEE Trnas Relieb*, 198-200.
- Okoh C, R. R. (2017). Predictive Maintenance Modelling for Through-Life Engineering Service. *Procedia CIRP*, 196-201.
- Pham, I. (2003). *Handbook of reliability engineering. 1. Reliability (Engineering)*. New York: Springer.
- Postnikov I, S. V. (2017). A Methodology for Optimziation of Component Reliability of Heat Supply Systems. *Energy Procedia*, 3083-3088.
- Pourahmadi, F. (2017). Application of Game Theory n Reliability-Centered. *IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS*, 936-946.
- Sacristán, F. R. (2001). *Mantenimiento Total de la Producción TPM, Proceso de Implantación y Desarrollo*. España: FC.
- Seung-Kyum, C. (2007). *Reliability-based Structural Design*. New York: Springer.
- Skrzypczak I, S. M.-O. (2017). The Application of Reliability Analysis in Engineering Practice – Reinforced Concrete Foundation. *Procedia Engineering*, 144-151.
- Suthep B, K. T. (2015). Combining reliability-centered maintenance with planning methodology and applications in hard chrome plating plants. *International Journal of Technology*, 442-451.

Capítulo 3. Assignment of trailers with constraints of hours for maintenance

Submitted for publishing to: The 15th Annual International Conference on Industrial Engineering Theory, Applications & Practice. October 17- 20, 2010

Abstract: The companies dedicated to give services of terrestrial transport for the movement of goods, face the challenges of satisfying its clients as for cost, delivery in time and form. This makes companies seek the way of lowering their costs and that the programming and routing of his vehicles is optimal. When a service of load transportation is requested, the company of transport is responsible of the goods arriving to its destination in time and form, including the level of service and its overall cost to the client. The suitable maintenance of the trailers are of vital importance for companies of transport because it assures the clients, manufacturing companies, the availability of vehicles to transport their loads and the certainty that those will arrive in the requested time, therefore they will not face delays on their production. The company must balance the needs of corrective maintenance, which are immediate, with the programming of the preventive maintenance, which can be programmed and coordinated to assure the availability of its traffic park. The present work looks to improve the operations of the companies of terrestrial transport, looking for the balance between cost and quality in the service, considering the availability of tractors and containers, as well as, the maintenance.

1. Introduction

The company where the problem develops resides in the city of Rio Blanco, Veracruz, México. It counts with trailers that carry merchandise throughout all the Mexican Republic, these trailers must receive preventive maintenance after circulating certain amount of Time. The company programs the maintenance of the trailers, taking them from where they are located at those moments, back to the city of Rio Blanco, Veracruz. The present work looks for the effective assignment of the loads to the trailers on-demand. The preventive maintenance is of vital importance for the companies that are dedicated to transport merchandise by land. Maintenance is a combination of actions intended to retain

an item in, or restore it to, a state in which it can perform the function that it is required to in order to provide a given service. The Preventive Maintenance is defined as maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of the equipment. Crespo (2007). The maintenance classification is given in the figure 1.

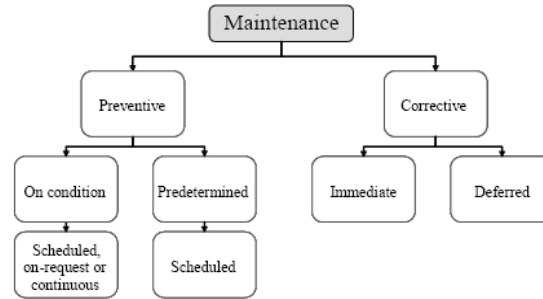


Figure 3. 1 Maintenance types according to EN 13306(2001)

2. The Linear Assignment Problem (LAP)

2.1 Linear Assignment Problem (LAP)

A commonly used intuitive introduction to the LAP as used by Hanan and Kurtzberg (1972) involves the assignment of n people to n jobs. For each job assignment, there is a related cost, c_{ij} , of assigning person i to job j . The objective is to assign each person to one and only one job in such a manner that minimizes the sum of each assignment cost, i.e., the total cost. Clayton (2005).

The mathematical programming formulation of the LAP has the form

$$\begin{aligned}
 L_n &= \min \sum_{i=1}^n \sum_{j=1}^n c_{ij} x_{ij} \\
 \text{s.t.} \\
 \sum_{i=1}^n x_{ij} &= 1, \quad j = 1, \dots, n \\
 \sum_{j=1}^n x_{ij} &= 1, \quad i = 1, \dots, n
 \end{aligned} \tag{1}$$

where the decision variables x_{ij} are binary: $x_{ij} \in \{0,1\}$; or non-negative: $x_{ij} \geq 0$, leading to an integer programming (IP) or linear programming (LP) formulations of the LAP, respectively. In the graph-theoretical setting, the LAP corresponds to finding a minimum-cost perfect matching in an edgeweighted bipartite graph; another useful interpretation of the LAP presents it as finding such a permutation of rows and columns of the cost matrix $C = (c_{ij})$ that minimizes the sum of the elements on the diagonal. Pavlo (2009)

2.2 The Generalised Assignment Problem

The Generalised Assignment Problem (GAP) can be described using the terminology as follows Wilson (1997).

$$\begin{aligned}
 \text{Min } z &= \sum_{i=1}^m \sum_{j=1}^n p_{ij} x_{ij} \\
 \text{st} \\
 \sum_{j=1}^n w_{ij} x_{ij} &\leq c_i \quad i \in M = \{1, 2, \dots, m\} \\
 \sum x_{ij} &= 1 \quad j \in N = \{1, 2, \dots, n\}, \\
 x_{ij} &= 0 \text{ or } 1 \quad i \in M, j \in N
 \end{aligned} \tag{2}$$

Given n items and m knapsacks with

p_{ij} = profit of item j if assigned to knapsack i ,

w_{ij} = weight of item j if assigned to knapsack i ,

c_i = capacity of knapsack i ,

Assign each item to exactly one knapsack so as to maximise the total profit, without assigning it to any knapsack a total weight greater than its capacity, i.e.,

$x_{ij} = 1$ if item j is assigned to knapsack i ,

$x_{ij} = 0$ otherwise.

2.3 Model considering time of maintenance

If we suppose that m workers exist and each one of them has certain amount of resources available and n tasks that must be carried out, we can modify the Generalised Assignment Problem in the following way: We take F_{ij} like P_{ij} . If P_{ij} is the profit that is obtained, F_{ij} is the factor that represents the proportion of kilometers that are left for the preventive maintenance of the trailer to be performed. When F_{ij} is closest to zero means that it only has a few kilometers left to travel before being programmed to maintenance. If F_{ij} is greater than 1, then that trailer does not have to be taken into account to make the task, then $0 \geq F_{ij} \geq 1$.

To calculate F_{ij} , the distance in kilometers that exists from city i to the city j is divided between total kilometers available by trailer subtracting the accumulated kilometers traversed by the trailer.

$$F_{ij} = \frac{D_{ij}}{T_i - A_i}$$

Where

F_{ij} : Proportion of kilometers left before the preventive maintenance of the trailer.

D_{ij} : Distance from city i to city j

T_i : Total kilometers available by trailer

A_i : Accumulated kilometers traversed by the trailer

R_i represents the number of kilometers left before maintenance of the trailer. R_i is the subtraction of the total kilometers available by trailer minus the accumulated kilometers.

$$R_i = T_i - A_i$$

Where

R_i : kilometers left before maintenance of the trailer

T_i : Total kilometers available by trailer

A_i : Accumulated kilometers traversed by the trailer

$$\begin{aligned}
\text{Min } z &= \sum_{i=1}^m \sum_{j=1}^n F_{ij} x_{ij} \\
\text{st} \\
\sum_{j=1}^n D_{ij} x_{ij} &\leq R_i \quad i \in M = (1, 2, \dots, m) \\
\sum x_{ij} &= 1 \quad j \in N = \{1, 2, \dots, n\}, \\
x_{ij} &= 0 \text{ or } 1 \quad i \in M, j \in N
\end{aligned} \tag{3}$$

R_i : Kms left before program to maintenance the trailer i -th

D_{ij} : Distance in Kms of the trailer i -th necessary to make j -th task.

F_{ij} : Factor between the distance of city i to arrive at city j and the total of kms programmed before maintenance of the trailer i -th - traversed kilometers of trailer i .

The first set of restrictions assures that no more resources than they are available for each trailer are used; the second set of restrictions strengthens the fact that each of the tasks is assigned to a single trailer.

When we minimize the factors we assure that the first trailers near the programmed maintenance are assigned. If we maximize them, we assign the task to the furthest ones to the programmed maintenance.

3. Example

The kilometers to be traversed by each trailer between maintenance services are of: 50000 kms.

3 services are required in the cities of Queretaro, Monterrey and Altamira. We have 1 trailer available in each of the cities of Rio Blanco, Coatzacoalcas, Monterrey, Querétaro and Altamira, for which we have the following kilometers traversed at the moment:

Table 3. 1 Kms traversed by trailer

Trailer	Kms crossed
1	20000
2	35000
3	45000
4	15000
5	10000

The distance between the different cities is, SCT (2010):

Table 3. 2 Distance between cities

City	Rio Blanco	Queretaro	Monterrey	Altamira	Coatzacoalcos
Rio Blanco	0	468	1151	643	333
Queretaro	468	0	696	632	800
Monterrey	1151	696	0	576	1484
Altamira	643	632	576	0	822
Coatzacoalcos	333	800	1484	822	0

F_{ij} factor = Distance between cities/(Distance between preventive maintenance - Kms crossed).

Table 3. 3 F_{ij} Factor

Ciudad	Rio Blanco	Queretaro	Monterrey	Altamira	Coatzacoalcos
Rio Blanco	0.000	0.016	0.038	0.021	0.011
Queretaro	0.031	0.000	0.046	0.042	0.053
Monterrey	0.230	0.139	0.000	0.115	0.297
Altamira	0.018	0.018	0.016	0.000	0.023
Coatzacoalcos	0.008	0.020	0.037	0.021	0.000

3.The developed model

$$\begin{aligned} \text{MIN} = & 0.016*x_{11} + 0.038*x_{12} + 0.021*x_{13} + \\ & 0.139*x_{21} + 0*x_{22} + 0.115*x_{23} + \\ & 0.020*x_{31} + 0.037*x_{32} + 0.021*x_{33}; \end{aligned}$$

$$468*x_{11} \leq 50000 - 20000;$$

$$1151*x_{12} \leq 50000 - 20000;$$

$$643*x_{13} \leq 50000 - 20000;$$

$$696*x_{21} \leq 50000 + 45000;$$

$$0*x_{22} \leq 50000 + 45000;$$

$$576*x_{23} \leq 50000 + 45000;$$

$$800*x_{31} \leq 50000 + 10000;$$

$$1484*x_{32} \leq 50000 + 10000;$$

$$822*x_{33} \leq 50000 + 10000;$$

$$X_{11} + X_{21} + X_{31} = 1;$$

$$X_{12} + X_{22} + X_{32} = 1;$$

$$X_{13} + X_{23} + X_{33} = 1;$$

$$X_{11} + X_{12} + X_{13} = 1;$$

$$X_{21} + X_{22} + X_{23} = 1;$$

$$X_{31} + X_{32} + X_{33} = 1;$$

$$X_{ij} = 0 \text{ or } 1.$$

Solved in Lingo version 10, the results are:

```
Global optimal solution found.
Objective value:                0.3700000E-01
Extended solver steps:          0
Total solver iterations:         0
```

Variable	Value	Reduced Cost
X11	1.000000	0.1600000E-01
X12	0.000000	0.3800000E-01
X13	0.000000	0.2100000E-01
X21	0.000000	0.1390000
X22	1.000000	0.000000
X23	0.000000	0.1150000
X31	0.000000	0.2000000E-01
X32	0.000000	0.3700000E-01
X33	1.000000	0.2100000E-01

Figure 3. 2 Results of the model.

3.1 Interpretation of results

The objective function has a result of 0.037, which is the smaller proportion of kilometers that can be assigned to each trailers for each of the tasks.

As shown in figure 2, the trailer at city 1 must be assigned to the task 1, the trailer at city 2 must be assigned to task 2 and the trailer at city 3 must be assigned to task 3.

4. Conclusions.

The proposed model assigns the trailers to the given tasks considering their time of availability before going through adequate preventive maintenance. In addition, it considers the restriction of the kilometers left before carrying out the preventive

maintenance of the trailers. Furthermore, a mean to calculate the proportion of time for preventive maintenance of the trailers is proposed. The following step is to generate the function of probability of the maintenance for the transport company and to consider it in the model. In addition, to solve it by means of a heuristic because the generalized assignment problem is considered NP-hard

5. References

Crespo A. (2007). *The Maintenance Management Framework*. Springer, Piscataway, NJ, USA

EN 13306:2001, (2001) *Maintenance Terminology*. European Standard. CEN (European Committee for Standardization), Brussels.

Pavlo A., Panos P.(2005). *Random Assignment Problems*. European Journal of Operational Research, Volume 194, Issue 1, 1 April 2009, Pages 1-17.

SCT: Secretaria de Comunicaciones y Transportes,

http://aplicaciones4.sct.gob.mx/sibuac_internet/ControllerUI?action=cmdEscogeRuta

Wilson, J. (1997). *A Simple Dual Algorithm for the Generalised Assignment Problem*. Journal of Heuristics, 2:303-311 (1997)

Conclusiones y trabajos futuros

Se obtuvo un procedimiento personalizado para la empresa bajo estudio, con el cual, se establece la supervivencia de los tractocamiones de reparto, esto quiere decir, que los tractocamiones no presentarán falla alguna siempre y cuando se cumpla con el mantenimiento hasta la probabilidad de falla establecida por el CEO de la organización.

Se identificó la distribución probabilística del sistema y subsistema, en los cuales se dividió el tractocamión, adecuando los datos históricos con los que contaba la empresa para cada uno de los tractocamiones utilizados en el estudio.

Se obtuvieron los parámetros del tiempo de falla de los subsistemas de los tractocamiones, tales como: intervalo de confianza al 95% de los kilómetros recorridos entre descomposturas y un intervalo de confianza al 95% de la tasa de riesgo (probabilidad de fallo).

El modelo de asignación asegura que cuando se minimice se asignen primero los tractocamiones que ya estén más cercanos al mantenimiento programado y si se maximiza se asignan primero los más lejanos al mantenimiento programado

Trabajos futuros

Crear un sistema de alertas que permita dar una notificación a la persona encargada de las actividades de mantenimiento dentro de la organización del momento ideal para ejecutar labores de mantenimiento de acuerdo a la probabilidad de falla.

Implementar el AMEF en un caso real de la presencia de fallas dentro de alguno de los subsistemas críticos de los tractocamiones.

Referencias

- Crespo A. (2007). The Maintenance Management Framework. Springer, Piscataway, NJ, USA
- Daneshkhah A, S. N. (2017). Probabilistic sensitivity analysis of optimised preventive maintenance strategies for deteriorating infrastructure assets. Reliability Engineering & System Safety, 33-45.
- De la Torre, E. M. (2014). Herramienta para la evaluación del riesgo de robo en el autotransporte de carga. Revista Electrónica Nova Scientia, 438-469.
- Dounce, E. V. (1992). Administración en el Mantenimiento. México: CECSA.
- EN 13306:2001, (2001) Maintenance Terminology. European Standard. CEN (European Committee for Standardization), Brussels.
- Gertbakh, I. (2000). Reliability Theory with Applications to Preventive Maintenance. New York: Springer.
- Hosford, J. (1960). Reliability Theory with Applications to Preventive Maintenance. Operations Research, 53-64.
- Joseph B. Bernstein, A. B. (2017). Reliability prediction with MTOL. Microelectronics Reliability, 91-97.
- Kapur, K. (1997). Reliability in Engineering Design. New York: John Wiley.
- Montgomery, H. (2005). Probability and Statistic in Engeneering. CECSA.
- Mora, L. A. (2009). Mantenimiento: Planeación, ejecución y control. Valencia, España: AlfaOmega.
- Naresky, J. (1970). Reliability definitions. IEEE Trnas Relieb, 198-200.
- Okoh C, R. R. (2017). Predictive Maintenance Modelling for Through-Life Engineering Service. Procedia CIRP, 196-201.
- Pavlo A., Panos P.(2005). Random Assignment Problems. European Journal of Operational Research, Volume 194, Issue 1, 1 April 2009, Pages 1-17.
- Pham, I. (2003). Handbook of reliability engineering. 1. Reliability (Engineering). New York: Springer.
- Postnikov I, S. V. (2017). A Methodology for Optimziation of Component Reliability of Heat Supply Systems. Energy Procedia, 3083-3088.
- Pourahmadi, F. (2017). Application of Game Theory n Reliability-Centered. IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, 936-946.
- Sacristán, F. R. (2001). Mantenimiento Total de la Producción TPM, Proceso de

Implantación y Desarrollo. España: FC.

SCT: Secretaría de Comunicaciones y Transportes,
http://aplicaciones4.sct.gob.mx/sibuac_internet/ControllerUI?action=cmdEscogeRuta

Seung-Kyum, C. (2007). Reliability-based Structural Design. New York: Springer.

Skrzypczak I, S. M.-O. (2017). The Application of Reliability Analysis in Engineering Practice – Reinforced Concrete Foundation. Procedia Engineering, 144-151.

Suthep B, K. T. (2015). Combining reliability-centered maintenance with planning methodology and applications in hard chrome plating plants. International Journal of Technology, 442-451.

Wilson, J. (1997). A Simple Dual Algorithm for the Generalised Assignment Problem. Journal of Heuristics, 2:303-311 (1997)

Apéndice A. Evidence of publication on Advances and Applications in Statistics



Advances and Applications in Statistics (0972-3617)
Corresponding Address:
Pushpa Publishing House
Vijaya Niwas, 198, Mumfordganj, Prayagraj -211002, INDIA
<http://www.pphmj.com>

General Manager
arun azad
arun@pphmj.com

Abstracting & Indexing
Emerging Sources
Citation Index (ESCI)
(New edition of Thomson Reuters' Web of Science)
Excellence in Research for
Australia (ERA 2018 ID: 883)
Google-based Journal Impact
Factor: 0.59
Google-based 5-Year CiteScore
(Average Citations per Article): 1.80
AMS Digital Mathematics Registry
CrossRef DOI databases
Current Index to Statistics Academic
Current Index to Statistics
EBSCOhost
Google Scholar
IndexCopernicus
J-Gate
ProQuest
RD Journal Impact: 0.05
(ResearchGate)
Scilit (Switzerland)
Statistical Theory and Method
Abstracts
Ulrichweb
Zentralblatt MATH
Some papers have been indexed by
PubMed.



Editorial Board of ADAS
Kuldeep Kumar, Australia
Gauss M. Cordeiro, Brazil
Jinyu Li, China
Xinmin Li, China
Angelo Mazza, Italy
Antonio Di Crescenzo, Italy
Sergei A. Nemnyugin, Russia
Kuan-Fu Shen, Taiwan
Shen-Ming Lee, Taiwan
Tsung-Chi Cheng, Taiwan
Yuan Chung Shew, Taiwan
Cem Kadilar, Turkey
Guvenc Arslan, Turkey
Fuxia Cheng, USA
Karan P. Singh, USA
Lianfen Qian, USA
Tomasz J. Kozubowski, USA
Wei Ning, USA
Xiaoqian Sun, USA
Xuan Li, USA

Our reference no.: PPH-2004022-ADAS

To
Professor Marcos Salazar Medina
Tecnológico Nacional de México Campus Instituto
Tecnológica de Oeizaba
Orizaba, Ver., México

May 29, 2020

Dear Professor Medina,

I am happy to inform you that your paper entitled "*Motor equipment reliability analysis*" jointly written with José Luis Martínez Flores, Diana Sánchez Parida and Patricia Cano Olivo has been accepted for publication in the Advances and Applications in Statistics.

Thank you for submitting your work to Advances and Applications in Statistics.

Yours sincerely

(ARUN AZAD)

22 research journals in the field of Mathematical Sciences, Statistics, Computer Science and Engineering are being presently published by us.

Apéndice B. Evidence of participation in 15th Annual International Conference on Industrial Engineering, Theory, Applications & Practice



The 15th Annual International Conference on Industrial Engineering Theory, Applications & Practice October 17- 20, 2010 Mexico City, Mexico

July 6, 2010

M. Salazar

Subject: Abstract acceptance of your paper at the IIE 2010 Conference in Mexico City, Mexico

Dear Author:

The organizing committee has accepted your abstract and invites you to present your paper titled *"ASSIGNMENT OF TRAILERS WITH CONSTRAINTS OF HOURS FOR MAINTENANCE"* at the 15th Annual International Conference on Industrial Engineering Theory, Applications & Practice to be held from October 17- 20, 2010 in Mexico City, Mexico.

Please note that this acceptance, as well as the publication of your paper in the Conference Proceedings is subject to attending and presenting your paper at the conference and registering for the conference. The registration can be done online using the PayPal system at our conference portal (http://www.ijenr.org/index.php?option=com_jumi&fileid=15&Itemid=77).

The deadline for submission of the full paper in electronic format is August 23, 2010. The paper has to be submitted through the conference portal. For more information about the paper format, please visit the conference portal http://www.ijenr.org/index.php?option=com_jumi&fileid=11&Itemid=74.

We are looking forward to receiving your manuscript soon and meeting you in Mexico City. We have several exciting things planned, so please keep checking the conference web page for program updates http://www.ijenr.org/index.php?option=com_jumi&fileid=12&Itemid=75

Sincerely,

A handwritten signature in black ink, appearing to read 'Anand'.

Anand Subramanian PhD, CSSBB
Organizing Committee
IIE 2010 Conference
Mexico City, Mexico
Email: IIE@jfa-inc.com