# A Framework to Support Automobile Maintenance Decisions in Militaries Using Analytic Hierarchy Process

NVL De Silva[1#], IDD Nishanka[2] and HSC Perera[3]

[1]*Department of Marine Engineering, Faculty of Engineering, General Sir John Kotelawala Defence University, Sri Lanka*
[2]*Department of Electrical Electronic and Telecommunication Engineering, Faculty of Engineering, General Sir John Kotelawala Defence University, Sri Lanka*
[3]*Faculty of Engineering, Sri Lanka Institute of Information Technology, Sri Lanka*

#virajdesilva@kdu.ac.lk

***Abstract**: The operational availability and reliability of automobiles significantly affect the smooth functioning of a military system. Militaries own massive automobile fleets, comprising automobiles with different capabilities. However, a military organization is unable to attend to all repair/ maintenance needs of its fleet concurrently, thus maintenance needs to be prioritized. Further, it is unobvious that a military organization equip adequate resources to attend all maintenance in-house, as a result, some portion of maintenance is to be outsourced. However, military expectations of outsourcing significantly deviate from a profit-oriented business firm, thus identifying the right maintenance activity to be outsourced is crucial, but challenging.*
*This paper develops a framework to support automobile maintenance decisions using Analytic Hierarchy Process (AHP). The framework provides an easier and simpler platform for maintenance prioritization and selecting the best maintenance approach i.e insourcing/ outsourcing. In the proposed approach, maintenance prioritization is achieved based on the criticality of automobiles. The criteria required for maintenance prioritization and maintenance approach selection are selected from previous literature. Then, their relative importance is calculated using AHP. Finally, two scoring models are developed to calculate automobile criticality and to select the maintenance approach. The simplicity of the scoring models makes them more user-friendly and numerical results enable fast, but wise decision-making for maintainers.*

***Keywords**: Automobile maintenance, decision support framework, maintenance prioritization, best maintenance approach, Analytic Hierarchy Process.*

## 1. Introduction

*A. Background of the study*

Automobiles are widely used in militaries for numerous applications. It would be unthinkable for any military operation to occur without the adequate support of automobiles. Their ability to support troop movements, travel over difficult terrains, and haul tons of supplies makes them invaluable to any military organization. Further, automobile transportation is the most popular mode of transportation used by most militaries in the world, as it is the cheapest way to physically connect scattered military units. Therefore, to cater to numerous transportation needs, militaries maintain massive automobile fleets irrespective of their specialized medium of operation. The operational readiness of the armed forces is highly dependent on the state of its equipment (Goh & Tay, 1995). Therefore, mere owning a large automobile fleet is not sufficient and it is essential to maintain desired operational availability and reliability of the fleet.

The performance of military ground vehicles rapidly deteriorates due to the high rate of operation and extreme operating environments (Rabeno & Bounds, 2009). Further, they degrade with age and ultimately become non-operational if no maintenance is carried out (Zhang & Liu, 2002). Maintenance affects machinery reliability (Endrenyi et al., 2001). Properly maintained equipment will have higher availability and longer life. On the other hand, poorly maintained equipment fail frequently (Swanson, 2003). Therefore, the desired output of machinery can be experienced only if it is maintained properly. Operating life, operational reliability and failure consequences of the automobile are influenced by the quality of maintenance (James et al., 2017). Accordingly, for consistent maintenance of desired performance of military automobiles, timely maintenance is vital.

The military automobile fleets comprise automobiles belonging to a wide range of categories. These automobiles are built by different manufacturers incorporating different technologies which have made the defects identification and rectification of them very complicated (Chen, 2014). However, due to the importance of the role played by automobiles, the military spends a significant portion of its allocated budget on the maintenance of the automobile fleet. Development of maintenance infrastructure, procurement of spare parts, tools and equipment, training of labour and outsourcing services are key areas that consume allocated military resources. However, even after all the expenditures and efforts, some military organizations struggle to meet the expected minimum level of performance of automobiles. The deep-rooted cause behind this issue is the adaptation of inappropriate maintenance approaches led by faulty Maintenance decisions.

*B. Research Problem*

Militaries are equipped with massive automobile fleets and consistent maintenance of its operational availability to the highest degree is crucial. However, maintenance management of a large automobile fleet is challenging and burdensome to maintainers. They should look into numerous aspects such as prioritizing maintenance needs, resource availability, in-house capabilities, possible alternatives if in-house capabilities are not adequate, the impact of such alternatives…etc., before the maintenance decision. Therefore, the availability of a framework to support maintenance decisions simplifies maintenance management in such a complex system.

However, military expectations on maintenance differ from the corporate world and thus, direct application of the decision support approach used in the corporate sector to the military context may lead to destructive repercussions. Therefore, only a decision support framework that finely fits with the military environment contributes to functioning maintenance management system effectively.

*C. Research Objective*

The objective of this research is three folds; to develop a method to identify maintenance priorities in a large automobile fleet, to identify military expectations on automobile maintenance and finally, to design a decision support framework applicable in the military environments to select the best maintenance approach for a given repair/ maintenance need.

## 2. Literature Review

*A. Maintenance Prioritization*

Prioritization of maintenance operations can be an effective decision support tool for maintenance engineers (Ni and Jin, 2012). It is very seldom that companies have adequate resources, monetary strength or organizational capabilities to work on all possible improvements in a manufacturing system at the same time (Bengtsson, 2011). When there are limited maintenance resources it is imperative to identify critical machinery, which is in real need of maintenance and prioritize them.

*B. Classification of automobiles*

In a complex machinery system with multiple machines, the focus of maintenance on a single machine is not effective. In such a case, classifying machines into groups will simplify maintenance operations. Machine classification is the basis for any maintenance planning (Rosqvist, Laakso and Reunanen, 2009; Waeyenbergh and Pintelon, 2002) Classification enables managers to focus on the most critical machines and facilitates the decision-making process (Syntetos, Keyes and Babai 2009). According to Stadnicka, Antosz and Ratnayake (2014), when machines are classified into groups, maintenance prioritization decisions can be made considering common characteristics of all machines in the group as a whole, on the other hand, it ease up the decision-making process (Gopalakrishnan and Skoogh, 2018).

Different studies explain the different basis for machinery classification. However, this study selected criticality-based classification approach, as it is the most adaptable in the military environment.

*C. Classification based on the criticality*

A critical machine is a machine that can make the highest impact for the intended purpose of a machinery system (Petrovic et al., 2008). Therefore, significant attention should be paid to the maintenance of a critical machine over to others (Baglee & Knowles, 2010).

Criticality analysis provides the basis for deciding what assets should be given priority in a maintenance management program (Márquez et al., n.d.). Criticality classification is a common way to group the different machines in a machinery system for a focused maintenance effort (Bengtsson, 2011). Several methods have been discussed in the literature for determining equipment criticality (Masmoudi et al., 2014). Criticality assessment performed using multiple factors is one of the most common ways (Márquez et al., n.d.). Gopalakrishnan and Skoogh (2018) state that assessing criticality through multiple factors, enables finding the critical machine from many different perspectives and grouping them together in terms of maintenance purposes.

*D. Criteria for criticality assessment*

Masmoudi et al., (2014), have designed a model to determine the maintenance strategy of medical devices based on equipment criticality. In that model, the criticality of medical devices is assessed using five (05) criteria; function, degree of maintenance complexity, level of importance of the mission, risk, and age and 6 sub-criteria; rate of use, availability of alternative devices, frequency of failures occurrences, detectability, and impact on the production of care and impact on safety. However, by comprehensively analyzing the factors used by Masmoudi et al. (2014) for criticality assessment and relevancy of them for automobile criticality in the military context, the followings are selected as the main criteria for criticality assessment of automobiles;

- Degree of complexity of maintenance
- Function
- Utilization
- Availability of alternative devices
- Age

*E. Maintenance approaches*

Most military organizations in the world owns in-house repair facilities to cope with their own machinery maintenance needs. However, it is very seldom that organizations equip with adequate in-house resources or capabilities to work on all maintenance activities at the same time (Bengtsson, 2011). Therefore, the respective military organization is compelled to outsource some part of maintenance needs as a measure to maintain the desired operational state of the machinery fleet.

Maintenance outsourcing is a successful approach widely applied by organizations in both military and corporate world. Outsourcing helps firms to focus and develop their core business activities. Simply, it gives a peace of mind for the firm (Wanigasinghe & Mahakalanda, 2018). However, military expectations on outsourcing differ from private businesses. Military organizations are non-profit-oriented and military commanders are not rewarded with profits and penalized with losses; nor can military units be taken over or made bankrupt (Hartley, 2004). Also, military leaders cannot wash their hands merely by delegating responsibility to an outside firm. Therefore, in the military environment, the maintenance approach i.e. insourcing/ outsourcing, is to be chosen very carefully and it should meet the organizational expectations of the respective military unit.

*F. Automobile maintenance*

Automobile maintenance falls under the service industry, where reliability and assurance of quality are essential for earning customers' goodwill for the maintenance service providers (James et al., 2017). The user is satisfied only when what the user expected from the repairer with respect to repair/ maintenance of his/ her automobile is fulfilled by the service received. Performance of repairer attributes to performance of maintenance (James et al., 2020), thus, it is super important to choose the right firm for maintenance. In most cases, the choice of repairer is governed by the preference of the decision makers (Ahmadi et al., 2010). The maintenance approach which satisfies user expectations the most could be considered the best approach corresponding to the organization.

Accordingly, service characteristics which lead to user satisfaction can be regarded as maintenance expectations of users in the field of automobile maintenance. In this study, we propose a novel mechanism to select the best maintenance approach for automobile maintenance based on user expectations in a local military context. During that both insource and outsource approaches were tested separately to ascertain their succession of meeting user expectations.

*G. User expectations on automobile maintenance*

Previous literature has discussed various factors relevant to user satisfaction and customer retention at automobile workshops. Our proposed method considers the following five (05) criteria as the user expectations of automobile maintenance for evaluating the best automobile maintenance service provider, thereby the best maintenance approach out of insourcing and outsourcing;

- Time taken for the maintenance
- Cost
- Warranty
- Quality of maintenance
- Reliability of service provider

## 3. Methodology

This research is conducted following the overall methodology shown in Figure 1, which shows the sequence of activities that are used to achieve the set objectives. The secondary information required for the study is gathered through a literature survey, expert opinion and questionnaire survey. Information gathered through the literature survey is presented to a panel of field experts to test its validity in the local military context. The researcher decided to use a quantitative approach under the survey strategy and survey data is analyzed with Analytic Hierarchy Process (AHP) using Expert Choice™ software. During this study, the secondary data is used to calculate the relative weights of selected criteria using Analytic Hierarchy Process (AHP)

To our knowledge, no decision support procedure is explained in literature for maintenance management of large automobile fleets, especially for militaries. Therefore, the researcher develops the hierarchical decision support procedure illustrated in figure 2, with a deep understanding of essential elements to be included, which ultimately enables to select the best maintenance approach in three simple steps;

Step 1: Calculate the criticality and thereby identify the criticality class an automobile belongs.

Step 2: Determine the need for outsourcing based on the non-availability of in-house capabilities.

Step 3: Determine whether to insource or outsource based on the extent each approach fulfils organizational expectations

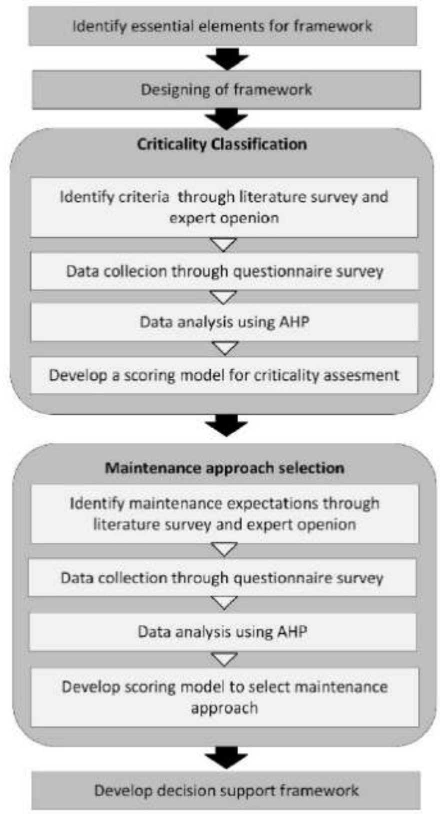


Figure 1. Research design

Source: Developed by authors

The procedure for formulating the proposed decision support model is explained in detail below;

*A. Calculate automobile criticality*

The availability of a simpler method to calculate automobile criticality is very helpful in maintenance prioritization, especially when there are thousands of automobiles in the fleet. It supports identifying critical automobiles easier and faster. Therefore, the objective of this section is to develop a novel, but user-friendly approach to calculating automobile criticality. In that case, we propose a simple formula to calculate an automobile's criticality and then develop a scoring model that enables us to calculate the criticality of an automobile easily;

$$Criticality\ (C) = \sum_{i=A}^{n} (W_i S_i) \qquad (1)$$

Where,

$W_i$ – Relative weight of $i^{th}$ criticality criterion

$S_i$ – Automobile's score with respect to $i^{th}$ criticality criterion

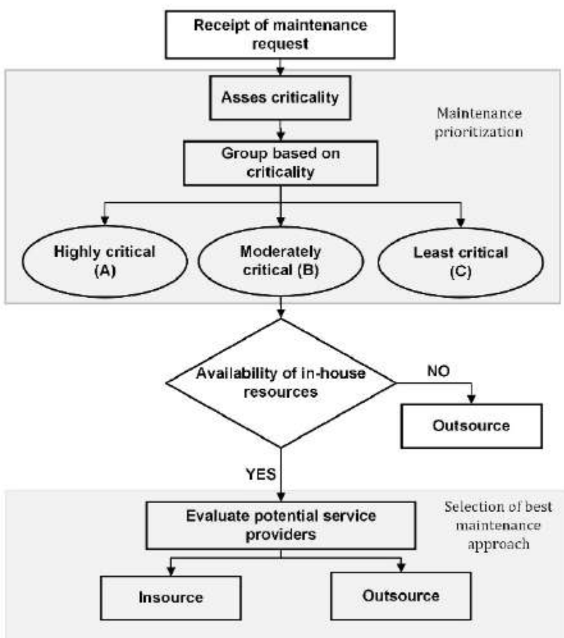


Figure 2. Proposed decision support model

Source: Developed by authors

*B. Analytic Hierarchy Process (AHP) to calculate the relative weights of criteria*

Criticality assessment and maintenance approach selection involve multi-criteria. There are several techniques to solve multi-criteria decision-making problems and amoung them Analytic Hierarchy Process (AHP) is a widely used and well-tested method (Perera & Costa, 2008). AHP is a Multi-Criterion Decision Making (MCDM) method which breaks down the question into smaller constituent parts. It is a computational technique for decision-making and involves in the ranking of decision elements and then making comparisons among pairs of clusters (Saaty, 1990). It is a widely used method for solving choice and ranking problems (Ishizaka et al., 2012). In AHP, relative weights of possible decision alternatives or outcomes are given a functional value based on a mathematical representation of pairwise comparisons. (Taghipour et al., 2011) employed AHP to determine criteria and sub-criteria weighting values during the criticality assessment of medical equipment.

Most of the current quantitative techniques use the weighted scoring method as a systematic way to calculate asset criticality (Duffuaa, Raouf and Campbell, 2000). During our proposed model, we use AHP to find relative weights of criteria used for criticality assessment and maintenance approach selection. Accordingly, the AHP models illustrated in Figure 3 and Figure 4 is formulated for automobile criticality assessment and maintenance approach selection respectively.

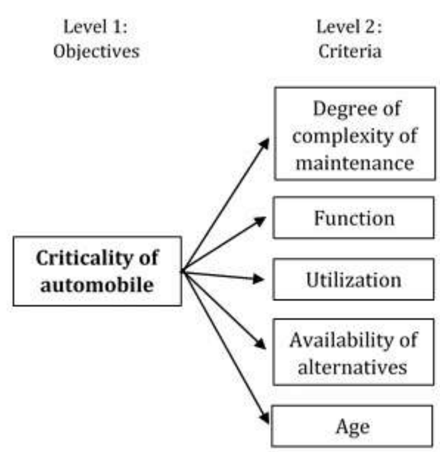


Figure 3. AHP model for the criticality assessment

Source: Developed by authors

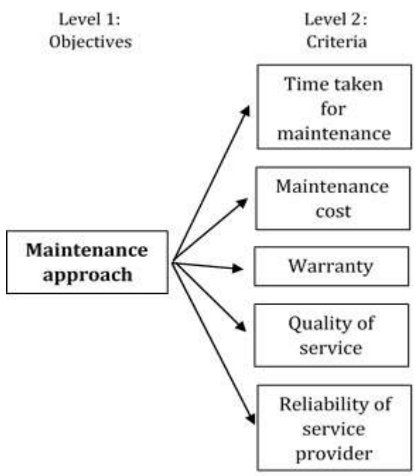


Figure 4. AHP model for selecting best maintenance approach

Source: Developed by authors

*C. Formulating a scoring model to criticality assessment*

Criteria used for the criticality assessment are layered considering their behavior in the military context. Then a unit score for each level is assigned based on its degree of impact in the following manner;

*1). Degree of complexity of maintenance (A): ):* Masmoudi et al. (2014) have proposed three levels under this criterion to calculate the criticality of medical devices. In our model, we propose five levels matching automobile maintenance with assigned scores from 1 to 5 according to its degree of impact as tabulated in table 1;

Table 1: The proposed levels and assigned unit scores of the criterion "Degree of complexity of maintenance"

| Level | Score |
|---|---|
| Highly complicated maintenance, OEM involvement is essential | 5 |
| Complicated maintenance; requires expert skills and specially designed tools/ infrastructure | 4 |
| Moderately complicated maintenance; requires expert skills but can be managed with ordinary tools | 3 |
| Ordinary maintenance; can be managed with ordinary skills and tools | 2 |
| Very basic level maintenance; no workshop assistance is required | 1 |

Source: Developed by authors

*2). Function (B):* The function is the specific purpose particular automobile is used. In the proposed model, five (5) levels for this criterion are assigned based on the range of applications and unit scores are assigned from 1 to 5 based on its degree of impact as tabulated in table 2;

Table 2: The proposed levels and assigned unit scores of criterion "Function"

| Level | Score |
|---|---|
| Emergency vehicles | 5 |
| VVIP/ VIP transportation | 4 |
| Combat vehicles | 3 |
| Logistics transportation | 2 |
| Troops transportation | 1 |

Source: Developed by authors

*3). Utilization (C):* The utilization indicated the numerical representation of the usage of the particular automobile. The average monthly mileage of an automobile is considered as the utilization of a particular automobile in this model. Accordingly, unit scores for each level are assigned based on the intensity of usage in a month (X km/month) as illustrated in table 3;

Table 3: The proposed levels and assigned unit scores of criterion "Utilization"

| Level | Score |
|---|---|
| 6000 < X | 5 |
| 4500 < X ≤ 6000 | 4 |
| 3000 < X ≤ 4500 | 3 |
| 1500 < X ≤ 3000 | 2 |
| X ≤ 1500 | 1 |

Source: Developed by authors

*4). Availability of Alternative Devices (D):* Five levels are introduced with respect to the criterion "Availability of alternative devices" considering the possibility to find an alternative to perform the desired function. Then, unit scores are assigned to each level based on the ease of finding an alternative as illustrated in table 4:

*5). Age:* It indicates the actual age (Y) of the automobile. For this criterion, five levels were proposed as shown in table 5.

Table 5: The proposed levels and assigned unit scores of criterion "Availability of Alternative Devices"

| Level | Score |
|---|---|
| No alternatives available for the desired function | 5 |
| It is very hard to find alternative. Further, selected alternative may disturbs an another function in the system | 4 |
| An alternative can be found with difficulties and it perform the desired purpose | 3 |
| Alternatives available and purpose can be managed | 2 |
| Ample of alternatives available and it is very easy to select one | 1 |

Source: Developed by authors

Table 4: The proposed levels and assigned unit scores of criterion "Age"

| Level | Score |
|---|---|
| 20 years < Y | 5 |
| 15 years < Y ≤ 20 years | 4 |
| 10 years < Y ≤ 15 years | 3 |
| 5 years < Y ≤ 10 years | 2 |
| Y ≤ 5 years | 1 |

Source: Developed by authors

The layout of the scoring model developed in our study is illustrated in Figure 5, and it is designed using basic computational features of Microsoft Excel software. More importantly, this model can be put into practice with diminutive training for the operator due to its simplicity. The model indicates the criticality value of the respective automobile in the "criticality value" column when the unit scores are fed by the operator in respective raw specific to the maintenance need. In that, the criticality is calculated using formula 1. More importantly, the criticality of any number of automobiles can be generated very easily with our simpler model.

The criticality value calculated using the proposed model is case-oriented. In other words, the criticality value of an automobile differs from case to case based on its association with criteria at the time of assessment. Therefore, this enables maintainers to get the contextual criticality of an automobile and thereby classify them in order to prioritize maintenance. Figure 5: scoring model to calculate automobile criticality. Figure 5: Scoring model to calculate automobile criticality.

*D. Formulating a scoring model to evaluate service providers.*

The objective of this section is to develop a novel method to select the best maintenance approach for a specific repair/ maintenance need. We propose a mechanism to evaluate potential service providers based on their ability to meet user expectations. In the proposed method, the in-house repair facility is also considered a separate repair entity and it is evaluated against potential outside service providers.

The availability of a numerical comparison method enables faster identification of the best potential service provider, therefore it is more efficient rather to other methods. Accordingly, we develop a scoring model to evaluate service providers that produce a score for each potential repairer based on their ability to meet organizational expectations with respect to particular repair/ maintenance. The following simple formula is used to calculate the individual score of potential repairers;

| SCORING MODEL 01: TO CALCULATE CRITICALITY OF AUTOMOBILE | | | | | | | |
|---|---|---|---|---|---|---|---|
| Criteria | | Degree of complexity of maintenance | Function | Utilization | Availability of alternatives | Age | Criticality value |
| Weight | | $W_A$ | $W_B$ | $W_C$ | $W_D$ | $W_E$ | |
| Unit score | 5.0 | OEM assitance required | Emergency vehicle | 6000< X | No alternative available | 20< Y | |
| | 4.0 | Expert skills & special tools required | VIP transportation | 4500< X ≤ 6000 | Very hard to find and disturbs another function | 15 < Y ≤ 20 | |
| | 3.0 | Expert skills required | Combat vehicle | 3000< X ≤ 4500 | Can be managed with difficulties | 10 < Y ≤ 15 | |
| | 2.0 | Managable with ordinary tools/ skills | Logistics transportation | 1500< X ≤ 3000 | Alternative available | 5 <Y ≤ 10 | |
| | 1.0 | Very basic level maintenance | Troop transportation | 1500 ≤ X | Ample of alternatives available | Y ≤ 5 | |
| Vehicle No. | | | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

Figure 5. The layout of scoring model to calculate automobile criticality
Source: Developed by authors

Score (x) = W*w*Y*x* + W*q*Q*x* -W*t*T*x* – W*c*C*x*
(2)

Where;

W*w* = Relative weight for Warranty
W*q* = Relative weight for Quality of service
W*t* = Relative weight for Time taken for maintenance
W*c* = Relative weight for Maintenance cost

Y*x* = Firm *x*'s score for warranty
Q*x* = Firm *x*'s score for quality of service
T*x* = Firm *x*'s score for maintenance time
C*x* = Firm *x*'s score for maintenance cost

Maintenance expectations used in formula 2 are having a different scale of measurement. Therefore, to scale them, we use normalized data and the Min-Max normalization technique indicated in formula 3, is used for normalization. Min-Max normalization technique provides linear transformation on original data within a given range. (Saranya & Manikandan, 2013).

$$V' = \left(\frac{V - \min(A)}{\max(A) - \min(A)}\right) \text{ x } (\text{new} \max(A) - \text{new} \min(A)) + \text{new} \min(A)$$
(3)

Where;

$V'$ – New value in required range (normalized value)
$V$ – *Value* to be normalized
$\min(A)$, $\max(A)$ – Minimum and maximum value of the original range of attribute
new $\min(A)$, new $\max(A)$ – Minimum and maximum value of the new range of attribute
$A$ – Attribute

Figure 6, illustrates the layout of the developed model. It is designed using Microsoft Excel software and it generates the score of each service provider by formula 2. The "Total Score" indicates how far each service provider meets user expectations with respect to a given maintenance need. With that result, the decision maker can come to a technical conclusion about whether to insource or outsource. For example, if the in-house repair facility scores the highest, the most appropriate approach would be insourcing, and outsourcing is the best when any outside service provider scores the highest. However, if the decision is to outsource, our model does not recommend selecting the service provider with the highest score as the best service provider for outsourcing as numerous other aspects pertinent to local organization need to be considered when selecting a service provider as explained in the literature

## 4. Case Implementation

The above framework was implemented in Sri Lanka Navy (SLN) which is equipped with a massive automobile fleet consisting of 4000 + automobiles. SLN comprises approx. 1000 technical workforce specialized in various subfields of automobile maintenance and repairs are undertaken at seven repair yards located at seven geographical locations.

SLN operates with an ageing automobile fleet and the majority of automobiles in the fleet are aged beyond 10 years. However, SLN pays

| SCORING MODEL 02 : TO SELECT MAINTENANEC STARTEGY | | | | | | |
|---|---|---|---|---|---|---|
| Criticality class : | | | | | | |
| Automobile No. : | | | | Job No. | | |
| Service Provider | Maintenance Expectations | | | | | Total score |
| | Maintenance Duration | Maintenance cost | Warranty | Quality of Maintenance | Reliability of Service Provider | |
| | (Realative weight) | (Realative weight) | (Realative weight) | (Realative weight) | (Realative weight) | |
| SLN | | | | | | |
| X | | | | | | |
| Y | | | | | | |
| Z | | | | | | |

Figure 6. Scoring model to evaluate service providers Source: Developed by authors

significant attention to the consistent maintaining of operational availability of its automobile at the highest possible level, as automobile transportation is the cheapest, but the fastest available mode of transportation for SLN needs. Accordingly, SLN annually spends a huge portion of its allocated budget for the maintenance of its large automobile fleet.

Automobiles are extensively used in SLN to cater to various transportation needs of scattered navel units. The extensive utilization and age cause the higher failure frequency of automobiles in the SLN fleet.

As a result, the repair yard receives about 20-30 maintenance requests daily as on average that exhausts available in-house maintenance capabilities. Presently there is no systematic mechanism with SLN to prioritize these maintenance requests.

Outsourcing is a key maintenance approach adopted by SLN for decades and a considerable number of maintenance activities are outsourced every year. However, these outsourcing decisions are mostly driven by the decision maker's discretion not backed by any scientific analysis. It can be the identifiable main deep-rooted cause of SLN's failure to maintain the required marginal level of operational availability of its automobile fleet

*A. Application of the developed model*

The validity of selected criteria for both criticality assessment and maintenance approach selection in the SLN context is tested by presenting them to a panel of experts. Thereafter, relative weights of criticality criteria are calculated through Expert Choice™ software by feeding secondary data acquired through the AHP questionnaire survey. Table 6 indicates the relative importance of criticality criteria valid in the SLN context.

Table 6: Relative importance of criticality criteria

| Criteria | Relative importance |
|---|---|
| Degree of complexity of maintenance | 4.0 % |
| Function | 7.0% |
| Utilization | 26.0% |
| Availability of alternatives | 55.5% |
| Age | 7.5% |

Inconsistency = 0.00249

Source: Developed by authors

Thereafter, three (03) criticality classes are defined to group automobiles upon the consultation of the SLN expert panel as indicated in table 7. In that, the expert panel opined that formulating three groups with an equal range would be more suitable for the SLN context considering the fleet size and the administrative and managerial ease.

Table 7: Defin ed criticality classes

| Group | Criticality range |
|---|---|
| Least critical | C < 2.3 |
| Moderately critical | 2.3≤C< 3.6 |
| Highly critical | C ≥ 3.6 |

Source: Developed by authors

The relative importance of maintenance expectations are context-oriented and it varies with the criticality of automobiles. Therefore, we calculated the relative importance of maintenance expectations under each criticality class following the same procedure explained during criticality calculation. The derived results pertinent to the highly critical class, moderately critical class and least critical class are tabulated in Tables 8, 9 and 10 respectively.

| SCORING MODEL 01: TO CALCULATE CRITICALITY OF AUTOMOBILE | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Degree of complexity of maintenance (0.039) | Function (0.070) | Utilization (0.260) | Availability of alternatives (0.555) | Age (0.075) | Criticality value |
| Unit score | 5.0 | OEM assitance required | Emergency vehicle | 6000< X | No alternative available | 20< Y | |
| | 4.0 | Expert skills & special tools required | VIP transportation | 4500< X ≤ 6000 | Very hard to find and disturbs another function | 15 < Y ≤ 20 | |
| | 3.0 | Expert skills required | Combat vehicle | 3000< X ≤ 4500 | Can be managed with difficulties | 10 < Y ≤ 15 | |
| | 2.0 | Managable with ordinary tools/ skills | Logistics transportation | 1500< X ≤ 3000 | Alternative available | 5 <Y ≤ 10 | |
| | 1.0 | Very basic level maintenance | Troop transportation | 1500 ≤ X | Ample of alternatives available | Y ≤ 5 | |
| Vehicle No. | NAHA 53xx | 4 | 5 | 1 | 3 | 2 | 2.6 |

Figure 7. Criticality assessment of vehicle number. 53xx (Source: Developed by authors)

Table 8: Relative importance of maintenance expectations pertaining to highly critical class.

| Criteria | Relative importance |
|---|---|
| Time taken in maintenance | 33.1 % |
| Maintenance cost | 6.8% |
| Warranty | 9.7% |
| Quality of maintenance | 22.4% |
| Reliability of service provider | 28.1% |

Inconsistency = 0.00053

Source: Developed by authors

Table 9: Relative importance of maintenance expectations pertaining to moderately critical class.

| Criteria | Relative importance |
|---|---|
| Time taken in maintenance | 9.8 % |
| Maintenance cost | 10.4% |
| Warranty | 11.5% |
| Quality of maintenance | 37.8% |
| Reliability of service provider | 30.5% |

Inconsistency = 0.00131

Source: Developed by researcher

Table 10: Relative importance of maintenance expectations pertaining to least critical class.

| Criteria | Relative importance |
|---|---|
| Time taken in maintenance | 5.8 % |
| Maintenance cost | 35.3% |
| Warranty | 14.0% |
| Quality of maintenance | 22.7% |
| Reliability of service provider | 22.7% |

Inconsistency = 0.00381

Source: Developed by authors

The developed framework is applied for a few randomly selected automobile maintenance jobs and one is explained below to demonstrate the operating procedure of the proposed model;

**Example**

Vehicle Number 53xx Ambulance visited the naval automobile repair yard due to an abnormal noise generated from its engine.

**Step I:** Calculate criticality and identify criticality class.

As Figure 7 illustrates, the calculated criticality of the vehicle is 2.6. According to the group margins defined above, this vehicle belongs to the "moderately critical" class.

**Step II:** Check the availability of in-house resources to undertake repairs

The facility audit carried out by the maintenance supervisor revealed that in-house resources are adequate to undertake particular engine repairs.

**Step III:** Selection of maintenance approach.

As this automobile belongs to the "moderately critical" group the scoring model developed with relative weights derived in Table 9 is used to evaluate service providers. Accordingly, the score of potential service providers is calculated as shown in Figure 8 and found that the SLN repair yard (in-house facility) has scored the highest. The finding leads to a technical conclusion that insourcing is the best maintenance approach for this particular repair/ maintenance need. More importantly, the developed model was applied for few more automobile maintenance jobs in SLN, results validated its accuracy.

## 5. Discussion

Maintenance prioritization through criticality classification is a successful approach for effective maintenance management of a large automobile fleet. In that case, Maintenance complexity, Function, Utilization, Alternatives availability and age are valid criteria for the criticality assessment of automobiles in the military context. Further, the availability of a scoring model simplifies the maintenance prioritization process and its ability to generate results in numerical format enable easy, but fast identification of priorities.

| SCORING MODEL 02: TO SELECT MAINTENANEC STARTEGY | | | | | | |
|---|---|---|---|---|---|---|
| Class : Moderately critical Automobiles | | | | | | |
| Automobile No. : NAHA 53xx | | | | Job No. M/01 | | |
| Service Provider | Maintenance Expectations | | | | | Total score |
| | Maintenance Duration | Maintenance cost | Warranty | Quality of Maintenance | Reliability of Service Provider | |
| | 0.098 | 0.104 | 0.115 | 0.378 | 0.305 | |
| SLN | 1.00 | 0.10 | 1.00 | 0.1 | 1.00 | 1.00 |
| Autoshine (Pvt) Ltd | 0.10 | 0.86 | 0.10 | 0.55 | 0.55 | 0.24 |
| Malima Enterprises (Pvt) Ltd | 0.55 | 0.86 | 0.10 | 1 | 1.00 | 0.69 |
| Wimal Motors | 0.33 | 1.00 | 0.10 | 0.25 | 0.10 | -0.88 |

Figure 8. Service provider evaluation for vehicle number 53xx

Source: Developed by authors

Maintenance expectations-based service provider evaluation is a novel, but successful approach. It enables an organization to select the best maintenance approach for a specific maintenance need meeting organizational expectations. Further, the findings of the study revealed that the organizational expectations on automobile maintenance change with the order of automobile criticality.

More importantly, the developed model can be used for any armed force for effective maintenance management of large machinery fleets with minor adjustments to fit with the respective organization.

## 6. Conclusion

Maintaining a large automobile fleet is a very costly event, nevertheless, militaries maintain massive automobile fleets to cater to countless transport needs. On the other hand, maintaining of the operational state of automobiles and reliability at a satisfactory level is vital as it directly affects the operational readiness of a military unit. It is maintainers' responsibility to maintain the operational state of the fleet at desired level, which is burdensome. Maintainers are required to identify maintenance priorities and adapt appropriate maintenance approach. Failure in doing so, result in waste of limited resources and lack in operational availability and reliability of the automobile fleet. It is realized that a properly designed framework which supports maintainers on maintenance decisions of maintenance prioritization and select appropriate strategy ease up maintenance decision making.

In this study, we have presented a decision support model to identify maintenance priority and best maintenance approach for automobiles. A novel approach was designed to identify maintenance priority based automobile criticality and criticality is calculated by a scoring model developed using five (05) criticality criteria and relative importance of them calculated using AHP.

Further, our framework is capable in assisting to select the best maintenance approach for automobiles. The maintenance approach is selected based on user's expectations on maintenance and result is generated in numerical form by a scoring model. Five (05) user expectations are taken as criteria and their relative importance is calculated using AHP. The simplicity of the developed model makes it more user-friendly and generate fast results. Further, this model is tested in Sri Lanka Navy and assured its accuracy.

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**Authors Biography**

Viraj De Silva is a Marine Engineer in Sri Lanka Navy and presently serving as a Senior Lecturer (GR II) attached to the Department of Marine Engineering, Faculty of Engineering, KDU. He earned his BSc (DS) MarEng from KDU, MSc in MarEng from Naval University of Engineering, China and MBA(MoT) from University of Moratuwa.

IDD Nishanka is a charted Electrical Engineer in Sri Lanka Navy and presently serving as a Lecturer attached to the Department of Electrical Electronic and Telecommunication Engineering, KDU. He earned his BSc (DS) Elec Eng degree from KDU. He is a corporate member of Institute of Engineers Sri Lanka (IESL)

HSC Perera is a Senior Professor in the Department of Mechanical Engineering, Sri Lanka Institute of Information Technology - SLIIT. He has also served as the Dean of SLIIT Business School. Prior to joining SLIIT, he was a Professor and the Head of the Department of Management of Technology, University of Moratuwa, Sri Lanka.