SIMULATION BASED LIFE-CYCLE ANALYSIS OF A VEHICLE FLEET

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Abstract: *Throughout the years the logistic experts have developed a variety of simulation models for specific applications. This paper addresses a discrete-event simulation model, which estimates the operational availability and maintenance cost of a vehicle fleet throughout complete life cycle, under a certain maintenance scenario. The model gives all necessary parameters to compute the total vehicle life cycle cost, linking reliability, operational tempo and maintenance scenario with vehicle acquisition and maintenance costs. Based on simulation results one can make cost-effective decision relative to buying adequate vehicles and organizing proper fleet maintenance, which gives required operational availability at lowest costs. In this work we have analyzed application of our model on an example – a light tactical vehicle fleet.*

Keywords*: vehicle, availability, maintenance, cost, simulation.*

1. INTRODUCTION

The technical performance of vehicles (such as speed, range, stability, fuel consumption, power generation) has improved significantly over the last several decades. On the other hand, suitability parameters (such as reliability, availability, and maintainability) have not been analyzed and improved. Suitability determinants are generally not addressed early enough during program development and are not prioritized with the same seriousness and discipline as performance parameters. The cost of operating and maintaining a vehicle fleet is a large expense for the owner, and suitability performance is a major factor affecting these costs. The existing off-the-shelf and best-practice methods to select maintenance strategies are mainly based on experience and manufacturers proposals. Improvements are usually done in a trial and error manner without taking into account cost effectiveness. Within the last few years, pressure on costs and delivery on time have dramatically gained importance to optimize maintenance process. Very often logistics and maintenance objectives are separately optimized and optimization results are moderate.

In this work an integration of required availabilityand maintenance optimization is done, based on vehicle life cycle simulation. The simulation model is a very flexible one, and gives the opportunity to change a variety of parameters: fleet size, vehicle reliability, operational tempo, work allocation between maintenance levels, time-to-repair distribution, maintenance cost – vehicle age correlation, preventive maintenance strategy, etc. The simulation results give a detailed insight into fleet life cycle: obtained availability of the fleet and every vehicle, every

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vehicle and fleet daily and total path, maintenance facilities utilization, queues, logistics administrative time, maintenance labor, maintenance cost (minimal, maximal, mean, standard deviation).

2. RELATED WORK

The development of life-cycle models is necessary to identify key factors that affect operational readiness and cost of required readiness. Modeling needs complex and time consuming research to examine many input parameters and possible scenarios, and models usually cover specific system or only a part of a life-cycle. One approach uses optimizations maximizing availability and profitability of the production system by varying both maintenance strategies and logistics factors. The obtained results indicate that a joint optimization of logistics and maintenance strategies provides better results than optimizing those elements independently and highlights the need for a comprehensive sophisticated model (Achermann, 2008). Some works are focused on a particular influencing parameter. The authors stress the problem of influence of the reliability parameters for final system functional measures (required time of delivery). The presented problem is practically essential for defining organization of vehicle maintenance and transport system logistics (Walkowiak and Mazurkiewicz, 2007). To establish a relationship between achieved reliability improvement and reduction in support cost, one model uses the Cost Analysis Strategy Assessment (CASA), combining the two relationships—investment in reliability to reliability improvement and reliability improvement to support cost reduction (Long at al., 2007). Many works are dedicated to transportation systems. One paper suggests analysis based on the modeling and simulating of the system behavior. Monte Carlo simulation is used to encourage reliability and stochastic functional parameters. The simulator is built using Scalable Simulation Framework (SSF) (Walkowiak and Mazurkiewicz, 2008). In some other works the primary goal is to conduct comparison of different support strategies of a system. Smith (2011) analyzes the cost per unit usage and operational availability of the military tactical vehicle. Transportation systems, with different levels of importance, are analyzed via simulation. Naidu at al. (2010) used a discrete event simulation to highlight the difficulties involved in a typical four-wheeler service center.

This work is aimed at developing simulation tool for revealing the mutual impact of acquisition and proving evidence for benefit of a joint optimization of logistics and maintenance, incorporating availability, logistics, and financial aspects. In this paper we suggest a simulation model, based on General Purpose Simulation System (GPSS), which allows integrated analysis of complete vehicle fleet life cycle, from acquisition to retirement.

3. SIMULATION MODEL

The simulation model was built using GPSS in such a way that software not only provides tools for modeling and simulation of a wide variety to maintenance services, manufacturing, but also has possibility to shape input data and carry out output statistics (Schriber, 1974). Simulation model describes a modern two-level maintenance concept, shown in Figure 1.

The first maintenance level includes preventive maintenance and corrective maintenance for minor failures, and all maintenance activities are done via one of M available mobile maintenance stations. The second level is dedicated to serious maintenance actions (repairs caused by serious failures), and maintenance depot with N working places is the available infrastructure of this level. Input and output parameters of the simulation model are as follows:
Input parameters: number of operational vehicles, fleet reserve (number of vehicles intendedto replace faulty vehicles),vehicle serial numbers, operational tempo, vehicle reliability, failuredistribution between minor and serious failures, maximal path between preventive

maintenance actions, first maintenance level capacity (M), second maintenance level capacity (N), time to execute preventive maintenance, time distributions to repair vehicles, labor and spares cost for mobile stations, labor and spares cost for depot maintenance, maintenance cost – vehicle age factor.

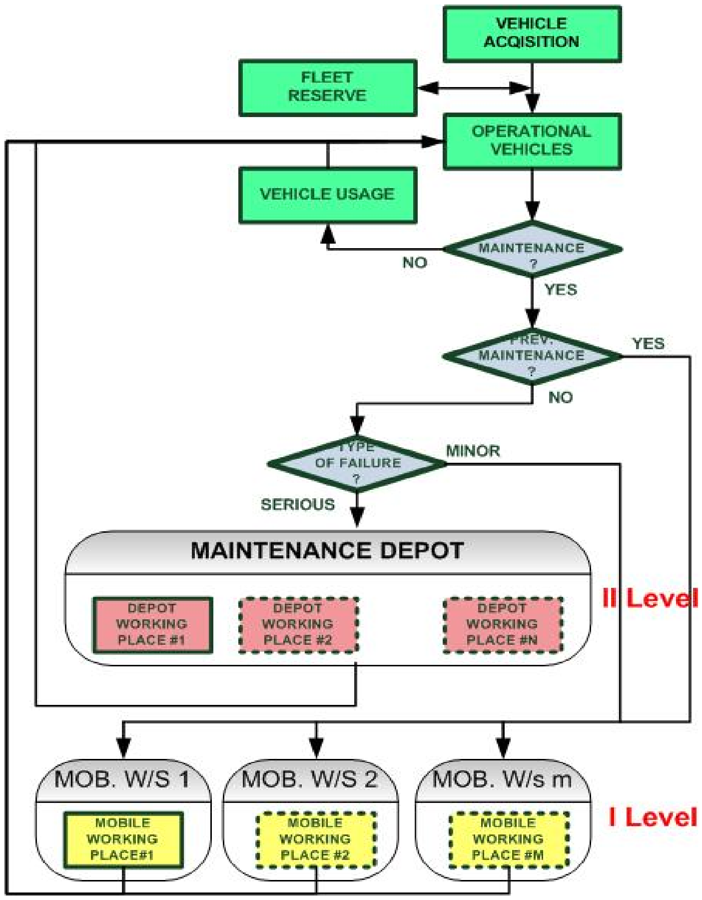

Figure 1. Two-level Maintenance Concept

Output parameters: fleet availability, vehicle availability, vehicle usage histogram, number of preventive maintenance actions, vehicle preventive maintenance histogram, number of first level corrective actions, number of second level corrective actions, mobile maintenance station utilization, mobile stations queue, depot utilization, depot queue, total preventive maintenance working hours, total first level corrective maintenance working hours, total second level corrective maintenance working hours, vehicle failure histogram, vehicle daily path, vehicle total path, vehicle maintenance cost.

Operational availability. Operational Availability is a measure of the percentage of the total inventory of a system operationally capable (ready for tasking) of performing an assigned mission at a given time, based on materiel condition.

$$A_O = \frac{t_{uptime}}{t_{uptime}+t_{downtime}} \tag{1}$$

Operational Availability also indicates the percentage of time that a system is operationally capable of performing an assigned mission and can be expressed as uptime divided by uptime plus downtime, where t_{uptime} is the time when a system is ready for operation, and $t_{downtime}$ is the maintenance down time, which includes repair time, administrative and logistics delay times. In this model Operational Availability is calculated for every vehicle and complete fleet using equation (1). Fleet t_{uptime} and $t_{downtime}$ are calculated as the sums of each vehicle's t_{uptime} and $t_{downtime}$.

*Operational tempo.*Operational tempo is a measure of the dynamics of an operation in terms of equipment usage. Operational tempo can be changed by increasing/decreasing daily number of driving hours. The driving speed depends on operational environment. Higher than expected utilization rates and fatigue caused by operating environment are resulting in reduced service life.

Maintenance. Maintenance depicts the entity of all technical, technological, organizational, and economic actions to delay wear out and/or recovery of functional capability, including technical safety, of a technical system. Two-level maintenance strategy, shown in Figure 1, with regular scheduled maintenance actions are restoring the lost capability of subsystem impairments, and these maintenance actions allow the vehicles to meet operational standards and requirements. That means - vehicle failure intensity can be considered constant throughout complete service life. In the case of extreme operational tempo (wartime operations of military vehicles, for example),maintenance done to counter the effects of it, to some degree, but regardless of the maintenance or "reset" completed, it does not bring the vehicle to a true "zero-km" condition (USA DoD, 2008).

Vehicle maintenance cost. The maintenance cost in our model is defined by equation (2), and consists of two components, cost of maintenance activities done by mobile maintenance stations (I maintenance level) and cost of depot level corrective maintenance (II maintenance level).

$$MC_{Total}=MC_{MobSt}+MC_{Depot} \tag{2}$$

$$MC_{MobSt}=WH_{MobSt}xC_{Labor}(1+S_{MobSt})\ xK_{Age} \tag{3}$$

$$MC_{Depot}=WH_{Depot}xC_{Labor}(1+S_{Depot})\ xK_{Age} \tag{4}$$

Calculations of the mobile stations and the depot maintenance level costs are defined by equations (3) and (4). The maintenance cost depends on working hours spent on each maintenance action (WH_{MobSt} and WH_{Depot}), average cost of one hour labor (C_{Labor}), average cost of spares replaced during one working hour ($C_{Labor}xS_{MobSt}$ and $C_{Labor}xS_{Depot}$), and aging maintenance cost correction factor (K_{Age}). Having in mind that older vehicles show greater probabilities of having repair costs, our cost model introduces the aging maintenance cost correction factor K_{Age}, which connects maintenance cost and vehicle age. Values and shape for K_{Age} maintenance cost factor is adopted from research report (Pint at al., 2008).

3. EXAMPLE

Importance of simulation and its use in optimization lies in the fact that many problems are too complex to be described in mathematical formulations. Nonlinearities, combinatorial relationships or uncertainties often give rise to simulation as the only possible approach to solution. Our simulation model is tested through relatively complex example: find the cheapest life cycle solution for a fleet of 220 light tactical vehicles with required availability 0.89.Light tactical vehicles are platforms capable for small-unit combat and tactical operations in complex urban and rural environments, convoy escort, troop transport, explosive ordinance disposal, and ambulance missions. Fleet consists of 200 operational and 20 reserve vehicles.The key reliability parameter is Mean Km Between Failure. This parameter depends on vehicle reliability and operational conditions. For HMMWV (High Mobility Multipurpose Wheeled Vehicle)example vehicle, under supposed operational conditions, simulated Mean Km Between Failure was 1300 km. Maintenance alternatives are generated by varying number of mobile maintenance stations and number of depot working places. Nine alternatives were tested. Level I is the field maintenance, consisting of preventive maintenance and 70% of corrective maintenance activities. Level II is the depot maintenance, covering 30% of vehicle failures (serious failures). Scheduled preventive maintenance labor was fixed - 2 hours per vehicle. Corrective maintenance working hours follow lognormal distribution, with mean equal 4 hours for minor failures, and 10 hours for serious failures.

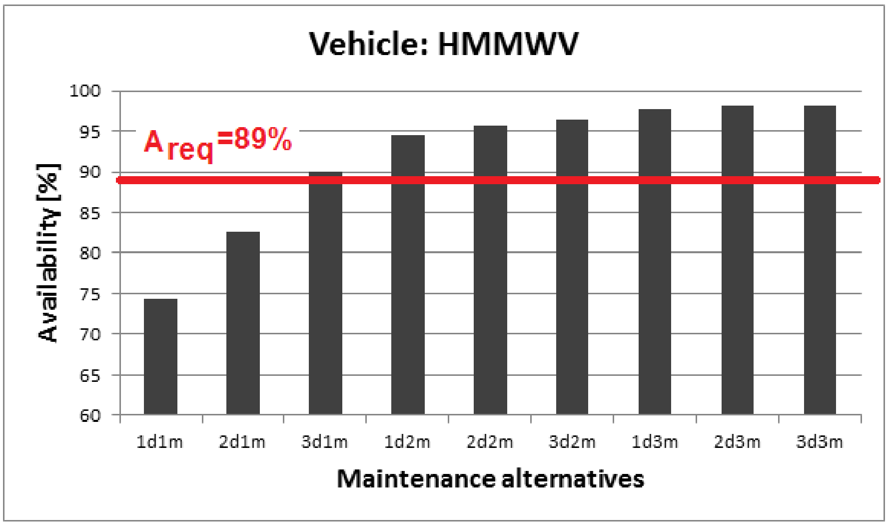

Figure 2. Fleet availability for different vehicle-maintenance alternatives

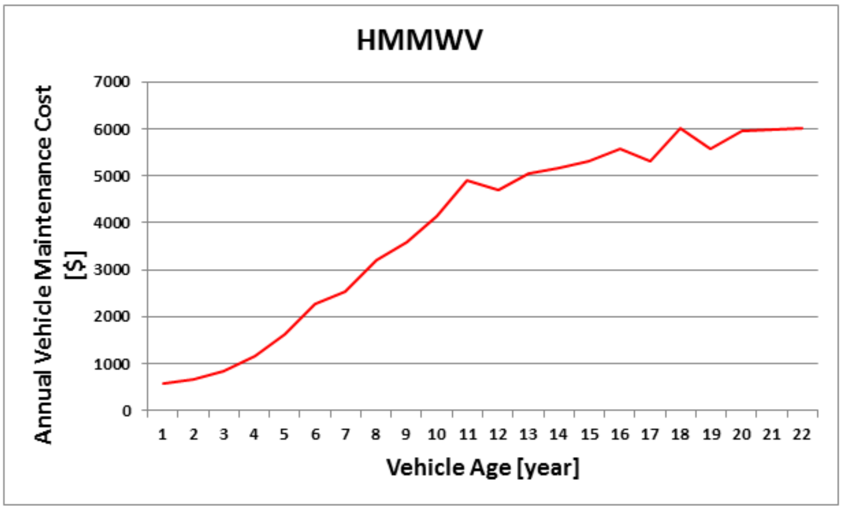

Figure 3. Average annual vehicle maintenance cost

Each maintenance alternative was tested in 20 operational conditions (a total of 180 scenarios). The presented simulation resultsare from one peacetime scenario. The results show, Figure 2, that 6 of 9 maintenance alternatives satisfy required fleet availability, one alternative is marginal (3d1m = 3 depot working places + 1 mobile station) and 2 alternatives do not satisfy requirements. For adopted maintenance alternative (1d2m = 1 depot working place + 2 mobile stations) under supposed operational tempo, during 22 year service life average vehicle availability was 0.8493 with 0.0509 standard deviation. Figure 3 shows a time dependentvehicle maintenance cost (average 6065 $ with 927 $ standard deviation).Results suggest that the effects of fleet aging on annual maintenance cost are significant. It is easy to observe that average annual maintenance cost for a vehicle 5 years old is 30% of the average annual maintenance cost at the end of vehicle life cycle.

4. CONCLUSION

Results of the simulation runs confirmed the assumption that system availability alone is an insufficient objective function for optimizing a maintenance strategy. Availability considerations have to be merged with financial aspects to achieve optimal maintenance strategy that satisfies both, the required availability and lowest possible total life cycle costs. Our simulation model is flexible enough to cover variety of scenarios: different requirements, different fleet size, different vehicles, different operational tempos, different maintenance strategies and infrastructure, etc. In addition to the classic optimization criteria, as minimizing costs and maximizing fleet availability, some other characteristics can be taken as supplementary objective functions. The model functionality was demonstrated through an illustrative example, fleet of 220 light tactical vehicles.

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