Optimization of Vehicle Maintenance Concept Using Simulation

Ivan Djokic[1], Ljubomir Lazic[2], Aldina Pljaskovic[3], Aleksandra Pavlovic[4]

Abstract – **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 variety of acquisition requirements, operational tempos, and maintenance scenarios. Based on simulation results one can make cost-effective decision relative to buying adequate vehicles and organizing proper fleet maintenance. In this work we have analyzed application of our model on an example - finding potential vehicles, capable of fulfilling requirements, under different maintenance conditions and working within a set of operational tempos.**

Keywords – **Vehicle, simulation, life-cycle, maintenance, availability, cost.**

I. INTRODUCTION

The technical performance of vehicles (such as speed, range, stability, payload, power generation) has been studied and 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. Most maintenance strategy optimization techniques are designed to increase system availability, without accounting for customer need as minimal service level or cost-effectiveness of the whole life cycle. Very often logistics and maintenance objectives are separately optimized and optimization results are moderate. 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.

This work is aimed at developing simulation tool for revealing the mutual impact of acquisition, operational tempoo and maintenance, proving evidence for benefit of a joint optimization, incorporating availability, logistics, and financial aspects. In this paper we suggest a simulation model, based on General Purpose Simulation System (GPSS) [1], which allows integrated analysis of complete transportation fleet life cycle, from acquisition to retirement. Simulation results show fleet availability for different acquisition alternatives, different maintenance strategies and different operational tempos. Simulation results are sufficient to estimate fleet life cycle ownership cost (fleet acquisition, scheduled preventive maintenance cost, and corrective maintenance cost).

[1]Ivan Djokic is with the State University of Novi Pazar, 36300 Novi Pazar, Vuka Karadzica bb, Serbia, e-mail: idjokic@np.ac.rs

[2]Ljubomir Lazic is with the State University of Novi Pazar, 36300 Novi Pazar, Vuka Karadzica bb, Serbia, e-mail: llazic@np.ac.rs

[3]Aldina Pljaskovic is with the State University of Novi Pazar, 36300 Novi Pazar, Vuka Karadzica bb, Serbia, e-mail: apljaskovic@np.ac.rs

[4]Aleksandra Pavlovic is with the State University of Novi Pazar, 36300 Novi Pazar, Vuka Karadzica bb, Serbia, e-mail: apavlovic@np.ac.rs

II. RELATED WORK

The development of life-cycle models is necessary to identify key factors that affect operational readiness and cost of required readiness. Transportation systems, with different levels of importance, are analyzed via simulation, covering specific aspect and using specific simulation technique.

One model utilizes expert knowledge to predict the operational requirements of a spacecraft concept, including the ground activities, flows, resources, and costs; all the components of the transportation system. The model incorporates simulation in order to include spaceport characteristics as alternative flows, processing variability, and other random events [2]. A method of reliability and functional analysis related to discrete transport systems is based on modeling and simulating of the system behavior. Monte Carlo simulation is used for proper reliability and functional parameters calculation. The simulator is built using Scalable Simulation Framework (SSF) [3], [4]. Simulation is also used to examine the dependency between safety factor and system availability. In addition to the classic optimization criteria, as minimizing costs and maximizing system availability, the overall cash flow and the discounted cash flow of the production system were taken as supplementary objective functions [5]. A simulation method of repairable one-unit system's reliability and spare requirement under preventive maintenance especially preventive maintenance with periodic testing is used. Simulating model is developed to solve the multi-objective constrained optimization problem of maximizing system availability and minimizing maintenance cost under constrains of repair time, test interval, spare number [6]. A specific case is the decision support system using simulation in the dynamic environment of vehicles repair and maintenance. Simulation results as decision support system and analysis have given a valuable insight of the systems involved [7]. To understand the bottleneck operations and to improve the service rate of the four wheeler service sector, a discrete event simulation model has been developed [8]. Modern logistics systems are much more than simply networks of material flow. For a sustainable practice of simulation in logistics a model-based approach which begins with a formal language is developed [9].

III. SIMULATION CONCEPT

The simulation model, used in this work, was built using GPSS in such a way that software not only provides tools for modeling and simulation of a wide variety to acquisition policies, operational plans and maintenance services, but also has possibility to shape input data and carry out output statistics. The vehicle life-cycle simulation concept is shown on Fig. 1. The proposed model is subdivided into three parts, acquisition module, operational tempo module, and maintenance and failure module. This subdivision provides easy maintainability and simple extendibility of the model. Within those modules, all cost-effective processes are modeled.

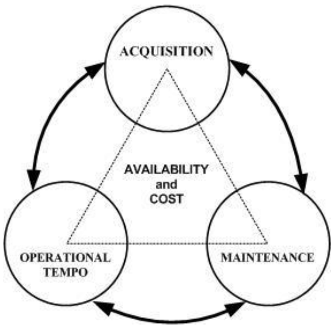

Fig. 1. Vehicle life-cycle simulation concept

Acquisition module defines number of vehicles (operational and reserve), vehicle delivery dynamics, vehicle serial numbers, vehicle reliability (probability to fulfill a daily mission without a failure), failure distribution between minor and serious failures, maximal path between preventive maintenance actions, vehicle acquisition price, etc.

Operational tempo. Operational tempo is a measure of the dynamics of an operation in terms of equipment usage. In this model operational tempo is defined by daily driving hours (5 days per week) and speed distribution, which gives average vehicle's path per year. Operational tempo can be changed by increasing/decreasing 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. Statistical data show that higher operational tempo have resulted in increased requirements for maintenance, and this maintenance is targeted at restoring the vehicles back to operational and mission-readiness standards through the replacement of consumable and repairable parts (e.g., tires, engines, transmissions, shocks, etc.).

Maintenance. Maintenance depicts the entity of all technical, technological, organizational, and economic actions to delay wearout and/or recovery of functional capability, including technical safety, of a technical system. A maintenance strategy defines type, content and temporal sequence of maintenance tasks for a technical system. Elaboration of a maintenance strategy optimization is a non-trivial issue since many different and partially contradictory requirements have to be incorporated. Different maintenance strategies are shown in Fig. 2, all of them are with regular scheduled maintenance actions for restoring the lost capability of subsystem impairments (restores assets to operational standards by replacing and/or repairing impaired consumables), 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 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.

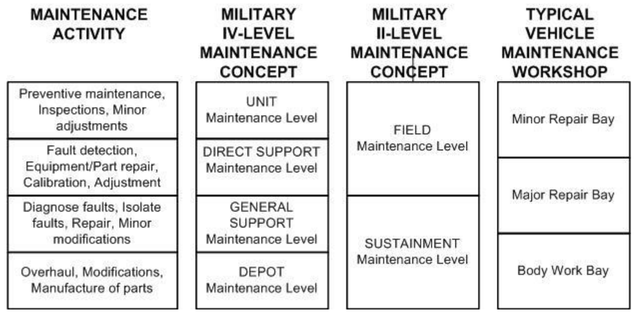

Fig. 2. Vehicle maintenance levels

Output parameters in our model are: fleet availability, vehicle availability, vehicle usage histogram, number of preventive maintenance actions, vehicle preventive maintenance histogram, number of minor corrective actions, number of serious corrective actions, field maintenance station utilization, field stations queue, depot utilization, depot queue, total preventive maintenance working hours, total field level corrective maintenance working hours, total depot level corrective maintenance working hours, vehicle failure histogram, vehicle daily path, vehicle total path, vehicle maintenance cost.

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. This can be expressed mathematically (as the number of operational items divided by the total population). 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:

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

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. Determining the optimum value for Operational Availability requires comprehensive analysis of the system and its planned use, including the planned operating environment, operating tempo, reliability alternatives, maintenance approaches, and supply chain solutions. In this model Operational Availability is calculated for every vehicle and complete fleet using Eq. (1). Clearly, Operational Availability can be improved by increasing reliability and/or decreasing repair or cycle-time. Thus, the two key issues to improve systems readiness are reliability improvement and cycle-time reduction.

The costs of owning and operating a vehicle fleet can be defined in many different ways: capital and operating costs; fixed and variable costs; direct and indirect costs; avoidable and unavoidable costs; average and marginal costs; current and future costs; fiscal and economic costs. The distinctions between these terms are not merely semantic, and decisions regarding the management of these costs can have a profound impact on a fleet organization. The goal of our simulation model is to predict the availability of a transportation fleet and to estimate vehicle total cost, consisting of ownership cost (fixed) and vehicle maintenance cost (variable). The maintenance cost is defined by Eq. (2), and consists of two components, cost of preventive and corrective maintenance activities.

$$MC_{total}=MC_{prev}+MC_{corr} \tag{2}$$

Fig. 3 shows simplified, easy understandable simulation algorithm, where all parts defined in simulation concept and their relationships are visible. Model has 1289 lines of GPSS code.

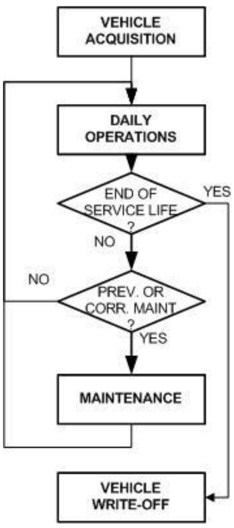

Fig. 3. Simplified simulation algorithm

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 several 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 vehicle and fleet daily and total path, maintenance facilities utilization, queues, logistics administrative time, maintenance labor, maintenance cost (minimal, maximal, mean, standard deviation). The simulation model applied on procurement (or development) and maintenance alternatives, supports decision makers in finding the optimal solutions at an early phase of a project.

IV. The 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 acceptable vehicle reliability for defined acquisition policy and set of two-level maintenance concepts (one depot and a number of mobile maintenance teams), and determine life-cycle maintenance cost. The vehicle fleet consists of 220 light tactical vehicles with required availability 0.89. The optimization process consists of six steps: (1) Requirements establishment, (2) Definition of vehicle procurement or development policy, (3) Definition of maintenance alternatives, (4) Fleet life cycle simulation for different vehicle reliability-operational tempo-maintenance concept combination, (5) Cost estimation for every simulation scenario, and (6) Selection of cost-effective fleet solution acceptable vehicle and efficient maintenance concept).

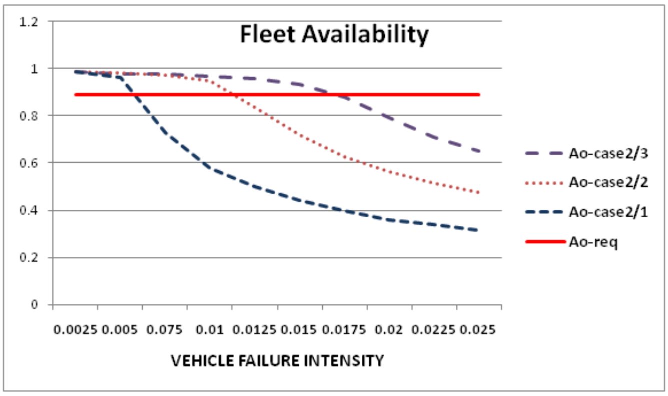

Fig. 4. Fleet availability as a function of vehicle failure intensity

The objective in our example was the satisfaction of availability requirement (0.89) with a modern two-level maintenance system. Optimization process consists of repetitive simulation runs with different values of the influence variables. Those variables are varied from simulation to simulation to find optimal combination of parameter values to solve the problem with respect to the objective function and constraints. Influence variables are vehicle failure intensity and maintenance alternatives. The total number of runs was 90 (10 vehicle failure intensities x 9 maintenance alternatives). Fig. 4 shows fleet availability as a function of vehicle failure intensity, for three maintenance alternatives (case2/3 = 1 depot + 3 mobile stations, case2/2 = 1 depot + 2 mobile stations, and case2/1 = 1 depot + 1 mobile station). The results clearly indicate that maximum acceptable vehicle failure rate for case2/3 is 0.016, for case2/2 is 0.0112, and for case2/1 is 0.006. Total vehicle maintenance cost, for the vehicle life-cycle of 22 years, was also analyzed for every maintenance case. Fig. 5 shows, as an example, the maintenance cost for case2/2.

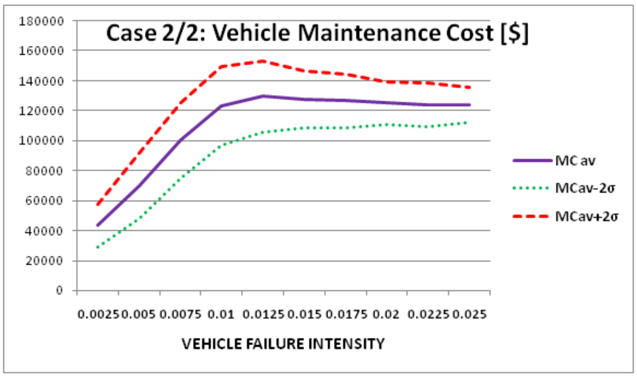

Fig. 5. Vehicle life-cycle maintenance cost as a function of vehicle failure intensity

Buying the vehicle with failure intensity of 0.0075 and applying maintenance case2/2, a buyer can expect 0.972 fleet availability and 100000$ mean life-cycle maintenance cost (per vehicle).

V. Conclusion

Many simulation runs confirmed the assumption that system availability alone is an insufficient objective function for determine and optimize a vehicle 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 acquisition requirements, different operational tempos, and different maintenance strategies. The model functionality was demonstrated through an illustrative example – finding potential vehicles, capable of fulfilling requirements, under a set of maintenance conditions and variety of operational tempos.

Further work would include new preventive maintenance concepts and different failure rate shapes.

Acknowledgement

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