Level of Repair Analysis a Tool for Integrated Optimization: A State of Art Review

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Abstract

This work provides an overview of level of repair optimizations addressed in the field of system design reliability and maintenance planning for fleet architecture. The review provides the detail in reliability design and various aspects of fleet maintenance planning viz., analysis of repair options, preventive maintenance optimization, and inventory level optimization. The interdependencies among all these decisions are also discussed. The scope of this work is to highlight the inputs from the literature. The gaps identified from the literature are also mentioned. The focused literature related to reliability design, analysis for LOR and multi-indenture inventory parts optimization has been reviewed. Literature related to joint consideration of these planning aspects in fleet system is also discussed. The literature review has helped in identifying recent work in the field of reliability design and fleet maintenance planning.

Keywords: Level of repair analysis; Optimization; Multi-indenture; Multi-echelon; Spare parts optimization.

1. Introduction

Failures of engineering system creates huge downtime losses as it incurs high life cycle cost of maintenance and operation. In many situations, the cost of maintenance is about 35% of the total operating cost of the equipment, and it can be as high as 50%–60% when both direct and indirect costs are considered (Roy et al., 2001). The maintenance cost is substantial contributed in the LCC performance of capital-intensive system (Saranga and Kumar 2006). Recently, owners of these system are making manufacturers further answerable for the breakdowns by connecting into service agreement with them. Service Agreement is a written commitment between the OEM and the user for certain availability level of the equipment over a given period. In other words, users pay a certain amount of money to OEM to get the availability assurance. The reliability and availability are therefore major factors affecting the profitability of business of OEMs. Reliability is applicable at the design stage of equipment, while availability comes into existence after installing the equipment or after a steady state of operation is reached (Murty and Naikan, 1995). Therefore, the optimization of reliability design, LOR, Preventive maintenance, spare level has the potential to improve the life cycle cost to the manufacturer(s) thereby gaining profit from service
agreement. OEM provides maintenance support to various users or bases (locations where one or more of its equipment are installed and operating) through multi-level repair facility. In literature, it is referred to as maintenance system for fleet. The main motive of this paper is to provide detailed review on various integrated optimization methodologies for reliability design and fleet maintenance decisions i.e. LOR, Preventive Maintenance (PM) and spare level. Fleet maintenance decisions considered in this research are reliability design, preventive maintenance and spare level. Keeping the objective in mind, a literature review is carried out to gain an insight into joint optimization of “LOR & design”, LOR & Preventive maintenance and LOR & Spare level planning. The literature review is categorized in the two parts as follows; Fleet maintenance planning, which includes the LOR, PM and spare level and Optimal reliability design. Literature related to these two categories is discussed in detail in the next sections.

2. Fleet Maintenance Planning

In fleet maintenance planning, the literature review is done in the area of level of repair optimization, spare level decisions optimization. Also, the integrated approaches in fleet maintenance planning are reviewed.

Figure 1. Pictorial representation of fleet maintenance Planning
2.1 Level of Repair Optimization

A significant amount of work related to level of repair analysis has received in the existing literature. The objective of this analysis is to identify economically optimal results relating to:

- Maintenance options i.e. Discard, Repair or Move on the components/parts;
- Level of indenture options i.e. subassembly/module and assembly;
- Level of echelon options i.e. OEM (Manufacturer), depot and base.

In existing work, more efficient models have been developed by the many researchers. An integrated model to optimize the problem of maintenance repair option and inventory level by Alfredsson (1997). Author considered the single indenture and two echelons levels fleet maintenance system. Additionally, author used individual maintenance resource for the individual parts and one common maintenance facility. This common maintenance facility can be used for one part or the other parts, which is considered as fixed cost investment. An integer-programming based optimization model for level of repair decisions presented by Barros (1998). The problem used the single base and single OEM based maintenance system and two indentures levels. The fixed and variable maintenance costs used as objective function to decide the option of repair. Further, the problem of number of echelon and number of indenture system is formulated and optimized by Barros and Riley (2001). Similarly, the same problem used by Saranga and Kumar (2006) and solved by metaheuristics genetic algorithm-based optimization technique. Brick and Uchoa (2009) presented the mixed-integer programming technique to optimize the level of repair decision. Authors mainly optimized the installation location of maintenance facilities. Basten et al. (2009) discussed a model to optimize LOR decisions considering the integer programming technique. Basten et al. (2011a; 2011b) proposed a model for LOR decisions considering the minimum cost flow during the LOR operations. In the discussed literature, most of the researchers have considered the owner cost i.e. LCC as an objective function to optimize the LOR decisions such as Barros (1998); Barros and Riley (2001); Saranga and Kumar (2006); Basten et al. (2009, Brick and Uchoa (2009)); Basten et al. (2011a; 2011b) are optimized the LOR problem considering a fixed spare inventory. Rawat and Lad (2016) proposed a LOR analysis model to optimize the reliability design of the multi-indenture system. Additional, A model to optimize the decisions of repair considering the preventive maintenance strategy proposed by Rawat and Lad (2017). The next section discussed the integrated optimization of LOR decisions and spare level considering fleet maintenance system.

2.2 Integrated Optimisation LOR and Spare Parts

In the existing literature, a significantly research work identified towards integrated optimization of level of repair and spare level. However, authors have addressed this joint problem with time dependent failure rate as well as constant failure rate of the components. Basten et al. (2011b) proposed an approach that purpose is to reduce the number of backorders considering the cost constraints. Basten et al. (2012) proposed a joint optimization model for LOR analysis & spare
parts decisions considering the base problem of (Alfredsson, 1997). Alfredsson (1997) considered
the finite resource capacity and infinite resource considered by Basten et al. (2012) in their model
development. Further, a joint optimization approach considering iterative algorithm for repair and
spare decision is presented in the work of Basten et al., 2015. It considers the number of indentures
and number of echelons with constant rate of failure behaviour. Authors presented joint results with
better performability compared other techniques such as integrated and sequential highlighted in
the work of Basten et al., 2012. A joint model with multi-indenture and single echelon level
presented by Fan et al. (2013) seeing the connection the trade-off between delay time (i.e. spares
waiting time) and inventory level. The problem presented with trade-off between spare stock level
and spare waiting time. An analysis considering the multi-item, multi-echelon inventory allocation
model in view of accessibility of airlines operated in fleet environment proposed by Juan et al.,
2014. Cranshaw et al. (2014) provided a joint optimization of level of repair and spare level
considering the multi-objectives while reducing the life cycle cost. Authors achieved the objectives
with use of Monte Carlo simulation based genetic algorithms technique.

2.3 Observations

In the above literature, more emphasis has been given in the development of efficient LOR
optimization technique. Moreover, the problem of LOR optimization has been solved considering
the single base, single OEM, and identical machine. Different systems or types of equipment may
have different and more complex fleet structure. For example, in machine tools, multiple bases are
associated with a multi-echelon maintenance network and these bases are associated with multiple
OEMs for their machines. Moreover, in some cases, these machines may not be identical, and it is
enclosed with modular and non-modular components. Additionally, type of maintenance and repair
facility at various echelons is also varied with specific systems. In the case of wind turbine system,
the operating site (i.e. base) does not have the enough maintenance & repair facility whereas, in the
case of machine tool users, they have significant repair facility at shop floor. Therefore, the problem
of multi-bases, multi-OEM and non-identical machine and the system structure related issues need
to address more effectively. Table 1 shows the literature summary on LORA Optimization
considering the different aspects of fleet maintenance system.

A detailed LCC model to examine the consequence of number of costs involved i.e.
maintenance facility, consumable, delay time, cost of transportation and inventory holding and
stock-out on LOR analysis requires more attention from the researchers. Also, part failure
behaviour is considered to follow constant failure rate models in most of the literature. Due to this,
the real-life behaviour of the components does not provide the real consequence of life cycle cost
performance. The consideration of time-dependent failure rate of the components while optimizing
the level of repair and spare parts stocking decisions has not reported. A time-dependent failure
rate model would make the analysis more practical. Besides, the preventive maintenance
optimization is done on the fleet system but outcome of PM to identify best economic solution of
repair options is totally overlooked in the literature. This is mainly due to constant failure rate
assumption and complexities to estimating the number of failures of the multi-modular systems.
No of work have been reported which considered the result of schedule maintenance while identifying the repair decisions except the work reported in Rawat and Lad (2017). Thus, this should be investigated in together while deciding the joint decisions making in the fleet maintenance planning.

Table 1: Literature Summary on LORA Optimization considering the different aspects

<table>
<thead>
<tr>
<th>Authors</th>
<th>LOR optimization</th>
<th>Optimization Technique</th>
<th>Spare parts optimization</th>
<th>Constant failure rate</th>
<th>Objective function</th>
<th>I-indenture and E-echelon</th>
<th>Multiple base/ OEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barros L., 1998</td>
<td>✓</td>
<td>Integer-programming</td>
<td>×</td>
<td>✓</td>
<td>LCC (Fixed and variable cost)</td>
<td>Single-I &amp; Two-E</td>
<td>×</td>
</tr>
<tr>
<td>Barros and Riley, 2001;</td>
<td>✓</td>
<td>branch-and-bound method</td>
<td>×</td>
<td>✓</td>
<td>&quot;</td>
<td>Single-I &amp; Two-E</td>
<td>×</td>
</tr>
<tr>
<td>Saranga and Kumar, 2006</td>
<td>✓</td>
<td>Genetic Algorithm</td>
<td>×</td>
<td>✓</td>
<td>&quot;</td>
<td>Multi-I &amp; Multi-E</td>
<td>×</td>
</tr>
<tr>
<td>Brick and Uchoa, 2009</td>
<td>✓</td>
<td>Integer programming</td>
<td>×</td>
<td>✓</td>
<td>&quot;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basten et al. 2009</td>
<td>✓</td>
<td>CPLEX</td>
<td>×</td>
<td>✓</td>
<td>&quot;</td>
<td>Two-I &amp; Two-E</td>
<td>×</td>
</tr>
<tr>
<td>Bouachera, T. et al., 2010</td>
<td>✓</td>
<td>Genetic Algorithm with Tabu-Search</td>
<td>×</td>
<td>✓</td>
<td>&quot;</td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td>Basten et al. 2011a</td>
<td>✓</td>
<td>CPLEX</td>
<td>×</td>
<td>✓</td>
<td>&quot;</td>
<td>&quot;</td>
<td>×</td>
</tr>
<tr>
<td>Basten et al. 2012</td>
<td>✓</td>
<td>Iterative algorithm</td>
<td>×</td>
<td>✓</td>
<td>&quot;</td>
<td>&quot;</td>
<td>×</td>
</tr>
<tr>
<td>Guo, L. H. et al., 2013</td>
<td>✓</td>
<td>PSO algorithm</td>
<td>×</td>
<td>✓</td>
<td>&quot;</td>
<td>&quot;</td>
<td>×</td>
</tr>
<tr>
<td>Costantino, F. et al., 2013</td>
<td>×</td>
<td>Marginal analysis</td>
<td>✓</td>
<td>✓</td>
<td>Availability</td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td>Cranshaw et al. 2014</td>
<td>✓</td>
<td>Multi-objective genetic algorithm</td>
<td>×</td>
<td>✓</td>
<td>LCC (Fixed and variable cost)</td>
<td>Two-I &amp; Two-E</td>
<td>×</td>
</tr>
<tr>
<td>Juan, X. et al. 2014</td>
<td>×</td>
<td>Marginal analysis</td>
<td>✓</td>
<td>✓</td>
<td>Availability</td>
<td>Single-I &amp; Two-E</td>
<td>×</td>
</tr>
</tbody>
</table>
3. Optimization of Fleet System Reliability Design

The researchers have been reported with reliability and/or redundancy allocation configurations like indenture modular system in the literature. The review is generally classified on the reliability optimization of system configurations (Kuo et al., 2001). Various authors addressed the following issues like types of redundancy (Yu et al., 2007), mixing of components (Coit and Smith, 1996a), multi-state system (Meziane et al., 2005; Tian et al., 2009a; Tian et al., 2009b), etc. Most of these problems are demonstrated using some theoretical system structure, like series or parallel or some complex configuration. The illustration of these problems to some real-life mechanical equipment, considering system specific issues i.e. fleet equipment are scarcely addressed in the exiting literature. Ivanovic (2000) applied the reliability allocation problem for a new vehicle design. Similarly, Zhang and Liao (2009) also studied the problem of reliability configuration in view of a mechanical components/systems. Authors applied it for direct drive hobbing machine. However, in most of the practical situations, customers generally do not specify their reliability requirements explicitly. Majority of literature on reliability and/or redundancy optimization, in general, it does not consider the effect of the LOR. However, there are many fleet systems, such as wind turbines, aircrafts, ships, machine tools, gas turbines, which undergo LOR analysis upon failure. Some approach is required to systematize the reliability design of equipment operated in the fleet maintenance architecture. It requires considering other issues, like, users specific reliability design, LOR, spare parts etc. at early product development stage. However, most of researchers considered the other issues, like, maintainability, maintenance, support, etc. at the design stage. Where, reliability as well as availability is considered as performance criteria in such systems. Therefore, in literature such problems are many times also referred as optimal availability design of system. The work of Misra (1974), Gurov et al. (1995), Monga et al. (1995), Kumar and Knezevic (1997), Nourelfath and Dutuit (2004), Yu et al. (2007), Ouzineb et al. (2006), Nourelfath and Ait-Kadi (2007), Lins and Droguett (2009), etc. deserve attention in this regard. The problems considered in such literature in general aim at obtaining the optimal number of one or more the followings: redundancy level, number of parts (spare), and number of maintenance facilities. For example, Misra (1974) proposed an integrated breakdown and repair rate allocation problem in order to maximize system availability considering the cost constraints. Lins and Droguett (2009) considered the effects of repair while allocating redundancy. A multi-objective optimization approach is applied that finding the middle ground between reliability and system cost. Monga et al. (1995) proposed a joint optimization problem for obtaining best configuration for the system, scheduled maintenance interval. In such cases, optimizing reliability and repair decisions integrated will be more significant for repairable systems (Rawat and Lad, 2016).

4. Conclusion

It can be seen from the above discussion that the reliability design and maintenance planning are widely studied topics in the literature. However, moderately less attention has been given in the case of industrial equipment, which is operated and maintained under fleet maintenance architecture. As far as the optimal reliability design is concerned, various approaches are available
that deal with allocation for reliability-redundancy, redundancy allocation and series system, parallel-series system. For the multi-indenture modular system, scare amount of work is reported for optimal reliability design. The significant amount of work reported for fleet maintenance decisions i.e. LOR, PM and spare level. The joint optimization of the reliability design and maintenance is necessary, and it is evident from the discussed literature. The selection of the optimal reliability design for indenture while optimizing the LOR decisions is scarcely addressed. Different integrated approaches to see the interaction effect between the decisions of “LOR and spare parts” and “PM and LOR,” are scarcely reported in the discussed literature. The LOR optimization is done considering the constant failure rates for the components. Apart from this, the detailed fleet structure problems need to be addressed while developing the integrated fleet maintenance approach. Moreover, the system’s specific issues have not addressed in optimizing the LOR, PM and spare level. More work is required to address a system specific issue in the framework of maintenance architecture for fleet.

Conflict of Interest: Authors do not have any known conflict of interest.

References


