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CANNIBALIZATION POLICIES: ADOPTION IN THE MAINTENANCE OF FLEET SYSTEMS

Summary. Fleet systems are considered complex due to the interaction between their units and components. Maintenance management systems face various challenges to achieve acceptable availability and reliability rates at a reasonable cost. A critical task for making maintenance decisions is understanding the system requirements to select maintenance policies appropriate for the actual and future system state. When there is a replacement shortage in a fleet system, and it is impossible to supply new spare parts quickly, cannibalization policies can mitigate this scarcity via the interchange of components. However, this procedure presents the maintenance manager with different evaluation effects, such as increased maintenance hours, decreased system reliability rate, and unavailability in some units. Finding an equilibrium between the benefits and risks has caught the attention of researchers. This work gathers diverse proposals for applying cannibalization policies and the effects that arise from using them. Models, methods, tools, and

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identified gaps in understanding what parameters of the components and environments of the fleet systems favor cannibalization are discussed.

Keywords: fleet systems, maintenance systems, cannibalization, availability, discrete event systems

1. INTRODUCTION

Fleet systems support passenger mass transportation, defense, industrial equipment, power generation, and energy services systems. A fleet comprises units with common attributes; for example, some systems share a similar component architecture [1]. Managing the maintenance system of a fleet system [2] is considered a complex problem [3] because of the number of units (modules and sub-modules), the relationships and dependencies between components, and the high availability rate, which is related to the number of units that can perform their function during a defined period, with approximately 96% required for the system to be profitable [4]. Selecting the appropriate maintenance policies and keeping an adequate stock of spare parts are critical aspects of maintenance management [5]. Under normal circumstances, the maintenance, repair, and operations system (MRO) provides the necessary resources to execute all maintenance activities. However, unforeseen events such as weather, trade or military wars, patent issues, political conflicts, or even a pandemic can limit the efficiency of spare parts supply. These events create environments of uncertainty, especially in transport fleet systems. The selection of optimal maintenance policies is a tool that has been studied for improving the management of maintenance resources [5]. A maintenance policy can help mitigate the shortcomings of an MRO system resulting from component shortages. Previous research has investigated maintenance policies [6]; however, these policies assume that the supply of components is continuous and no problems exist in the spare parts inventory. On the contrary, cannibalization policies as the supplier of used components have been used satisfactorily in complex fleet systems with efficient results in terms of the availability rate of the system and the supply of the used parts. [7], [8], [9]. Therefore, integrating cannibalization policies allows for a resilient maintenance system in the uncertain environments surrounding fleet systems and impacts the availability rate [10].

This paper is organized as follows: a review of the published works is presented, a classification of the most relevant results is made, the findings on the applicability of cannibalization policies are analyzed, and some conclusions are proposed.

2. BASIC CONCEPTS AND GENERAL BACKGROUNDS

A cannibalization policy consists of the interchange of identical or compatible components between different locations or units of a system when spare parts are scarce [11]. In these policies, a unit named the “donor” houses a functional component, and another unit called the “receiver” presents a failure in the same part that prevents it from fulfilling its function. Figure 1 shows an example of cannibalization between two similar vehicles with the same component architecture, A, B, and C. Therefore, to benefit from a cannibalization policy, the fleet system should comprise compatible or identical components [12], with, for example, a homogeneous fleet system, meaning it has the same component architecture as that system [13].

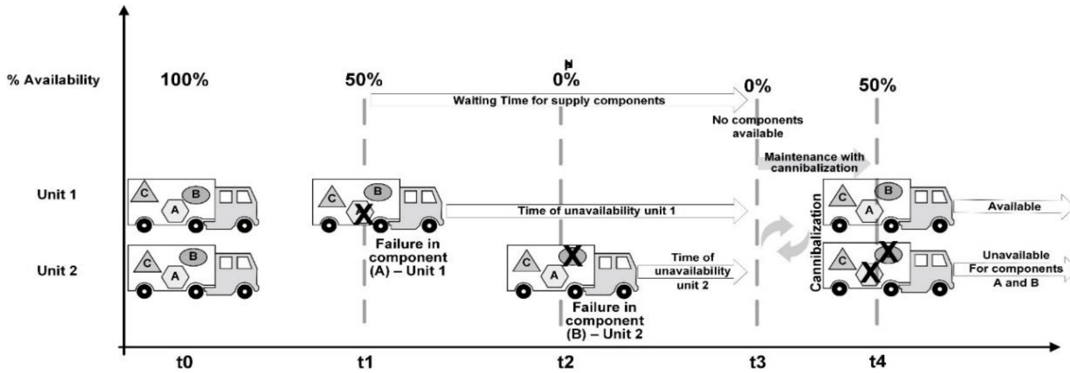

Fig. 1. Basic cannibalization policy

In summary, cannibalization policies can increase the availability rate of fleet systems [14]. However, it is necessary to identify the requirements for using cannibalization policies in transport systems. This work examines the application of cannibalization policies to fleet system maintenance systems, their impact on availability rate, their effect on maintenance resources and models, and the critical elements for applying them. The following section describes the use of cannibalization policies in fleet maintenance systems.

3. METHODS

Cannibalization has an impact on the management of maintenance resources. Therefore, topics related to decision-making, procedures, and modeling resources for maintenance were considered in the literature review. To gather the principal bibliography, primary databases, such as Scopus, Science Direct, Web of Science, IEEE, and Taylor-Francis Online, were consulted without time restrictions. The search was conducted on July 31, 2023, identifying major primary sources such as original research, review papers, and technical reports.

For this study, only publications in English were utilized. The principal terms used in the search were “cannibalization,” “maintenance,” and “fleet.” Terms such as “remanufacturing,” “refurbishing,” “remanufactured,” “retail,” and “product” were eliminated because these words relate cannibalization with product remanufacturing since they involve retrieving the components of scrapped products; the search terms listed below were employed to identify pertinent articles, with a focus on their relevance to the title, abstract, and keywords:

Cannibalization AND fleet AND maintenance -remanufacturing -refurbish -retail -product

Criteria such as the specific model defined, the cannibalization policies used, the fleet system studied, and the maintenance experiences were considered to identify papers relevant to this review. This group of documents was analyzed in terms of three fundamental criteria:

- The purposes, procedures, and policies for including cannibalization tasks in fleet maintenance systems.
- The typical systems and tools used to incorporate cannibalization policies into fleet maintenance systems.
- The proposed techniques and models for representing cannibalization activities.

Figure 2 summarises the methodology for this review.

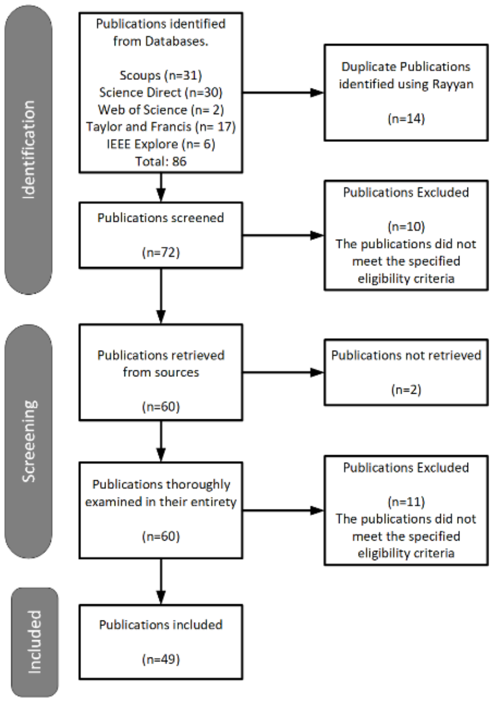

Fig. 2. Literature search diagram

4. RESULTS

Cannibalization policies are considered a tool to mitigate deficiencies in spare parts and promote fleet system availability [15]. However, it is still necessary to counteract its use's effects or engineering risks [16]. Common topics in literature are related in Figure 3. These last are extended to apply cannibalization policies and are summarised in Table 1.

Tab. 1

Aspects addressed in the literature about cannibalization

Aspects		References	Observations
Implementation	Effects on maintenance times	[16]	The unavailability of a component increases wait and maintenance times
	Information flow of the cannibalization process	[9], [17]	Instantaneous cannibalization is not evaluating all activities around a cannibalization task. At the operational level, some cannibalization tasks may be reported.
	Tracking of components (traceability)	[18]	Limiting the interchange of a component to multiple units can improve the system's reliability.
	Tracking of cannibalization orders	[19]	Knowing the cannibalization process and the flow of information helps mitigate the effects on maintenance resources.

Indicators	Performance indicators	[20], [21], [22]	Indicators such as mean time to repair (MTTR) and mean time between failures (MTBF) establish the efficiency of applying cannibalization policies.
	Reliability and availability	[20], [23], [24], [25], [26], [27], [21], [28], [29]	Although availability is the most commonly mentioned feature, the reliability of component cannibalization should also be evaluated.
	Maintenance quality indicators	[22], [30]	Quality indicators show if a maintenance task improves the reliability of the system.
	Maintenance personnel and workforce limitations	[9], [31], [30]	Identify what the aspects that allow making cannibalization tasks with better ability are.
Context	Uncertain environments adequate for using cannibalization policies	[32]	Uncertainty in the component supply chain facilitates decisions about cannibalization.
	Civilian environments	[33], [34], [35], [36]	Cannibalization has been used in civilian systems. However, there is no sufficient information about the methodologies used.
Making Decisions	Characteristic of fleet systems for applying cannibalization	[26]	Size, components architecture, modules, and maintenance resources are essential for applying cannibalization policies.
	Decision criteria for Cannibalisation policy applications	[20], [37]	Cost is a significant variable for assessing whether a cannibalization policy is viable. However, decision-making should not only consider minimizing this aspect.
	Optimizing the stock of components in inventory helps to manage deficiencies in the supply chain.	[38], [39], [40]	High stocks in the component inventory are a budget investment that may not be recoverable due to the component system's lack of use, obsolescence, or updating. This aspect provides one of the most significant advantages when applying cannibalization policies in fleet systems.

	Maintenance resources for cannibalization tasks	[17]	Maintenance resources are the most critical constraint when planning to use cannibalization policies.

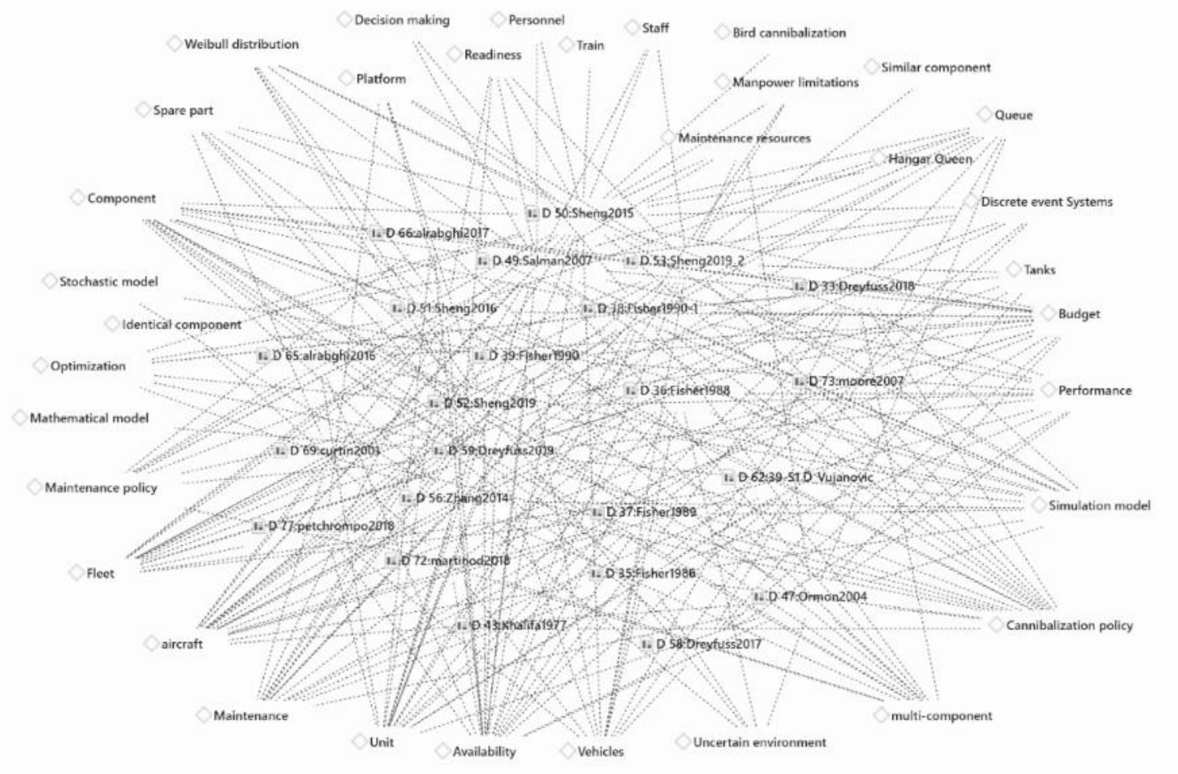

Fig. 3. Topic network in literature selected

The cannibalization policies have characteristics that should be considered when an approach is required. The principal advantages and drawbacks of cannibalization systems are shown in Table. 2.

Tab. 2

Advantages and disadvantages of using cannibalization in fleet systems

Topic	Advantages	Disadvantages
Increasing availability rate [7], [8]	Failed equipment is returned to operation quickly without affecting system operations (missions).	Cannibalization involves disassembling and reassembling the cannibalized functional component.
Decreasing mean time to repair and supply [21]	Decreasing the time to repair and supply is only possible if the mean supply response time (MSRT) is greater than the time to cannibalize.	Increased hours for assembling and disassembling components lead to wear and tear on maintenance personnel. This increases the probability of committing or generating new errors when interacting with the system.

Increasing component inventory [39], [40], [41]	Cannibalised components can be installed immediately or added to inventory.	Components may deteriorate during disassembly, transportation, or storage. Without defined criteria, the best part may not be selected for cannibalization.
Reducing the cost per storage and mitigating the obsolescence of components [9]	Component storage requires suitable infrastructure. Low rotation of parts can increase the obsolescence of the stored elements.	The cost saved by reducing storage can be lost in additional maintenance team hours or, perhaps, in induced failures in the components around the part to be cannibalized.
Minimizing the environmental impact [42]	Cannibalization policies can better re-use the components, thus reducing their premature loss.	Not applicable
Altering system lifetime [43]	Selecting the best cannibalization component can return a system to an "as good as new" status.	The cannibalization of components at the last moment can impact the entire useful life of the receiving system; the reliability can be affected, resulting in a higher repair cost later.

Lastly, different models for describing cannibalization were found, with a DES being the most common form of modeling, see Table 3.

Tab. 3

Tools to model cannibalization applications

Tool	References	Observations
DES model with transformation and structure functions	[23], [24], [25], [44]	Analytical models consider different properties of the system. However, its understanding is limited when representing large systems.
DES simulation model with MNTMOD system developed in SLAM and FORTRAN terminology	[31], [17], [45]	Different configurations of modules and sub-modules are included, considering different location levels for maintenance, with resource restrictions.
DES model with continuous Markov processes	[31], [46]	One of the first proposals incorporating strict concepts from DES models evaluating various cannibalization policies.
DES simulation model with Arena Software and Visual Basic	[20], [37], [47]	This tool introduces the concept of closed network simulation. The use of simulation models as a decision-making tool is considered.
DES simulation model with CPN and Bespoke C# software	[48], [49]	This tool presents a hierarchical CPN for both maintenance and fleet system models. The Monte Carlo simulation technique has been widely used.

Simulation model, hybrid formulae, and Skellam variables, along with Monte Carlo simulation	[39],[40]	Simulation decision-making models can insert delays due to the number of simulations required.
Formulae and simulation models (tools not specified)	[21], [27], [43]	Equations based on parameters such as mean time to repair (MTTR) mean supply response time (MSRT), mission completion rate (FMC), and customer wait time (CWT) are presented.

5. CONCLUSIONS

The present work shows models, methods, tools, and identified gaps related to cannibalization policies in fleet systems. Cannibalization policies are an essential tool in the maintenance of fleet systems when a shortage of components occurs and the supply chain cannot provide the details within a specific time window [28]. However, these same policies cause an increased demand for maintenance resources, and mitigating these effects allows systems to take advantage of the benefits of cannibalization.

5.1. Cannibalization policies in fleet systems

The cannibalization policies in the literature have been classified into reliability, inventory, and simulation [20]. Figure 4 shows the number of citations in which terms like availability, cannibalizing policy, components, and so on appear in the selected papers. In this way, the relationship between the aspects listed in Table 1 and the essential elements of a fleet, such as units, components, and maintenance, is shown. These aspects show that cannibalization can be considered in three fleet operating phases. In the short term, implementing cannibalization policies requires measuring the impact of a policy and how the components are used (indicators and implementation). In medium-term planning, cannibalization policies must be selected and managed (decision-making) because it is necessary to identify when a policy could benefit the system. Lastly, in the long term, the context influences the behavior that would guide the systems’ optimal use of maintenance resources, and random environments, such as war or pandemics [50], that compromise the supply chains should be identified. The traceability of components is an underlying problem identified in this work. Cannibalizing a part to different receivers is a risk that may decrease the system's reliability. Therefore, based on this review, limiting the interchange for a piece is a strategy that could be recommended to improve the cost-benefit relationship when cannibalization is conducted.

5.2. Effects on maintenance resources

Cannibalization policy is assumed to be a form of the provided components. However, maintenance resources are the most affected when cannibalization policies are used due to increased workforce costs and damage risk over unmounted components and around components. Not addressing this problem limits a cannibalization policy's possible advantages to a fleet system (Table 2). Few studies have evaluated the impact on maintenance personnel, as shown in Figure 5 when cannibalization policies are used. However, some proposals were found to assess restrictions on this maintenance personnel resource. However, based on this research, proposing indicators related to the skills and abilities of personnel in cannibalization activities is warranted in future studies.

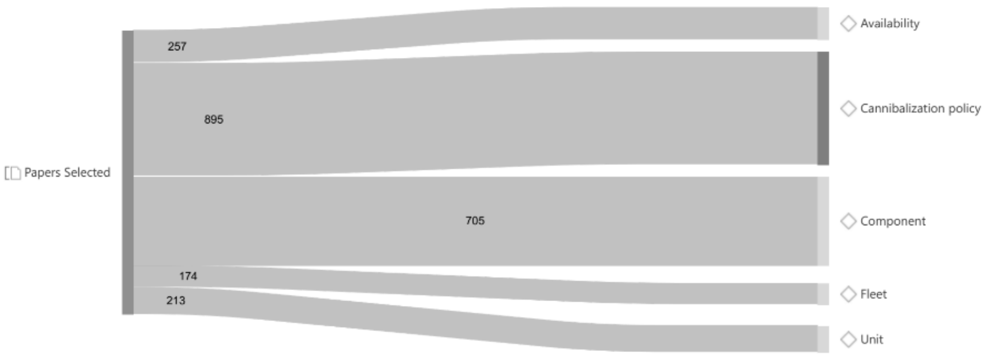

Fig. 4. Sankey diagram between literature and relevant parts of a fleet system

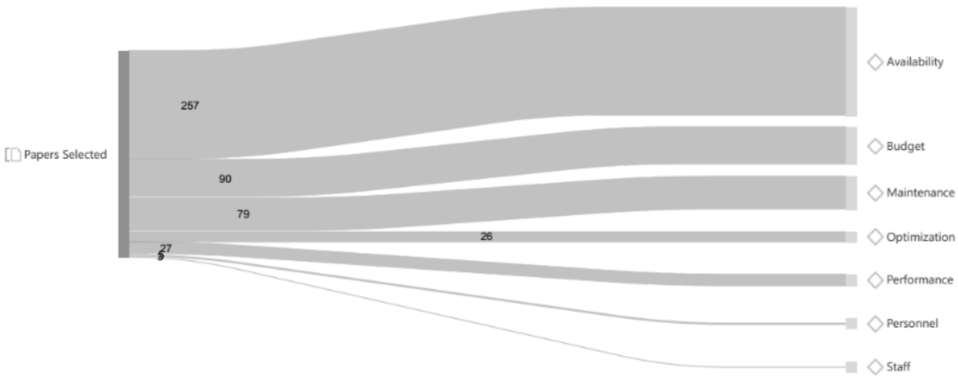

Fig. 5. Sankey diagram between literature and effects of cannibalization policies

5.3. Models and Vital elements regarding the Use of cannibalization policies

Cannibalization has been applied in fleet systems with interchangeable components. Additionally, the commonality index extends the capabilities of cannibalization policies by focusing on the function rather than the equality of components. In addition, this review highlights that DES is the most commonly used paradigm to represent systems and activities that use cannibalization. DES is among the most suitable tools for studying these policies through simulation models and queuing theory for waiting modeling. In recent years, the use of simulation models has increased due to factors such as the increasing complexity of interactions in the fleet system and the advancement of the capacity of computational methods (Table 3) (See Figure 6). Criteria like availability, reliability, fleet size, and time of mission were found concerning cannibalization in fleet systems, and it is necessary to identify measures that allow cannibalization to be extended to civilian systems. Indeed, most of these systems are found in military and manufacturing systems, but few studies have proposed their utilization in a civil fleet system [35], [51].

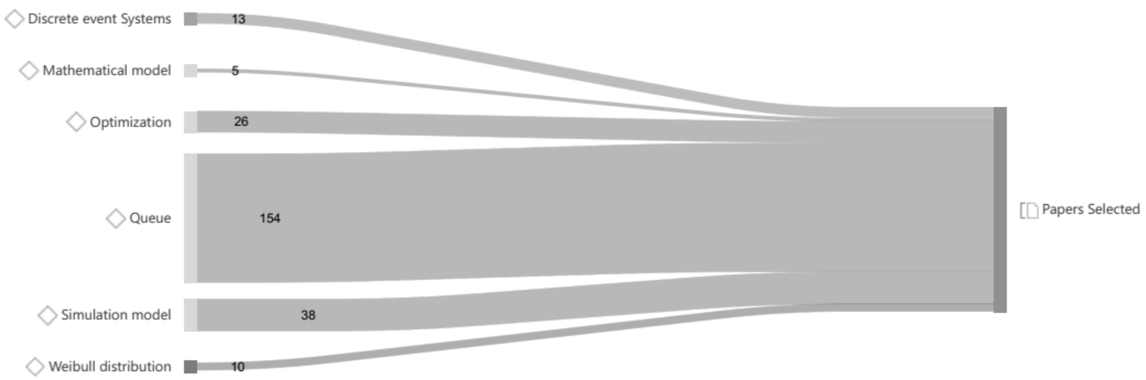

Fig. 6. Sankey diagram between literature and critical elements in fleet models with cannibalization

Disclosure statement

The authors report no potential conflict of interest.

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