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Assessment of Frugal Innovation in Spare Parts of End-of-Life Vehicles

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Abstract

Emerging markets forced companies to deliver frugal innovative products with acceptable customer value at affordable prices. This study, therefore, identifies the frugal innovative spare parts of End-of-life vehicles (ELVs) for car maintenance firms in Jordan. ELV inventory classification, spare part nature, and price ranking based on High-Middle-Low (HML) prices were conducted to rank spare parts. Twenty-seven second-hand spare parts were then evaluated based on three frugal innovation criteria including substantial cost reductions, concentration on core functionalities, and optimal level of performance. Results showed that about50% and 80% of A-class and B-class spare parts achieved frugal innovation criteria, respectively. Furthermore, about 14.28% and 100% of frugal innovative spare parts belonged to the L and H classes, respectively. Such innovative parts save costly inventory costs and increase profitability. In conclusion, the proposed frugality assessment for the spare parts of ELVs is valuable and can be used to assess other innovative products in different applications.

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Keywords: Frugal Engineering, Maintenance, Spare parts, Automobile industry.

1. Introduction

The invention of vehicles has brought many positive and negative impacts on every aspect of society [1-7]. Recently, a significant number of vehicles have introduced the issue of costly maintenance and spare parts for non-affluent customers [8-14]. Moreover, the demand for spare parts has increased and natural resources are exploited [15-16]. Generally, 5% of the world's industrial waste is attributed to the Vehicle sector. Components of end-of-life vehicles (ELVs) are usually recycled, reused, remanufactured, or disposed. On the other hand, the ability of consumers from low-income economies to pay is not high. Therefore, companies are working hard to develop frugal low-cost innovative products and services for emerging markets at acceptable customer value [17-18]. Using frugal innovative spare parts may lead to significant cost reductions in vehicle maintenance costs while delivering parts of an optimized level of performance with core functionalities.

Frugal innovation is a resource-scarce solution that aims to develop and design significantly cheaper products than their competitive offerings while being good enough to give non-affluent customers opportunities for consumption [19-20]. Frugal innovation involves minimizing the use of resources for the basic functionality of products, increasing the reuse of raw materials, reducing waste, and focusing on minimizing needless costs [21].

In practice, frugal innovation should fulfill the criteria of affordability, acceptability, availability, and awareness [22-24]. Specifically, the population of Jordan has increased significantly over the last 60 years and reached about 8 million in 2020. Many of Jordan's population is budget-constrained and in demand of frugal products and services. In 2022, the vehicle market in Jordan showed a 26.7% increase in total from the prior year, which is the highest level. These facts make adopting frugal innovation using ELVs for vehicle maintenance important to serve low-income markets [25-26].

This study, therefore, examines the use of frugal innovative spare parts of ELVs for car maintenance to satisfy the demands of non-affluent customers in Jordan. Three criteria are used to identify frugality: cost reduction, optimized performance level, and core functionalities. The results of this study may enhance the efficiency and profitability of vehicle maintenance activities and increase customer satisfaction by offering innovative spare parts at affordable prices. The remainder of this research including the introduction is outlined as follows. Section two reviews relevant previous studies on frugal maintenance and ELVs. Section three presents the application of frugal innovation for ELVs and conducts data collection and analysis for a real case study. Section four discusses the

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research results. Section five summarizes conclusions and future research.

2. Literature Review

2.1. Frugal innovation

Recently, frugal innovation has received significant research attention. For example, Rao[27] compared the prices of thirteen frugal innovative products and services using Internet searches. The results revealed that cost reduction was between 58% and 97%. Brem and Wolfram [28]introduced a conceptual framework for frugal innovation utilizing three dimensions: sophistication, sustainability, and emerging market orientation. Zeschky, et al. [29] compared frugal, well-enough, and cost innovations. Results showed that frugal innovation provides the highest technical and market novelties. Angot and Ple[30] determined the major keys to frugal innovation including affordability, good performance, sustainability, and usability. Radjou and Prabhu[31] revealedthat frugal innovation significantly affects business performance and enhances social value while minimizing the consumption of limited resources. Kuo & Ng[32] employed case studies on frugal innovation by developing simple, affordable products for emerging markets. Results showed that product quality and robustness while cutting costs are the drivers of successful frugal innovations. Weyrauch and Herstatt [33]determined the necessary criteria of frugal innovation including substantial cost reduction, concentration on essential functions, and focus on essentials.Sharmelly & Ray [8] proposeda product innovation strategy for a corporation case in India. Results showed the significant effect of product innovation on firms' capabilities of a. Niroum and et al. [34] used a mixed research approach to propose a framework for the enablers of frugal innovation for the home appliance manufacturing industry of Isfahan province. The key enablers of frugal innovation were world-class design, human aspects, prototyping, cost-cutting models, and low-cost production. López-Sánchez& Santos-Vijande [35] employed the partial least squares structural equation modeling to examine the impacts of market-focused learning and organizational ambidexterity in developing firms' innovation capability in low-end markets. Dabić et al. [36]conducted the Delphi study of prolific practitioners working on frugal innovation in combating the COVID-19 pandemic. Sarkar & Mateus [37] provided a framework for frugal innovation in healthcare services. Hossain et al. [38] examined how frugal innovation contributes to sustainable development in rural areas in South Asia. Rossetto et al. [39] assessed frugal innovation in Brazil, India, and the USA based on three major dimensions: focus on core functionalities, substantial cost reduction, and shared sustainable engagement capabilities.

2.2. ELVs

As manufacturing and supply of vehicles become increasingly efficient, the environmental impacts of ELV become more critical[40-43].For example, Bellmann & Khare [44] investigated the environmental damage from ELVs. Sakkas and Manios [45] identified and evaluated investment strategies for ELVs' management in the Northern EU. Mathieux et al. [46] improved product recovery at the ELVs' partsvia two strategies: either curative action or preventive actions. Cruz-Rivera [47] suggested a management system for ELVs in Mexico and modeled ELVs as an unqualified facility location problem. Harraz and Galal [48] designed a sustainable recovery network for ELVs in Egypt using lexicographic mixed integer goal programming. Cecchin et al. [49] introduced an extended producer responsibility (EPR) mechanism to shift the environmental and financial burden of ELV products from public management to producers in in Ecuador. Al-Refaie et al. [50] proposed a procedure for optimal maintenance scheduling under emergent failures. Numfor et al.[51]reviewed the ELVs' recycling processes and activities to identify the strengths, weaknesses, opportunities, and threats. Khan et al. [52] assessed ELVs from the perspective of industry players through a comprehensive observation of the ELVs management practices in Malaysia. Huang [18] proposed a framework for utilizing the waste from ELVs in construction industries in Malaysia. Modoi & Mihai[53] investigated the links between the e-waste of ELVs and the circular economy in Romania. Al-Refaie & Al-Hawadi [54] considered optimal fuzzy repairs' scheduling and sequencing of failure types over multiple periods. Alawadi et al. [55] prioritized factors influencing outsourcing maintenance decisions in thermal power plants. Al-Refaie et al. [56] predicted maintenance activities using generalized sequential patterns and association rules in data mining. Al-Refaie et al. [57] proposed a web for maintenance prediction of machine conditions and failure using machine learning. Al-Refaie & Aljundi [58] developed a fuzzy FMEA-resilience approach for maintenance planning. Al-Refaie & Hamdieh [59] used data mining for maintenance prediction of faulty products under warranty.

2.3. Research gap

Most of the previous research reported conceptual and theoretical studies on ELVs, circular economy, and frugal innovation [60-64]. Moreover, the technical and practical adoption of frugal innovation in automobile maintenance services was rarely examined [65-68].This research contributes to the theory and practice of frugal innovation by conducting a realistic assessment of innovative spare parts of ELVs utilizing three assessment of spare parts criteria including substantial cost reduction from a customer perspective, concentration on core functionalities, and optimized performance level. The assessment methodology is an original contribution and can be used to assess the frugal innovation of products in a wide range of applications.

3. Case Study

Generally, ELVs are grouped into two categories, high-salvage ELVs (HSELVs) and low-salvage ELVs (LSELVs). The ELVs pass through various processes including (1) the pretreatment process, in which all hazardous parts, oil, refrigerant, tire, and fluids are removed, (2)the dismantling process of breaking down the components into individual parts or materials to reuse them directly, re-manufacturing and reuse, or recycling. Remanufacture or reconditioning extends the life of spare parts by reprocessing or upgrading processes. Recycling process is used to transform ELV waste into new products when other options for recovery cannot be achieved. The disposal process deals with the remaining waste, and (3) product recoverability.

4. Data collection

This research considers a specialized company of vehicle maintenance and spare part services. New spare parts are sold at different prices; H (highest selling price over $220), M (moderate selling price between $45- $220), and L (the lowest selling price of less than $ 44), and different movement types; A (fast moving), B (moderate movement), and C (least moving). After conducting ABC and HML analyses for all spare parts in the inventory, twenty-seven randomly new spare parts are selected for comparison with the corresponding second-hand spare parts dismantled from ELVs. The data was collected from various sources including:

- Historical sales reports and sales price for spare parts: One year's sales history for all items was used between the periods of Jun/2020 to Dec/2020 to trace the demand behavior of spare parts. Also, the sales price of new spare parts on the first day of Feb was presented to compare it with the second-hand price.
- Service Manual: The service manual addressed inspection, disassembly, and reassembly procedures and instructions for spare parts.
- International Dismantling Information System (IDIS)was used to address data for the pre-treatment and dismantling procedures of ELVs.
- Observations were used to obtain an understanding of how and when to inspect spare parts with the tools required for the inspection procedure. Discrete observations were collected between the period Sep/2020- Nov/2020 at different spare part types.
- Semi-structured, in-depth interviews with employees, vehicle owners, and second-hand spare parts shop owners. Twelve interviews were conducted to obtain opinions on frugal innovative second-hand parts during the period of November/2020–March/2021.Each interview lasted between 10 min and 50 min.

5. Data analysis

The data analysis was conducted and is outlined in the following steps:

Step 1: Classify spare parts based on ABC, HML, and nature. The ABC analysis is shown in Table 1, where Class A parts contributedabout59 %of total sales and 3.3% of the total inventory line (line means a group of parts that have the same part number regardless of the quantities).Class B parts contribute around 30.7 % of the totals for sales and inventory lines. Finally, Class C parts constitute around 10%oftotal sales and 66% of total lines. Further, the results of the HML analysis are displayed in Table 2, where it is noted the H, M, and L classes cover about parts 2.6 %, 86 %, and 11.4 % of the total parts inventory, respectively.

Table 1. ABC analysis of spare parts.

Classification	Total sales (Pieces)	Number of lines in the inventory
A	15721	51
B	8194	471
C	2624	1010
Total	26539	1532

Table 2. Results of HML analysis.

Classification	Total sales	Number of lines
H	692	125
L	22831	1017
M	3016	390
Total	26539	1532

Table 3 displays the classification of spare parts based on their nature into three main groups:

1. General parts (GNP), which are used for vehicle repairs, such as engines, steering gears, steering pumps, starters, AC compressors, wheel discs, disc clutch, plate clutch, and brake linings. The GNP class covers about 14.7 % of the total sales.
2. Consumable parts (CP) that are used for vehicle maintenance, such as regular replacement parts including filters, belts, and wipers. The CP class covers about 51 % of the total sales.
3. Body parts (BP) cover the vehicle's internal and external components, such as glass, bumpers, panels, and mirrors. The BP class covers about 14.7 34.3 % of the total sales.

Tables 4 and 5 display the classification and annual consumption of spare parts, respectively. Based on technical knowledge, twenty-seven different classes of random spare parts were selected as listed in Table 6 for frugality assessment.

Table 3. Inventory list based on the nature of spare parts.

Classification	Total sales (Pieces)	Number of lines in the inventory
BP	3894	444
CP	13525	105
GNP	9120	983
Total	26539	1532

Table 4. Inventory list based on classifications.

	H				L			Total	M			Total	Grand Total
	BP	CP	GNP	Total	BP	CP	GNP		BP	CP	GNP		
A	0	0	1	1	3	28	9	42	4	4	2	10	53
B	19	0	13	32	62	34	226	322	44	9	64	117	471
C	56	2	34	92	152	16	487	655	104	12	147	263	1010
Grand Total	75	2	48	125	217	78	722	1019	152	25	213	390	1534

Step 2: Assess frugality criteria for the second-hand parts

The frugality assessment for the selected spare parts was conducted and is described as follows:

1. Substantial cost reduction

A second-hand part is considered a frugal innovative part if it results in a significant reduction in maintenance cost from the customer's perspective. Thus, the selling prices of the selected spare parts were compared with the average selling prices of high-quality and guaranteed spare parts purchased from local shops as shown in Table 7. Let *NSPSP* and *USPSP* denote the selling prices of new and used spare parts, respectively. The cost reduction for one-pieces (*CROP*) is then estimated using:

$$CROP(\$) = NSPSP - USPSP \quad (1)$$

Let QSPRV be the quantity of spare parts required in the maintenance or service of each vehicle. The cost reduction (ACR) is then calculated as:

$$ACR(\$) = CROP.QSPRV \quad (2)$$

Finally, the cost reduction percentage (CRP %) is obtained using:

$$CRP\,\% = \frac{CROP}{NSPSP}.100\% \quad (3)$$

Table 5. Spare parts annual consumption.

	H			Total	L			Total	M			Total	Grand Total
	BP	CP	GNP		BP	CP	GNP		BP	CP	GNP		
A	0	0	92	92	1251	11777	1435	14463	215	809	142	1166	15721
B	295	0	155	450	1188	693	4538	6419	395	165	765	1325	8194
C	93	3	54	150	272	39	1638	1949	185	39	301	525	2624
Grand Total	388	3	301	692	2711	12509	7611	22831	795	1013	1208	3016	26539

Table 6. The selected spare parts.

No.	Parts Name	ABC	HTML	Nature	No.	Parts Name	ABC	HML	Nature
1	Aluminum Wheel DISC	C	H	GNP	15	Cooling Fan	C	M	GNP
2	Front DOOR	C	H	BP	16	Horn High Note	C	M	BP
3	Windshield Glass	B	H	BP	17	Absorber Assembly Front	B	M	GNP
4	Speed Sensor Front Wheel	B	H	GNP	18	Cylinder Slave	C	M	GNP
5	Lower Arm	C	H	GNP	19	Thermostat Heater	C	L	GNP
6	Front Bumper	A	M	BP	20	Air Filter	A	L	CP
7	Water Pump	C	M	GNP	21	Belt Cooling Fan	B	L	CP
8	Side turn Lamp	B	M	BP	22	Retainer Front Bumper	A	L	BP
9	Clutch Plate	A	M	GNP	23	Bulb Side Turn Signal	A	L	GNP
10	Front Brake Pads	A	M	GNP	24	Drum Rear Brake	C	H	GNP
11	Piston	B	M	GNP	25	Evaporator Assembly heater	B	M	GNP
12	Fuel Filter	B	L	CP	26	Turbocharger	C	H	GNP
13	Guard Mud Rear	C	M	BP	27	Switch Power Window	B	M	GNP
14	Cap Wheel	B	L	BP					

Table 7. Comparison between the price of second-hand spare parts and prices of new parts.

No.	Part Name	QSPRV	NSPSP ($)	USPSP ($)	CROP	ACR ($)	CRP (%)
1	Aluminum wheeldisc	4	580.49	254.24	326.25	1305.01	56.20
2	Front Door	2	458.56	282.49	176.07	352.15	38.40
3	Windshield Glass	1	427.22	225.99	201.23	201.23	47.10
4	Speed Sensor Front Wheel	2	422.95	169.49	253.46	506.92	59.93
5	Lower Arm	2	327.82	120.06	207.76	415.53	63.38
6	Front Bumper	1	208.33	105.93	102.40	102.40	49.15
7	Water Pump	1	201.53	77.68	123.85	123.85	61.45
8	Side Turn Lamp	2	60.00	39.55	20.45	40.90	34.09
9	Clutch Plate	1	126.70	39.55	87.15	87.15	68.79
10	Front Brake Pads	1	142.00	32.37	54.85	54.85	62.88
11	Piston	4	95.40	39.55	55.85	223.41	58.55
12	Fuel Filter	1	8.20	Not Available	0	0	0
13	Guard Mud Rear	2	31.16	16.95	14.21	28.42	45.61
14	Cap Wheel	4	32.10	17.77	14.33	57.30	44.63
15	Cooling Fan	1	57.14	25.31	31.83	31.83	55.70
16	Horn High Note	1	54.30	35.31	18.99	18.99	34.97
17	Absorber Assembly Front	2	51.30	16.95	34.35	68.70	66.96
18	Cylinder Slave	1	48.95	25.42	23.53	23.53	48.06
19	Thermostat Heater	1	9.32	Not Available	0	0	0
20	Air Filter	1	25.20	Not Available	0	0	0
21	Belt Cooling Fan	1	13.40	Not Available	0	0	0
22	Retainer Front Bumper	10	2.40	Not Available	0	0	0
23	Bulb Side Turn Signal	1	1.60	Not Available	0	0	0
24	Drum Rear Brake	2	325.57	91.81	233.76	467.52	71.80
25	Evaporator Assembly	1	197.64	105.93	91.71	91.71	46.40
26	Turbocharger	1	2170.00	776.84	1393.16	1393.16	64.20
27	Switch Power Window	1	201.60	63.56	138.04	138.04	68.47

2. Concentration on core functionalities

The spare parts were evaluated for the fulfillment of their specified core functionalities as shown in Table 8.

3. Optimized performance level

An inspection of the selected spare parts was performed by observing the vehicle's maintenance and inspection procedures and checking the service manual to ensure that the performance of the spare parts from ELVs meets the required performance levels. For illustration, the inspection and checking of the Aluminum Wheel Disc, Clutch Plate, and Drum Rear Brake are shown in Figs. 1 to 3, respectively.

Step 3: Assess part fulfillment of frugal innovation criteria.

Twelve experts assessed the conformance of the selected spare parts to the frugality criteria. The evaluation results are frugal shown in Fig. 4.

Step 4: List the spare parts that achieve frugal innovation criteria

For the cost reduction criterion, as shown in Fig. 5, twenty-one out of the twenty-seven ELV spare parts achieved significant cost reduction with cost reduction percentages ranging from 34.97% to 71.8%. The parts that do not fulfill this criterion are parts 12, 19, 20, 22, and 23.

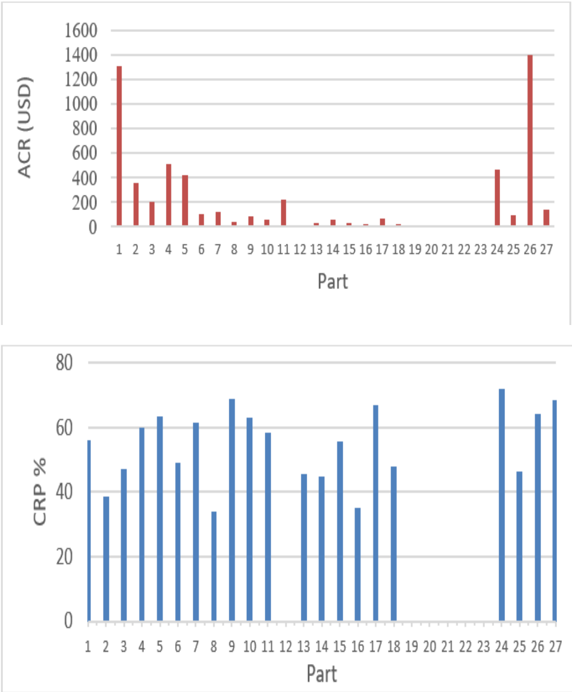

Figure 5. Cost reduction.

Table 8. The functions of spare parts.

No.	Part name	Function
1	Aluminum Wheel Disc	1. Load-carrying element in static and running vehicle conditions. 2. The barrel of the wheel disc creates a surface for mounting the tire. 3. The barrel edges are shaped to form flanges to ensure that the tire does not slip off when the vehicle is in motion.
2	Front Door	1. Provide access to the vehicle. 2. Secure the vehicle when closed. 3. Protect passengers from side collisions 4. Give a decorative appearance to vehicles
3	Windshield Glass	1. Protect passengers from the wind and flying debris. 2. During a collision the windshield is just another barrier alongside the airbag. 3. Allow vehicles to be aerodynamic to reduce fuel consumption and improve the vehicle's efficiency.
⋮	⋮	⋮
26	Turbocharger	Improve the overall engine efficiency and increase performance.
27	Switch Power Window	Regulate the opening and closing of the vehicle's windows.

Concentration on essential functions

As light change in external appearances is accepted. The essential functions that must be available are:

- Carry loading even vehicle static and running conditions.
- The barrel of the wheel disc creates a surface for mounting the tire.
- The barrel edges are shaped to form flanges to ensure that the tire does not slip off when the vehicles are in motion.

Optimal performance level achievement

- Ensure that the aluminum wheel disc works at optimal performance level:
- The vertical and horizontal run-out do not exceed a specific value.

Cost reduction due to the use of second-hand parts: 56.20%

Aluminum wheel disc.

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Optimal performance level achievement

The lower arm assembly shall work at optimal performance levels. If the arm has huge damage, or corrosion or the ball joint does not move normally without catching or getting stuck when moving it by hand and the lower arm and bushing are in good condition, then the ball joint can be replaced.

Concentration on essential functions

1. By inspection, the functions that must be available are:
✓ Core components of a suspension system operating.
✓ Steering vehicles.
✓ Have a necessary role in a vehicle's overall stability and drivability

Cost reduction due to the use of second-hand parts: 63.38%
Cost reduction due to repair of the parts:82.05%-90.60%

Lower Arm Assembly.

Optimal Performance Level Achievement:

- Both visual and functional inspections are required to ensure that the second-hand water pump works at optimal performance level.
- The water pump will only work at optimal performance level if there is no excessive looseness or abnormal noise.

Cost reduction due to the use of second-hand parts: 61.45%

Water pump.

Optimal Performance Level Achievement

- Both visual and functional inspections are required to ensure that second-hand clutch plate works at optimal performance level.
- The clutch plate will only work at optimal performance level if the fluctuation is less

Concentration on Essential Functions

By inspection of the second-hand parts, the functions that must be available is to transmit power from the engine or shut it off

Cost reduction due to the use of second-hand parts: 68.79%

Clutch plate.

Optimal Performance Level Achievement

- Both visual and functional inspections are required to ensure that second-hand front brake pads work at optimal performance level.
- The front brake Pads will only work at optimal performance level if the thickness of the brake shoe is more than the limit value.

Concentration on Essential Functions:

By inspection of the second-hand parts, the functions that must be available are:
✓ Slow or stop the motion of a vehicle. The brake pads are used in the disc brake system.

Cost reduction due to the use of second-hand parts: 62.88%

Front plate pads.

Concentration on Essential Functions:

1. By inspection of the second-hand parts, the functions that must be available are:

✓ It is a moving component that transfers the force from the gas that expands in the engine cylinders to the crankshaft to turn the wheels.

✓ Converting linear motion in the cylinders to a circular motion.

Optimal Performance Level Achievement

- The piston will only work at optimal performance level if the clearance between the inner diameters of the cylinder block and the outer diameter of the piston between the acceptable range.

Cost reduction due to the use of second-hand parts: 58.55%

Piston.

Optimal Performance Level Achievement

- Only visual inspection is required to ensure that second-hand guard mud works at optimal performance level:
- The guard mud will work at optimal performance level if it is not cracked or broken.

Concentration on Essential Functions:

According to the experts' and manufacturer's points of view, second-hand rear mudguards must have the same functions compared with the new

Cost reduction due to the use of second-hand parts: 45.61%

Guard mud rear.

Optimal Performance Level Achievement

only visual inspection is required to ensure that the second cap wheel disc works at optimal performance level.

The cap wheel disc will work at optimal performance level if it is not cracked or broken.

Core Functions Achievement

- **Easy to Use:**

Second-hand cap wheel discs have the same installation and inspection procedure as new parts, which avoids any confusion or delay in the service time

- **Lower impact on the environment:**

Second hand cap wheel disc reducing the industry's production of new parts

Cost reduction due to the use of second-hand parts: 44.63%

Cap wheel disc.

Optimal Performance Level Achievement

- Both visual and functional inspections are required to ensure that second-hand cooling fan at optimal performance level.
- The cooling fan will only work at optimal performance level if it does not rotate easily during the inspection when the clutch temperature becomes around 85 °C.

Concentration on Essential Functions

- **Easy to Use**

Second-hand cooling fan have the same installation and inspection procedure of new parts, which avoids any confusion or delay in the service time

- **Lower impact on the environment**

Second hand cooling fan reducing the industry's production of new parts

Cost reduction due to the use of second-hand parts: 55.70%

Cooling fan.

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Optimal Performance Level Achievement

- Both visual, measurement and functional inspections are required to ensure that second-hand front absorber work at optimal performance level.

Concentration on Essential Functions

- **Easy to Used:**

  Second hand front absorber have the same installation and inspection procedure of new parts, which avoid any confusion or delay in the service time

- **Lower impact on the environment:**

  Second hand front absorber reducing the industry's production of new parts

Cost reduction due to the use of second-hand parts: 66.96%

Front absorber.

Optimal Performance Level Achievement

- Both visual and functional inspections are required to ensure that

Concentration on Essential Functions

- **Easy to Use**

  Second-hand cylinder slave have the same installation and inspection procedure of new parts, which avoid any confusion or delay in the service time

- **Lower impact on the environment:**

  Second-hand cylinder slave reduces the industry's production of new parts.

Cost reduction due to the use of second-hand parts: 48.06%
Cost reduction due to repair parts:59.93%

Cylinder slave.

Optimal Performance Level Achievement

- Both visual and measurement inspections are required to ensure that the second-hand drum works at optimal performance levels.
- the drum will work at optimal if the measuring of the drum's inner diameter is less than the limit value in the table.17

Core Functions Achievement:

Concentration on Essential Functions:

- **Easy to Used:**

  Second hand drum have the same installation and inspection procedure of new parts, which avoid any confusion or delay in the service time

- **Lower impact on the environment:**

  Second hand drum reducing the industry's production of new parts

Cost reduction due to the use of second-hand parts: 71.80%

Drum rear brake.

Optimal Performance Level Achievement

- Both visual and measurement inspection, the evaporator is checked for no leakage on refrigerant

Concentration on Essential Functions

- **Easy to Used:**

  Second hand evaporator have the same installation and inspection procedure of new parts, which avoid any confusion or delay in the service time

- **Lower impact on the environment:**

  Second hand evaporator reducing the industry's production of new parts

Cost reduction due to the use of second-hand parts 46.40 %

Evaporator assembly

Figure 4. Assessment of frugal innovation of some of the selected spare parts.

The cost reduction classification according to inventory class, nature of spare parts, and selling price are depicted in Figs. 6 to 8, respectively. From Fig. 6, 50%, 80%, and 91% of the parts from classes A, B, and C achieve significant cost reductions. The nature of the parts in Fig. 7 shows that about 0%, 87.5 %, and 87.5% of the CP, BP, and GNP can result in significant cost reduction. Finally, all parts with high and moderate prices fulfill this criterion. However, not all low-price items achieve substantial cost reductions.

Further, for the core functionalities criterion, the following guidelines were adopted in assessing the core functionalities criteria for spare parts:

1. Concentration on core benefits and essential functions: Second-hand spare parts should perform the same functions or at least the essential functions compared with the new genuine spare parts. Meanwhile, a slight change in external appearances like minor scratches or color changes in spare parts can be tolerated. However, internal damages or changes are not tolerated because they affect optimized performance levels.
2. Easy to use and reduced complexity. This criterion is concerned with how quickly and economically the repair or maintenance activity can be accomplished while ensuring no increase in the installation or inspection efforts.
3. Low environmental impact. The use of second-hand parts should reduce industrial pollution resulting from processing new parts.

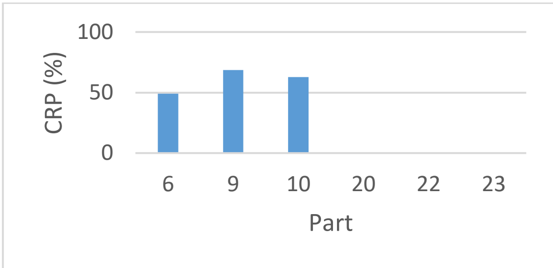
Table 9 lists the potential spare parts that perform the core functions; where three parts from the CP category as well as the retainer front bumper fail to meet this criterion because according to the manufacturer's recommendations reusing CP affects negatively part performance. Finally, regarding the optimized performance level of the selected spare parts, it is found that twenty-three out spare parts preserve the performance level at the required value based on the manufacturer's recommendations. The parts that did not achieve the optimized performance level include (a) Clips,screws, seals, and retainer front bumper because such parts usually incur invisible wear that affects performance level, and (2) CP, where part manufacturers suggest replacement of such parts rather than reusing.

Table 9 also shows that all twenty-seven parts maintain the required quality levels; except three parts classified as CP in addition to the retainer. Typically, the inspection type is required based on the type of spare part. That is,

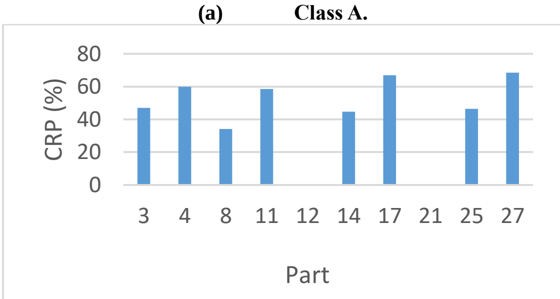
1. Body Parts (BP): Only visual inspection is required to ensure that the second-hand spare parts work at optimal performance levels.
2. General Parts (GNP) which are assessed by visual inspection as well as measurement inspection, and functional inspection- both or one of them - to ensure that the second-hand spare parts perform at optimal performance level.
3. Consumable Parts (CP), where no inspection is required to ensure that second-hand CP works at an optimal performance level. Part replacement with a new one is the technical recommendation.

Table 9. Frugal innovative spare parts.

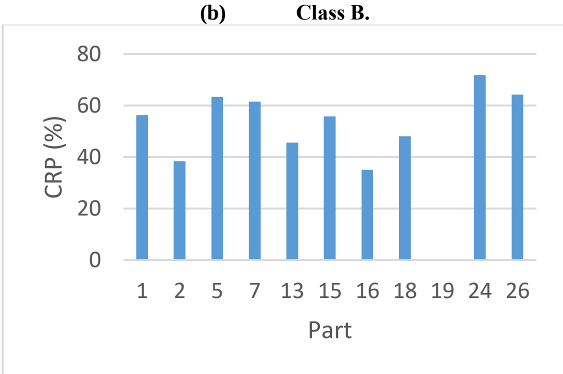
No.	Cost Reduction	Core functionalities	Optimal performance	Frugal innovation
1	56.20	Yes	Yes	Yes
2	38.40	Yes	Yes	Yes
3	47.10	Yes	Yes	Yes
4	59.93	Yes	Yes	Yes
5	63.38	Yes	Yes	Yes
6	49.15	Yes	Yes	Yes
7	61.45	Yes	Yes	Yes
8	34.09	Yes	Yes	Yes
9	68.79	Yes	Yes	Yes
10	62.88	Yes	Yes	Yes
11	58.55	Yes	Yes	Yes
12	-	No	No	No
13	45.61	Yes	Yes	Yes
14	44.63	Yes	Yes	Yes
15	55.70	Yes	Yes	Yes
16	34.97	Yes	Yes	Yes
17	66.96	Yes	Yes	Yes
18	48.06	Yes	Yes	Yes
19	-	Yes	Yes	No
20	-	No	No	No
21	-	No	No	No
22	-	No	No	No
23	-	Yes	Yes	No
24	71.80	Yes	Yes	Yes
25	46.40	Yes	Yes	Yes
26	64.20	Yes	Yes	Yes
27	68.47	Yes	Yes	Yes



(a) **Class A.**



(b) **Class B.**



(c) **Class C.**

Figure 6.CRP for each inventory class.

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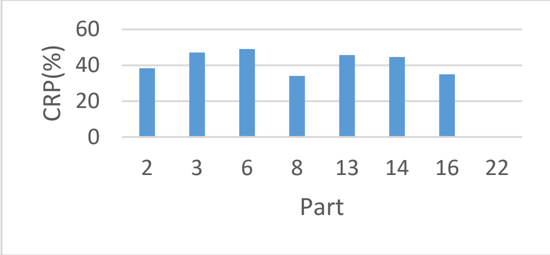
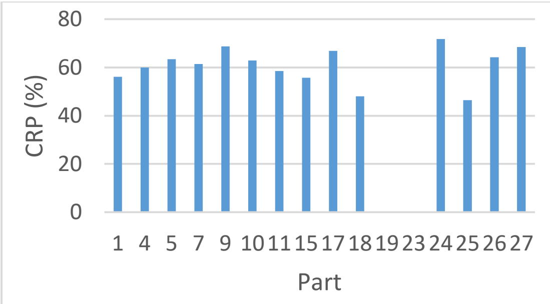
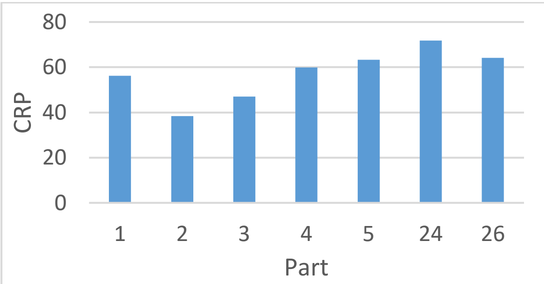


(a) BP.

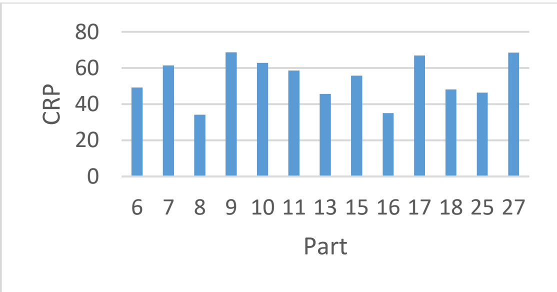


(b) GNP.

Figure 7. CRP for each nature of the spare part.



(a) High price.



(b) Moderate price.

Figure 8. CRP for each price level.

Research Results

The assessment results of spare parts for frugality are displayed in Table 9, where it is noted that: (i) Twenty-one out of twenty-seven of the studied spare parts achieved frugal innovation criteria, (ii) the spare parts that were not qualified for frugality included the fuel filter, Thermostat heater, air filter, belt cooling fan, retainer front bumper, and bulb side turn signal, (iii) the largest amounts of cost reduction ($) of 1393.16 and 1305.01 were contributed by the turbochargers and Aluminum wheel discs, respectively, and (iv) the, largest percentages of cost reduction corresponded to drum rear brake (71.8 %), switch power window (68.47 %), clutch plate (68.79 %), absorber assembly front (66.96 %). These results have proved the existence of a great opportunity to implement frugal innovation in ELV spare parts in Jordan. Such implications can support and satisfy low-income owners of automobiles at affordable prices, preserve the environment, and enhance business performance.

Conclusions

This study conducted a valuable framework for the frugality assessment of the spare parts from ELVs.A firm specialized in vehicle maintenance and spare parts services was considered. Initially, the ABC and HML analyses were conducted for twenty-seven random spare parts. All parts were assessed to three criteria including providing core functionalities, optimal performance level, and cost reductions. Results showed that about 77.7% of the randomly selected parts achieved frugal innovation criteria.In conclusion, the use of innovative spare parts may contribute to solving supplier stock out and shipping delays, decreasing the necessity of holding risky parts, increasing service level, and increasing customer satisfaction. Future study considers examining the willingness of frugal innovation adoption by industrial and service sectors.

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