Autonomous Delivery Robot (ADR)

Trade-off Analysis

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1. Purpose and Metric

This section identifies the purpose of the trade-off analysis. The objective of the tradeoff analysis is to provide and recommend design options for ADR that meet the stakeholder's requirements and are efficient. The purpose of this report is to :

1. Understand and perform Pareto Front Analysis for multiple options and find Pareto optimal solutions.
2. Understand and perform multi-attribute value function (MAVF) using the optimal solutions and customer inputs.
3. Understand and perform MAVF Trade-Off Analysis to find the best solution for the given stakeholder/customer.

The system's principal stakeholders and their roles are described in Table 1.

Table 1: Stakeholders(SH) and their roles

ID	Stakeholder	Role(s)	Priority
SH1	**Uber Eats**	Customer, User & Maintainer	Primary
SH2	**DoorDash**	Customer, User & Maintainer	Primary
SH3	**Grubhub**	Customer, User & Maintainer	Primary
SH4	**FedEx**	Customer, User & Maintainer	Primary
SH5	**UPS**	Customer, User & Maintainer	Primary
SH6	**Public Universities**	Potential Customer & User	Secondary
SH7	**Private Universities**	Potential Customer & User	Secondary

Note: Refer to Appendix A for acronyms.

The cost and the reliability of the components are the metrics that are important to the current stakeholders. The cost is dependent on the ability of the ADR to successfully avoid collisions using sensors, operational distance from the central server and the payload capacity.

High value of reliability and low value of cost would be the best design solution to the stakeholders.

2. Design Options and Factors

This section indicates a reference design and a set of alternative design options and how the design options were identified and generated. The reference design is shown in Figure 1. The design consists of 6 wheels, camera sensors for perception and array of other sensors to avoid obstacles, motors to drive the wheel to reach the destination.

Figure 1 : Reference Design of ADR from Starship Robotics

The design metrics that affect cost of the system would be the sensors mounted on the ADR, the payload capacity that can be moved by the propulsion system and the active communication range of the ADR.

Table 2: Design Choices

System	Components	Specifications	ID	Cost (USD/$)	MTBF (Hours)
Telemetry	Antenna	2 Mile Range	ST1	400	160
		1.5 Mile Range	ST2	305	145
Propulsion	Motors	400 lbs load carrying capacity	SP1	1735	84.5
		500 lbs load carrying capacity	SP2	1765	102
Sensor	Cameras, Proximity Sensors, Batteries	Rolling Shutter, 30m,65Ah	SS1	2200	139.5
		Global Shutter, 20m,70Ah	SS2	2305	149.5

Note: Refer to Appendix A for acronyms.

Table 3: Generation of Design Options

Design ID	Design Options	Cost (USD/$)			Cost (USD / $)	MTBF (Hours)			MTBF (Hours)
D1	ST1,SP1,SS1	400	1735	2200	4335	160	84.5	139.5	384.00
D2	ST1,SP1,SS2	400	1735	2305	4440	160	84.5	149.5	394.00
D3	ST1,SP2,SS1	400	1765	2200	4365	160	102	139.5	401.50
D4	ST1,SP2,SS2	400	1765	2305	4470	160	102	149.5	411.50
D5	ST2,SP1,SS1	305	1735	2200	4240	145	84.5	139.5	369.00
D6	ST2,SP1,SS2	305	1735	2305	4345	145	84.5	149.5	379.00
D7	ST2,SP2,SS1	305	1765	2200	4270	145	102	139.5	386.50
D8	ST2,SP2,SS2	305	1765	2305	4375	145	102	149.5	396.50

Note: Refer to Appendix A for acronyms.

3. Analysis Approach

This section describes the approach used for the analysis. The design options are created using a platform-based design approach to develop the Table 3 that showcases the possible system design options with their associated total cost and system reliability as shown in Table 2.

The total value function is a measure of the degree to which a capability or set of capabilities is subjectively valued by a stakeholder. If a total value function is dependent on more than one attribute or metric, then it is a multi-attribute value function (MAVF).

The pareto frontier analysis consists of the set of “solutions” to a problem that maximize the performance to a set of N performance metrics. And this is used to find the Course of Actions (COAs) whose values for a set of performance metrics are “optimal”.

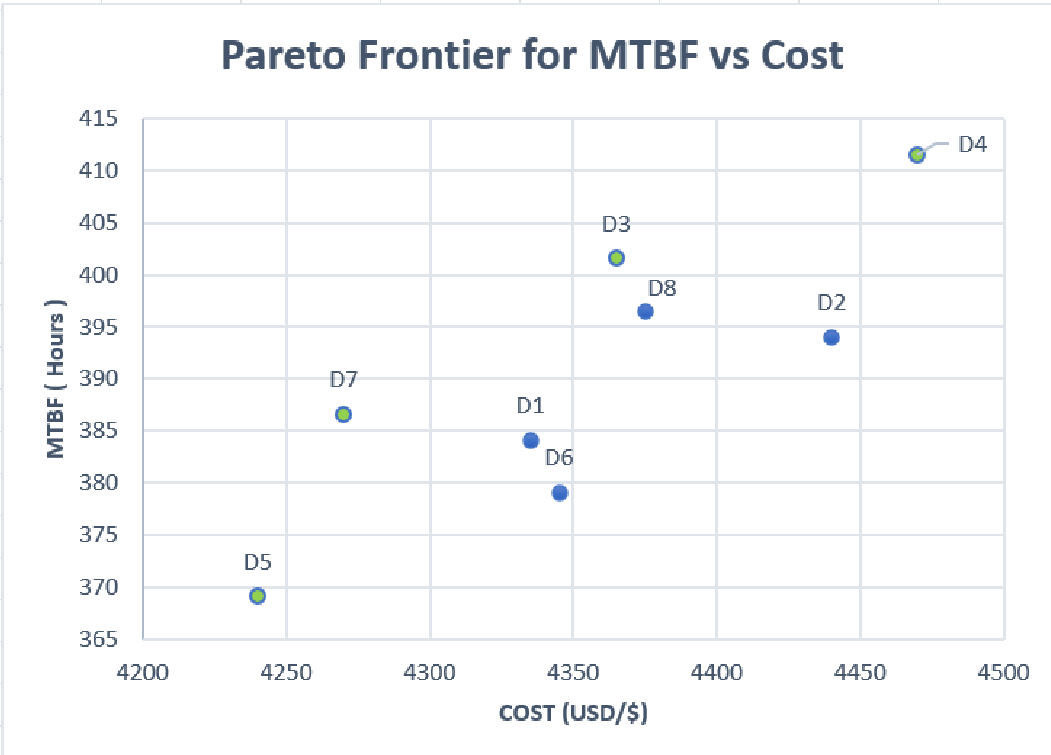

Figure 2 : Pareto Frontier Analysis for Total Cost Versus Total MTBF

If the design options generated are many in number, the Pareto Front allows one to choose a subset of the set of all the design options that prove to be optimal. Then, performing a Multi-Attribute Value Function analysis on the Pareto Solution set, one can choose the best design option that provides the greatest value to the customer after ranking the attributes according to the customers' preferences.

In order to obtain the best possible solution (COAs) for the system that reflect the relative importance of each metric, Multi-attribute Value Function Analysis (MAVF) on the Pareto Optimal Solutions is performed. To determine the weighting weights, Swing weighting method was used and the ranks and the weights are tabulated in Table 4.

Table 4: Swing Weights for Stakeholder and Rank

	SH Rank	SH Weight (Weights = Ri / ΣRi)
Worst	0	
Worst C, Best R	30	0.23
Best C, Worst R	100	0.76
Sum	130	

Note: Refer to Appendix A for acronyms.

4. Analysis

The Total Value (Utility) Function (Vt) associated with a decision option characterized by a set of decision attribute values (av) namely: Cost, MTBF, is given as follows:

$$\mathbf{Vt(av_i, w_i) = w_1 * V_1(av_1) + w_2 * V_2(av_2)}$$

- w_i is the weight the stakeholder places on the decision attribute *i*.
- $V_i(av_i)$ is the single attribute value associated with a given attribute value (av_i).

To identify the swing weight options, the highest and the lowest values for the two attributes are as in Table 5.

Table 5: Highest and Lowest Attributes Values

Cases	Cost (USD / $)	MTBF (Hours)
Worst	4470	369.00
Worst C, Best R	4470	411.50
Best C, Worst R	4240	369.00

Note: Refer to Appendix A for acronyms.

The Value function weight is assigned for the best case (when the attribute Cost is considered) is when the Cost value is low i.e., Vc = 1 (when cost is lowest).

The Value function weight is assigned for the best case (when the attribute MTBF is considered) is when the MTBF value is highest i.e., Vr = 1 (when MTBF is highest).

Therefore for this analysis, the equations would be

$$Vc = (4470 - av1) / 230$$

$$Vr = (av2 - 369) / 42.5$$

Utilizing the stakeholders' weights for each attribute according to their preference, the multiplication of $Vc*Weight_{Cost}$ and $Vr*Weight_{MTBF}$, we get the Multi-Attribute Value Function (MAVF) to be as shown in the following Table 6.

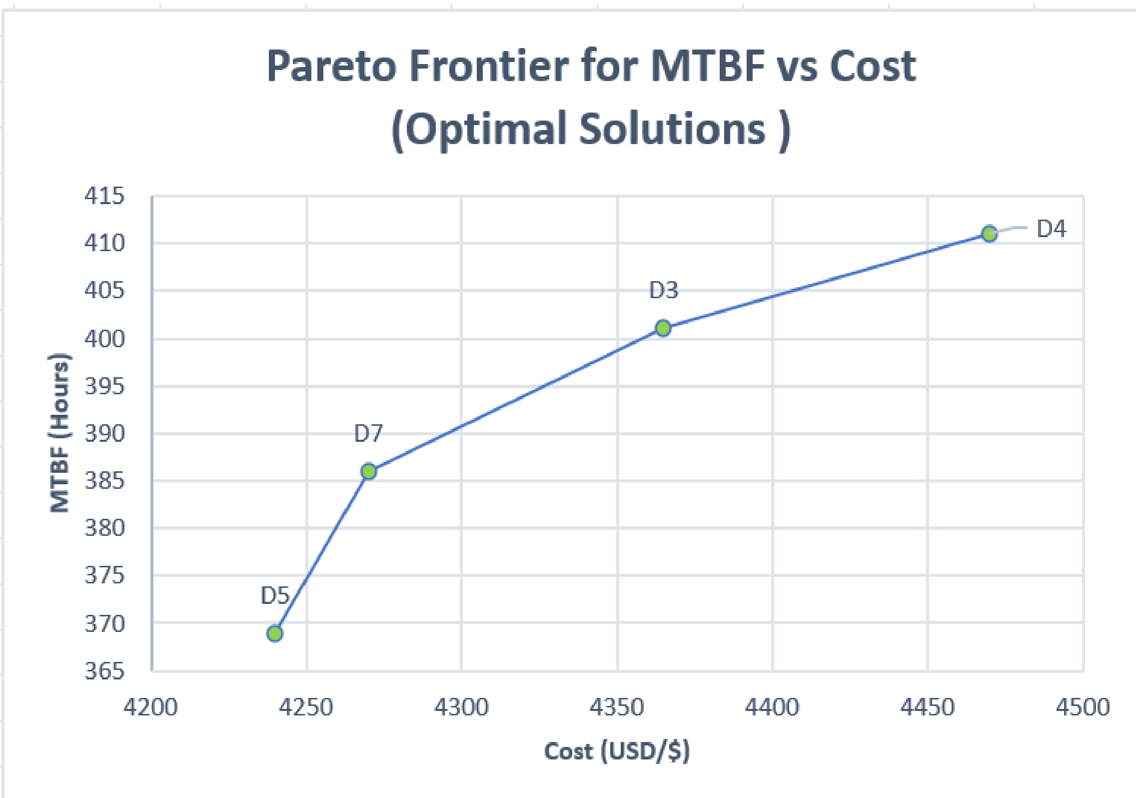

Figure 3 : Pareto Optimal Solutions

The MAVF analysis is performed only on pareto optimal solutions, i.e , the design solutions D5, D7, D3, D4. The MAVF for the pareto optimal solutions are tabulated below in Table 6:

Table 6: Design Options after Analysis

Design ID	Cost (USD)	MTBF (Hrs)	SAVF 1	SAVF 2	MAVF
	av1	av2	Vc	Vr	SH2
D3	4365	401.5	0.456	0.764	0.522
D4	4470	411.5	0	1	0.230
D5	4240	369	1	0	0.760

Note: Refer to Appendix A for acronyms.

5. Analysis Results and Recommendations

Design ID D5 is being recommended as the MAVF value is 0.760 which is the highest amongst other values.

According to the results, Design ID D5 provides the greatest value to the stakeholder if the cost is ranked higher than reliability.

6. References

This section provides a list of references that were used for the analytical methods used and/or the data that was used.

[1] 621 HW 11 Project Trade-off Analysis - Template, Dr. Tony Barber, 2022.

[2] 621 Lecture 11.3 Deterministic MAVF Trade-off Analyses, Dr. Tony Barber, 2022.

[3] Pareto Optimality - an Overview, ScienceDirect Topics, accessed on December 5, 2022 [Crosslink] .

[4] The Meanings of Trade-Offs in Multiattribute Evaluation Methods: A Comparison, S-K Lai and L D Hopkins, 1989. [Crosslink]

Appendix

A. Acronyms:

This Appendix defines all acronyms used in the main body of the document.

- ADR- Autonomous Delivery Robot
- SH - Stakeholder
- ST - Telemetry Specification
- SP - Telemetry Specification
- SS - Telemetry Specification
- D - Design
- MTBF - Mean Time Before Failure
- WR- Reliability Weighted Values
- WC - Cost Weighted Values
- MAVF - Multi Attribute Value Function
- SAVF - Single Attribute Value Function
- COA - Course of Action
- Vc - Value function weight for Cost
- Vr - Value function weight for Reliability/MTBF
- R- Reliability
- C- Cost