Technical Memo: Evaluation of Design Solutions - Scissor Lift Collision Prevention System

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Problem Statement and Key Decisions from Selection Process

Scissor lifts can collide with many objects around a given construction site (ex: door frames, piping, columns, etc.). These collisions result in heavy damage, leading to financial burdens, and injuries and fatalities. An object detection device is necessary to alert workers to potential collisions, thereby reducing overall damage and injuries on the construction site.

We generated 4 unique solutions from over 50 brainstormed ideas by using screening matrices and a morph chart. The screening matrices, which compared key categories such as sensor types, motor options for the sensors, power sources, and mounting methods, were used to rank each concept against the design criteria. From these, the morph chart combined the top options – up to four per block – to form the final solution concepts. Out of these solutions, solution C was the most feasible and effective solution to move forward with in our prototyping process. This solution prioritizes ease of setup, low maintenance and durability to effectively tackle our client's problem.

Ideation and Selection Process

We initially began the ideation process by decomposing our solution into multiple design blocks: mounting methods, types of sensors, sensor locations, charging/power methods, alerting methods, and types of motors for the sensors. Within these various categories, we used the writing slip method to brainstorm over 50 ideas. Each member was assigned a certain design block, and came up with 3-10 solutions.

After initial brainstorming, some ideas were eliminated using common sense and logic, taking into account the project's scope. Next, the team used 4 different Pugh Screening Matrices [Appendix Tables 1.1-1.4] to narrow down most of the brainstormed ideas. We evaluated the mounting methods, sensor types, charging/power methods, and motor types against our design criteria using the Pugh Screening Matrices. The most feasible brainstormed ideas for each category were then ranked based on our design criteria, with the most effective design concepts being chosen for the creation of the morph chart.

Once the Pugh Screening was completed, our team organized a morph chart [Appendix Table 2.0] to generate solution ideas. This morph chart sets a varied amount of options – dependent on the screening matrices – for each design block, with a maximum of four options per block. Using the same design blocks and design criteria listed above, we mixed the different options in each block to create 4 unique solution ideas. Our general process for creating solution options using the morph chart was to use as many of the options in each design block as possible across all the four solutions, unless certain options did not apply. A few options, such as "optical sensors" or "5 sensors on the lift," were not chosen, as the other options in their design blocks were better choices in terms of overall cost or functionality. Certain options were chosen more often than others in their design block, such as "ultrasonic sensors" over "LiDAR sensors" and "9 sensors" over "8 sensors" because they were more functional for our final solution and scored better in their respective Pugh Screening Matrix. The four unique solutions were then used in the Pugh Scoring Matrix to determine the solution we will begin to prototype.

Pugh Scoring Matrix

Selected Final Solutions for Evaluation

Solution A: Magnetic mount, 8 sensors placed in corners, ultrasonic, replaceable batteries, alert using lights, no motor
Solution B: Clamp mount, 9 sensors placed in corners and basket, LiDAR sensor, powered using lift, alert with rapid beeps, DC servo motor
Solution C: Magnetic mount, 9 sensors placed in corners and basket, ultrasonic sensor, powered using lift, alert with loud beeps, AC servo motor
Solution D: Clamp mount, 9 sensors placed in corners and basket, ultrasonic sensor, powered using lift, alert with beeps and lights, stepper motor

Design Criteria	**Weight**	**Solution A**		**Solution B**		**Solution C**		**Solution D**	
		Rating	Weight score	Rating	Weight score	Rating	Weight score	Rating	Weight score
Ease of Setup	25%	5	1.25	3	0.75	4	1	3	0.75
Low Maintenance	30%	2	0.6	4	1.2	5	1.5	3	0.9
Functionality	20%	1	0.2	4	0.8	3	0.6	4	0.8
Durability	15%	5	0.75	2	0.3	4	0.6	3	0.45
Low Cost	10%	3	0.3	1	0.1	3	0.3	2	0.2
Total Score	100%	3.1		3.15		4		3.1	
Rank	-	3rd (tie)		2nd		1st		3rd (tie)	
Continue	-	No		No		Yes		No	

Relative Weighting for Design Criteria:

The design criteria weighting was selected based on our previous rankings. We wanted to emphasize the importance of an easy setup process and more importantly, little maintenance. Since none of our pairwise comparison charts had ties, we knew that the relative weights would all be different. As a result, we gave low maintenance the highest weighting at 30%, and then decreased each successive weight by 5%, following our previous ranking of the design criteria. We recognize that each design criteria is considerably important, so we did not want to decrease the weights by any more than 5%.

1-5 Scoring Explained for Each Design Criteria [Appendix Table 3.2]:

- *Ease of Setup* - based on the total time required to install the system. Systems that take more than two hours to install receive the lowest score because they demand more labor, time, and potentially technical expertise, which limit usability in field conditions. As installation time decreases, the score improves, highlighting the value of a design that minimizes complexity and requires fewer setup resources. A system that can be installed in under 20 minutes earns the highest score, as it demonstrates excellent usability and less time for the operator to be off the job.
- *Low Maintenance* - measures the amount of time required per month to service the system. Designs requiring over six hours of maintenance per month receive the lowest score because they are less reliable and take time away from construction. As the required maintenance time decreases, the scores improve, with systems needing less than one hour, and especially less than 30 minutes per month, earning the highest scores since they minimize the time an operator is off the job.
- *Functionality* - focuses on detection accuracy and reaction speed. Solutions that do not effectively sense intruding objects or perform worse than alternatives receive the lowest scores. The highest score is given to designs that can detect objects within 0.5 meters and automatically stop the lift in under 0.5 seconds. Additionally, high accuracy within 0.1 meters is necessary for safe and efficient operation.
- *Durability* - the system's ability to withstand environmental and physical stress. A system without an IP65 or higher rating and that cannot survive a 1-meter drop scores lowest, as it lacks protection against dust, water, or impact. The highest-rated systems combine IP65+ environmental sealing with the ability to withstand drops of more than one meter, providing reliable performance in demanding conditions.
- *Low Cost* - considers the total cost per system. Systems costing over $1,000 receive the lowest score, while systems priced below $400 per unit receive the highest score because they are both affordable and easier to produce and replace.

Selected Solution and Justification

- **Components of Solution C:** The solution has a magnetic mounting system that will attach directly to the metal on the lift, 9 sensors placed in corners and beneath the basket, ultrasonic sensors, power coming from the lift's duplex outlet, an alert with beeps that increase in volume, and an AC servo motor for the sensor under the basket.
- Solution C successfully meets the design criteria of ease of setup, low maintenance and durability. It is necessary for the proposed solution to be intuitive for the operators and have a simple setup process, which this solution accomplishes. The solution's two-pole magnets and use of the scissor lift's existing power source allow for a quick, straightforward setup in under 30 minutes. In addition, the AC servo motor is the most reliable motor option, offering consistent performance and reducing the need for maintenance compared to the other solutions. More time spent on maintenance would make the device a hindrance to fast construction, negatively impacting its need and overall benefit as a solution. Finally, Solution C has a brushless AC servo motor with sealed housing, providing a durable alternative to DC servo and stepper motors. The magnetic mounting will also be a reliable system, leading to a high score in durability.

Appendix

Table 1.1: Pugh Screening Matrix 1 for Types of Sensors

Design Criteria	Ultrasonic Sensor	Optical Sensors	Backup Camera	Touch Sensors	LIDAR Vision
Low Maintenance	+	0	0	0	+
Ease of Setup	-	-	0	-	-
Durability	+	0	0	-	+
Low Cost	+	-	0	-	-
Functionality	+	+	0	0	+
Sum	3	-1	0	-2	1
Rank	1st	4th	3rd	5th	2nd

Table 1.2: Pugh Screening Matrix 2 for Types of Motors

Design Criteria	Stepper Motor	AC Motor	DC Motor	Servo Motor
Low Maintenance	+	+	0	-
Ease of Setup	-	-	0	-
Durability	+	+ +	0	+
Low Cost	-	-	0	- -
Functionality	+	-	0	+ +
Sum	1	0	0	-1
Rank	1st	2nd	2nd	4th

Table 1.3: Pugh Screening Matrix 3 for Powering

Design Criteria	1 Battery per module.	remote Station - 1 cable split to all modules	Powered by Scissor lift via micropower	one replaceable battery for all	remote Station Separate cable to each
Ease of Setup	0	–	–	0	–
Durability	0	–	+	0	–
Low Cost	0	+	+	+	0
Low maintenance	0	0	+	+	–
Functionality	0	–	+	–	0
Totals	–	-2	+3	+1	-3

Table 1.4: Pugh Screening Matrix 4 for Mounting Methods

Design Criteria	A	B	C	D	E	F	G
Ease of Setup	–	0	0	0	–	0	0
Durability	+	0	0	0	+	–	0
Low Cost	0	–	–	0	–	+	+
Low Maintenance	+	+	+	0	+	–	–
Functionality	+	+	0	0	–	–	–
Sum	+2	+1	0	0	-1	-2	-1
Rank	1	2	3	3	5	7	5

A = Temporary clamp/clip
B = Two pole magnet
C = Flat magnet
D = Velcro
E = Screw mounting (Permanent)
F = Adhesive strips / puddy
G = Adhesive pad

Table 2.0: Morph Chart

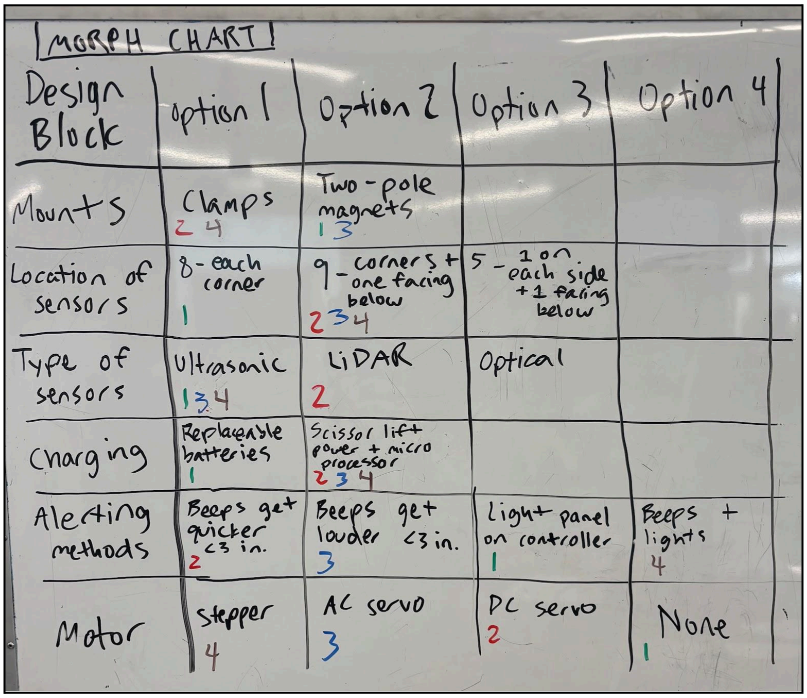

Table 3.1: Ranked Design Criteria

Rank	Objectives, Constraints	Target Value / Performance Criteria	Justification
1	Low Maintenance (objective)	≤1 hour/month; automated startup diagnostics	Reduces false security from sensor failure [10]; aligns with OSHA findings on preventable accidents [12].
2	Easy Setup (objective)	≤30 minutes install; <3 steps; only basic tools needed	Operators often lack advanced technical training [12]; minimizes downtime and increases adoption.
3	Durability (objective)	IP65+ rating; withstands vibration & 1 m drops; ≥3-year lifespan	Construction sites are harsh [7]; durability ensures long-term reliability and cost-effectiveness [18].
4	Low Cost (constraint)	≤$500 per lift (full system)	Cheaper than CAT retrofit cameras ($600–$800) [8]; avoids repair costs ($5k–$15k per incident).
5	Functionality (objective)	Obstacle detection up to ≥0.5 m; stop within ≤1s for objects ~0.1 m of lift	Scissor lifts move at 0.22–1.34 m/s; stopping within 1 s prevents collision [4].

Table 3.2: Scores for Each Design Criteria Explained

Criterion	Score 1 (Lowest)	Score 2	Score 3	Score 4	Score 5 (Highest)
Easy Setup	> 2 hours to install system	1–2 hours to install system	30 min – 1 hour to install system	20–30 minutes to install system	< 20 minutes to install system
Low Maintenance	> 6 hours per month	3–5 hours per month	1–2 hours per month	< 1 hour per month	< 30 minutes per month
Functionality	Fails to meet a requirement of the problem / worse than other solutions	Solves the problem, but does it worse than another solution	Detection up to 0.5 m, stop 1–2 s within 0.1 m	Detection up to 0.5 m, stop 0.5–1 s within 0.1 m	Detection up to 0.5 m, stop < 0.5 s within 0.1 m
Durability	No IP65+ rating & can't withstand 1 m drop	No IP65+ rating & can withstand 0.1–<1 m drop	IP65+ rating & can withstand 0.1–<1 m drop	IP65+ rating & can withstand 1 m drop	IP65+ rating & can withstand > 1 m drop
Low Cost	> $1000 per system	$700–$999 per system	$500–$700 per system	$400–$500 per system	< $400 per system