



Semi-Automatic Portable Car Cover Design: A Contribution to Efficient Vehicle Protection for Online-Taxi Drivers

Ian Hardianto Siahaan¹, Damar Erlangga¹, Ninuk Jonoadji¹, Willyanto Anggono^{1*}, Yuli Panca Asmara²

¹ Department of Mechanical Engineering, Petra Christian University, Surabaya, Indonesia

² INTI International University, Malaysia

*Corresponding author: willy@petra.ac.id



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Abstract

Vehicles left in open parking areas are continuously exposed to sunlight, which accelerates degradation of both exterior and interior components. This study presents the design and evaluation of a semi-automatic portable car cover intended to protect vehicles from ultraviolet radiation and other environmental factors, particularly for online-taxi drivers who typically do not have access to a private garage. The development process comprised several stages: concept design, technical calculation of frame strength and motor capacity, component selection, assembly, and functional testing of the open–close mechanism. A simplified structural check of the main C-channel/hollow-iron frame indicated an estimated bending stress of approximately 81.7 MPa under an idealized midspan load, corresponding to a safety factor of about 3.0 against the yield strength of mild steel; a torque–balance check likewise showed that the installed 0.63 N•m AC gear motor provides only a narrow margin (estimated safety factor of 1.03–1.09) over the torque required to overcome rail friction, indicating limited but adequate capacity under the assumed conditions. Functional testing showed that the prototype opens in an average of 34.8 s and closes in an average of 36.94 s, both within the 40 s design target, over a limited set of three trials; a larger sample size is recommended to statistically confirm repeatability. The system extends up to 4 m in length and operates through a semi-automatic AC-motor-driven controller, offering a practical and comparatively low-cost alternative to commercial products such as Lanmodo and Krisbow's Prestige cover line.

Keywords: Automotive accessory; Car cover; Portable structure; Semi-automatic mechanism; UV protection

1. Introduction

The online-taxi industry, including services such as Gojek's GoCar and GoBluebird, and Grab, has grown rapidly in recent years, with providers continuously adding driver-partners to meet rising demand [1]. This growth has occurred alongside an evolving regulatory and economic landscape for app-based drivers: recent labor-focused studies note that ride-hailing and courier drivers bear vehicle wear, operating, and depreciation costs directly out of their own earnings, with limited employer-style protections against these costs [2], and platform-level analyses further suggest that driver earnings are especially sensitive to competitive and socio-economic pressures in the markets where these platforms operate [3]. A safe place to store the vehicle, such as a private garage, is an important consideration for these drivers: although regulations do not explicitly require garage ownership, urban parking supply is often constrained relative to demand [4], and public parking policy in many cities does not guarantee drivers, especially those operating a small fleet, a dedicated space to keep their vehicle when it is not in operation [5]. Consequently, the majority of single-vehicle driver-partners on GoCar, GrabCar, and GoBluebird simply rely on a home parking spot rather than investing in a permanent garage. This reliance on informal, low-cost storage solutions reflects broader, well-documented pressures on the working conditions and economic security of ride-hailing driver-partners [6], underscoring the practical need for a low-cost vehicle-protection alternative. A portable car cover is therefore a practical and comparatively affordable option, protecting exterior components such as body paint, wiper rubber, and the air-conditioning system from direct sunlight, in the same way that other polymer-based components are known to degrade under prolonged environmental exposure [7]. This complements, rather than

replaces, dedicated paint-protection treatments such as wax, ceramic, or graphene-based coatings, which improve surface hardness and UV resistance but do not shield the vehicle's other exterior components or interior from sustained sun and rain exposure [8]. Continuous UV exposure fades paint, hardens and cracks wiper rubber, and raises cabin temperature, which in turn forces drivers to run the air-conditioning harder, increasing fuel consumption [9]. By using a portable cover, drivers can protect their vehicles without the cost of a permanent garage, helping to preserve vehicle condition and reduce day-to-day operating costs.

Portable car covers protect vehicles from sunlight and weather regardless of whether the car is garaged, and are available in various sizes to fit different vehicle shapes. Modern products use heat- and water-resistant materials suited to outdoor use, and textile research on moisture transport in vehicle covers shows that such materials must also manage air circulation carefully, since a fully sealed, non-breathable layer can trap moisture against the vehicle body during rain [10]. Selecting a cover material that also allows air circulation therefore helps reduce the combined risk of sun and humidity damage. As a more capable form of protection, the portable cover developed in this study incorporates a semi-automatic open–close mechanism targeting a 40 s cycle time, together with a strong, safe frame and a folding design intended to extend component life and cover the full vehicle body efficiently.

Two existing commercial products informed the direction of this development: although already commercially available, both leave room for improvement in material choice, ventilation, strength, safety, and ease of use. The Lanmodo canopy is a semi-automatic, remote-controlled cover that deploys in an umbrella-like motion, made of 201D Oxford cloth over a fiberglass frame; depending on model size (from roughly 3.5 m × 2.1 m up to 4.8 m × 2.3 m for the “Pro” variant), it retails for approximately US\$269–799 and covers only the upper body of the vehicle [11]. Krisbow’s “Prestige” line of car covers, by contrast, is a manually fitted five-layer fabric cover (no automated frame) priced at roughly IDR 1.5–3.4 million (about US\$95–215) depending on vehicle size: the two outer layers resist UV and water, the third layer is porous for ventilation, the fourth resists scratches, and the innermost cotton layer protects the paint finish [12]. Both therefore trade off automation against layered protection, cost, or coverage, a gap the present design seeks to close by combining an automated rail-and-sling mechanism with a low-cost, single-layer weatherproof fabric.

2. Methods

To design an effective vehicle protection system, problem analysis was carried out as the first step. Based on this analysis, three main design requirements were identified. First, the cover needs adequate air circulation so that

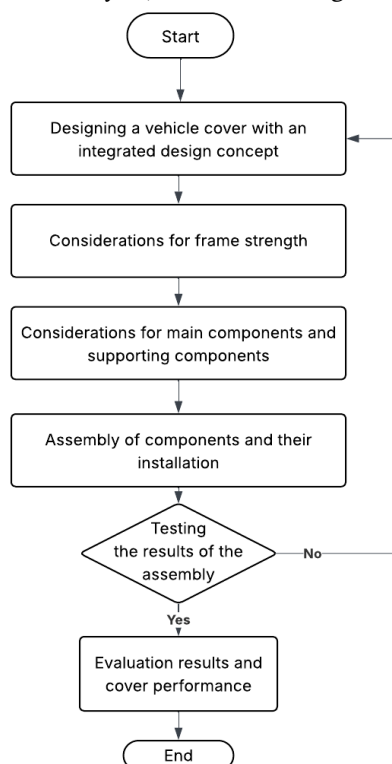


Figure 1. Research design

the temperature inside remains stable when it is closed, which is important for user comfort and to prevent heat-related damage [13]. Second, the protective design must be portable, meaning it is easy to move or fold while remaining sturdy and safe in use. Third, an open-close mechanism is needed that can cover the entire vehicle body efficiently, allowing the user to operate the cover without extensive labor or complicated procedures.

These requirements were translated into a structured sequence of prototype-development steps, shown in Figure 1. Development began with a detailed design of the vehicle cover: an initial concept was produced through manual sketches and computer-aided design (CAD) software, taking into account the vehicle’s dimensions, the air-circulation requirement, and ease of installation and disassembly, following a systematic vehicle-development approach in which engineering and industrial-design considerations are integrated from an early stage [14]. Once the concept was finalized, structural calculations were carried out on the frame and drive motor to confirm that the frame could support the weight of the system and withstand external loads, and that the motor had sufficient capacity to drive the open-close mechanism smoothly and safely. Suitable components were then selected on the basis of strength, durability, ease of installation, and cost efficiency, and assembled into a complete prototype following the finalized design.

After assembly, the prototype was tested to evaluate its mechanical performance, the reliability of the open-close mechanism, and its overall effectiveness in protecting the vehicle. Where testing revealed inconsistencies or technical obstacles, the design was evaluated and revised, consistent with the view that systematic evaluation is central to producing an effective design outcome [15], and this cycle of testing and refinement was repeated until the prototype met all of the performance criteria set out in the initial requirements analysis. Conclusions were then drawn from the results of this evaluation.

Taken together, these steps form an integrated prototype-development workflow: from structural analysis and component selection to assembly and testing, each stage feeds into the next, so that any performance issue identified during testing can be traced back to a specific design or component decision and corrected before the next iteration. This systematic approach is intended to ensure that the resulting prototype meets the level of protection, functionality, and ease of use identified during the initial requirements analysis.

2.1. Design concept

Vehicles parked outdoors need protection from extreme weather, impact, and humidity that can damage their appearance. To meet this need, the cover must be both structurally sound and practical to use, with air circulation to prevent excess moisture, lightweight materials for easy handling, and an automated opening/closing mechanism that removes the need for manual effort. Three design alternatives were developed and compared, as shown in Figure 2, each offering a different balance of protection, comfort, and practicality. The first alternative uses a semicircular frame sized to standard vehicle dimensions, prioritizing efficiency and a lightweight yet strong structure, with a drive motor mounted at the center of the cover to enable fully automatic operation. The second and third alternatives share the same overall footprint. Model 2 adds a support member to each frame section but does not include a stabilizing stand beneath the upper frame; under the sling-driven opening/closing motion, this omission allows the upper frame to shift laterally relative to the rail. Because the drive iron used in Model 2 is smaller in cross-section than the rail channel, this misalignment increases contact friction and risks intermittent binding during translation, undermining reliable operation, this is why Model 2 was not carried forward. Model 3 instead uses a frame measuring 4 m (length) $\times$ 2.04 m (width) $\times$ 1.6 m (height), with rail wheels running on a base frame, a rear-mounted motor and drive assembly, and a sling attached to the front of the upper frame to actuate opening and closing. Model 3 was selected as the final design because it offers better stability, a more efficient opening/closing mechanism, and a more user-friendly layout than the alternatives. Table 1 summarizes the comparative rationale.

Table 1. Rationale for model selection based on comparative evaluation

Model	Advantages	Limitations	Reason not selected / selected
Model 1	- Semicircular shape matched to vehicle dimensions - Full vehicle protection - Strong yet lightweight structure - Automatic mechanism via drive motor	- More complex construction - Requires more installation space - Higher estimated production cost	Not selected: more complex and costlier to build than the alternatives.
Model 2	- Same footprint as Model 3 - Support member added to each frame	- No stabilizing stand under the upper frame - Higher friction from an undersized drive iron relative to the rail	Not selected: lack of a stand risks lateral misalignment and binding during operation (see Design Concept for the mechanism)
Model 3	- Stable frame construction (4 m $\times$ 2.04 m $\times$ 1.6 m) - Smoother, more efficient rail-wheel mechanism - Motor/drive placement and sling improve stability and functionality	Somewhat greater material use for the additional rail-wheel and stand hardware than a bare-frame design; a formal cost/weight/assembly-time comparison across the three models was not performed and is recommended for future work	Selected: best combination of stability, mechanical efficiency, and ease of application observed during prototyping.

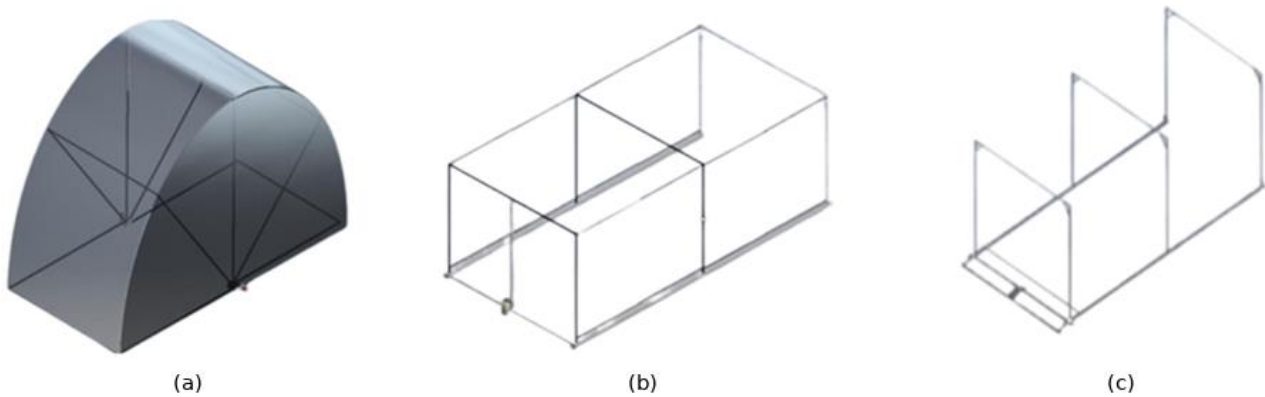


Figure 2. Alternative designs: (a) Model 1, (b) Model 2, (c) Model 3

2.2. Frame strength considerations



Figure 3. C-channel section

The frame is installed beneath the fabric cover to preserve air circulation and to shield the vehicle from falling objects, using box-section hollow iron for ease of assembly, with C-channel ("Canal C") sections used as the rail base for their straightness, symmetry, and favorable strength-to-weight ratio, as shown in [Figure 3](#). C-channel is a widely used "C"-shaped structural steel section, valued for its combination of strength, light weight, ease of installation, and corrosion resistance when properly coated. Its main limitations are a reduced capacity for heavy loads, a risk of deformation if joints are not properly designed, and comparatively low torsional (twisting) stiffness. [Table 1](#) summarizes these characteristics.

Table 2. Considerations of the advantages and disadvantages of C-Channel material

Aspects	Excess	Deficiency
Weight	Lighter than H/I-beam profiles, easing transport and installation	Not suitable for heavy structures without additional reinforcement
Ease of installation	Easy to cut, drill, and assemble	Joints require care to avoid deformation
Cost	Economical for light-to-medium structures	Uneconomical for heavy loads without extra reinforcement
Availability	Widely available in standard sizes	Limited availability in large dimensions
Corrosion resistance	Generally galvanized or coated	Corrodes readily if the protective coating is damaged
Structural behavior	Adequate for light-to-medium compressive and bending loads	Weak in torsion; needs additional stiffening
Application	Suitable for roof frames, ceilings, light walls, and solar-panel mounts	Not suitable for high-rise or long-span main structures without extra columns

Material selection also considered water resistance and ventilation: a waterproof outer layer reduces the risk of corrosion, while sufficient clearance between the cover and frame limits moisture buildup that could cause mould or odor. Common cover materials reported in the literature include polyester, PVC, and parachute fabric, all of which offer useful water and UV resistance. A 100% polyester fabric with double coating was selected for the outer cover because it resists heat, rain, dust, and light scratches without fading quickly, and because a double coating is known to substantially reduce the puncture-strength loss and water-resistance degradation that plain polyester (PET) fabric otherwise experiences under prolonged UV weathering [16]. The design is available in multiple sizes, uses rubber or strap fasteners to resist wind lift, and folds compactly for storage. Together with the frame, this gives the cover a structurally sound, mechanically efficient, and easily maintained system.

To provide a first-order quantitative check of frame adequacy, beyond the qualitative comparison in [Table 2](#), the main rail (30 mm × 30 mm square hollow section, 1.8 mm wall thickness, up to 4 m span) was idealized as a simply supported beam carrying the approximate 15 kg mass of the moving cover assembly as a single point load at midspan. For this section, the second moment of area is $I \approx (30^4 - 26.4^4)/12 \approx 2.70 \times 10^4 \text{ mm}^4$, giving a section

modulus $Z = I/(a/2) \approx 1.80 \times 10^3 \text{ mm}^3$. The applied load is $P = 15 \text{ kg} \times 9.81 \text{ m/s}^2 \approx 147.2 \text{ N}$, so the maximum bending moment is $M = PL/4 \approx 147.2 \text{ N} \times 4000 \text{ mm} / 4 \approx 1.47 \times 10^5 \text{ N}\cdot\text{mm}$, and the resulting bending stress is $\sigma = M/Z \approx 81.7 \text{ MPa}$. Compared with the yield strength of typical structural/galvanized mild steel ($\approx 250 \text{ MPa}$), this corresponds to an approximate safety factor of 3.0. This magnitude of reserve strength is broadly consistent with recent numerical and experimental studies on the flexural and axial behavior of cold-formed steel channel sections, which likewise report substantial reserve capacity for light-gauge channels under service-level bending and axial loads [17]. Nonetheless, the present calculation remains an idealized, first-order estimate: it assumes a uniform cross-section, a concentrated midspan load, and simple supports, and it neglects dynamic and wind loading. A full finite-element analysis or physical load test is therefore recommended to validate the frame design rigorously.

2.3. Considerations for main and supporting components

2.3.1. Electric motor

An AC gear motor (110/115 V, 8 RPM rated output speed), shown in Figure 4, was selected for its high torque (0.63 N·m) at low rotational speed, which suits automatic open/close systems and other slow, steady-motion drive applications. Its compact, rugged, brushless induction construction allows installation in confined spaces with low maintenance, low noise, and stable operation without excessive heat generation. As the device is intended for permanent outdoor installation, the motor's ingress-protection (IP) rating against rain and dust should also be verified, or the motor housed in a supplementary weatherproof enclosure; this was not formally assessed in the present study and is recommended before field deployment.

2.3.2. Motor torque and transmission requirement check

Because the motor drives the load through a belt-and-pulley reduction, its rated torque was checked against the torque required to move the cover along the rail, rather than assumed adequate by capacity alone. The transmission uses a 1:3 speed ratio between a 50 mm-diameter drive pulley (24 rpm) and a 150 mm-diameter driven pulley (8 rpm), connected by a small V-belt of approximately 650 mm length over a 160 mm pulley spacing. Assuming a conservative rolling/sliding friction coefficient of $\mu \approx 0.15$ for the plastic rail wheels (no direct friction measurement was available), the resistive force on the approximately 15 kg cover assembly is $F = \mu mg \approx 0.15 \times 15 \text{ kg} \times 9.81 \text{ m/s}^2 \approx 22.1 \text{ N}$. At the driven-pulley radius of 75 mm, the required torque is $T_{\text{req}} = F \times r \approx 22.1 \text{ N} \times 0.075 \text{ m} \approx 1.66 \text{ N}\cdot\text{m}$.

On the drive side, the motor's rated 0.63 N·m is amplified by the 1:3 pulley ratio to a theoretical 1.89 N·m at the driven pulley under ideal (100%) transmission efficiency. Accounting for the typical mechanical efficiency of small V-belt drives (about 90–95%), the torque actually delivered is approximately 1.70–1.80 N·m. This modestly exceeds the estimated requirement of 1.66 N·m, corresponding to an estimated safety factor of only about 1.03–1.09. Given the uncertainty inherent in the assumed friction coefficient, together with the additional resistance that could arise from wind loading, dust accumulation, or long-term wear, this margin should be regarded as narrow rather than generous and interpreted with appropriate caution. Specifying a motor with a moderately higher torque rating, or reducing rail friction through improved wheel-bearing selection, would improve operational reliability; an experimental torque/load measurement is recommended to confirm this estimate.

2.3.3. Pulley and V-belt

Given the roughly 15 kg mass of the moving cover, pulley material was chosen for strength and durability, with aluminum or mild cast iron identified as suitable low-cost options given the relatively small transmitted load. Ease of installation, maintenance, and spare-parts availability were also considered so that the mechanism could operate smoothly and reliably throughout its service life. A small V-belt (e.g., type A or 3V) was selected for the 650 mm belt length and 160 mm pulley spacing because its higher coefficient of friction reduces slip at low torque and speed, and because V-belts generally show better wear resistance than flat belts under sustained, relatively constant load, consistent with the mechanical-efficiency assumption (90–95%) used in the torque check above. The resulting pulley and V-belt assembly is shown in Figure 5.

2.3.4. Pulley and sling

To move the roughly 15 kg cover horizontally, a pulley-and-sling arrangement was used rather than a vertical lifting system. A 3 mm-diameter, 18 m-long sling is anchored at the front pillar with a welded flat-plate clamp,

routed over an aluminum pulley at the rear to keep the pulling load light on the motor. This configuration is intended to move the cover smoothly within the 40 s target time while remaining easy to maintain, as illustrated in Figure 6.

2.3.5. Rail wheel

Plastic, bearing-mounted rail wheels allow the cover to move forward and backward with low friction while supporting the approximately 15 kg load. The sling described above is routed through a frame-mounted pulley so that motor rotation is transmitted, via the pulley and sling, into translation of the cover along the rails. This rail-wheel assembly is shown in Figure 7.



Figure 4. AC gear motor used to drive the open-close mechanism.



Figure 5. Pulley and V-belt assembly



Figure 6. Pulley and sling arrangement



Figure 7. Rail-wheel assembly

2.3.6. Component assembly and installation

Assembly began with the base rails, formed from 30×30 mm hollow iron (1.8 mm wall thickness, 4000 mm length), which provide the running surface for the rail wheels and overall stability for the open-close system; C-channel sections were welded beneath the rails to keep the running surface flat, preventing curvature that could otherwise obstruct wheel travel. The upper frame (204 cm wide, 160 cm tall, with a top support for added stability) was then installed onto the rail wheels. Hollow iron measuring 20×20 mm was cut to 1570 mm and 2040 mm lengths for the upper frame members, and additional 60 mm lengths of the same section were welded in a triangular pattern at the top of the frame as reinforcement, using T-joint welds to connect frame members, as shown in Figure 8.



Figure 8. Welding of frame components (T-joints)

The fixed (non-moving) side of the frame reuses the offcut 30×30 mm rail iron (1600 mm tall, 2040 mm wide) as a support for both frame sections. The motor mount and bearing were fabricated from offcut C-channel, adjustable back-and-forth to set sling tension, and secured with 50 mm-thick elbow plates (360 mm long), as shown in Figure 9. A 2250 mm shaft transmits rotation from the motor to the cover mechanism, positioned at the rear so as not to obstruct vehicle entry. The sling (3 mm diameter, 18 m length) transfers this

rotation from the rear pulley to the front pillar clamp, similar in principle to a chain drive. Finally, the fabric cover (2040 mm × 4000 mm × 1600 mm) was fitted onto the completed frame, completing the open-close system, as shown in [Figure 10](#).



Figure 9. Motor mount and bearing



Figure 10. Cover installed on the completed frame

3. Results and Discussion

3.1. Result

Testing evaluated whether the assembled components, including the rails, upper frame, motor mount, and welded joints, functioned according to the design and operated without excessive obstruction. Open-close time testing assessed whether the mechanism met the 40 s design target, since consistent, obstruction-free movement is central to the system's overall efficiency. Tests were



Figure 11. Open-close mechanism under test

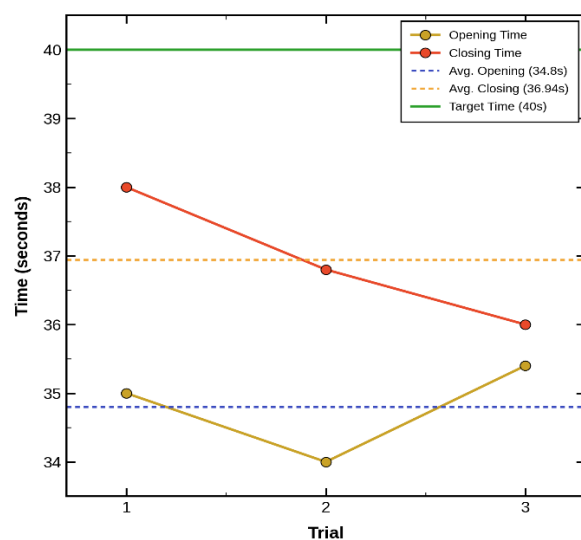


Figure 12. Opening and closing time results against the 40 s design target

conducted indoors under ambient laboratory conditions (approximately 27–30 °C, negligible air movement) on a clean, level rail surface; environmental variables such as wind speed, ambient temperature variation, and rail-surface contamination were not systematically varied in this study and should be examined through outdoor field testing in future work. Operational simulations were used to evaluate power transmission from the motor through the shaft and sling, and to observe load resistance and smoothness of motion under realistic operating conditions. [Figure 11](#) shows the mechanism under test, and the resulting opening and closing times are presented in [Figure 12](#).

Across three trials, the mean opening time was 34.8 s and the mean closing time was 36.94 s, both within the 40 s target with an adequate margin. Opening times showed relatively low spread between the three attempts, whereas closing times varied somewhat more but remained within the target in every trial. Because only three trials were performed, this outcome should be interpreted as an indication of low variability rather than a statistically confirmed measure of consistency; a larger sample with explicitly reported standard deviations is recommended to substantiate a claim of "stable and consistent" performance in future work. The observed difference between opening and closing times is plausibly attributable to differing mechanical resistance (e.g., sling geometry or belt tension)

between the two directions of travel, although this was not isolated experimentally. Overall, the results indicate that the mechanism satisfies its design target and represents a viable basis for further development and refinement. Table 3 places these results alongside publicly available specifications for the two commercial products discussed in the Introduction, to make the qualitative comparison of the Introduction more concrete.

Because the design in this study currently exists in a single frame size (4 m × 2.04 m × 1.6 m), it may not accommodate the full range of vehicle sizes used by online-taxi drivers, from compact hatchbacks to larger MPVs and SUVs; commercial products address this either through multiple fixed sizes (as with Krisbow's Prestige range) [12] or a stretchable/adjustable cover (Lanmodo) [11]. Developing a small number of standardized frame-size variants, or an adjustable-length rail, is recommended future work to improve compatibility across common taxi-fleet vehicle types.

Table 3. Indicative comparison with commercial portable/automated car covers

Aspect	Lanmodo (commercial)	Krisbow "Prestige" (commercial)	Present design
Mechanism	Remote-controlled, umbrella-style fiberglass frame	Manually fitted fabric cover, no frame or automation	Semi-automatic, AC-motor-driven rail-and-sling frame
Approx. size	3.5 m × 2.1 m up to 4.8 m × 2.3 m (Pro)	Sized to vehicle class; no fixed frame dimension	4.0 m × 2.04 m × 1.6 m (single size tested)
Deploy time	~8 s frame deployment (manufacturer figure)	Not applicable (manual fitting, several minutes)	34.8 s open / 36.94 s close (measured, n = 3)
Material	201D Oxford cloth, fiberglass frame	5-layer non-woven fabric (UV/water/dust/scratch protection)	100% polyester double-coated fabric, mild-steel hollow frame
Indicative retail price	≈ US\$269–799 (model-dependent)	≈ IDR 1.5–3.4 million (≈ US\$95–215, size-dependent)	Not yet commercialized; components are low-cost, non-proprietary (hollow iron, C-channel, standard AC gear motor); a detailed bill-of-materials cost analysis is recommended for future work

3.2. Discussion

The measured 34.8 s/36.94 s open–close cycle was achieved with a comparatively simple pulley-and-sling drive rather than a fully optimized kinematic linkage. More rigorous kinematic mechanism design methods, such as those recently used to optimize a Class IV linkage for a retractable roof module and nearly double the covered area for the same number of drive units [18], illustrate that further gains in cycle time or coverage efficiency may be achievable with a more elaborate linkage design; this is left as an avenue for future refinement rather than a requirement of the present prototype. Separately, the 90–95% mechanical efficiency assumed for the V-belt drive in the torque check (see Motor torque and transmission requirement check) is broadly consistent with efficiency ranges reported for V-belt transmissions elsewhere, where losses are dominated by belt–pulley slip and internal hysteresis rather than gross misalignment [19]; as with any friction-based transmission, this efficiency will degrade with belt wear, tension loss, and contamination over time, so periodic inspection and re-tensioning of the belt is recommended over the system's service life.

The bending-stress safety factor of approximately 3.0 obtained for the main rail (see frame strength considerations) is broadly consistent with the reserve capacity reported for light-gauge cold-formed steel members under service-level loading [17]. However, recent finite-element studies of light-gauge steel frames show that combined geometric defects and buckling-mode interactions rather than first-order bending alone, can govern the true margin of safety, and that the most damaging buckling mode is not always the one that a simplified, single-mode check would assume [20]. This reinforces that the bending-stress check reported here should be treated as a preliminary screening calculation rather than a substitute for a full structural validation, consistent with the limitation already noted for the idealized load case.

Because testing was conducted indoors under still-air conditions, the results reported above do not capture wind loading, which is a documented concern for lightweight, canopy-like structures. Free-standing and rooftop canopies

are known to be highly susceptible to wind-uplift failure, with panel corners and separation-vortex regions identified as the most vulnerable locations even at moderate wind speeds [21], and codified wind-force coefficients for this class of structure remain an active subject of study and revision [22]. Wind-tunnel or field testing is therefore an important next step, as already noted, before the frame's wind resistance can be considered validated rather than assumed. Likewise, the T-joint welds used throughout the frame were not subjected to destructive or non-destructive testing in this study; tensile testing of welded steel connections is a standard, comparatively low-cost way to verify that a chosen welding procedure meets its intended strength [23], and is recommended before the frame is used in field conditions. The frame's protective coating was likewise not subjected to accelerated weathering, even though standardized cyclic and artificial-weathering test methods exist for evaluating waterborne and acrylic coatings on outdoor steel structures [24] and could be used to substantiate the expected service life of the coated finish under sustained rain and humidity exposure. Finally, because testing was conducted indoors, the AC gear motor's practical suitability for continuous outdoor operation, specifically, its ingress-protection rating against dust and rain under the IEC Ingress Protection (IP) Code [25], was not verified and should be confirmed, or a supplementary weatherproof enclosure fitted, before field deployment.

4. Conclusion and Limitations

The portable cover was completed in line with its original design intent. The rail-wheel stop point allows the system to extend up to 3.8 m in a controlled, damage-free manner, and the frame's structural design and material selection supported by the simplified stress check reported above (estimated safety factor ≈ 3.0) are expected to provide adequate resistance to typical wind loads encountered during normal outdoor use. This has not, however, been verified quantitatively through wind-tunnel or field wind testing, and such testing is recommended before the design is considered fully validated for wind resistance. Functional testing confirmed that the open–close mechanism operates within the 40 s design target, and component selections were adjusted during development to improve reliability and efficiency.

Several limitations should be addressed in future iterations. First, the motor must be stopped carefully to avoid damaging the sling holder, and the rear of the cover needs to be raised slightly to avoid interference with the strap-on pulley mechanism. Second, the thin-walled hollow iron used for the rails can deform locally during welding, potentially obstructing the closing mechanism; local reinforcement, for example, a welded gusset plate at the joint, or a modest increase in wall thickness at rail-to-frame junctions is recommended as a concrete mitigation. Third, no destructive or tensile testing of the T-joint welds was performed in this study, despite their load-bearing role in the frame; a simple tensile or pull test on representative weld samples is recommended to quantify joint strength and durability. Fourth, no accelerated or long-term UV-exposure testing of the polyester cover material was performed, despite polymer materials being generally known to degrade under prolonged UV exposure; such testing would help substantiate claims of long-term fade and embrittlement resistance. Finally, the motor's suitability for continuous outdoor use (in particular, its ingress-protection rating against rain) was not formally assessed and should be confirmed, or a supplementary weatherproof enclosure added, in future development.

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Conflict of Interest - The authors declare that there are no conflicts of interest.

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