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# Designing for Fit: An Iterative Ergonomic Car Trash Bin Prototype via Design Thinking and House of Quality

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**ABSTRACT**
Vehicle interior cleanliness affects travel comfort, particularly when a car is used by families or multiple passengers. This study developed and tested an ergonomic car trash-bin prototype using Design Thinking and Quality Function Deployment through the House of Quality (HoQ). The study used archived product-development evidence, including aggregate questionnaire charts, an empathy map, existing-product observations, brainstorming records, HoQ, hand sketches, fabrication videos, static-fit photographs, and prototype-testing documentation. Because respondent-level questionnaire data were not retained, the analysis was descriptive and did not use inferential statistics. Three user needs were prioritised: easy reach, no interference with passenger movement, and prevention of waste scattering. The documented initial under-seat concept measured 440 x 450 x 200 mm and did not fit the selected vehicle space. After cardboard trials at the highest and lowest seat positions, the revised under-seat design measured 280 x 250 x 100 mm and achieved documented static fit. An initial door-trim trial was blocked by the cavity geometry; a custom door-pocket configuration of 160 x 65 x 130 mm was subsequently documented in static placement. The 2 mm black-acrylic prototype was assessed only for basic fit and intended use. The findings support vehicle-specific product development and identify the need for dynamic driving, usability, and cost-validation tests. For automotive-accessory designers and small manufacturers, this record offers a practical, replicable reference for translating cabin-cleanliness complaints into a vehicle-specific prototype before committing to tooling and mass production.

**Keywords:** Car Trash Bin, Design Thinking, Ergonomics, House of Quality, Prototype Testing.

## I. Introduction

Private vehicles function not only as transportation but also as temporary activity spaces where users eat snacks, open beverage packages, carry receipts, and travel with family members. Small waste may therefore accumulate in cup holders, door pockets, or footwells when no appropriate bin is available. In a constrained cabin, a waste container must be reachable, stable, easy to clean, and unobtrusive to leg movement. Human-centred design requires the product concept to be derived from users, their tasks, and the

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relevant context of use (Giacomin, 2014; Sankowski & Krause, 2023). In practice, however, aftermarket car trash bins are typically produced in a single generic size and mounting style, so they often intrude on legroom, fail to stay in place, or simply do not fit the available cabin cavity — a mismatch that undermines the very cleanliness and comfort benefits they are intended to deliver. Design Thinking is relevant to this type of problem because it supports an iterative movement from user understanding to definition, ideation, prototyping, and testing. It is commonly framed as a human-centred approach to innovation and iterative learning, rather than a generic sequence of steps (Micheli et al., 2019; Auernhammer & Roth, 2021; Magistretti et al., 2021; Mayer & Schwemmle, 2025; Minet et al., 2024; Olivares Ugarte & Bengtsson, 2024; Verganti et al., 2021).

Quality Function Deployment (QFD) and its House of Quality (HoQ) complement Design Thinking by translating the voice of the customer into prioritized technical responses. Voice-of-customer work provides the basis for identifying, structuring, and prioritising customer needs before they are translated into technical characteristics (Griffin & Hauser, 1993). Recent studies illustrate how QFD can structure product-concept selection, prioritise customer requirements, and link user needs to design parameters (Sharma, 2021; Shen et al., 2022; Shvetsova et al., 2021). Recent integrated applications further show that Design Thinking and QFD can be combined to translate user requirements into structured design specifications (Koswara & Alifin, 2024). Prior vehicle-design research has also applied HoQ to translate accessibility and user requirements into technical vehicle-design parameters, demonstrating the relevance of HoQ for transport-related product development (Sugiono et al., 2022). Related automotive HMI and interior-design studies underline the importance of user-centred and context-specific evaluation when developing products for vehicle environments (Lindner & Stoll, 2023; Grobelna et al., 2025; Song et al., 2023). The quality of human-centred design activities can also be assessed at an early development stage before final product validation (Sankowski & Krause, 2023).

Prototyping supports iterative learning by allowing concept assumptions, geometric constraints, and use interactions to be examined before greater resources are committed to fabrication. Paust et al. (2025) characterise prototypes as artefacts that support testing, exploration, and decision making. Accordingly, this study treats cardboard mock-ups and acrylic prototypes as evidence for preliminary fit learning rather than as final safety validation. The prior manuscript described the product concepts but did not fully document the prototype iterations contained in the archived course-project presentation. This revised manuscript therefore addresses two questions: (1) what design requirements were derived from user needs and HoQ priorities, and (2) how did iterative static fit testing modify the under-seat and door-pocket prototype configurations? The contribution is an evidence-based record of early product development, not a claim of generalizable user behaviour or final engineering validation. Taken together, this body of work indicates that Design Thinking supplies the iterative, human-centred exploration needed to understand cabin-use problems, while HoQ offers a transparent mechanism for turning those problems into prioritised technical requirements. Combining both approaches, as this study does, is therefore consistent with recent integrated applications of Design Thinking and QFD in transport-related product development (Koswara & Alifin, 2024; Sugiono et al., 2022).

## II. Literature Review

### 2.1. Design Thinking as a Human-Centred Development Approach

Design Thinking has evolved from its origins as a designer's problem-solving mindset into a widely adopted management practice for early-stage product development (Auernhammer & Roth, 2021). At its core, the approach reframes ambiguous, "wicked" problems by privileging direct empathy with users over assumptions drawn purely from specification sheets or market averages (Micheli et al., 2019). Magistretti et al. (2021) describe this as a dynamic capability: organisations that repeatedly cycle through empathising,

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defining, ideating, prototyping, and testing become progressively better at converting fragmentary user signals into workable concepts, even when each individual cycle is informal or resource-constrained.

This framing is directly relevant to a student-originated, coursework-based project such as the present one. Verganti et al. (2021) note that critics of Design Thinking often assume it requires large research budgets and formal ethnographic studies, but the evidence base for its critical success factors tells a different story. In a recent review of theoretical mechanisms underlying Design Thinking outcomes, Mayer and Schwemmle (2025) find that the strongest and most consistently reported driver of successful concept development is not the sophistication of the data-collection method, but the tightness of the feedback loop between user observation and physical prototyping — precisely the loop this study documents between the ISYE8009 coursework materials and the acrylic mock-up iterations. Minet et al. (2024) extend this point by comparing physical and virtual Design Thinking environments and conclude that physical, hands-on prototyping retains a distinct advantage for spatial-fit problems specifically, because participants can directly assess dimensional conflicts (e.g., whether an object obstructs a seat mechanism) in a way that is difficult to replicate digitally without specialised software.

Contextual factors also matter. Rösch et al. (2023) analysed the process conditions under which Design Thinking produces useful innovation outcomes and found that team composition, the phase at which prototyping is introduced, and the willingness to treat early prototypes as disposable learning tools are more predictive of a successful outcome than the formality of the initial requirements-gathering stage. This is a useful frame for the present study: the empathy map and aggregate questionnaire summaries retained from the original coursework project function as the "define" and "empathise" artefacts in this framework, while the acrylic prototype and its iterations function as the "prototype" and "test" artefacts, even though no single continuous protocol document links them.

### 2.2. Quality Function Deployment and the House of Quality as a Prioritisation Tool

Whereas Design Thinking is responsible for the exploratory and user-facing aspects of development, Quality Function Deployment (QFD) and its House of Quality (HoQ) matrix are in charge of the translation mechanism that transforms qualitative "voice of the customer" statements into prioritized technical needs. Before being incorporated into a design brief, raw user statements should be clustered, weighted, and cross-checked against technological feasibility. The underlying logic was created by Griffin and Hauser (1993), whose voice-of-the-customer framework continues to serve as the reference point for this process. Sharma (2021) revisits this logic and argues that the primary value of QFD lies less in the numeric priority scores it generates and more in the discipline it imposes. This discipline requires a small design team to make its assumptions about "what matters to the user" explicit and inspectable, rather than leaving them implicit in the intuition of a single designer.

The most recent applications provide an illustration of how this discipline is applied in practice. By applying QFD to the process of selecting product design concepts, Shvetsova et al. (2021) demonstrated that the method is most useful precisely at the stage that this study occupies, which is the process of narrowing down a set of candidate concepts to one or two that are worth prototyping. This is in contrast to the stage of finalizing manufacturing tolerances, which is the stage at which the method is most useful. Shen et al. (2022) proposed a real-time voice-of-the-customer extension to QFD that integrates live customer feedback streams; while the present study's data are static rather than real-time, the underlying argument — that QFD outputs should be treated as provisional priorities to be revisited as new user information arrives — supports this manuscript's own position that the HoQ-derived requirements here are a starting point for the next design iteration rather than a final specification.

There are two fairly recent applications that are related to automobiles that further clarify the concept. A vehicle sliding-door inner handle was redesigned by Ünlükal İlhan et al. (2025) using a structured customer-to-technical-parameter translation process, which is conceptually parallel to HoQ. The researchers discovered that customer-perceived quality could be significantly improved by concentrating engineering efforts on the two or three technical parameters that were most strongly linked to user complaints. This was in contrast to the traditional approach of attempting to optimize every measurable parameter simultaneously. This is a reflection of the prioritization logic that was utilized in the House of Quality from the current study. In that study, placement stability and non-interference with cabin space were considered to be the most important technical requirements, taking precedence over secondary considerations such as material finish. Separately, Yahaya and Mohammad (2025) redesigned a household umbrella by combining HoQ with the Theory of Inventive Problem Solving (TRIZ). They did this in order to explicitly address situations in which two customer requirements are in conflict with one another (for instance, compactness versus structural rigidity). Furthermore, the conditions "small enough not to obstruct legroom" and "large enough to hold a reasonable volume of waste" are also in tension and might benefit from a similar contradiction-resolution process. Their technique provides a valuable blueprint for a future iteration of the notion of a car trash bin, which could be used in the future.

Sugiono et al. (2022) utilized HoQ to the design of a minibus that was meant to transport people who were visually impaired or wheelchair-bound. They translated accessibility complaints into prioritized technical specifications for door width, ramp angle, and seat positioning. This was done within the context of the automotive industry. The underlying methodological move, which is treating a physically constrained cabin as the binding design constraint and letting user complaints about physical accommodation dominate the early HoQ rows, is the same move that was made in this study. This move lends methodological precedent to the "fit-first" prioritization that was adopted here. Although the product category is significantly different from a car trash bin, the underlying methodological move is the same. It is not a novel or unusual choice for this study to have made, as Koswara and Alifin (2024) also integrated QFD with Design Thinking for a UI/UX application design task. This serves to reinforce the fact that the combination of the two methods (rather than either one in isolation) is becoming an increasingly common and well-documented pairing across product categories.

### 2.3. Prototyping Fidelity and Early-Stage Validation

A recurring question in the product development literature is how much fidelity a prototype needs before it can support meaningful design decisions. Tiong et al. (2019) provide an economic framing of this question, arguing that prototyping decisions should be driven by the specific information a team needs at a given stage rather than by a fixed standard of realism: a low-cost, low-fidelity mock-up is entirely appropriate for answering a fit-and-placement question, whereas the same question about long-term durability or thermal performance would require a higher-fidelity, more expensive prototype. Applied to this study, the choice of 2 mm acrylic sheet, manually cut and heat-bent, is consistent with what Tiong et al. (2019) would characterise as an appropriately "cheap and fast" prototype for a placement-fit question, even though it is not adequate — and was never claimed to be adequate — for questions about long-term wear, heat exposure, or repeated-use durability.

Paust et al. (2025) extend this reasoning through an integrative review of how prototyping is discussed across the management literature, and note a persistent gap between how academics define prototyping rigour and how practitioners actually build and use prototypes in resource-constrained settings such as student projects or small design teams. Their review explicitly calls for research agendas that document these informal, resource-constrained prototyping processes rather than treating them as a lesser version of formally protocolled laboratory testing. The present manuscript's transparency about its own boundaries — that its prototype demonstrates static placement fit and nothing more — is consistent with the kind of honest scoping that Paust et al. (2025) argue the field needs more of.

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### 2.4. Ergonomics of Vehicle Interiors and Receptacle Design

The manuscript's object of study sits at the intersection of two more specific literatures: vehicle-interior ergonomics, and the ergonomic design of waste receptacles. On the first point, human-centred design theory (Giacomin, 2014) holds that a product concept should be derived from users, their tasks, and their context of use, rather than from an assumed "average" user. Sankowski and Krause (2023) operationalise this principle with a "Human-Centredness Metric" intended to let design teams assess, at an early stage, how well a given development activity actually incorporated user input — a metric that, if applied retrospectively to this study's coursework-derived evidence base, would likely score the empathy-mapping and complaint-aggregation activities as procedurally human-centred, even though they fall short of a fully documented protocol.

Within the vehicle cabin specifically, Blaga (2023) reviews how ergonomics has been defined and applied to vehicle interiors and shows, through a bibliometric mapping of the field, that legroom, reach envelopes, and unobstructed movement remain the most frequently studied ergonomic factors in cabin design — the same factors that this study's own internal evidence base (complaints about interference with passenger movement and about size mismatch) independently surfaced. Grobelna et al. (2025) similarly discuss how automotive human-machine interface design must continuously balance new functional additions (in their case, digital interfaces) against the risk of degrading the basic usability and safety of the cabin — a caution equally applicable to adding a physical accessory such as a trash bin, which must not compromise sightlines, pedal access, or emergency egress. Song et al. (2023) apply Kansei engineering and eye-tracking to Chinese consumers' automotive interior preferences and find that perceived quality and comfort judgments are highly platform-specific: what works in one vehicle's interior geometry does not necessarily transfer to another, which is consistent with this study's own repeated observation that a single trash bin design could not be assumed to fit multiple, differently proportioned vehicle interiors. Lindner and Stoll (2023) further caution that human-centred design activities, when applied to in-cabin systems, need explicit guidance for novice researchers to avoid conflating user experience observations with formal human-factors testing — a distinction this manuscript already tries to maintain by describing its evidence as descriptive rather than validated.

On the second, more specific point — receptacle design — several recent QFD-based studies offer close methodological parallels even though none of them are set inside a vehicle. Rimantho (2025) applied QFD together with anthropometric data to an organic-waste shredding machine and found that ease of cleaning, low noise, and ergonomic height were the dominant user priorities identified through the House of Quality process, a finding that echoes the present study's own identification of interference and size mismatch as the dominant complaint categories. Gutierrez et al. (2021) redesigned the physical form and labelling of campus waste bins to improve sorting behaviour and demonstrated, through direct observation of usage patterns, that even modest changes to a receptacle's shape and placement produce measurable behavioural effects — lending indirect support to the proposition that a better-fitting car trash bin could plausibly improve usage rates, although this study does not itself measure usage behaviour and does not claim to. Noor et al. (2026) describe a more technologically elaborate smart waste bin that integrates automatic sorting and IoT-based tracking, evaluated jointly against ergonomic, functional, and aesthetic criteria; while such added functionality is well beyond the scope of the present low-fidelity prototype, their evaluation framework — that a receptacle design should be judged jointly on ergonomic fit, function, and aesthetics rather than any single dimension alone — is a useful template that the present study's discussion section already gestures toward when it notes that only the ergonomic-fit dimension has so far been addressed.

### 2.5. Synthesis and Positioning of the Present Study

Read together, this literature supports three positioning claims for the present manuscript. First, the combination of Design Thinking and HoQ used here is a well-established and increasingly common pairing

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across product categories, from minibuses (Sugiono et al., 2022) to UI/UX applications (Koswara & Alifin, 2024) to household goods (Yahaya & Mohammad, 2025), rather than an unusual or under-justified methodological choice. Second, the low-fidelity, informally sourced nature of the evidence base is a recognised and actively studied category of product-development practice (Tiong et al., 2019; Paust et al., 2025; Rösch et al., 2023), not simply a shortfall relative to a formal study design. Third, the specific technical priorities surfaced by this study's House of Quality — physical fit and non-interference with cabin movement — are consistent with what the broader vehicle-interior ergonomics literature identifies as the dominant concern in cabin-adjacent product design (Blaga, 2023; Grobelna et al., 2025; Song et al., 2023), and with what the waste-receptacle literature identifies as the dominant concern in that adjacent product category (Rimantho, 2025; Gutierrez et al., 2021). The remainder of this manuscript should therefore be read as an early, transparently scoped stage within a well-precedented development pathway, rather than as a self-contained validation study.

## III. Research Method

This study used an exploratory user-centred product-design approach. Evidence was taken from internal ISYE8009 Industrial System Design assignments and archived course-project documentation prepared in 2023. The evidence was supplemented by original hand sketches, fabrication videos, static-fit photographs, and short test videos retained from the development process. The workflow combined Design Thinking, HoQ, prototype construction, and static fit testing. The documented evidence was analysed descriptively. No. respondent-level questionnaire file, controlled experiment, or dynamic driving dataset was available.

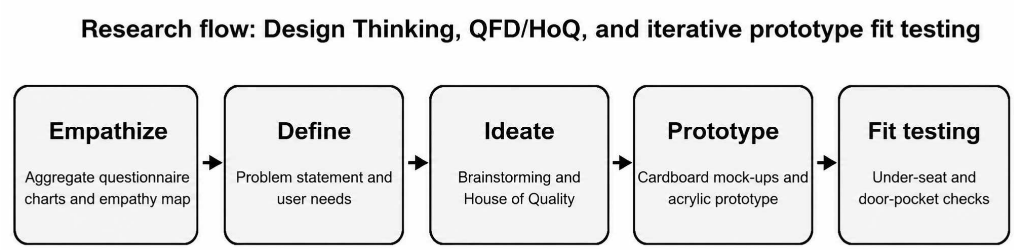


**Figure 1. Research flow combining Design Thinking, HoQ, and prototype fit testing.**

### 3.1. Internal Evidence Base

The evidence base is traceable but limited. It includes aggregate questionnaire charts, an empathy map, a problem statement, internal observations of existing products, brainstorming records, an HoQ matrix, concept sketches, CAD-style structure drawings, hand-dimensioned sketches, fabrication videos, material comparison, and photographs from prototype-test iterations. These documents establish the development sequence and make the dimensional evolution auditable, but they do not provide raw responses, a sampling frame, or a formal test protocol. Consistent with this, the study does not claim a documented sampling frame or standardized data-collection protocol for the original coursework materials; only the retained aggregate summaries are used here as descriptive design evidence.

**Table 1. Internal evidence base and its role in the study**

| Internal source | Main evidence | Role in this manuscript | Design stage |
|---|---|---|---|
| Assignment 1 | Aggregate questionnaire charts and empathy map | User-problem exploration | Empathize |
| Assignment 2 | Problem statement and observations of existing bins | Definition of design requirements | Define |

| Internal source | Main evidence | Role in this manuscript | Design stage |
|---|---|---|---|
| Assignment 3 | Brainstorming, HoQ, product concepts, preliminary feedback | Prioritisation and concept selection | Ideate |
| Assignment 4 / final course-project presentation | Material screening, structure drawings, prototype photographs, fit-test iterations | Prototype development and static fit verification | Prototype and Test |

### 3.2. Design Requirements and Prototype-Test Logic

The analysis proceeded in six steps. First, aggregate charts and the empathy map were reviewed to identify the user situation. Second, the recurring needs were stated as a problem statement. Third, the HoQ was examined to determine relative priorities. Fourth, the retained concepts were translated into nominal dimensions and a material choice. Fifth, prototypes or mock-ups were placed in the intended vehicle locations. Sixth, the results of each placement were used to modify the next iteration. This logic is consistent with the view that prototypes should be selected according to the design information and decision required at each development stage (Tiong et al., 2019; Paust et al., 2025).

This staged view of prototyping is echoed in the broader Design Thinking literature: Rösch et al. (2023) find that the phase at which a physical prototype is introduced, relative to the initial user-observation phase, is one of the strongest predictors of whether a Design Thinking process produces a usable outcome, more so than the formality of the observation method itself. Micheli et al. (2019) similarly argue that treating early prototypes as disposable, low-stakes objects — built quickly, tested for a narrow question, and discarded or revised rather than preserved as a finished product — is a defining and productive feature of the Design Thinking approach, not a limitation of it. The acrylic mock-up in this study was treated in this spirit: as a disposable object built specifically to answer a placement-fit question, consistent with the scope defined in Section 2.3, rather than as a near-final product awaiting only cosmetic refinement. Design Thinking and HoQ were selected jointly rather than separately because the former structures qualitative user exploration while the latter converts that exploration into ranked, actionable design priorities — a combination shown to be effective in prior transport-product development work (Sugiono et al., 2022; Koswara & Alifin, 2024).

### 3.3. Research Boundaries

The term stable in this study refers only to the static placement outcome documented in the project materials. Specifically, a configuration is recorded as 'fitting' when it can be placed in the intended location without obstructing the seat mechanism, door closure, or passenger footwell, as observed and photographed during the static trial; no dynamic loading, vibration, or repeated-use criterion is implied. Three boundaries govern interpretation. First, the questionnaire evidence is limited to aggregate charts; the study therefore reports percentages descriptively and does not perform statistical inference. Second, the prototype test was a static in-vehicle fit and stability check, not a controlled ergonomic experiment. Third, the final acrylic prototypes were not tested under acceleration, braking, vibration, collision, heat, or long-term use. The door-pocket documentation demonstrates static placement only; door-closing clearance, repeated insertion/removal, and dynamic stability were not formally tested.

## IV. Result and Discussion

### 4.1. User Problem Exploration

The empathy stage indicated that interior cleanliness is experienced as a comfort problem rather than merely a waste-storage problem. In the archived empathy map, users described insufficient attention to vehicle cleanliness, expressed a need for a convenient aid, reported cleaning waste after travel, and associated an unclean interior with discomfort. These insights were used to define a compact product that would be accessible without requiring substantial body repositioning.

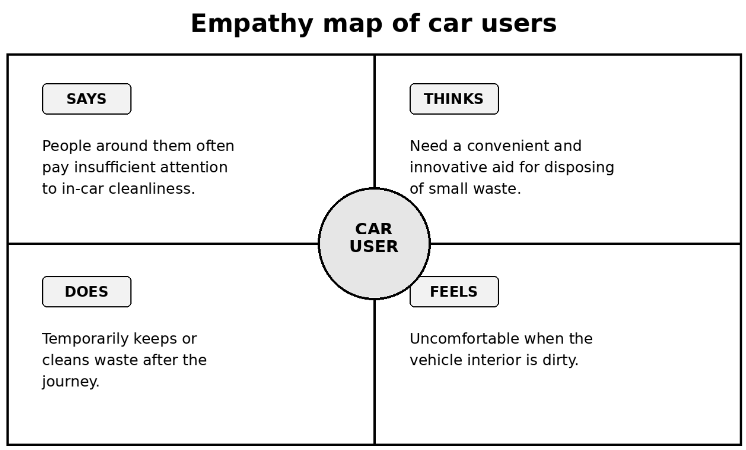


**Figure 2. Empathy map of car users.**

4.2. Definition of User Needs and HoQ Priorities

The project problem statement was: 'Car users need an alternative car trash bin that is easy to reach, does not interfere with passenger movement, and prevents waste from scattering.' The aggregate complaint chart reported that interference with passenger movement was selected by 57.1% of respondents, a too-small size by 46.4%, and difficult reach by 41.1%. The values are not inferential statistics; they are retained as documented design signals.

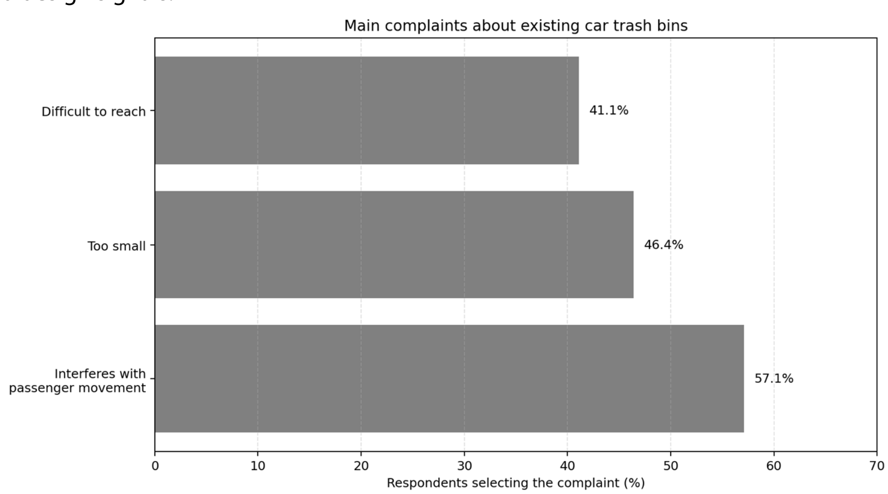


**Figure 3. Main complaints about existing car trash bins.**

**Table 2. Voice of customer and preliminary technical responses**

| Voice of customer | Interpretation | Preliminary technical response |
|---|---|---|
| Easy to reach | Dispose of small waste without substantial repositioning | Locate near seated users; provide reachable opening |
| Does not interfere with movement | Avoid footwell obstruction and ingress/egress interference | Use under-seat or door-pocket volume; maintain slim envelope |

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| Voice of customer | Interpretation | Preliminary technical response |
|---|---|---|
| Waste does not scatter easily | Retain waste during normal cabin use | Use sufficient wall height, stable placement, and a partially constrained opening |
| Affordable | Support accessible prototype and product development | Use material that can be cut and assembled with simple processes |

The HoQ record assigns the largest relative weight to no interference with passenger movement (50%), followed by prevention of waste scattering (33%) and ease of reach (17%). This prioritisation supports locating the product in unused interior volumes rather than on the floor. The HoQ translates user requirements into a practical selection rule: the design should first preserve passenger movement, then maintain containment, and then improve reach.

**Table 3. Summary of HoQ priorities**

| User need | Relative weight | Design implication | Priority |
|---|---|---|---|
| Easy to reach | 17% | Opening orientation and location near seated occupants | Medium |
| No interference with passenger movement | 50% | Slim geometry; use under-seat or door-pocket envelope | High |
| Waste does not scatter easily | 33% | Stable base, adequate wall height, and constrained opening | High |

### 4.3. Retained Concepts and Material Selection

Three alternatives were initially considered: a horizontal under-seat bin, a vertical door-pocket bin, and a small bin below the dashboard. The under-seat and door-pocket variants were retained because they use space that does not directly occupy the principal footwell. The under-seat configuration is intended to offer a concealed and comparatively larger container, whereas the door-pocket configuration is intended for lightweight waste such as tissue, receipts, and packaging. The prototype used 2 mm black acrylic. The material choice was based on an internal qualitative comparison of forming convenience, light weight, visual appearance, local availability, and perceived affordability. The comparison is not a standardized material test; it should therefore not be interpreted as proof of strength, heat resistance, or crash safety. Future material selection should be validated through tests of heat exposure, cleaning compatibility, edge condition, attachment integrity, and long-term durability. The fabrication tools used were limited to manual acrylic-cutting and heat-bending equipment available in the course workshop; no CNC or injection-moulding process was involved, which further restricts the prototypes to demonstration rather than production-representative status.

**Table 4. Internal material-screening summary**

| Material option | Internal qualitative observation | Decision relevance |
|---|---|---|
| Fabric | Flexible and light, but less able to preserve a rigid container form | Not retained for the rigid prototype |
| Polycarbonate | Considered robust but less convenient for the available prototype-forming process | Not selected for the first prototype |
| Black acrylic, 2 mm | Rigid, lightweight, easy to cut and assemble, visually acceptable, and locally obtainable | Selected for the prototype |

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### 4.4. Detailed Prototype Configuration

Figure 4 documents the dimensional evolution using the original project sketches. The initial under-seat concept was specified at 440 x 450 x 200 mm (length x width x height). Its size was subsequently reduced after the first placement trial did not fit the selected vehicle space. The revised under-seat configuration measures 280 x 250 x 100 mm (length x width x height). The custom door-pocket configuration measures 160 x 65 x 130 mm (width x depth x height), with a documented upper opening. All dimensions are nominal and vehicle-specific; they require confirmation before fabrication because seat rails, wiring, floor contours, door-pocket geometries, and trim details differ between models.

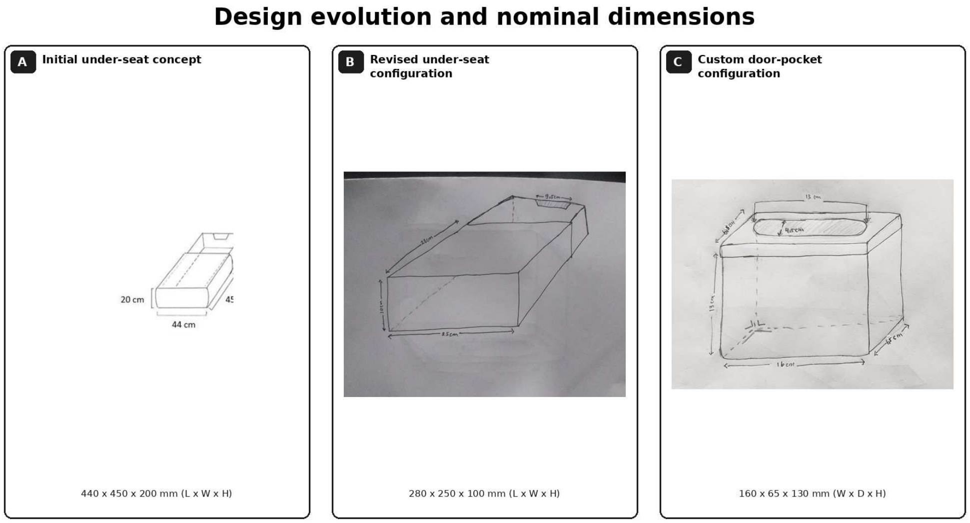


**Figure 4. Documented design evolution and nominal dimensions of the prototype configurations.**

**Table 5. Nominal prototype configurations and fit constraints**

| Prototype | Reference vehicle/location | Nominal dimensions (orientation) | Functional features | Critical clearance |
|---|---|---|---|---|
| Under-seat bin | Toyota Rush; beneath the front seat | 280 x 250 x 100 mm (L x W x H) | Shallow horizontal container with accessible upper opening | Seat elevation, seat rails, floor contour, and cable clearance |
| Door-pocket bin | Mitsubishi Xpander; door-pocket cavity | 160 x 65 x 130 mm (W x D x H) | Slim vertical insert with recessed opening | Door-pocket geometry, trim interference, door closure, and retained access to adjacent trim |

### 4.5. Iterative Prototype Fit Testing

The original experiment record provides a clearer sequence of static-fit learning. In the first under-seat trial, a large acrylic configuration was fabricated from the early concept and could not be accommodated beneath the selected seat; an exposed in-cabin placement was also documented as obstructive to passenger access. The second iteration used a cardboard mock-up. Although it was easier to modify, the mock-up was

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compressed when the seat was set to its lowest elevation. In the third iteration, the available space was remeasured while considering the highest and lowest seat elevations and the floor contour below the seat. The revised 280 x 250 x 100 mm configuration was then documented as fitting statically in the selected under-seat location. A separate initial door-trim trial was blocked by the cavity geometry. A custom door-pocket configuration was subsequently documented in static placement in the selected door pocket. These outcomes are vehicle-specific and do not establish dynamic driving safety.

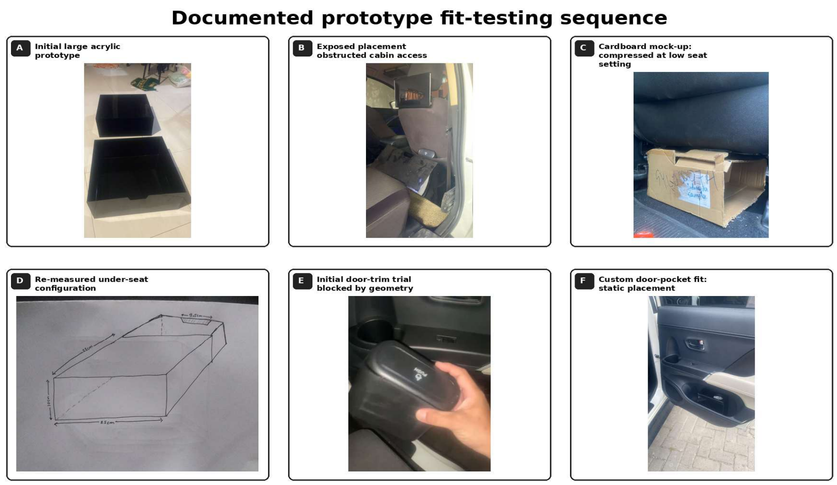


**Figure 5. Documentary evidence of prototype fit-testing iterations and door-pocket refinement.**

**Table 6. Iterative prototype fit-test outcomes**

| Iteration | Prototype / method | Observed result | Design learning |
|---|---|---|---|
| 1 | Large early acrylic under-seat prototype | Could not be accommodated beneath the selected seat; exposed placement was also obstructive | Initial size and placement approach were unsuitable |
| 2 | Cardboard mock-up under the seat | Compressed at the lowest seat elevation | Seat-adjustment range must be included |
| 3A | Re-measured cardboard mock-up under the seat | Documented static fit at the tested seat positions | Use revised clearances and floor contour |
| 3B | Initial door-trim placement trial | Could not be installed because the container was blocked by the cavity/trim geometry | Door-pocket geometry requires a custom fit |
| 3C | Custom door-pocket configuration | Documented static placement in the selected door pocket | Vehicle-specific door-pocket design is feasible at the static-fit stage |
| Final | Acrylic prototypes derived from the refined configurations | Used for basic placement and intended-use demonstration | Not equivalent to dynamic driving, durability, door-operation, or crash validation |

The documented sequence demonstrates why final dimensions should not be treated as generic dimensions for all cars. Under-seat designs are sensitive to minimum seat clearance, rail arrangement, floor shape, and seat-adjustment range. Likewise, the initial door-trim trial shows that a container cannot simply be transferred from one door-pocket geometry to another without dimensional adaptation. The use of cardboard mock-ups and repeated static checks was appropriate for identifying fit-related design errors before final

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acrylic fabrication. This reflects the prototyping principle that early, lower-fidelity models can efficiently identify fit-related design errors (Tiong et al., 2019; Paust et al., 2025).

### 4.6. Preliminary Feedback and Interpretation

The archived feedback chart indicates that 80% of respondents were satisfied with the concept, 10% were neutral, and 10% were dissatisfied. The same chart indicates that 75% expressed an intention to use the product. These figures can be used as preliminary concept feedback, but they cannot establish market acceptance because the number, selection method, and individual responses are not available. The results are best interpreted as an early positive signal that justified movement to the prototype stage.

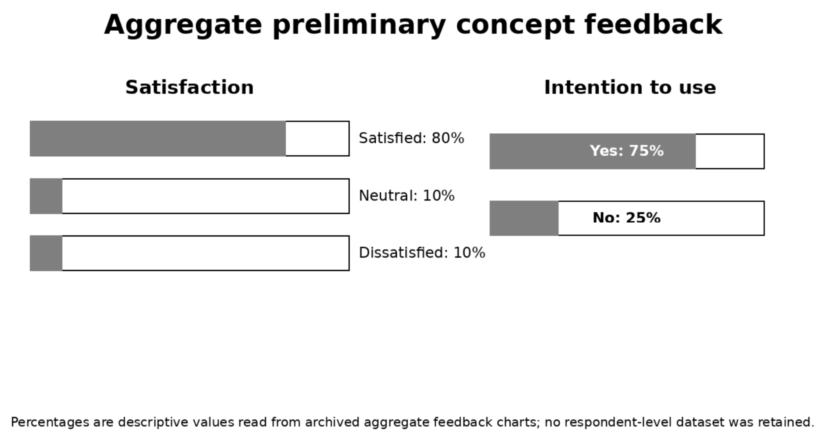


**Figure 6. Aggregate preliminary concept feedback.**

### 4.7. Discussion and Research Limitations

The expanded evidence makes the study stronger than a concept-only report because it documents both unsuccessful and refined fit attempts. The initial under-seat configuration was too large, the cardboard mock-up was compressed at the lowest seat position, and the first door-trim attempt was blocked by the cavity geometry. The later under-seat and custom door-pocket configurations were documented only as static fits in selected locations. Accordingly, the ergonomic claim remains limited: the project demonstrated fit-oriented placement, not measured reach time, posture, muscle load, comfort score, door-closing clearance, or user performance. This fit-first approach parallels Sugiono et al. (2022), who likewise prioritised physical accommodation constraints before refining comfort-related criteria in transport-product design, and echoes Song et al. (2023), who found that automotive interior components require iterative dimensional adjustment specific to each vehicle platform rather than a single generic specification. Related automotive HMI and interior-design studies similarly emphasise the importance of user-centred and context-specific evaluation for vehicle-environment products (Lindner & Stoll, 2023; Grobelna et al., 2025; Song et al., 2023).

This sequencing — resolving physical fit before quantifying comfort or performance — is not unique to this study. Ünlükal İlhan et al. (2025) followed the same order in redesigning a vehicle door handle, first isolating the technical parameters most linked to user complaints before pursuing further quality refinement, and Sugiono et al. (2022) did likewise in designing an accessible minibus, prioritising physical accommodation of wheelchair users ahead of secondary comfort criteria. Outside the automotive domain, Rimantho (2025) and Gutierrez et al. (2021) both treat ergonomic fit and placement as the entry point for receptacle design, with functional and behavioural evaluation reserved for later stages once a workable physical form has been established. Positioned against this body of work, the present study's fit-first scope is consistent with how early-stage HoQ-driven product studies are typically bounded, rather than an isolated methodological gap.

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At the same time, the literature also indicates where this study's next steps should lead. Song et al. (2023) show that comfort and quality perceptions of automotive interior elements are highly specific to the vehicle platform on which they are tested, implying that any future performance testing of the trash bin prototype would need to be repeated across several representative cabin types rather than validated once and assumed to generalise. Similarly, Grobelna et al. (2025) caution that any addition to the cabin environment — even a small accessory — should be assessed for its effect on sightlines and control access, which suggests that a future revision of this study's testing protocol should explicitly record whether the trash bin's placement affects the driver's or front passenger's view of mirrors or dashboard controls, a factor not addressed in the current evidence base.

The present results should not be interpreted as evidence of crash safety, vibration resistance, resistance to heat or cleaning chemicals, or suitability for all vehicle models. Nor do the available documents demonstrate a full feasibility study: the slide deck reports an estimated basic prototype cost of IDR 50,000 per unit and mentions costing and break-even analysis, but it does not retain the detailed calculation inputs. Accordingly, no financial feasibility claim is made in this manuscript. A complete commercial feasibility assessment would additionally require a documented bill of materials, unit production time, packaging and distribution cost, a defined target customer segment (e.g., ride-hailing drivers, families with young children, or fleet operators), and a comparison against existing aftermarket car-organiser price points, none of which were retained from the original project documentation. Future work should include documented bill-of-materials data, production process time, packaging, attachment method, and realistic selling-price scenarios.

**Table 7. Research transparency and future validation requirements**

| Evidence supported by the project | Not supported by the current evidence | Recommended next validation |
|---|---|---|
| Needs identification, HoQ priority, concept selection, static fit outcomes, and basic intended-use demonstration | Population-level market acceptance, statistical associations, or broad generalisation | New survey with retained respondent-level data and defined sampling |
| Static under-seat fit at selected seat positions and static custom door-pocket placement | Dynamic stability during braking, turning, vibration, collision, or door operation | Road or bench vibration test; door-closing/trim-clearance test with recorded conditions |
| Prototype form, nominal dimensions, and acrylic fabrication choice | Long-term material durability, heat resistance, or safe crash behaviour | Thermal, cleaning, edge-safety, and durability tests |
| Early cost estimate | Verified break-even point or commercial feasibility | Bill of materials, labour, overhead, price, and demand scenarios |

## V. Conclusion

The revised evidence records a sequence of dimensional learning. The original under-seat concept was specified at 440 x 450 x 200 mm and did not fit the selected vehicle space. A cardboard mock-up was then compressed at low seat elevation. After re-measurement, the 280 x 250 x 100 mm under-seat configuration achieved documented static fit. The initial door-trim attempt was blocked by the cavity geometry, whereas a custom 160 x 65 x 130 mm door-pocket configuration was later documented in static placement. Final prototypes were fabricated in 2 mm black acrylic for basic fit and intended-use demonstration. The contribution is therefore a traceable, vehicle-specific early product-development record based on documented sketches, fabrication records, and fit trials. The findings do not establish general ergonomics, driving safety, door-operation clearance, long-term durability, or commercial feasibility.

Future validation could also draw more directly on QFD's contradiction-resolution extensions. Yahaya and Mohammad (2025) demonstrate how TRIZ can be layered onto a House of Quality analysis specifically to

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resolve cases where two customer requirements pull in opposite directions — in the present case, the requirement for a compact footprint that does not obstruct legroom and the requirement for adequate waste capacity. Applying a similar contradiction-resolution step in the next design cycle could help the project move from the current single fit-tested concept toward a small set of competing concepts that make this trade-off explicit and testable, rather than resolving it implicitly through the choice of a single prototype dimension. In parallel, Shen et al. (2022) suggest that QFD outputs are best treated as provisional and revisited as new user data becomes available; consistent with this, the technical priorities identified in this study's House of Quality (Section 2.2) should be understood as a starting point to be revisited once a documented, purpose-built user study — rather than archived coursework materials — becomes available.

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