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Robbie Napper

Arthur de Bono

Karen Burns

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Reducing variation not function: Lessons from applied route bus design research

Robbie Napper¹, A/Prof Arthur de Bono², Dr. Karen Burns²

¹Ph.D Candidate, Department of Design, Faculty of Art and Design, Monash University, Melbourne Australia

²Department of Design, Faculty of Art and Design, Monash University, Melbourne Australia

robert.napper@artdes.monash.edu.au

Abstract

Individual bus operators specify vehicles in line with their own unique requirements. Collectively, diversity across vehicle specifications increases costs and lead time and decreases quality in local bus manufacture, paradoxically having negative consequences for the very function that specifications were intended to improve. The vehicle specifications are driven by functional requirements and are therefore difficult to reconcile with manufacturing by simply reducing them. This research set out to develop bus designs balancing user and manufacturer needs.

Investigation found that specification diversity results from bus operators determining designs to meet their requirements – resulting in a raft of solutions to the same or similar problems. Two interventions to this situation were formulated; that a higher-specification product could offer equal or better function to bus operators while being of standardised manufacture; and that a system of modular design could be implemented where specification differences were functionally justified.

These approaches were tested in the design, manufacture and implementation of a new driver's area for route buses. It was found to meet the functional requirements of several Australian bus operators while streamlining manufacture. It resulted in a definitive design strategy for the development of better public transport vehicles.

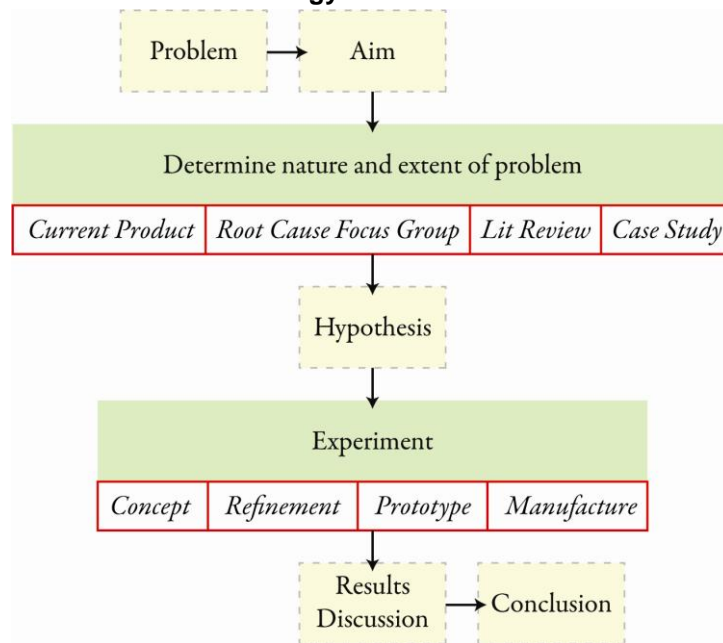
1. Introduction

Route buses are an important part of our transport system. The ubiquity of roads allows buses to offer an inexpensive and versatile means of public transport (Griffin et al. 2005). As capital goods, buses are used by transport operators to create a commodity, public transport (Acha et al. 2004). The nature of bus operators varies from government organisations to small family businesses; operators are typically responsible for bus services in a defined geographical area. Operators create transport services within the constraints of their locale and business strategy; reflected in varied methods of operation and marked physical variations in bus vehicles. This research sets out to alleviate the pervasive problems – high vehicle cost and constraints on quality - caused by specification diversity, through the development of a new driver's area for route buses.

This research investigates variation in bus bodywork manufacture; manufacture of buses for public transport by the fabrication of a bus body on a chassis. This manufacturing methodology is typical in countries where markets cannot support widespread investment

into chassis manufacturing capabilities, such as Australia. European marques (brands) lead the bus chassis market (Vuchic 1981), and the chassis are shipped to Australia before the bodywork build process. The Australian bus market is dominated by bus bodywork manufacturers, although alternatives are available in the form of locally made complete buses albeit with imported drivetrains. This research was undertaken using an experimental methodology, with the principal method being design studio experimentation. An outline of the method is shown in Figure 1.

Figure 1: Flowchart of research methodology.



1.1 The problem

Variation in bus vehicles leads to a bespoke bodywork manufacture process. In this context, a bespoke (or *custom-made*) process is characterised by manufacturing buses on an individual or short-run basis, the bespoke method allows the manufacturer to accommodate small differences in specification. While a bespoke process delivers a bus in-tune with operator specifications, it is also comparatively expensive and slow when contrasted with mass production. Expense in the bespoke manufacturing process is caused by constant re-design and re-engineering of components and systems, which leads to a reduction in economies of scale which might otherwise be possible. A lack of repetition in components and processes increases lead times and necessitates a craft-like approach to design, fabrication and assembly. Variation also makes quality control more difficult.

Bespoke buses take longer to build and are dependent on larger inventories of spare parts and are therefore more costly to purchase and maintain. As capital goods, the life cycle cost of the bus is of principal importance to operators (Frank & Bernanke 2004) which may be in conflict with the scope of variation offered in bespoke manufacture.

Despite causing manufacturing difficulties, variation in bus vehicles is operationally justified in the pursuit of creating public transport, as the specifications allow operators to have a fleet of vehicles which represents their operational ideals. Paradoxically, variety in specifications also makes bus-based public transport less effective because of the cost and time associated with manufacture.

1.2 Aim

This research is concerned with resolving the conflict between bus operator needs and subsequent variation in bus specifications on one side; and the need for manufacturers to offer a commercially competitive, quality bus product on the other.

2. Data

Information sources and data are documented and a research hypothesis is formed in this section. At the outset of this research, no hard data existed regarding the extent of product diversity. Once these were determined by means of product review; focus groups were conducted to determine the root cause of the specification diversity. Case study and literature review were then used to determine possible approaches to the design problem – reducing the negative impact of this diversity.

2.1 Current product

At project commencement in 2008, the product in question was the present-generation driver's area in route buses made by Volgren Australia Pty Ltd. A study of this design concluded that across two key product variants – plastic and fibreglass – there were myriad product variations used to meet bus operator requirements. For example, the driver's security screen is subject to variations in size and material; there exist two possible places for chassis electrical components; and the positioning of switchgear and vehicle controls for the driver vary almost infinitely according to operator preference.

Variation in the driver's area is summarised in Table 1. While the variation is simple to represent in such a table, it has impact throughout the supply chain up to the operator who bears the cost and long lead time resultant from this specification diversity. It is suggested that this has a negative impact on the effectiveness of buses as a mode of transport.

Table 1: The extent of variation in the driver's area.

Extent of Variation in Driver's Area		
Component	Choice Type	Total Options
Consoles	Configurable	∞
Demister specification	Choice of	3
Driver's Door	Yes / No	2
Driver's locker locations	Choice of	5
Electrical centre location	Choice of	2
Material of components	Choice of	2
Security Screen	Custom	∞
	Design	
Surround material	Design	∞
Wheel Arch Cover	N/A	N/A

A review of driver's area designs across public transport modes was conducted, highlighting some key characteristics of a bus driver's area as distinct from other modes. This review determined that the driver's area must be considered as part of the ingress and egress

strategy for the bus saloon, with particular reference to the impact of ticketing and other sundry tasks on the buses' operation. The bus driver's area must accommodate an array of switchgear which is dependent on the chassis and operator needs. Driver's areas from other modes exemplify the difference in operational requirements, particularly between buses and rail modes, where driver protection is provided by complete segregation from passengers. The additional segregation provided in train and tram modes creates the design opportunity for enhancing the driver's view of the outside environment. A significant difference in route bus driver's areas to those in other modes is that the bus driver is expected to maintain contact with passengers. This naturally leads to tension between driver-passenger contact and driver safety as explored later in the focus groups.

2.2 Root cause analysis

With the extent of diversity in the driver's area known, it was necessary to determine why the variation in specifications existed. The root causes of the individual specifications are required to prioritise the specifications and provide the design process with a basis of understanding user needs. Data were discovered using a focus group method, conducted in two separate sessions in Victoria and New South Wales.

The focus groups were held around the general theme of what could be done to improve driver's area design. Discussion was guided through several topics; contact with passengers, comfort and safety, vision, electrical, utilities and appearance.

A representative sample of participants for the focus groups was established by approaching private and public route bus operators. Across these two types, fleet sizes varied from fewer than 50 to over 1900 buses in operation. To further ensure a complete cross-section of users the participants represented fleet management, operations management, maintenance and drivers.

The nature of contracts for bus operation resulted in participants viewing their counterparts from other bus operators as colleagues rather than competitors. The focus groups were therefore a successful forum to seek bus improvement for any and all bus operators. Predictably, there were several conflicts of needs across participants, mirroring the conflicting attributes of manufacturer, operator and passenger normal to any design situation. Participants were empathetic to the views of other professions in the bus industry, expressing their own perspectives with an understanding of the needs of others. The strongest example of this was the prioritisation of tasks by mechanics, which appears to conflict with the priorities of the driver.

The different perspectives across the sample of operators and personnel generated discussion reconciling many of the specification differences in their buses. For example, the variety of specifications in electrical centre location exists because it is generally located in an inconvenient position – yet both locations are something of a compromise. In this instance, the root cause for variation is that neither specification is completely adequate. In the case of driver security, it was discovered that there is variation in the user needs creating variation in specifications; some drivers prefer uninhibited open contact with passengers, while others require full physical protection.

Bus operators generate bus specifications in response to their own needs. In order to protect business interests, the bodywork manufacturer tends to manufacture to these specifications

rather than risk losing the customer. The focus group determined that bus operators generate more specifications of their own where the “standard” design does not meet their needs. As there are many operators; so there are many specifications. Thus, the root cause for variation in bus specifications is a variation in user needs, set against the background issue of current driver’s area designs not meeting this gamut of needs.

In eliciting this information from the focus group participants, a significant number of design preferences were also established. These preferences are important to the design process and will be applied in the experimental phase where a solution to the research problem is developed.

2.3 Literature Review

Following on from the determination of user needs as the root cause of variation in the bus driver’s area, a literature review was conducted to determine possible approaches to the problem of specification diversity.

“Any customer can have a car painted any colour that he wants so long as it is black.”
(Batchelor 1994, p. 40)

Ford’s often quoted yet reputedly never uttered phrase (ibid) nevertheless neatly summarises both the beauty and boundaries of mass production – the system will work if consumer demand is limited to the product in a single configuration. In the other extreme – bespoke manufacturing as found in bus bodywork – a satisfactory product may also be generated if the customer is willing to carry the burden of lengthy and expensive development and manufacturing. Examples of these extremes in standardisation and personalisation are not impossible; however they are inappropriate for the manufacture of route buses because of user needs on one hand, and cost and timing on the other.

Consumers seek balance, for example between cost and quality (Redaelli, Sorlini & Boer 2006). Cost and quality are only two of a multitude of consumer desires, so the standardised offering of one manufacturer rarely meets the needs of an entire market. Each manufacturer has large enough share to sustain operations while consumers have a choice of product allowing them to select the most suitable. In this case, the marketplace hosts product variety. Manufacturers strive for more market share on a variety of competitive platforms; better quality, lower price, or perhaps by manufacturing a product variant. Here we can witness the modern system of mass-production fragmenting into the postmodern system of smaller markets for goods and services, more in-tune with consumer needs (Day 2007). For a manufacturer to survive in a fragmented market requires either small overheads and market share, or a manufacturing strategy affording economies of scope, known as “Mass Customisation” (Davis 1987; Pine 1993).

Stan Davis suggests that manufacturers should “...*mass customise as much as necessary and as little as possible*” (in Gilmore & Pine 2000). A balance is desirable between customer satisfaction and efficient manufacture. It is important to balance customer needs and manufacturing capabilities, the gap between these constraints being known as “customer-sacrifice” (ibid). As discussed earlier, customers are willing to trade off features against one-another, so long as a better compromise is not found with a competitor in the same market. Therefore a manufacturer must carefully manage their customer sacrifice gap.

Mass customisation (MC) refers to a range of strategies normally used to broaden the scope of products offered by mass producers. Typically this is done through product modularity (Du, Jiao & Tseng 2000; Pine 1993; Simpson, Siddique & Jiao 2006); where components are shared, swapped, cut, configured in bus and sectional scenarios (Ulrich, K & Tung 1991) and mixed (Pine 1993) to form new products and variants.

Product modularity is a strategic business decision which product design must accommodate in the development phase (Ulrich, KT & Eppinger 1995). Several strategies of designing for MC have been developed, based on the idea of designing not a product, but a family of products. Product families rely on a “product family architecture” (PFA) or “product platform”, a framework enabling new products to be created by changing modules, while ensuring that the communication between modules remains effective (Jiao, Simpson & Siddique 2007). PFA supports the creation of new products which offer consumers more choice in the same product sector, while remaining within the capabilities of the supply chain, especially the manufacturer.

Two knowledge-gaps are apparent in the literature on mass customisation; capital goods, and bespoke manufacture. Mass customisation is primarily concerned with consumer goods. Consumer goods conform to a simple model of use; the consumer is the end user of the product. There are few examples of capital goods in MC (Napper (in press - accepted 23/7/2009)) so the nature of customising goods with a complex use structure is underexplored. The dominance of mass production has led to a dearth of research concerning MC of bespoke products, as MC strategies are described in terms of difference to mass production. The critical difference is that bespoke manufacturing already offers customers significant scope for product variation yet with an apparent lack of strategy. Customers are more likely to positively perceive new customisation opportunities, whereas in the move from bespoke to MC it is likely customers will perceive a reduction of options.

2.4 Case study

Implementation strategies for MC are still in a formative stage (Jiao, Ma & Tseng 2003) and are best represented by case studies (Moser & Piller 2006). Existing case studies describe a range of different MC strategies, but few product sectors. There is not enough information to set a precedent for the design of bespoke capital goods, or parts thereof such as the driver’s area. The case study sets out to determine how the design for mass customisation of bespoke capital goods might be carried out. Further to discovering *how* MC is implemented, the case studies may also determine *which* MC strategies are implemented in relevant fields. There exists no direct analogy of route bus vehicles in contemporary society, however several other products cover many elements of route buses and would provide suitable cases.

MC may be applied in the driver’s area design, where a flexible product is required to meet user needs. The case study sets out to determine methods of implementation. A critical element in this research is the context for MC, as the literature review found that most MC knowledge is in the context of mass produced consumer goods. Yin (2009) describes the nature of case studies to be apt for studying contextual conditions, as opposed to a scientific experiment which intends to divorce the situation from its context in order to reduce variables. The case study is used in this instance to discover the knowledge between theory and implementation of MC (Breslin & Buchanan 2008).

Large Commercial Aircraft (LCA) was chosen as the first case, sharing many attributes with route buses; LCA are capital, transport goods, made in short production runs exhibiting a high degree of customisation. Literature resources are augmented by data directly disseminated by manufacturers aimed at those purchasing aircraft. The second case chosen for this research was the private car. Although traditionally associated with mass production and Fordism (Batchelor 1994) the modern, global auto industry exhibits many examples of MC. Of particular note are the customer interface and the sharing of components – both large and small – across vehicles and brands.

The multiple case approach, and the LCA and private car cases themselves allow the case study to cover the relevant driver's area issues. A multiple case study subjects the results to comparison within the same case study protocol, and if the same conditions are found to exist in the two different cases, the findings may be more rigorously generalised to the project in question (Yin 2009). The field procedure comprises literature and primary artefact review. The literature involved in this case study will include works on the specific topic of the case in question, as well as secondary sources from the field of MC which cite examples of the cases. Primary artefacts are a second source of information, and seek to validate the literature with real-life examples of products and associated business materials such as customer-interface websites which are set up to facilitate the act of customising goods. The case study was conducted by setting out questions regarding the implementation of MC in the two fields, the summary of which is described below.

The cases demonstrate that users value customised goods, and this value is linked to product utility. If customers value product utility, and bespoke manufacturing is just a means to this end it stands to reason that MC will offer the customer the same level of value if it too meets functional needs. Customers value the process of customisation somewhat less than the product itself. The customisation available should reflect critical functional elements. If large variations are required which change the function of the product, a modular system can accommodate this heterogeneity. Any amount of customisation accommodated in the product should be designed in and managed by the manufacturer, enabling control of inventories. Customer interaction should be considered one of the design constraints in the product design, as the customer must be able to determine the best design for their needs, within their level of ability. The design of the product should be sympathetic to the customisation task.

MC can be implemented in the design of bespoke capital goods by understanding the functional requirements which must be met in order for the product to remain acceptable, or indeed improve upon what is currently offered in the bespoke system. The functional basis for implementing MC extends beyond purely mechanical functions; the product must also account for the value to the customer of undertaking the customisation process, and the cultural value of cosmetic customisation. These objectives can be met by designing the product for customisation where functionally necessary.

Product diversity in the route bus driver's area is significant across several functional areas, and causes difficulty and higher costs in manufacturing and bus operation. The root causes for this diversity are diversity in bus operator requirements and a gap between user needs and what is supplied in the present design. Literature review has determined mass customisation as a reasonable approach to reducing the specification diversity without negatively impacting function, and thus reducing the issues of cost and manufacturability.

Case study analysis has suggested that user needs should dictate the implementation of MC into the driver's area design, with the family of modular differences controlled by the manufacturer.

2.5 Hypothesis

This research hypothesises that it is possible to design and manufacture route bus components reducing the problems caused by specification diversity. It is proposed that this will benefit bus operators by simplifying the specification process, reducing costs and lead times without adversely affecting bus transport performance. This hypothesis is tested in the next phase of this research to determine whether it stands up to criticism in a commercial setting.

3. Development of a driver's area

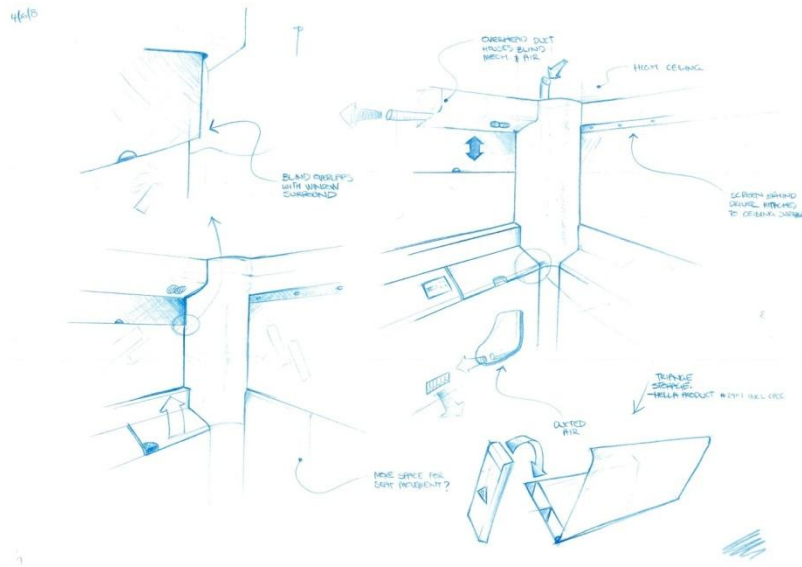
This section describes the experimental process of product development culminating in the design, manufacture and implementation of a new bus driver's area. The processes of ideation, critique, refinement, prototyping and production are documented. For the purposes of brevity, the product is described only in section 3.3 in finalised form.

“Design, then, like Science, is not so much a discipline as a range of disciplines united by a common intellectual approach, a common language system and a common procedure. Design, like Science, is a way of looking at the world and imposing structure upon it. Design, then, can extend to any phenomenon to which we wish to pay designerly attention, just as Science can extend to any phenomenon to which we wish to pay scientific attention.” (Archer 1981)

Design as a research method allows a hypothesis to be tested in an experimental setting. The process of design forms the test, and should a successful result be forthcoming, the material artefact provides proof for the existence and degree of this success. From this point it is possible to formulate a strategy to develop buses overcoming the conflict between function-driven specification diversity and manufacturing. As with a commercial design project, the design research project moves through several stages of increasing detail, each of which contains opportunities for critique, reflection, correction and comparison to the project constraints. At a practical level, the development begins with sketches, progresses through to computer-aided-design (CAD) models of defined geometry, physical prototypes and then production-ready designs. At the stage of being production-ready, the design is implemented as a new product for sale to customers. Although no one definitive “design process” exists, the procedure described above bears strong similarities to several published processes (Green & Bonollo 2002; Lawson 2006; Nelson & Stolterman 2003; Ulrich, KT & Eppinger 1995), of which a common feature is the flexibility of design to a given project.

3.1 Concept development

Figure 2: Example sketch from initial concept stage.



The design experiments began by giving form to possible solutions. This was carried out by means of sketching – a process allowing a low-risk and high-productivity test for ideas. The sketch also serves the purpose of recording the ideation process for later assessment by stakeholders. Although somewhat rudimentary in appearance, the sketch is a crucial step in giving form to “*that which does not yet exist*” (Nelson & Stolterman 2003). Sketches are not subject to physical constraints such as materiality or fits and tolerances – these are introduced later in the development process. In this phase of the experiment 51 pages of sketches were used to formulate a range of possible solutions; their effectiveness was then assessed by project stakeholders including the designer/researcher, engineering and sales staff. An example sketch is shown in Figure 2, where the storage utility of the driver’s area is being developed in order to reduce variations.

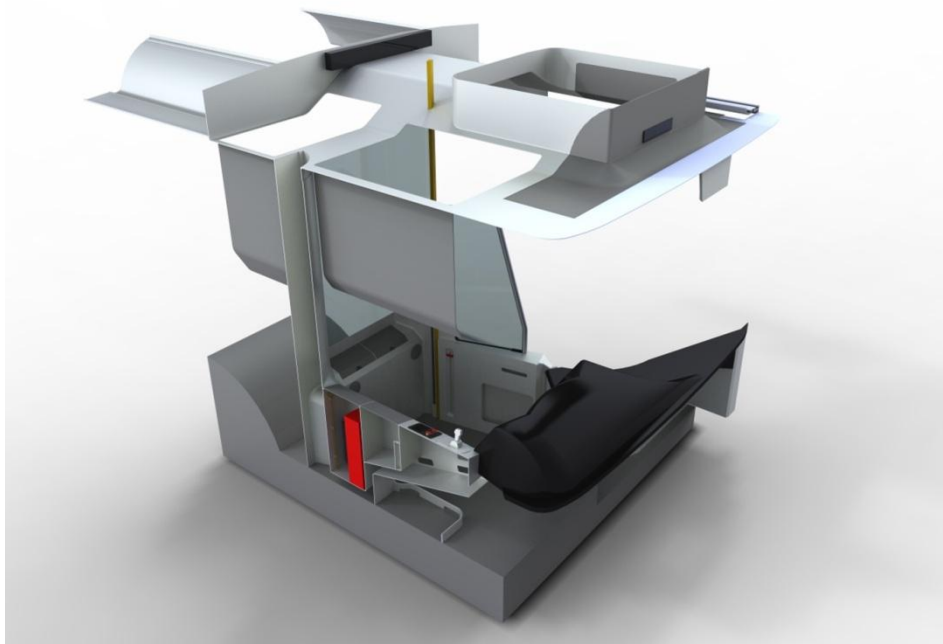
The assessment of ideas in sketch form led to the process of refinement, where the disparate proposed solutions were honed to a single unified concept for the driver’s area. This singular refined concept was developed in a three-dimensional CAD model requiring dimensional accuracy to fit inside the design envelope – the bus interior. The CAD model affords the design increased detail, but still in a virtual environment facilitating incremental change. The CAD model facilitates a more detailed, focussed critique of the design against performance requirements and a more cohesive representation of the overall form, as shown in Figure 3.

The present concept is deemed to meet requirements from the customer focus groups and legislation. The concept is beginning to demonstrate a positive result to the hypotheses proposed at the outset of product development. Concept critique during development had been carried out by the project team of designer, engineers, managers and sales; it is necessary at this point to take to concept back to the customer to broaden the sample of critique sources to other stakeholders.

Design critique is a necessary part of the product development process, as occurs concurrently with the generation of ideas, and more formally in meetings. Customers from the focus groups in section 2.2 were invited to participate in another session to critique the present concept. A focus group methodology was applied to capture data and create an environment familiar to participants. The fundamental difference in this third focus group was

that the topics of discussion were applied towards a rationalised product proposal as opposed to critique of existing product and discussion of the hypothetical. The concept was presented in a 3D format; and although the discussion was still speculative, it was in light of a considered proposal. The purpose was to critique the concept as presented, leading to further refinement of the design.

Figure 3: Example of rendered CAD model used for refinement critiques.



3.2 Refinement and prototyping

Figure 4: Photo-composite image of the prototype driver's area.



Following customer critique, the process of refining the design was undertaken. At this stage of the experiment, a favourable response to the hypothesis appears to be emerging, however the success of the product is largely determined by detailing. The process of refinement was continued in CAD format for another iteration, which was then followed by the construction of a prototype.

The prototype enabled analysis of the spatial and ergonomic decisions made in the development process, and necessitated several changes in the design as a result. This validation was also carried out with customers in the context of bus specifications. The driver's area had formed part of two tender responses to supply bus vehicles to large public operators, and once these were successful the operators were invited to take part in the refinement process as part of their own bus specification process. As the new driver's area was progressing towards production, it was essential at this stage to determine its suitability for purpose – the customer prototype test allowed this. The prototype is shown in Figure 4.

Decisions made in the prototype stage were interpreted back into the CAD model, at which stage it represented a finalised statement of design intent. This model was then turned over to mechanical and electrical engineers for the generation of production-ready drawings.

3.3 The new bus driver's area

The new bus driver's area shows that it is possible to design and manufacture route bus components which reduce the problems caused by specification diversity. Product improvement was the main technique for meeting the conflicting constraints of manufacturing and customer needs. This was achieved by reducing the number of components – and thus the noise generated by their intersection, relocating the electrical centres to new ceiling cavities creating more passenger and driver space, and offering the driver more thermal control over their working environment. All of these features are standardised in the new driver's area.

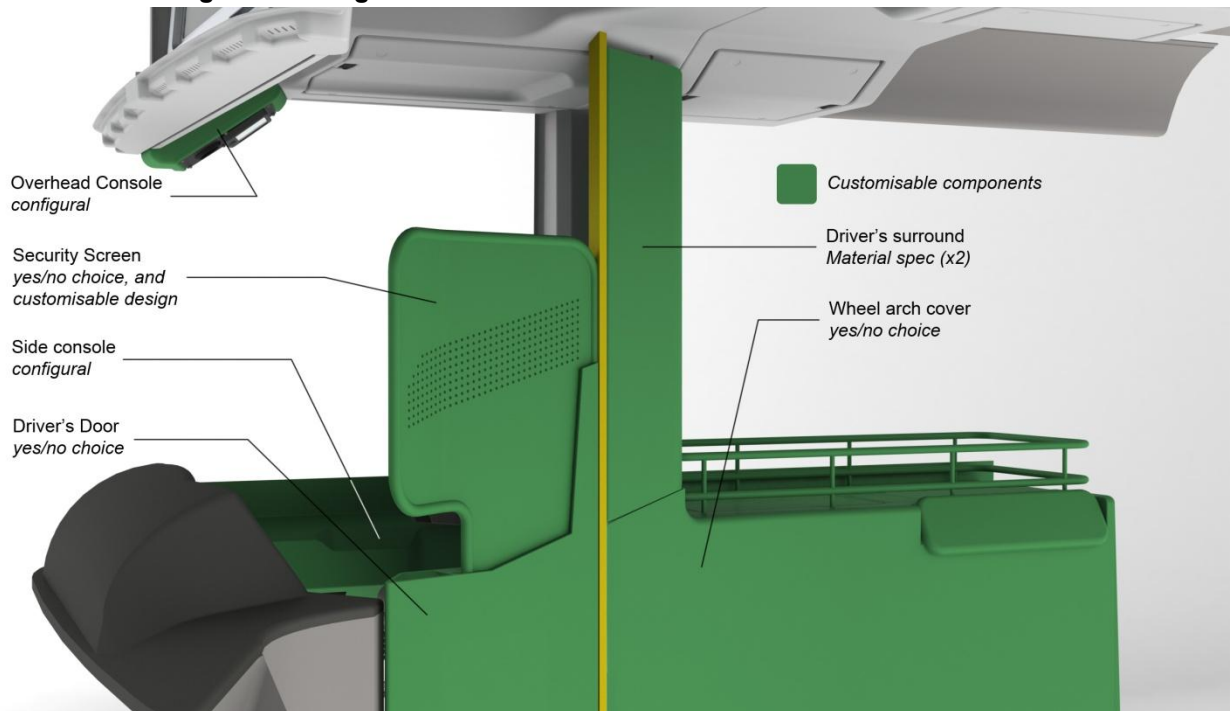
Figure 5: Photograph of the new driver's area, as viewed looking in the front doors.



Product diversity is only present where functionally justified. The choice of specifying a driver's door is required according to the operator's security needs; for example the difference between an urban and country service is typically quite large. A further sub-option in this area is that the door itself accommodates a security screen which can be redesigned and redeployed according to needs – housed in a modular mounting system. The material specified for the driver's surround can be specified in either tinted or opaque polycarbonate according to operator preference – and as an OEM part has little bearing on the production process. A wheel arch cover is offered behind the driver's surround to create additional storage space for sundry equipment such as security recording devices and GPS – the cover takes the place of two passenger seats. Finally, the configuration of switchgear on the side and overhead consoles is generated in a flexible configuration framework, in order to accommodate controls for air-conditioners, doors, and other vehicle controls. The dashboard remains a configurable component and was outside the scope of this project.

Limited to these options, product diversity in the driver's area has been significantly reduced from a large family to nine discrete components as shown in Figure 6. The new driver's area strategically applies MC where functionally required, and a standard design of higher specification where it is not.

Figure 6: The configuration range of the new driver's area.



Two large delivery contracts have been established which include the new driver's area as part of the bus design. Further to this, the new driver's area is in production for smaller contracts of vehicle delivery for customers in three Australian states and one Territory. The design has therefore been subjected to the tests of specification, manufacture, assembly and operation, which makes it possible to determine the strategic benefits of the design. The specification process – occurring before production – is simplified because of a reduction in possible options, reducing labour in arriving at a production-ready bus. Repair and maintenance of components is also simplified and made more cost effective by this standardisation. The bus operator is no longer obliged to develop their own solutions to

design issues in the driver’s area, as any customer-sacrifice has been accommodated by modularity. Finally, the standardisation of processes and inventories and the refinement of production processes and materials have delivered a substantial cost saving to the bus operator, in addition to the product being of higher quality and usability.

Table 2: Summary of flexible components in the driver’s area.

Extent of Variation in Driver's Area - Comparison				
Component	OLD		NEW	
	Choice Type	Total Options	Choice Type	Total Options
Driver's locker locations	Choice of	5	Standardised	1
Demister specification	Choice of	3	Standardised	1
Electrical centre location	Choice of	2	Standardised	1
Material of components	Choice of	2	Standardised	1
Consoles	Configurable	∞	Configurable	∞
Driver's Door	Yes / No	2	Yes / No	2
Security Screen	Custom Design	∞	Modular swapping	2 at present
Surround material	Custom Design	∞	Choice of 2	2
Wheel Arch Cover	N/A	N/A	Yes / No	2

4. Discussion and conclusions

Development and release of the driver’s area has shown that the hypothesis stands up to criticism of commercial realities. This section describes the benefits and drawbacks the design has exhibited in the bus vehicle market, discusses the broader implications of this research on the transport system, suggests further research and forms conclusions.

This research was precipitated by a situation of high-cost and general inefficiency caused by a bespoke manufacturing system – itself a method of accommodating variation in bus operator needs in bus bodywork manufacture. Further investigation of this situation revealed that although strategies existed to overcome these issues, little was known about the customisation of bespoke capital goods. A design development process was undertaken to test the hypothesis “...that it is possible to design and manufacture route bus components reducing the problems caused by specification diversity.”

The development of a new bus driver’s area demonstrated two approaches to mitigating the inherent disadvantages of excessive product variation. Firstly, the majority of the driver’s area was designed to more closely align with user needs as determined by focus group, and thus remove much of the need for variation. Secondly, where user needs dictated variation in products, a mass customisation strategy was employed to offer variations in a manner allowing both efficient manufacture and satisfaction of user needs.

By setting out to determine the root cause for variation in bus specification, the research discovered disconnection between user needs and product offerings. The existing strategy from bus operators to cope with this gap was to determine their own solutions – in the form of bus specifications – and then dictate these to the manufacturer. In this scenario, the manufacturer is not able to apply their own expertise in the development of products, and

must produce what is specified to maintain commercial interests. The process developed in this research requires a manufacturer's design response to user needs. This may seem to offer more to the manufacturer than the bus operator, but is still subject to the basic check of commercial integrity – the bus operator's interests must be represented lest they purchase elsewhere. The result of this approach to product development is a driver's area reconciling the conflicting requirements of manufacturer and bus operator.

The two interventions suggested by the hypothesis were shown to work in this situation. Two further interventions to the problem were forthcoming during the research. Firstly, an understanding of user needs was sought before the bus specification process. This enabled the second; that with this information in-hand, the manufacturer could assume a leadership role in vehicle development.

The design methodology developed in this research has upheld a hypothesis and therefore suggests that it is one possible solution to the problems caused by diverse specification in route bus bodywork. Further research should be concerned with expanding the scope of design to other bus components and public transport vehicles to determine how robust the conclusions are in different situations, refining the approach and discovering its limitations.

4.1 Conclusions

A new bus driver's area was developed with the aim of reconciling the conflicting needs of bus operators and the bus bodywork manufacturer. The determination of user needs showed that bus operators were creating their own solutions to usability shortcomings in the bus driver's area, resulting in the symptom of product diversity. A new driver's area was developed to overcome these shortcomings – and therefore the attendant problems of specification diversity – by offering a higher-specification product, and to implement a system of mass customisation where variations were necessitated. The development process upheld the hypothesis that a product could be developed to reduce the problems caused by specification diversity. The subsequent adoption of this design into production buses demonstrates the benefits of the approach to be saving in labour and capital cost for the bus operator and manufacturer. This has improved public transport operation by increasing the buses' fitness for purpose in purchase, running, repair and usability.

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