A decision consequence-based model to understand the phenomena in motorcycle engineering design from a human factor's perspective

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Abstract: Research has shown that motorcycle riders' persona and posture have a large impact on motorcycle safety, bringing these challenges into the domain of human factors. Besides these aspects, motorcycle designers must consider the emotional values of such artefacts for it to be successful in the market. Indeed, motorcycle designers must take into account multitude of factors when developing such artefacts. These all pose challenges to designers whilst carrying out motorcycle design. A study was carried out with motorcycle designers to investigate their current design practices, and challenges faced during motorcycle design. A critical literature review revealed that there is a research gap in decision consequence models which do not take a holistic view of the underlying phenomena during design decision-making of motorcycle designers. The gap in literature together with the outcome of the study, collectively led to the development of a decision consequence-based phenomena model during motorcycle design. The model is validated with two case studies from the motorcycle industry through the use of a comparative-validation approach.

Keywords: phenomena model; decision consequences; ergonomics; emotions; design synthesis; human factors; persona.

Reference to this paper should be made as follows: Agius, S., Farrugia, P. and Francalanza, E. (2021) 'A decision consequence-based model to understand the phenomena in motorcycle engineering design from a human factor's perspective', *Int. J. Design Engineering*, Vol. 10, No. 1, pp.72–96.

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1 Introduction

Motorcycling offers an agile means of transport, especially in congested urban areas. Motorcycles can take up to 48% less time to cover the same urban trip as a car, whilst at the same time consuming up to 81% less fuel than cars (Federation of European Motorcyclists Associations, 2009). In no other mode of transportation do users face such a wide spectrum of environmental and collision hazards which may put them critically at risk (Hancock et al., 2006). According to WHO (2018), motorcycle occupants constitute in 28% of all road traffic fatalities. This percentage consumes 380-thousand lives around the world every year, with another 40-million riders suffering from non-fatal, but severe injuries.

Motorcycle accidents occur due to various reasons. Numerous factors contribute to these accidents, such as riders' actions and decisions, the actual vehicles, road, surroundings layout, etc. The authors of this paper firmly believe that motorcycle accident prevention and safety should be factored in during the artefact's design-phase. Furthermore, addressing these challenges in the early phases of the motorcycle life-cycle means that cost of design change implementation is greatly reduced, increasing motorcycle companies' sales and boosting their competitiveness. Farrugia et al. (2019) claimed that motorcycle designers have to consider the emotional value of such artefacts as it has a huge impact on the success of a motorcycle design. This is because, riders are more likely to purchase motorcycles which enhance positive emotions and experiences. In the *synthesis design activity*, designers make decisions which will ultimately have an impact on the safety and success of the artefact. For this reason, it is imperative that during this activity, motorcycle designers are aware on their design consequences and how these may potentially impact riders.

According to Hancock et al. (2006), not many studies on the domain of motorcycles have been undertaken. Indeed, critical literature review revealed that there is a lack in knowledge, specifically on the challenges faced by designers during the design process of motorcycles. Through this paper, the authors seek to address some of this imbalance. This is achieved by developing a decision consequence-based model which highlights the phenomena occurring during motorcycle design. Two case studies of real motorcycle designs, which made success in the motorcycle industry, were employed to validate the developed motorcycle design phenomena model. Validating the model with the case studies was essential for the contribution of a robust scientific model to the design engineering research.

The novelty of this paper lies in a validated, motorcycle design phenomena model, directly derived from actual motorcycle designers in the field, which portrays deficiencies in the current motorcycle design process from human factors perspective. This model is key to highlight challenges (currently unaccounted for) faced by motorcycle designers, and prove the need to support designers in developing safer motorcycle designs while at the same time enhancing the emotional value of such artefacts.

In view of this context, the main objective of this paper is to present and explain the underlying phenomena by modelling how consequences are generated from motorcycle design decisions. This objective will be fulfilled through the following goals:

- To critically review the literature on motorcycle design, human factors and relevant decision consequence models.
- To understand current design practices, challenges faced by designers during the motorcycle design process.
- To develop the decision consequence-based phenomena model.
- To validate the developed phenomena model with case studies from the motorcycle industry.

This section laid the foundations by introducing the motivation and highlighting the problems that will be addressed together with the objectives set out in this paper. Section 2 characterises the synthesis design decision-making and their human factors *use-phase* consequences. A critical review of the literature is then presented later in this section, highlighting phenomena models relevant to this research. Section 3 focuses on the methodology, presenting how the data from actual motorcycle designers was collected and analysed. The method used to validate the developed model will be also presented in Section 3. The developed phenomena model is then presented in Section 4. Section 5 presents the validation results of the developed phenomena model with actual case studies from the motorcycle industry. Section 6 discuss the study outcome and concludes this paper by highlighting the scientific contribution of this research paper.

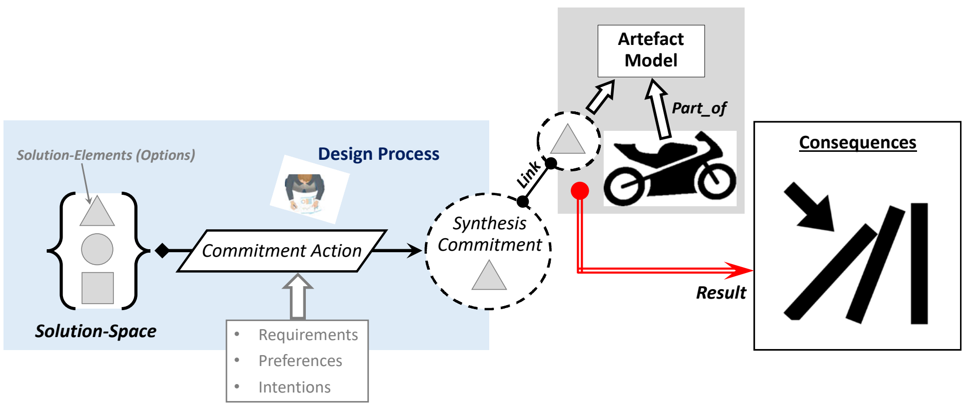
2 Literature review

To be able to understand the phenomena in motorcycle engineering design, it is imperative to explain the synthesis decision-making activity (Section 2.1) and how these decisions may potentially lead to *use-phase* consequences from human factors perspective (Section 2.2).

2.1 *Synthesis decision-making in engineering design*

According to Roozenburg and Eekels (1991), the product is achieved through a number of activities in the basic design cycle. *Analysis*, *synthesis*, *simulation* and *evaluation* are the activities that designers carry out to facilitate the effective completion of design stages. Roozenburg and Eekels (1991) defined *synthesis* as the combining of separate things, such as ideas, evolving the design solution into a complete whole. During the course of the synthesis design activity, the designer reaches a stage where a decision query is made based on numerous options from various elements in a solution-space. Borg et al. (1999) have provided a synthesis decision-making model, illustrated in Figure 1.

Figure 1 Synthesis decision commitments simplistic model (see online version for colours)



Source: Adopted from Borg et al. (1999)

As explained by Borg et al. (1999), given numerous options, the designer engages in a decision-making process to select one from the space. During the decision-making process, the designer considers a number of issues, such as the (customer) requirements that have to be fulfilled, the intentions and preferences of the designer. Furthermore, other complex variables such as the brand identity, past design solutions, success and failure of motorcycle designs, and market trends often skew design decisions (Cocco, 2013). Following these considerations, the designer would explicitly select one of the options through a commitment action, resulting in a decision commitment. Commitments that result from synthesis decisions form a link between the *design process* and the *artefact model* (Borg et al., 1999). This synthesis commitment is then added to the evolving artefact model.

According to Olsen (1992), design decisions have consequences when the artefact meets with different life-phase systems of products, namely *design*, *manufacturing*, *use* and *disposal*. Thus, during design synthesis, designers have to cope with the co-evolution of problems which make it difficult for humans to be aware of them all. That is, trying to predict the consequences from a set of alternative options. As explained by Borg et al. (1999), synthesis decision commitments lead to intended and unintended consequences. Unintended consequences are those consequences that the designer is not aware of when committing to the design decision. It is this type of decision consequence that the designer needs to be made aware of for design guidance.

2.2 Characterising human factors – potential consequences of unintended motorcycle design decisions

2.2.1 Ergonomics

The chances of making driving errors are increased when riders adopt poor ergonomic postures, owing from muscle fatigue, pain or numbness (Road Safety Research, 2017). Stedmon et al. (2012) argue that these scenarios mostly arise because the type of motorcycle dictates who rides it. Stedmon et al. (2012) found that fitting the rider to the motorcycle leads to a bad ergonomic application. The situation worsens as riders get older and muscle strength, cognitive abilities, coordination, grip, and general freedom of neck and limb movements deteriorate (Groeger, 2000). Pain, fatigue and discomfort are all symptoms of products or systems that require the ergonomic attention in their design phase (Marek and Pokorski, 2004).

2.2.2 Human psychology and cognition

Hancock (1995) analysed the demands involved in riding a motorcycle and has indicated that distractions from the primary task, i.e., lane keeping and roadway hazard monitoring, can cause dangerous situations which may lead to accident scenarios. Overload of cognitive processing results in a rider's mental fatigue and thus, reducing rider's alertness (Stedmon et al., 2012). Distractions can manifest themselves through uncomfortable riding positions, physical fatigue, pain or numbness (Hancock et al., 2006). Other distractions are owed to the overwhelming cockpit design or bad positioned motorcycle controls such as mirrors, throttle and braking levers (Stedmon et al., 2012).

Most of the experienced riders tend to feel overconfident. Overconfidence leads to inattention and carelessness (Hancock et al., 2006). Riders exhibiting this behaviour are particularly vulnerable to serious or fatal injuries associated with excessive speed. Hancock et al. (2006) argue that motorcycle riders with these vulnerabilities need to be factored in during motorcycle design. Designing for thrill-seeking riders by having a motorcycle with low powered engine or wide tyres (for better road stability) is keys to help them ride safely.

2.2.3 Emotions

The vast majority of individual riders fall into the combined category in which the goals is explicit travel needs, combined with the pleasure of motorcycle use (Hancock et al., 2006). Therefore, besides this ergonomic aspect, a motorcycle designer has to consider the emotional value of such artefacts. Designing for emotions should be an explicit goal from the initiation of each project (Hancock et al., 2005).

When looking at a product, there are three levels of emotional processing which occur by a human brain. These are the visceral, behavioural and reflective levels (Norman, 2013). Instinctive reactions to a product such as attractiveness or repulsiveness occur at the visceral level. The behavioural level deals with the expectations and perceptions that a customer has of a particular product. Personality inscribed in the product is target by the reflective processing level. Unlike visceral and behavioural, the reflective level is conscious, and the emotions produced at this level are the most prolonged. These are generated and continuously evolving during product use. Motorcycle aesthetics, style and appearance are the prime features that drive the visceral and behaviour levels, whereas the reflective level can be driven by ergonomics, amongst other factors. All three levels of processing work together, and aim to improve human interaction with systems by enhancing user satisfaction and increasing acceptance (Lee et al., 2017). Motorcycle designers should give importance to all three levels as these can all have a huge impact on the success of a motorcycle design (Farrugia et al., 2019), thereby affecting company profits.

In this research, ergonomic, emotions and persona aspects are considered in motorcycle design, which amongst other aspects enable designers to develop safe and aesthetically pleasing motorcycles. The *persona* term defines the personality, attitude and road experiences of motorcycle riders. Furthermore, persona, ergonomic, emotion studies and their interaction with motorcycles fall within the discipline of human factors.

2.3 Critical review of design phenomena models

This section provides a review of the state-of-the-art in phenomena modelling in context of design research. The following review criteria are based on the motorcycle design process and human factors:

- *Product life-phase:* Product life-phase/s (i.e., design, manufacturing, use, disposal or others) impacted by unintended consequences during motorcycle design decisions. Furthermore, it was seen that an interaction can occur within the design stage. For example, an interaction can occur between synthesis decision-making at an early design stage (i.e., the conceptual stage) and the decision commitment at a later stage (i.e., embodiment or detailed design stage).
- *Aspects (solution-elements):* Aspects (i.e., ergonomics, emotions, riders' persona or others) in the solution-space which are available to designers when making design decisions. Moreover, a product, throughout its life-phase will interact with users or systems. This interaction can have a predictable (objective) behaviour arising from the product specifics or can have a variable (subjective) behaviour owing to different users' human factors characteristics.

Kaljun et al. (2012) developed an intelligent advisory system based on a phenomena model, composed of two aspects, aesthetics and ergonomics. These two aspects can be applied simultaneously or independently for the same design project. This intelligent advisory system proposes, to the designer, recommendations for possible product design improvements from an ergonomic and/or aesthetics perspective. The intelligent advisory system developed by Kaljun et al. (2012) does not take in consideration the users' persona aspect and the model lacks evaluation of the interaction between aesthetics and ergonomics when simultaneously applied for the same design case study. The model developed by Kaljun et al. (2012) considers designers' decision commitments in the embodiment stage, as the system improves on the conceptual design. Thus, there is no early design decision assistance and consequently, no interaction between early and late design stage motorcycle models. The intelligent advisory system is not used in the context of motorcycle designs and so, does not cater for the design process of motorcycles. This intelligent advisory system is presented with pre-defined rules captured from literature (predictable behaviour) and therefore, does not capture the different emotions elicited by users for the same product.

Francalanza et al. (2017) developed a phenomena model based on factory life-cycle consequences (LCCs) for *cyber physical production systems* (*CPPS*). During *CPPS* synthesis design, the production system designer makes a decision commitment on the current needs. However, Francalanza et al. (2017) discuss that *CPPS* requirements, such as products and processes evolve over time. A united consequence arises between the decision committed for the current and future *CPPS* requirements. Furthermore, an interaction exists between different decision commitments. These decisions include the machines that are going to be utilised, the layout of the productions system, and the IT infrastructure. This means that the developed model by Francalanza et al. (2017) does not take into consideration the ergonomics, emotions and persona using the *CPPS*. The unintended consequences (described above) affect the *CPPS* use-phase. Therefore, the developed phenomena model by Francalanza et al. (2017) does not factor for design decisions taken for the actual design of the *CPPS*. The model also lacks the interaction between the synthesis decision-making at an early and late design stages.

The study carried by Barone and Curcio (2004), focuses on a model which analyse motorcycle ergonomics. Barone and Curcio (2004) argue that the decision taken by motorcycle designers to use physical mock-up systems and two-dimensional simulations lead to consequences which have adverse effect on the design process itself. The consequences of using these ergonomic analysis systems lead to an expensive and time consuming design process. Barone and Curcio (2004) argued that physical mock-ups used for ergonomic analysis can only be used at a later stage of the design process which results in a high cost of design change implementation. The model developed by Barone and Curcio (2004) does not capture emotions and persona aspects. Hence, there is no relation between the rider's persona, postural data and emotions elicited to different motorcycle designs. Furthermore, Barone and Curcio's (2004) model focuses on scooters, thus, applications are limited to a scooter layout. The model proposed by Barone and Curcio (2004) focuses on the design-phase. Consequently, this model does not factor in for consequences arising in the use-phases of the product's life-cycle.

The model presented by Mamo (2018) is used for the development of sport-bikes. Mamo (2018) highlighted that the phenomena model is based on riders' elicited emotions to different sport-bikes' aesthetic designs. Besides emotions, Mamo (2018) considers motorcycle aerodynamic characteristics as part of the solution-space available for sports-bike designers. The model developed by Mamo (2018) does not capture ergonomic and persona aspects such as personality type and user experience. Hence, there is no relation between the rider's personality and experience, postural data and emotions elicited to different motorcycle designs. Furthermore, due to the nature of the aerodynamic aspect, the model is limited to sports-bike designs and performant motorcycles. The model developed by Mamo (2018) does not factor in the designers' decision commitments at the early and late design stages. Consequently, no interaction is considered between early and late design stage motorcycle models of Mamo's (2018) phenomena model. Moreover, only the motorcycle use-phase of its product life-cycle is impacted by the unintended consequences during design decisions.

Farrugia and Borg (2016) developed the *emotional consequence model*, observed during manual assembly of products by operators. The product designer in this case, commits to a product from a solution-space having different shapes, sizes and materials. During manual assembly, there is an interaction between the operator (user) and the part. This means that the model proposed by Farrugia and Borg (2016) focuses on the manufacturing-phase of the product's life-cycle. Consequently, this model does not factor in for consequences arising in the design and use-phases of the product's life-cycle. Furthermore, this model does not feature any interaction which occurs between different design stages. Farrugia and Borg (2016) state that the emotional consequence effects are cost, time and quality. On the other hand, the *emotional consequence model* does not take into consideration the ergonomic and persona aspects during design decision-making. These two aspects together with the emotional aspect can give rise to various consequences. It can dictate the level of safety of a particular motorcycle design while interacting with a particular rider (due to the ergonomics and rider's persona). It can also influence the level of product attachment (due to emotions and ergonomics). The phenomena model developed by Farrugia and Borg (2016) does not consider variable behaviour which occurs when the same product interacts with various riders having different emotions, anthropometric data and persona. In such a case balance of the aspects is key to reach as many customers as possible, and not only those customers for whom the product is intended.

The *LCC* model developed by Borg et al. (1999) describes a generic approach to guide designers when making decisions during the early stages of mechanical product design. Borg et al. (1999) presents a model on how unintended consequences encountered in life-cycle-phases can impact the designer's attention early on in the synthesis activity of the product. The *LCC* model is directed mostly towards the manufacturing and use life-cycle-phases of the designed product. A weak designed snap-fit will have an effect on its use-phase, while a sink mark will have an effect in both the manufacturing and use-phase. The *LCC* model does not reflect the product in its design-phase, but rather considers other parts'/tools' design-phase which interact with the product. For example, the design of a mould tool which will be used to form/produce the product. As such, the *LCC* model does not factor unintended consequences generated through the design decisions taken for the actual design of the product. Specifically, it lacks the interaction between the synthesis decision-making at an early design stage and the decision commitment at the late design stage. The unintended consequences in the model developed by Borg et al. (1999), derive from properties (e.g., a hole which is close to the edge) pertaining to the product and the manufacturing process. As indicated above, the aspects are constructed from the product's material and geometrical properties together with its manufacturing process. As such, the *LCC* model lacks the human factors aspects. As human factors are not considered in the *LCC* model, the product-to-user interaction during the use-phase has a predictable behaviour. As such, the model does not cater for unintended consequences in situations where the interaction is variable (subjective) owing to different users' human factors characteristics.

The critical literature review indicates that the state-of-the-art decision consequence models do not take a holistic view of the underlying phenomena during design decision-making of motorcycle designers. Table 1 summarises the findings from the literature review, and highlights the limitations of the above reviewed phenomena models.

Table 1 Summary of the state-of-the-art phenomena models (see online version for colours)

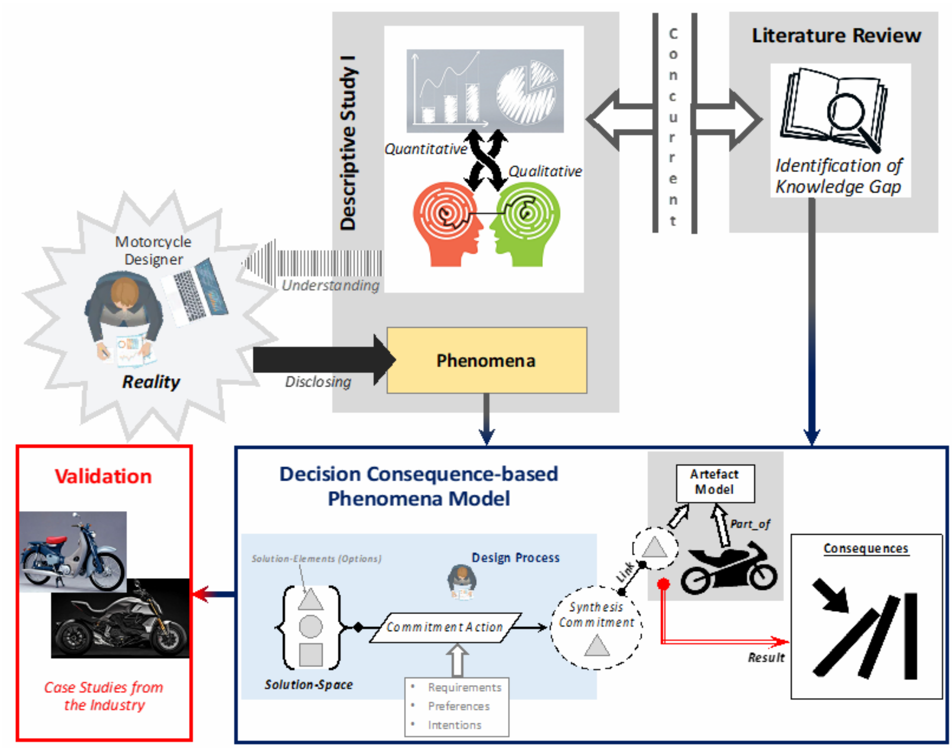
Reference	*Product life-phase*				*Aspects (solution-elements)*			
					Human factors			
	(Within) design	*Manufacturing*	*Use*	*Disposal*	*Ergonomics*	*Emotions*	*Persona*	*Other*
Kaljun et al. (2012)			✓		✓	✓		
Francalanza et al. (2017)			✓					✓
Barone and Curcio (2004)	✓				✓			
Mamo (2018)			✓			✓		✓
Farrugia and Borg (2016)		✓				✓		✓
Borg et al. (1999)		✓	✓	✓				✓

Table 1 and the critical literature review collectively indicate that there is no decision consequence-based phenomena model which impacts the design and use-phase of a motorcycle life-cycle. Specifically, reflecting the interaction between the early (conceptual) and the later (embodiment/detailed) design stages, considering ergonomics, emotions and persona. Furthermore, collectively there is a limitation when addressing the product-to-users interaction, which can have a variable behaviour owing to different users' human factors characteristics. This is keys to solve existing challenges faced by motorcycle designers and generate knowledge explicitly for their needs.

3 Methodology

The methodology utilised to develop and validate the decision consequence-based phenomena model is presented in Figure 2.

Figure 2 The methodology used to develop and validate the model (see online version for colours)



As illustrated, this methodology has two starting points: the design problem observed through the *descriptive study* (understanding designers' *reality*) and concurrently the literature review. In the context of this research, the designers' *reality* encapsulates current motorcycle design practices and challenges faced by designers when designing motorcycles. In turn, the underlying design phenomena are disclosed by first observing and then analysing designers' reality.

Validation guides the development and evaluation of new methods and is essential to the formulation of scientific theory as it deals with the justification of knowledge claims. In their paper, Barth et al. (2011) found out that comparative case studies are used to validate theoretical models. The comparative case study approach validates the developed model by comparing it to benchmarked case studies in the industrial field. As indicated in Figure 2, the comparative case study approach was employed to validate the developed motorcycle design phenomena model with real motorcycle case studies which made success in the motorcycle industry.

3.1 Method used to understand motorcycle designers' reality

Semi-structured interviews combine aspects of structured and standardised open-ended interviews. Structured questions are used to obtain 'factual or quantitative' information, while open-ended questions acquire qualitative explanations and descriptions for the phenomena being studied (Creswell, 2007). For this reason, a semi-structured interview data collection instrument was used to collect responses from designers.

A sample of eight European motorcycle designers participated in this study. All of the respondents had a *bachelor's degree* in either a *mechanical, vehicle* or *design engineering*. The designers' experience varied between 2 and 30-years, with a mean of 17-years. Participants worked with top brands such as *Honda*, *Yamaha*, *Suzuki*, *Triumph*, *Ducati*, *Aprilia*, *MV Agusta*, *Piaggio (Vespa)*, *Moto Guzzi*, *KTM*, *Harley Davidson* and *Indian*.

All semi-structured interviews were conducted on a one-to-one. The interviews were tape-recorded and transcribed verbatim. Relevant phrases, sentences and sections were *coded* from the transcripts. *Codes* which were relevant with each other were sorted and grouped into categories. Themes were identified from patterned *codes* and linked together to form core themes. An *inter-rater reliability* (IRR) test was used in this study to assess the replicability and consistency of the qualitative analysis. *Kappa's index* for IRR was 0.78, suggesting a good agreement between the two raters and thus, a good qualitative reliability (Bajpai et al., 2015).

3.2 Method used to validate the developed phenomena model

A literature search was conducted to identify which motorcycle designs were successful. While scientific papers are repositories of scientific knowledge, generally magazines are repositories of information related to realistic experiences in the industrial field. Articles presenting list of 'best motorcycles' in reputable motorcycle magazines were selected. These articles identified successful motorcycle designs according to experts in the field. Following this premise, the five selected motorcycle magazines, together with their featured article are presented in Table 2.

Every motorcycle mentioned in the 'best motorcycle' list, for each article in Table 2, was noted. Two noticeable motorcycles, which classified in top places, were the *Honda Super Cub* and the *Ducati Diavel*. These two motorcycles are illustrated in Figure 3 and Figure 4, respectively. The two motorcycles were mentioned in 3 out of the 5 reviewed magazines. This procedure eliminated subjectivity in the selection of successful motorcycles to be used as case studies in this paper. Objectively, this implies that the Honda Super Cub and the Ducati Diavel motorcycle designs are successful in the motorcycle market and industry.

Table 2 Reputable motorcycle magazines and their corresponding articles on the best motorcycles

ID	*Magazine*	*Article title*	*Reference*
1	*Cycle World*	Ten best motorcycles	*Cycle World* (2019)
2	*Rider Magazine*	25 Best motorcycles of the past 25 years	*Rider Magazine* (2016)
3	*HiConsumption*	The 30 greatest motorcycles of all time and 10 best cruiser motorcycles	*HiConsumption* (2019, 2018)
4	*Gear Petrol*	The 51 most iconic motorcycles of all time	*Gear Petrol* (2013)
5	*Ride Apart*	The 5 best cruisers on the market	*Ride Apart* (2020)

Figure 3 The Honda Super Cub (see online version for colours)

Source: From *Cycle World* (2018)

Figure 4 The Ducati Diavel (see online version for colours)

Source: From *Gear Petrol* (2019)

In addition, the Ducati Diavel won 'Best of the Best at Top Design 2019 Awards' (*Gear Petrol*, 2019; *Ride Apart*, 2019). The Ducati Diavel classified first based on the criteria of how much entrants added value to their segments, are pleasing to look at, whether or not they are functional, and if they elicit strong positive emotions. On the other hand, the Honda Super Cub is the most produced motor vehicle in history, where by 2017 Honda announced that they have sold 100-million units (*Cycle World*, 2018), making it one of the most successful motorised vehicle ever produced.

From the above-mentioned claims, both the Honda Super Cub and Ducati Diavel motorcycle designs have features which distinguish them from the rest of the motorcycles. Having established the two case studies from the industry, a literature search was carried out to discern the design process employed to develop the two motorcycles. To have neutral objective view of the in-house design process, interviews were gathered from designers employed at Honda and Ducati. The design processes according to Honda and Ducati were then compared to the developed phenomena model.

4 Results

4.1 Main themes identified from designers' interviews

The following main themes, highlighting motorcycle designers' reality, were identified from the interviews carried out with the designers:

T1 *Collection of riders' information:* Designers stated that it would be very useful if riders' information is gathered and channelled in the form of knowledge, to the designers. Designers stated that this information should not be the same information collected in the task clarification stage (i.e., for the intended customer). But rather it should have a wider reach to the general riders. A particular designer suggested that "Something is needed to try to gather customer information and then try different solutions before moving to the next stage." Such information should consist of riders' experiences, personality type and motorcycle use context, as well as emotions elicited to different motorcycle types/styles.

T2 *Collection of riders' ergonomic/anthropometric information:* Following from T1, designers suggested to collect ergonomic information from a hardware tool, which is capable of acquiring real-postural (anthropometric) data of motorcycle riders. The information collected should be accessible to motorcycle designers during the design process. A particular designer specified that "A hardware tool can be used to collect ergonomic information of the motorcycle design in consideration … Information can be acquired on different motorcycle geometries with different rider characteristics such as weight, height, dimensions of one's arms and legs."

T3 *Design stage conflict:* Aesthetics are manly considered in the conceptual stage, while ergonomics are considered in the embodiment design stage. Ergonomics restrain the whole design if considered in the conceptual stage. Interviewed designers stated that "The normal procedure is to start from the motorcycle aesthetics … This is the first thing that you need to check, whether it is going to be an aggressive or relaxed motorcycle … In the first stage you do not want to focus much on the ergonomics because it closes your creativity. So, you have to move it in the embodiment design stage." A potential solution can be by considering them both at the same stages as suggested by a particular designer: "It would be nice to have something which assist us to sketch a motorcycle really fast while being parametric at the same time."

Generally speaking, interviewed designers agreed that the most important design considerations are dealt with, in the conceptual design stage. This is because in the conceptual design, stage 1 tends to focus the attention to aspects or features that spark interest the most.

T4 *Aspects interdependency:* The right balance must be set between aesthetics and ergonomics for emotive and safety considerations. Some motorcycles are ergonomic oriented while others are aesthetic oriented, some are both. A designer stated that "Aesthetics and ergonomics must constantly be in balance, as the latter will remain important across the whole range of motorcycles. If you had to have something that communicates constantly between aesthetics and ergonomics will be very beneficial."

T5 *Compromise between design aspects:* To reach as many customers as possible compromise between several motorcycle aspects is crucial. A designer stated that "In the end you need to have a mix between ergonomics, aesthetics, trends and other aspects, such as, knowing the rider profile you are designing for."

4.2 A motorcycle design phenomena – a decision consequence model

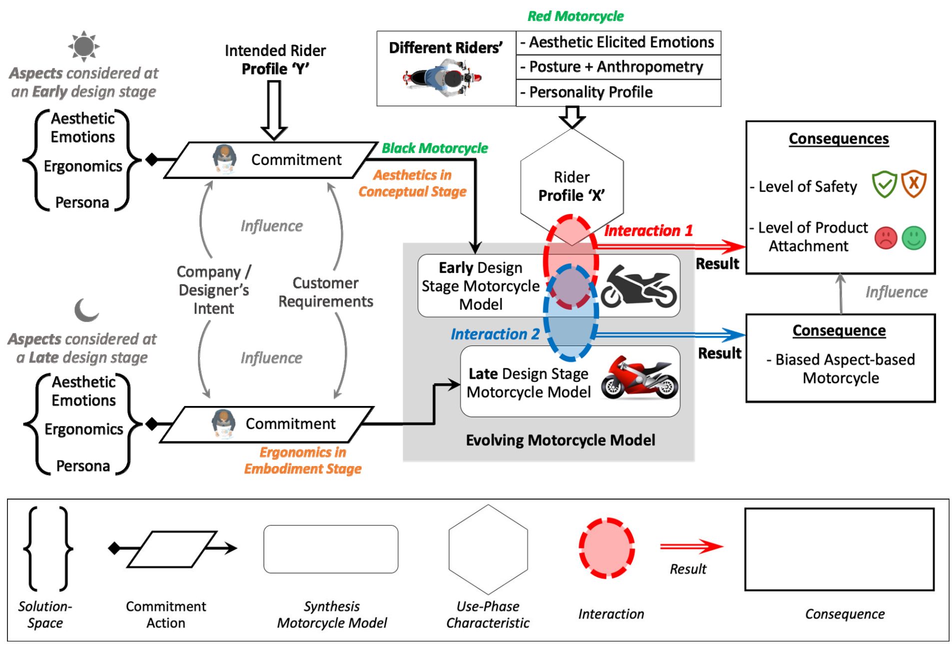
According to Duffy and O'Donnell (1999), "Phenomena models are based upon observations and analyses of the reality of design and hence, reflect design practice." The characterisation of synthesis decision-making, consequences on human factors, together with the observations made from the study conducted with motorcycle designers, are used as foundations to model the phenomena. The phenomena model describing how motorcycle design decision consequences are generated will now be explained. As this model reveals, through Figure 5, motorcycle design consequences are generated from two conditions:

- rider's profile decision commitment
- design stage decision commitment.

4.2.1 The rider's profile decision commitment phenomenon

The design process is a decision intensive activity (Borg et al., 1999). For early motorcycle design, the designer has various options from the solution-space of motorcycle parameters. In this research, the solution-space contains motorcycle parameters from the previously defined aspects (i.e., ergonomic, persona and emotion aspects). For example, an ergonomic-based parameter can be the distance between the handlebar, the seat and the footpegs. A parameter that elicits emotion to a rider can be the motorcycle's colour scheme. A persona-based parameter can be a rider who is a thrill seeker and thus, enjoys high engine powered motorcycles.

Figure 5 Motorcycle design decision consequence-based phenomena model (see online version for colours)



During motorcycle design synthesis, a designer commits to a set of motorcycle parameters, which are sometimes influenced by the company (through *product design specifications*), designer's own intents, or by customer requirements. As indicated by Borg (1999) decision commitments introduce consequences. This research will follow on the argumentation made by Borg et al. (1999), that is, "the artefact model is governed by the commitments resulting from synthesis decisions in the design process." Borg et al. (1999) also explained that "Due to the phenomena of propagation effects, consequences resulting from a design–decision commitment can affect multiple life-phases, which make it difficult for designers to be aware of them all." Design-decision commitments can have significant consequences during the product use-phase, where the designer has no more control over the product. Moreover, adverse product outcome will result from unintended and problematic consequences, which have a direct effect on the product's success. As explained by Borg and Yan (1998), unintended consequences are those consequences that the designer is not aware of when committing to design decision. This research focuses on the consequences arising from decisions concerning the choice of motorcycle parameters in the human factors domain. From the presented phenomena model (Figure 5), consequences will result from the interaction between a specific synthesis commitment and rider's human factors characteristics during product use-phase. Different consequences will arise given different riders characteristics for the same motorcycle attributes. These consequences will untimely affect the level of rider's product-attachment and rider's safety.

A case scenario of unintended problematic consequence arises when a designer commits to a motorcycle parameter which does not elicit positive emotions to riders. As an example, consider a designer which committed to a black motorcycle (motorcycle parameter), intended for a particular rider (*rider profile 'Y'*). During the manufacturing-phase, this parameter results in an attribute. This attribute will interact with different riders' characteristics (*rider profile 'X'*) during product use, giving rise to a consequence. The interaction between the black motorcycle and the general riders which elicit positive emotions to red motorcycles gives rise to a low level of product attachment.

4.2.2 The design stage decision commitment phenomenon

Extending the explanation of Borg et al. (1999) on the *phenomena of propagation effects*, decision commitments can also affect multiple design stages. It follows explicitly from designers' reality observations through theme T3 that decisions which seem good for one stage may lead to problems in another. Indirectly, themes T4 and T5 also support this statement. These observations clearly show that aspects, are influenced by design life-cycle issues, and should be guided by the relevant design LCC knowledge.

During motorcycle design, a designer commits to a particular human factor aspect, considered at an *early* design stage. From the presented phenomena model (Figure 5), consequences will result from the interaction between an aspect committed at an *early* design stage and another aspect considered at a *later* design stage. A case in point of the latter interaction is the one observed through theme T3, that is, ergonomic aspect restrains the whole motorcycle design if considered in the *early* stage. As designers have stated, important and critical aspects are considered in the *early* design stage. Therefore, a biased motorcycle design consequence will arise as a particular aspect is given priority over others considered at a *later* stage. These consequences will untimely affect the level of rider's product-attachment and rider's safety.

A case scenario arises when during motorcycle design a particular designer commits to only aesthetics in the conceptual design stage. The designer sketches the motorcycle, intending it to be as aesthetically pleasing as possible. Once the conceptual sketch has been approved in the evaluation activity, the designer moves to the next design stage (i.e., embodiment stage). Here, the committed aesthetic aspect will interact with the ergonomic aspect, as the latter is considered in the embodiment design stage. This gives rise to a problematic unintended design consequence, reflecting a conflict between the two aspects. In this case, the designed motorcycle will not be ergonomically oriented which on the other hand will influence the level of safety once the motorcycle is in its use-phase.

As seen in this section, the two phenomena concerned in this research are that motorcycle design decisions generate unintended consequences arising from interactions between the product and riders (during product life-phase), as well as interactions within design stages (during product design-phase). As illustrated in Figure 5, these two interactions will in turn have an effect on each other, giving rise to further consequences. These consequences will untimely affect the level of riders' product attachment and riders' safety.

5 Validation of the developed phenomena model

5.1 The Honda Super Cub case study – rider's profile decision commitment

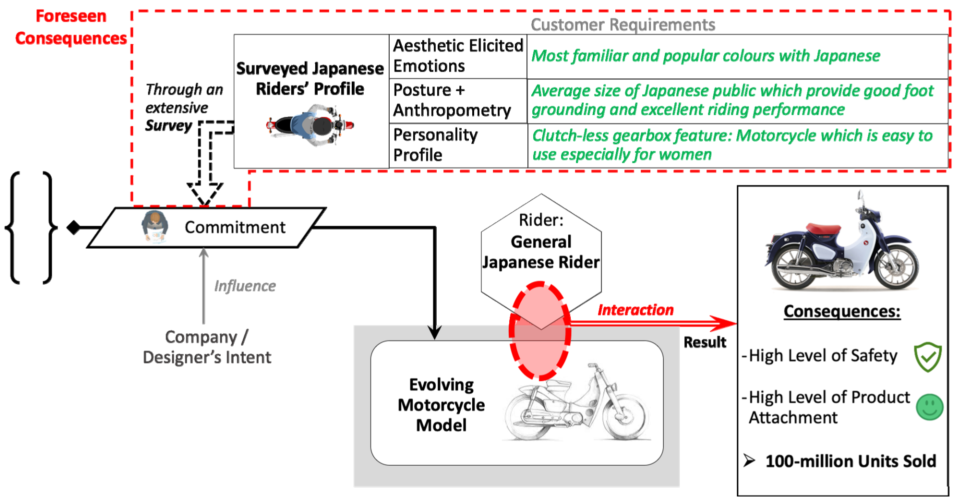
In an interview (Honda, 2018), Jozebo Kimura, an industrial designer who was part of the Super Cub design team (led by Honda and Fujisawa), explained how this motorcycle was conceived. In accordance with the developed phenomena model (Figure 5), the standard design practice is to carry out customer analysis. Amongst other factors in this analysis, intended riders are identified and the motorcycle would be developed according to their needs. However, the phenomena model highlights that this approach often leads to unintended problematic consequences during product use-phase. Consequences will arise when different riders' characteristics (other than the intended riders) interact with the developed motorcycle. This manifest itself in a low level of product attachment or low level of safety.

From the interview, Kimura noted how Honda and Fujisawa gave special attention to this problematic consequence, which is schematically demonstrated in Figure 6. Kimura stated that in that time Fujisawa conducted extensive local and overseas customer requirement analysis, capturing the general requirement of a larger population: "The new motorcycle would be neither a moped nor scooter. Instead, it would be something that the people really desired. An entirely new concept in handling ease and styling that would be unique." Besides conducting research on what the general public needed as a motorcycle type, size, their intention of use, and the motorcycle's aesthetics, the design team also enquired about their persona. This can be verified from an interview (Honda, 2019) where Goto (one of the Super Cub development team) stated: "The team wanted answers to numerous questions, one of which was why women did not ride bikes in the city. The development team travelled the country in search of answers … interviewing women and tape recording them." Based on the requirements gathered from the general public, the team agreed to focus their efforts to produce a popular small bike for the masses. "The design brief was to develop a chassis and bodywork of a size and shape that even women could easily get on and off, and ride … with a friendly aesthetics according to the requirements of many. Therefore, the colours which were the most familiar and popular with most Japanese were chosen … as the Super Cub was designed to be a vehicle for the masses, the design team wanted to use familiar colours" stated Kimura in his interview. Kimura added that "although in those times many mopeds' tyres in Europe were between 610 and 660 mm, the Honda design team took out a survey to determine the average size of Japanese public. Then they extracted the most appropriate size that could ensure easy mounting and dismounting, and which provide good foot grounding and excellent riding performance. The calculated tyre size was found to be 530 mm."

One of the top requirements of the general public was to have a motorcycle which is easy to use, to concentrate better on the road. As such, the Honda design team invented the clutch-less gearbox to meet the general public's requirements. The Super Cub's semi-automatic four-speed transmission is great for learners, and enjoyable for experienced riders. In regions outside of Japan, such as Asia, Europe and the USA, the Honda Super Cub series has evolved to accommodate the unique culture and diversifying customer needs, building products close to the general public for each country.

The above statements provide a degree of evidence that made the Honda Super Cub a successful motorcycle design. By foreseeing the unintended consequences, that is, by surveying the general public instead of the intended riders Honda managed to develop a motorcycle which in 60 years managed to sell 100-million units.

Figure 6 Phenomenon model for the Honda Super Cub case study (see online version for colours)

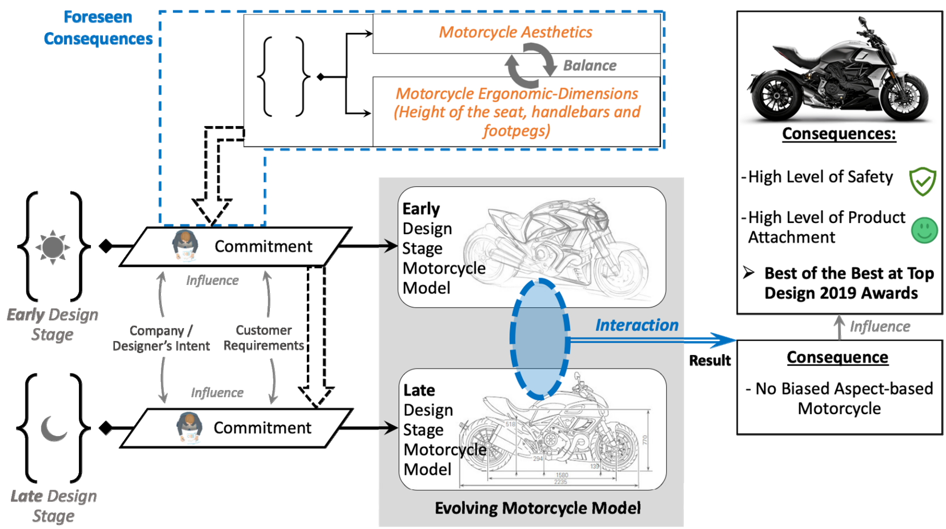


5.2 *The Ducati Diavel case study – design stage decision commitment*

An interview to Andrea Ferraresi, the design director of Ducati, was conducted by Digital Trends (2019) to understand how the Ducati Diavel went from a sketch to a production model. According to Ducati's design director the design-phase of the Diavel is similar to the standard product design process with minor but significant divergence. Ferraresi stated that "like with any other project, the design-phase of the Diavel started by incorporating market analysis, competitor analysis and customer analysis data." This is in accordance with Figure 5 and implies that designers made design decisions based on the influence of specific customer's requirement, and market trends on ergonomics and emotions. The design brief was then transferred to the design department, where a sketch was used to conceptualise the ideas for the Diavel.

According to the phenomena model many designers focus on a certain aspect in the early (conceptual) design stage. Ultimately, this yield in unintended consequences during the use-phase of the product. Riders may not purchase the motorcycle because although it is aesthetically pleasing for them, it may be uncomfortable. Or although it is comfortable riders do not feel emotionally attracted to the motorcycle. In the case of the Diavel, the design team diverged from the standard design process. This is schematically demonstrated in Figure 7. As claimed by Ferraresi, after finalising the conceptual sketch of the Diavel and before going to the embodiment stage, the design team have set the height of the seat, handlebars and footpegs, amongst other parameters. This added procedure modified the original sketch from an aesthetics point of view. The process of altering the sketch for aesthetic and ergonomic reasons was iterated until the design team was satisfied with the results. That is, achieving a compromise between ergonomics and aesthetics. The elimination of the problematic interaction between the early and late design stage models of the Diavel indicated that design stage unintended consequences were addressed, making the Diavel a successful motorcycle. Confirmation of the balance that the Diavel's design team managed to achieve, through their design decisions, are in the riders comments: "The Diavel is so comfortable that it is like a touring bike, but with a greater style and attitude unlike any motorcycle I have ever seen", "The Ducati Diavel has a sitting position and ergonomics that are really comfortable, I drove for three hours without stopping. But the driving factor for purchasing this motorcycle were its striking aesthetics."

Figure 7 Phenomenon model for the Ducati Diavel case study (see online version for colours)



The above statements provide a degree of evidence that made the Ducati Diavel a successful motorcycle design. By foreseeing the unintended consequences, that is, by considering both the aesthetics and ergonomics in the early design stages, and by finding the right balance between the two aspects, Ducati managed to develop a motorcycle which has won 'Best of the Best at Top Design 2019 Awards'.

6 Discussion and conclusions

The main objective set out in this paper was to present and explain the underlying phenomena by modelling how consequences are generated from motorcycle design decisions. This was directly derived from actual motorcycle designers in the field, portraying deficiencies in the current motorcycle design process from human factors perspective. This was further substantiated by the literature in the field of motorcycle design. These two resources assisted to the contribution of this paper, a validated motorcycle design phenomena model which explains the consequences of decisions made during the synthesis activity of motorcycle designs. It was observed that problematic unintended consequences affect directly the design and product use-phase from human factors perspective. Moreover, a critical literature review revealed that there is no decision consequence model which takes a holistic view of the underlying phenomena during design decision-making of motorcycle designers.

The field of motorcycle design is very specific. Besides challenges faced to find participants with relevant background and expertise, only 18% of the contacted designers were willing to contribute in this study. The small sample posed a limitation to the study from a quantitative perspective. This limitation was addressed by validating the phenomena model. Two case studies of real motorcycle designs, which made success in the motorcycle industry, were employed to validate the developed motorcycle design phenomena model. Validating with case studies was essential for the contribution of a robust scientific model to the design engineering research.

The arguments presented in this paper together with the phenomena model emphasise the need to support motorcycle designers during the synthesis decision-making activity, by making them aware of the unintended consequences in motorcycle design. As such, in future work, the phenomena model will be the foundation upon which a detailed information model, forming a knowledge structure, and organised in such a way to form a framework, will be developed. The framework will proactively support motorcycle designers to develop rider-centred, safer motorcycle designs, while at the same time enhancing the emotional value of such artefacts from human factors perspective. The framework will in turn be translated into a motorcycle design computational tool, subjected to an industrial evaluation, with the use of numerous case studies and industrial data, to further prove the validity of the proposed arguments.

Acknowledgements

This work was supported by the Malta Council for Science and Technology (MCST), through the FUSION Technology Development Programme (R&I-2017-003-T).

The authors would like to thank the interviewed motorcycle designers, for participating in this study, sharing their experiences and current motorcycle design practices.

References

Bajpai, S., Bajpai, R. and Chaturvedi, H.K. (2015) 'Evaluation of inter-rater agreement and inter-rater reliability for observational data: an overview of concepts and methods', *Journal of the Indian Academy of Applied Psychology*, Vol. 41, No. 3, pp.20–27.

Barone, S. and Curcio, A. (2004) 'A computer-aided design-based system for posture analyses of motorcycles', *Journal of Engineering Design*, Vol. 15, No. 6, pp.581–595, DOI: 10.1080/09544820410001731146.

Barth, A., Caillaud, E. and Rose, B. (2011) 'How to validate research in engineering design?', *ICED 11 – 18th International Conference on Engineering Design – Impacting Society Through Engineering Design*, August, Vol. 2, pp.41–50.

Borg, J.C. (1999) *Design Synthesis for Multi-X – A 'Life-cycle Consequence Knowledge' Approach*, PhD dissertation, Department of Design, Manufacture and Engineering Management, University of Strathclyde, Glasgow.

Borg, J.C. and Yan, X.T. (1998) 'Design decision consequences: key to support for "design for multi-X"', in *Proceedings of the 2nd International Symposium on 'Tools & Methods for Concurrent Engineering*', pp.6169–6184.

Borg, J.C., Yan, X.T. and Juster, N.P. (1999) 'Guiding component form design using decision consequence knowledge support', *Artificial Intelligence for Engineering Design, Analysis and Manufacturing: AIEDAM*, Vol. 13, No. 5, pp.387–403, DOI: 10.1017/S0890060499135030.

Cocco, G. (2013) *Motorcycle Design and Technology: How and Why*, Nada, G. (Ed.), 2nd ed., Vimodrone, Italy.

Creswell, J.W. (2007) 'Qualitative inquiry and research design: choosing among five approaches', *Western Journal of Nursing Research*, 2nd ed., SAGE Publications, London.

Cycle World (2018) 'The Honda Super Cub, the best-selling motorcycle of all time, gets a modern makeover' [online] https://www.cycleworld.com/honda-super-cub-is-updated-for-2018-and-cuter-than-ever/ (accessed 15 October 2020).

Cycle World (2019) 'Ten best motorcycles' [online] https://www.cycleworld.com/ten-best-motorcycles-2019/ (accessed 15 October 2020).

Digital Trends (2019) *How VR, 3D Modeling, and Craftsmanship Help Ducati Design Alluring Motorcycles* [online] https://www.digitaltrends.com/cars/how-a-ducati-motorcycle-goes-from-a-sketch-to-production/ (accessed 15 October 2020).

Duffy, A.H.B. and O'Donnell, F.J. (1999) 'A design research approach', in *AID'98 Workshop on Research Methods in AI in Design*, Lisbon, Portugal, pp.20–27, DOI: 82-91917-08-6.

Farrugia, L. and Borg, J. (2016) 'Design for X' based on foreseeing emotional impact of meetings with evolving products', *Journal of Integrated Design and Process Science*, Vol. 20, No. 2, pp.85–100, DOI: 10.3233/jid-2016-0017.

Farrugia, P., Mamo, J. and Sant, T. (2019) 'An intelligent computer-based framework for integrating emotions and aerodynamics in sportsbike design', *International Journal of Design Engineering*, Vol. 9, No. 1, pp.1–21, doi: 10.1504/IJDE.2019.104122..

Federation of European Motorcyclists Associations (2009) *A European Agenda for Motorcycle Safety*.

Francalanza, E., Borg, J. and Constantinescu, C. (2017) 'A knowledge-based tool for designing cyber physical production systems', *Journal of Computers in Industry*, Vol. 84, pp.39–58, Elsevier BV, DOI: 10.1016/j.compind.2016.08.001.

Gear Petrol (2013) 'The 51 most iconic motorcycles of all time' [online] https://www.gearpatrol.com/cars/motorcycles/a80431/50-most-iconic-motorcycles/ (accessed 15 October 2020).

Gear Petrol (2019) 'Ducati just won one of the most prestigious design awards' [online] https://www.gearpatrol.com/cars/motorcycles/a564468/ducati-won-most-prestigious-design-award/ (accessed 15 October 2020).

Groeger, J. (2000) *Understanding Driving: Applying Cognitive Psychology to a Complex Everyday Task*, Psychology Press, Philadelphia.

Hancock, P., Oron-Gilad, T. and Thom, D. (2006) 'Human factors issues in motorcycle collisions', in Karwowski, W. and Noy, I. (Eds.): *Haandbook of Human Factors in Litigation*, pp.512–536, CRC Press, Boca Raton, FL.

Hancock, P.A. (1995) *Motorcycles in Intelligent Transport Systems*, Technical Report for the Motorcycle Safety Foundation. Irvine, CA.

Hancock, P.A., Pepe, A.A. and Murphy, L.L. (2005) 'Hedonomics: the power of positive and pleasurable ergonomics', *Ergonomics in Design*, Vol. 13, No. 1, pp.8–14, DOI: 10.1177/106480460501300104.

HiConsumption (2018) *10 Best Cruiser Motorcycles* [online] https://hiconsumption.com/best-cruiser-motrcycles/ (accessed 15 October 2020).

HiConsumption (2019) 'The 30 greatest motorcycles of all time' [online] https://hiconsumption.com/best-motorcycles-of-all-time/ (accessed 15 October 2020).

Honda (2018) *How was the Super Cub Born?* [online] https://global.honda/products/motorcycles/supercub-anniv/story/vol1.html (accessed 15 October 2020).

Honda (2019) *Market Research – Tape Recorder in Hand* [online] https://global.honda/heritage/episodes/1976roadpal.html (accessed 15 October 2020).

Kaljun, J. et al. (2012) 'Aesthetics as parameter of intelligent design support', in *Proceedings of International Design Conference, DESIGN*, pp.1293–1300.

Lee, J.D. et al. (2017) *Designing for People: An Introduction to Human Factors Engineering*, 3rd ed., CreateSpace, Charleston, SC.

Mamo, J. (2018) *A Computer-based Support System for Integrating Emotions and Aerodynamics in Sportsbike Design*, University of Malta.

Marek, T. and Pokorski, J. (2004) 'Mechanisms of visual attention and driver error', *International Journal of Ergonomics and Human Factors*, Vol. 26, No. 3, pp.201–208.

Norman, D. (2013) *The Design of Everyday Things: Revised and Expanded Edition*, Basic Books Publisher, New York.

Olsen, J. (1992) *Concurrent Development in Manufacturing-based on Dispositional Mechanisms*, Lyngby.

Ride Apart (2019) 'The 2019 Diavel just won best of the best at top design awards' [online] https://www.rideapart.com/articles/315679/2019-diavel-wins-at-design-awards/ (accessed 15 October 2020).

Ride Apart (2020) 'The 5 best cruisers on the market' [online] https://www.rideapart.com/articles/397511/the-5-best-cruisers-motorcycles/ (accessed 15 October 2020).

Rider Magazine (2016) '25 best motorcycles of the past 25 years' [online] https://ridermagazine.com/2016/10/25/25-best-motorcycles-of-the-past-25-years/ (accessed 15 October 2020).

Road Safety Research (2017) *Common Motorcycle Crash Causes*, Road Safety Research Institute, Birmingham, UK.

Roozenburg, N.F.M. and Eekels, J. (1991) *Product Design: Fundamentals and Methods*, John Wiley & Sons Ltd., Chichester, England.

Stedmon, A.W. et al. (2012) 'MotorcycleSim: a user-centred approach in developing a simulator for motorcycle ergonomics and rider human factors research', *Advances in Transportation Studies*, No. 27, pp.31–48, DOI: 10.4399/97888548486723.

World Health Organization (WHO) (2018) *Global Status Report on Road Safety 2018*.

Appendix 1

Data handling and analysis

Difficulties are likely to develop if one chooses exclusively a quantitative approach in a small sample study. On the other hand, using a qualitative approach on its own present challenges in quantifying the observations made. Due to such limitations in qualitative and quantitative methods, a mixed method approach, which combines the two, was used to disclose the phenomena pertaining to this study. Mixed methodology takes a more pragmatic and realistic view of data, as it can simultaneously address a range of exploratory questions, providing a strong approach to tackle small sample size research. The result is a robust triangulation method composed of the mixed method and the concurrent use of the literature review to validate the obtained study results. The qualitative analysis will furthermore describe what all designers (participants) have in common, universal essence.

Quantitative questions were ordinal ones, composed of a rating from 0 to 3 (0 = no priority, 1 = low priority, 2 = priority, 3 = high priority/importance). With a small sample, it is more difficult to get statistical significance as variance tends to get magnified in small samples and numerous categories. The above ordinal categories were reduced and grouped into two nominal categories, 0 and 1 were set to 'no priority/importance' while 2 and 3 represented 'priority/importance given'. To analyse if there is a significant difference between the nominal categories, the one-tailed exact probability test method and test for one proportion method were used.

Relevant phrases, sentences and sections were coded from the qualitative transcripts. Codes which were relevant with each other were sorted and grouped into categories. Themes were identified from patterned codes essence and connected together to form core themes. IRR was used in this study to assess the replicability and consistency of the qualitative analysis. The percent agreement test was used to measure the agreement of two independent researchers while coding. This was done by calculating the number of concordant coding divided by the total number of generated codes. The measure can vary between 0% (no agreement) and 100% (full agreement). Values from 75% to 90% demonstrate an acceptable level of agreement while values above 90% suggest a higher agreement. The Cohen's kappa index was then used to assess the IRR for the thematic categorisation. The following criteria were used to interpret the kappa coefficient: < 0.2 = poor agreement, 0.2–0.4 = fair agreement, 0.4–0.6 = moderate agreement, 0.6–0.8 = good agreement and 0.8–1.0 = very good agreement. The percent agreement for this study was 97%, while kappa's index was 0.78. These values suggest a good agreement between the two raters and thus, a good qualitative reliability.

Appendix 2

Semi-structured interview questionnaire structure

Questions on ergonomics in design

Q1 From 0 to 3, 0 means low priority and 3 means high priority, to what extent does your company give priority to motorcycle ergonomics? Please expand on your arguments.

Q2 If the answer to Q1 is 2 or 3, how ergonomics are taken into consideration during motorcycle design, and in what design phase? Please expand on your arguments.

Q3 From 0 to 3, 0 means never used and 3 means highly used, to what extent does your company use anthropometric data during motorcycle design? Please expand on your arguments.

Q4 If the answer to Q3 is 2 or 3, how anthropometric data is taken into consideration during motorcycle design, and in what design phase? Please expand on your arguments.

Questions on aesthetics and emotions in design

Q5 From 0 to 3, 0 means low priority and 3 means high priority, to what extent does your company give priority to motorcycle aesthetics? Please expand on your arguments.

Q6 If the answer to Q5 is 2 or 3, how motorcycle aesthetics are taken into consideration during the design, and in what phase? Please expand on your arguments.

Q7 From 0 to 3, 0 means low priority and 3 means high priority, to what extent does your company give priority to riders' elicited emotions to different motorcycle styles and shapes? Please expand on your arguments.

Q8 If the answer to Q7 is 2 or 3, how riders' elicited emotions are taken into consideration during the design, and in what phase? Please expand on your arguments.

Questions on persona in design

Q9 From 0 to 3, 0 means low priority and 3 means high priority, to what extent does your company give priority to riders' road experiences? Please expand on your arguments.

Q10 If the answer to Q9 is 2 or 3, how riders' road experiences are taken into consideration during motorcycle design, and in what design phase? Please expand on your arguments.

Q11 From 0 to 3, 0 means low priority and 3 means high priority, to what extent does your company give priority to riders' personas in relation to the chosen type of motorcycle? Please expand on your arguments.

Q12 If the answer to Q11 is 2 or 3, how riders' personality types are taken into consideration during motorcycle design, and in what design phase? Please expand on your arguments.

Importance to consider human factors in design

Q13 From 0 to 3, 0 means not important and 3 means very important, rate how much it is important to consider ergonomic factors whist designing motorcycles.

Q14 From 0 to 3, 0 means not important and 3 means very important, rate how much it is important to acquire real customer postural data and ergonomic feedback.

Q15 From 0 to 3, 0 means not important and 3 means very important, rate how much it is important to consider riders' elicited emotions to different motorcycle styles and shapes while designing motorcycles.

Q16 From 0 to 3, 0 means not important and 3 means very important, rate how much it is important to consider riders' personas and their motorcycle experiences while designing motorcycles.

General suggestions

Q17 Do you have any concerns or challenges which hinder you in the design process from human factors perspective?

Q18 Do you have any requirements to assist you during motorcycle design when considering ergonomics, emotions and persona which can eventually improve the motorcycle design? Please expand on your arguments.

Q19 What is required to reach as many as customers as possible? Please expand on your arguments.

Appendix 3

Quantitative analysis

Table A1 illustrates the descriptive statistics for each investigation/question carried out. The mean and standard deviation were found from the score, 0 to 3 (explained in Section 3). Green highlighting cells indicate that there is a statistical significance. The red highlighted cells indicate that the mean is lower than 1.5, showing an adverse effect of the investigation.

Table A1 Descriptive statistics of current practises and designers' experiences during design (see online version for colours)

Investigation		*Mean*
Q1	Priority to ergonomics given by designers' company	1.75
Q3	Use of anthropometric data given by designers' company	1.25
Q13	Importance to consider ergonomic factors whilst designing	2.75
Q14	Importance to acquire real customer postural data and ergonomic feedback	2.75
Q5	Priority to aesthetics given by designers' company	3.00
Q7	Priority to riders' elicited emotions given by designers' company	2.63
Q15	Importance to consider riders' elicited Emotions whilst designing	2.88
Q9	Priority to riders' road experience given by designers' company	1.25
Q11	Priority to riders' personas given by designers' company	1.13
Q16	Importance to consider riders' road experience and personas whilst designing	2.00