ETHICS AND STRATEGY IN DECISION-BASED DESIGN FRAMEWORKS: PROBLEMS AND SOLUTIONS

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ABSTRACT

Engineering Design decisions impact customers, the environment and society at large in ways that have profound ethical and strategic implications for designers. Previous research in decision-based design has proposed the decisions should be made on the basis of maximizing the expected utility of the design to the designer. This paper discusses ethical and strategic challenges for these frameworks across five levels: the axioms that underlie utility, the definition of utility, the consideration of multiple stakeholders, the modeling scope, and resulting design framework implementation. Based on these problems, solutions are suggested to account for each in the development of improved, ethically-informed frameworks. Challenges presented here do not prohibit the prudent use of decision-based design frameworks per se, but instead point to cases that must addressed in practice while providing grounds for further research towards the development of decision-based design frameworks that are ethical by design.

Keywords: Decision making, Ethics, Design theory

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1 INTRODUCTION

Engineering design impacts economic development and progress, public safety, global conflicts, and environmental sustainability. Often, design decisions have high stakes, up to that of lives lost. For example, the decision of safety risk for various events deemed "acceptable" presents a clear, profound, and difficult trade-off between the economic and practical usefulness of a system and the potential for disaster, but nevertheless a decision must be made. As Goebel *et al.* (2019) note in the field of prognostics and health management, the increasing automation of previously human tasks is pushing the purview of ethical decision-making from management to engineering. Considering the profound impact of engineering decisions and the increasing bearing of ethics on engineering decision-making, it is important that prescribed decision-making processes are not only based on sound axioms and evidence, but consistent with fundamental human values.

Decision-based design (DBD) has been proposed in the design literature as a normative approach to engineering decision-making (Hazelrigg, 1998). Such approaches, as presented by Lewis *et al.* (2006), as well as the value-driven design approaches of Collopy and Hollingsworth (2011) are constructed on the principle of maximizing the expected utility of the design to the producer, following the axioms of Von Neumann and Morgenstern, where utility is most often a function of cost. "Normative" as it is used when referring to decision-making frameworks (and throughout this paper), refers to the way decisions *ought to be made.* This definition takes lineage from the use of the term in economics (Simon, 1959), where normative economics (the prescription of policy measures to meet desired outcomes) is often contrasted with positive economics (the science of objectively characterizing the behavior of the economy (Friedman, 1953)). However, the claim that decision-based design is normative is quite extraordinary, because the concept of normativity is defined not just by the pursuit of self-interest, but by ethics, values, and the interests of society (Amy, 1984).

While some critiques have been presented to decision-based design, it has largely been upheld as a generally valid theory in the design community for good reason–not only are the underlying axioms of decision-based design generally defensible (Thurston, 2001), the approaches present real improvements over previously-adopted decision-making approaches in terms of logical consistency (Hazelrigg, 1996) and validity to design (Olewnik and Lewis, 2008). Previous critiques, however, have not been made from the perspective of design ethics. As decision-based design approaches become recommended as best practice for design, it becomes increasingly important to consider and address the ethical issues apparent in existing approaches so that they can be further developed into generally-applicable ethical frameworks. While some (mostly parenthetical) comments have been given in the context of decision-based design approaches to formulate such decision processes based on organizational and ethical values (see: (Lee and Paredis, 2014), (Soban *et al.*, 2012) and (Wood, 2004)), the concept has not been explored in depth and very little guidance has been given as a result.

1.1 Contribution and approach

The contribution of this work is a constructive critique of decision-based design frameworks from the perspective of ethics which will spur the development of decision-based design theories that are not only axiomatically valid, but consistent with the engineer's ethical role in society. In service of this critique, potential ethical problems are presented across the epistemic scope of decision-based design, from the axioms and definitions of utility (i.e. the theoretical foundation) to the implementation of such frameworks (i.e. the framework as it is used in practice), as illustrated in Figure 1. As the purpose of this paper is to provide a constructive critique, for each problem identified, some attempts at a solution are provided which may be incorporated and validated in future approaches.

The approach taken to form this critique is as follows: Potential issues were identified using an affinity diagram–specific potential problems were first brainstormed and then organized around general assumptions required for decision-based design to be normative. Then, literature was reviewed in engineering design and fields adjacent to decision-based design frameworks, including economics, management/operations research, marketing, and sustainability to find support for any of these themes. Then, for each of these issues found in literature, potential solutions for these issues were brainstormed and reported in this review after a check to see if any similar solutions exist in the literature of the reviewed fields.

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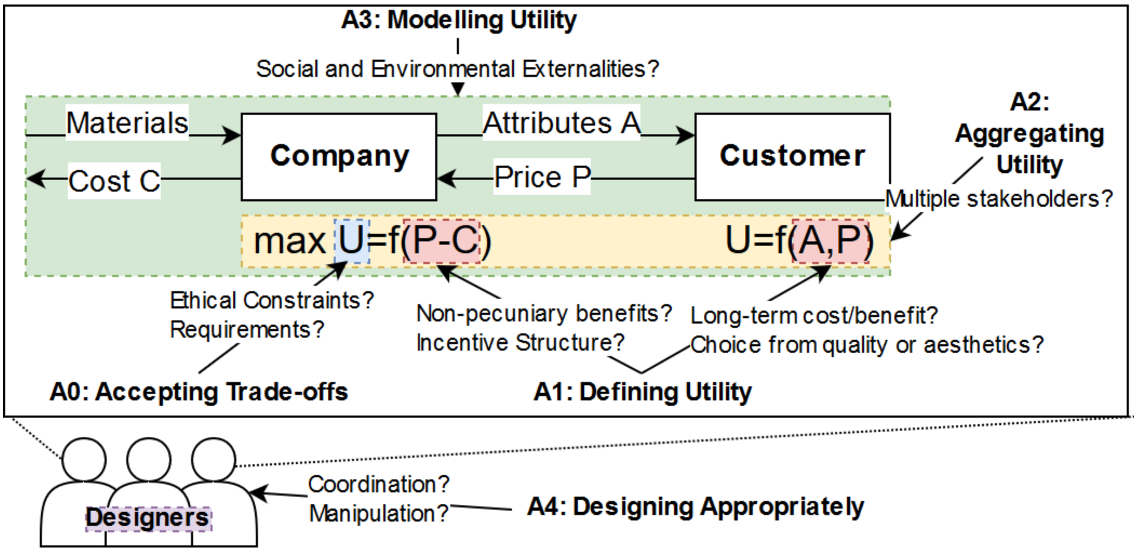

Figure 1. The validity of decision-based design frameworks relies on key assumptions about trade-offs, utility form, the scope of consideration, and designer behavior.

2 PROBLEMS AND SOLUTIONS

To accept decision-based design as a *normative* (rather than merely expedient) approach to engineering decision-making, one must first first accept a series of assumptions, as shown in Figure 1 for a typical framework. In this framework, the company exchanges a product with attributes A to a customer, which chooses between several products with different attributes A and pays a certain price P in exchange for their chosen product. Based on the total demand of a series of customers paying prices for different products, the company then realizes revenue from those transactions, as well as costs C associated with producing those attributes, which in combination give a net profit for the set of attributes of the product. The utility U is then a function of this profit as well as the uncertainty the designer has in achieving it according to their risk preferences.

Five main assumptions are required for accepting the this approach as ethical, which will be expanded on in the next subsections. The foundational assumption (A0 in Figure 1) is that trade-offs may be made ethically in the design as a utility value and that there are no “must have” constraints that the designer simply cannot ethically violate, and is discussed in Section 2.1. The first assumption (A1) is then that the attributes used to define this utility number completely characterize the actual normative preferability of a design, and is discussed in Section 2.2. The second assumption (A2) is that only the company’s utility is worth considering to achieve an ethical design, and is discussed in Section 2.3. The third assumption (A3) is that it is appropriate to only consider and model the transaction between the company and customer, and not interacting social and environmental effects, and is discussed in Section 2.4. The final assumption (A4) is that designers, using this framework, will design appropriately without manipulating decisions to unethical ends, and is discussed in Section 2.5.

2.1 Assumption 0: The appropriateness of accepting trade-offs

In decision-based design frameworks, using expected utility as the sole design metric allows designers to make trade-offs between competing and uncertain objectives in the design (Hazelrigg, 1998) (Collopy and Hollingsworth, 2011). However, for the use of this metric to be truly normative, the metric must negotiate these trade-offs in a way that is not only expedient, but ethical as well. In many design cases, however, ethical trade-offs simply cannot be made due to legal requirement. Additionally, some ethical frameworks do not allow the consideration of tradeoffs, because they do not encode values as objectives, but as rules that must be followed, as outlined in Table 1. Furthermore, there are many design cases in which, because of legal and contractual considerations between the designer and the buyer, the designer cannot make trade-offs that would violate that agreement. The general solution to these problems is to incorporate these considerations as constraints and only explore design options the designer has a right to explore, however these problems cannot be fixed easily if one does not accept utilitarianism for the purpose of design.

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Table 1. Examining the appropriateness of accepting trade-offs in design.

Issue	Basis in Literature	Potential Solution
Ethical Frameworks	Multi-criteria decision analysis is incompatible with non-utilitarian ethical frameworks (Wenstøp, 2005).	Accept utilitarianism for the purpose of design. Incorporate deontological obligations as constraints, despite problems identified by (Le Menestrel, 2005).
Legal Considerations	Engineering design is often constrained by contracts that dictate requirements (Schwartz, 2010).	Revise contracts to allow for value optimization. Incorporate requirements as constraints.
	Engineering design is constrained by regulation that reflects the public's will (see: (Newman, 2004) for an example).	Incorporate regulation as a constraint.

2.2 Assumption 1: defining utility

Key to maximizing the expected utility of a design is first modelling the utility as a function of desirable attributes or objectives. In typical approaches, utility is a function of the benefit of the product to the producer (Hazelrigg, 1998), which can be determined by modeling the cost of production and the revenue generated by the customer's probability of choice resulting from their hidden utility for the product (Wassenaar and Chen, 2003). However, to accept that this process is good for the customer, one must first accept that the choice the customer makes is directly correlated to their welfare. Recent developments in behavioral economics and marketing literature have challenged this notion, as shown in Table 2. Additionally, the direct profit of a design is not always the sole metric that a design organization must consider, since incentive structures vary for different organizations and there may be good reasons to invest in non-choice determining variables for long-run returns. The prospective approach to account for these issues is to additionally consider the costs and benefits of the product to customers outside of the benefit the producer experiences from their direct choice. Considering the consumer's appreciation of quality over time (Pahl and Beitz, 2007, Sec. 5.3), this consideration may even pay off in the long run as the customer gains an affinity for the product and brand. Finally, an organization's utility function may need to be extended from profit to align with the organizational goals and incentive structure if it does not operate purely as a profit-maximizing company. However, much further work will need to be done in this area to enable this, since current frameworks rely heavily on direct profit from an immediate transaction.

2.3 Assumption 2: aggregating utility

Decision-based design frameworks aim to maximize the utility of the design to the producer Hazelrigg (1998) as a means of avoiding perceived social choice problems (Hazelrigg, 1996). However, framing design as merely an optimization of producer utility presents a number of moral hazards in the design process, as shown in Table 3. If the incentives of the design organization represented by the utility metric are not properly aligned with stakeholder interests (that is–if it will not receive meaningful punishment or reward as a result of its design work), merely considering the organization's utility could cause it to design features that are of undesirable quality. While market mechanisms often allow for producer and stakeholder interests to be aligned, design does not always take place in a market scenario, and the market does not always function well. For a true, general claim of normativity, therefore, some consideration of the utility created by the design to all stakeholders must take place, even if doing so results in challenges due to aggregation. Creating design frameworks to approach these problems will likely require further adaptation of new innovations in social choice literature as well adapting ethical frameworks about justice and fairness.

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Table 2. Examining the appropriateness of considering profit and/or choice as a the sole metric of utility.

Issue	Basis in Literature	Potential Solution
Utility as Choice	Consumers are not rational agents whose preferences reflect their actual well-being. Consumers can choose products that actually harm them in the long-run (Thaler, 1980) (Gruber, J. and Köszegi, B., 2001).	Consider the explicit lifecycle cost/benefit of the product to the customer in overall assessment of utility. Examine inconsistencies between the customer's stated and revealed preferences to determine if the choice is rational or compulsive (Noor, J., 2011).
	Consumer choice is subject to manipulation based on the framing of the product (Tversky and Kahneman, 1981).	"Nudge" consumers to ethical choices that are in their own interest (Thaler and Sunstein, 2008).
	Customer judgements are aesthetic and based on signifiers, rather than true engineering variables (Nelissen and Meijers, 2011) (Dawar and Parker, 1994).	Ensure the design delivers on the value proposition implied by the signals given to the customer.
Considered Attributes	Organizations do not always maximize profit, and may have varying non-pecuniary benefits (Furubotn, 1985) (Feinberg, 1975) and incentive structures (James, 1983) depending on the type.	Define utility differently from profit, when required to express organizational goals and values.
Timescale	Customer choices change over long timescales based on customer's assessment of brand quality (Dawar and Parker, 1994) (Doyle, 1989).	Consider quality as a long-term investment and model its long-term effects on choice (Sheth and Sisodia, 2002) and customer well-being.

Table 3. Examining the appropriateness of considering the producer to be the sole stakeholder in design.

Issue	Basis in Literature	Potential Solution
Stakeholder Scope	Moral hazards exist when considering the designer or design organization to be the sole stakeholder because the designer (see: (Toh *et al.*, 2015)) or design organization (see: (Bresnahan, 1999) (Anton and Yao, 1995)) will be prone to manipulate the competitive environment for its own benefit at the expense of other stakeholders.	Consider and aggregate the utility of multiple stakeholders in design (such as (Zhuang and Mousapour, 2017)). Draw from social choice innovations, such as the utilitarian voting (Hillinger, 2005) and majority judgment (Balinsky and Laraki, 2011) which are not subject to Arrow's Impossibility Theorem.
Allocation and Equity	Severe competing interests can exist in the design process, making it difficult to prioritize one stakeholder over another, such as considering the safety of passengers versus pedestrians (Awad *et al.*, 2018).	Draw from philosophical theories of justice, such as the "veil of ignorance" principle proposed by Rawls (1971) to trade off between competing interests.

2.4 Assumption 3: modeling utility

Modelling assumptions about the environment can play a significant role in the ethical consideration of decision-based design frameworks. From the point of view of sustainable design, this is because of

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the effects of the engineered system in three interacting environments: the environmental, social, and economic system (Rosen and Kishawy, 2012) (Howarth and Hadfield, 2006), as illustrated in Figure 2. As discussed in Table 4 from this perspective, a broader consideration of utility (one based on overall well-being), would require the larger system to be considered in the design of the product to account for externalities–effects of the product not accounted for in the the market price–which realize themselves in the environment and social system. Additionally, considering the utility from the perspective of fairness requires a consideration of the proportion of utility gained by each stakeholder as well as the power dynamics between them. This becomes important, for example, in a monopoly market situation between customers and producers in which the producer has the power to set both price and product attributes without the customer having a meaningful choice.

The general approach identified here to solve these problems is to change the incentives to directly represent the overall cost or benefit of a given design, such as by quantifying and incorporating the cost or benefit of the external effect or by designing as if there was competition when there is none in reality. However, because of complexities in these environments, without a good model it may be difficult to achieve desired effects, and there may be unintended consequences, as identified by Walsh *et al.* (2019). Approaching the problem of environmental complexity may, as a result, require the use of systems thinking or systems modelling approaches, as proposed in early decision-based design frameworks to help comprehend complexity in the engineering process (Mistree, 1990) .

Table 4. Examining issues with developing models of utility based on direct cost.

Issue	**Basis in Literature**	**Potential Solution**
Market Function	Examples exist (Gilbert and Newbery, 1982) (Leitzel, 1992) in which the engineering market environment is not competitive and as a result does not give customers meaningful choices, making profit-maximization economically inefficient (Taylor *et al.*, 2014, Chapter 9-10).	Make decisions as if the market situation was competitive by presenting alternative choices to sampled customers.
Environmental Externalities	Environmental effects of products, such as pollution and resource use often do not factor into the direct cost of the product, but nonetheless create real harms (Taylor *et al.*, 2014, Chapter 12).	Make decisions based on broad economic and environmental effects over the lifecycle of the product by quantifying the costs of environmental effects (see: (Kobayashi, 2005) and (Bradley *et al.*, 2018)).
	The environmental effects of products are often complex and counter-intuitive when viewed solely from the perspective of efficiency (Alcott, 2005) (Meadows, 1999).	Model environmental effects using appropriate system modelling approaches, such as system dynamics approaches (as in (Meadows *et al.*, 1972)) or probabilistic graph modelling Telenko (2012).
Social Externalities	Products often have social and political effects, such to power dynamics between warring nations (Killmister, 2008) and the rise of new political movements (Shirky, 2011).	Use systems thinking approaches (as in (Watz and Hallstedt, 2018)) or strategic game models to identify the external social effects to various actors.

2.5 Assumption 4: designing appropriately

The final problem for decision-based design is the implementation and execution of the framework in practice. Even if the theory and inputs of a design framework are correct, there is still room for error in the way people use the frameworks in practice. Some literature has explored these issues using computational models (see: (Collopy and Poleacovschi, 2012) (Bhatia *et al.*, 2016)) because they are of direct relevance to the actual effectiveness of decision-based design frameworks in practice. However, present issues are shown in Table 5. To summarize, effective design is contingent on coordinating designers

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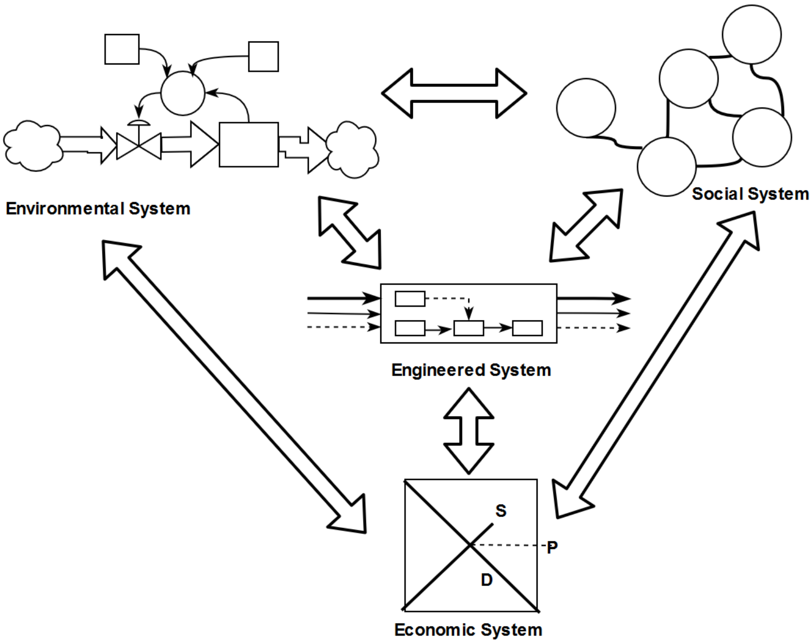

Figure 2. Three important modelling aspects of the product environment used in sustainable design: the economic, social, and environmental systems.

effectively (illustrated in Figure 3) and preventing manipulation of the decision-making process by bad actors. Generally, approaches exist to approach these issues in the decision-based design and systems engineering literature by coordinating incentives and increasing verification in the design process.

Table 5. Examining ethical issues with implementing a value-driven design approach in practice.

Issue	**Basis in Literature**	**Potential Solution**
Design Coordination	Decomposing design to individual designers can cause sub-optimization behaviors in value-driven frameworks even when incentives are aligned (Kannan, 2015) (Hulse *et al*., 2018), as illustrated in Figure 3.	Enable coordination, either between designers or using Multidisciplinary Design Optimization in a computational environment (Kannan, 2015).
Manipulation	A lack of verifyability in decision-making can lead to moral hazards (Hölmstrom, 1979) which has ethical implications in that the modeller can "push" predetermined decisions into the model (Baker, 2017).	Develop and adapt practices from Systems Engineering (e.g. (Ramesh, 1998)) to make decisions tractable, traceable from attributes, and having a clear justification that acknowledges any subjectivity.

3 CONCLUSIONS AND IMPLICATIONS FOR FURTHER RESEARCH

This paper presents ethical problems within decision-based design that must be addressed in order for the set of approaches to be considered normative. While many problems were discussed, it should be noted that these problems do not necessarily prohibit the ethical and prudent use of such frameworks as they are implemented today. Indeed, considering and addressing each problem presented here would not be practical for designers, who must ultimately be able to make decisions with clarity, and are not served by engaging in paralyzing analysis which ultimately will lead to no "right answers." Instead, it points to ethical cases that must be made to support and constrain decision-based design, as well as extensions and elaborations of these frameworks which should be developed in support of using comprehensive value analysis for ethical engineering decision-making.

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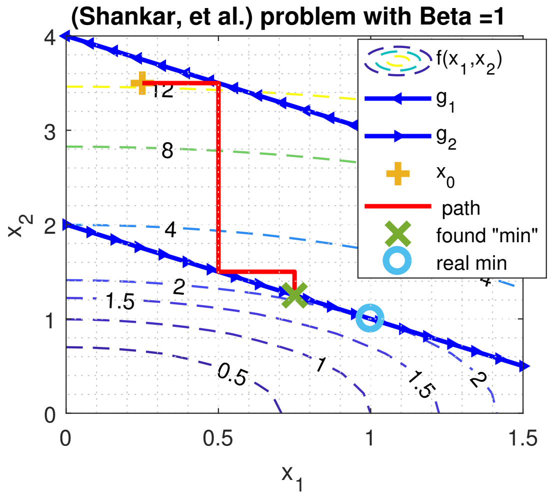

Figure 3. Optimization of a simple design problem presented by 3 with two constraints, in which the optimization of each variable has been distributed between two agents. Optimization converges to a Nash Equilibrium rather than the true minimum, since each agent cannot lower the objective function value through their individual actions.

Finally, it should be noted that, because of the nature of this review as a productive critique meant to spur the development of future approaches, there still remain ethical cases *for* using Decision-Based Design frameworks not mentioned here that could justify their use both in specific cases and generally. For example, while it was noted in Section 2.1 that some regulations may be unethical to violate, it should be noted that in many cases the regulations themselves are often decided based on cost-benefit analysis (Sunstein, 2012). In this case, there may be a legitimate argument that the designer has as much right to determine the best design based on their own cost-benefit analysis, as long as it is performed prudently. Furthermore, there is a case that any attempt to deviate from immediate profit-maximization is effort that is "stolen" from the customers, stakeholders, or workers (Friedman, 2008). However, these ethical cases rely on assumptions (many of which are identified here) that need to be stated explicitly and explored further in the context of the design environment to be taken as true.

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