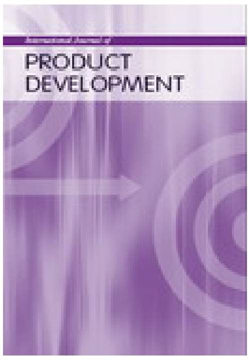

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A formal consideration of user tactics during product evaluation in early-stage product development

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Abstract: Frequent and effective design evaluation is foundational to the success of any product development effort. Products used, installed or otherwise handled by humans would benefit from an evaluation of the product while formally considering both the physical embodiment of the technology, termed technology, and the steps a user should take to use that technology, termed tactics. Formal and simultaneous evaluations of both technology and tactics are not widespread in the product design literature. Although informal evaluation methods have advantages, formal methods are also known to be effective. In this paper we propose a formal method for evaluating tactics and technology simultaneously. Unlike the published literature, this evaluation involves explicitly defined tactics in the form of a written description of the actor, environment and series of steps. It also involves the use of stage appropriate, explicitly defined tactics-dependent criteria, which include criteria from a broad range of impact categories.

Keywords: conceptual design evaluation; tactics evaluation; human-centred design; human factors; ergonomics.

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1 Introduction

When developing a product that will be used by humans, at least two questions should be considered: *What is the product?* and *how is it to be used?* The consideration of both the hardware design and the design of the product's use has been explored in many research fields, and among those fields there exist many different terms to represent the notion of product use. Here, for simplicity's sake, we will refer to the product's use as *tactics*. And we further specify for clarity that tactics are the steps a person takes to use a product to achieve an objective (Owens provides a detailed comparison of tactics with other notions in Ulrich and Eppinger (1988)). While a person can take a variety of different steps to use or attempt to use a product, in this paper we are concerned specifically with the steps the development team *intends* the product users to take.

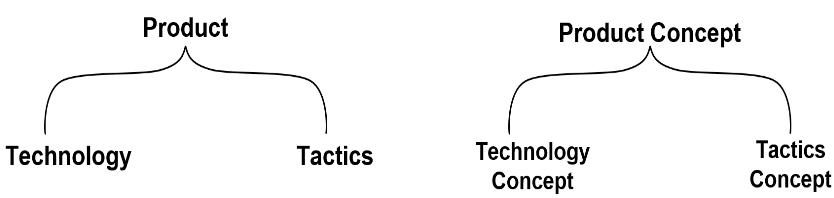
The goal of product development is to evolve ideas into fully detailed manufacturable solutions that will delight the customer (Kano, 1984; Ullman, 1992). Both technology and tactics are of high importance in creating delightful products (Ullman, 1992; González-Cristiano and Sandberg, 2019). Therefore, it is valuable to explicitly consider both technology and tactics during product development (Stapleton et al., 2019; Thacker et al., 2018). Both the tactics design and the technology design undergo evolution throughout the development process. For instance, a technology might evolve through various states of increasing detail, such as from a vague idea to a verbal description, to a visual description (a sketch), to a prototype, to a 3D model, and so on (Mattson and Sorensen, 2019). Tactics also evolve but there is less consensus in the literature and in practice of how to illustrate the evolution of tactics.

In this paper we focus on the conceptual design stage, where the tactics and technology exist at relatively low levels of detail, and a set of concepts for evaluation exists. According to Ullman (1992), an evaluation is an assessment of a *Subject of Evaluation* (*SOE*) against one or more criteria. Otto further indicates that a *formal* concept evaluation involves an explicitly defined SOE and explicitly defined criteria (Otto, 1995).

Nevertheless, informal evaluations are common in product development. An informal evaluation is one where either the SOE or the criteria or both are not explicitly defined. An example of this is role plays, where the SOE is the acted-out tactic (explicitly defined) but the criteria are often not explicitly defined, and instead the goal is described as 'to gain insights' (Buchenau and Suri, 2000). The insights arise as participants compare the acted-out tactic with the implicit criteria they have in their minds.

In product development, a common SOE is the current state of the product. Hereafter, a *product* refers to the complete solution to the design problem, which includes both tactics and technology (see Figure 1). *Product Concept* as it is used here refers to the product in a conceptual stage, and therefore is composed of the tactics concept and the technology concept.

Figure 1 In this paper, *product* refers to the complete solution to the design problem and therefore involves both tactics and technology



While there are advantages to using informal evaluation methods, formal methods can also be effective (Pugh, 1991). In this paper we focus on a formal method for evaluating tactics and technology simultaneously. In order for such a simultaneous evaluation of both tactics and technology to be also formal, it must contain two explicitly defined SOE's – the tactics concept and the technology concept – and two explicitly defined sets of criteria – one to evaluate the tactics and another to evaluate the technology.

We use the term *tactics representation* to refer to the SOE for the tactics concept, and the term *tactics-dependent criteria* to refer to the criteria that can be used to evaluate a tactics concept. It is clear that a product concept's performance in a certain criterion may be dependent on the tactics concept, the technology concept, or both. For example, a product concept's *manufacturability* is solely dependent on the technology concept, while its *ease of use* is dependent on both the technology and tactics concept.

We have so far established that a formal and simultaneous evaluation of tactics and technology concepts at least involves a representation of the tactics concept, a representation of the technology concept, tactics-dependent criteria and technology-dependent criteria. We have said little as to what traits might be found in high-quality tactics-dependent criteria or tactics representations. We can identify at least three goals to this end:

- *Goal 1*: That tactics representations contain information about the actor, environment and series of steps. It is critical to know information about each of these items in order to evaluate the quality of a tactic concept (Suri and Marsh, 2000). For example, the age/experience of the actor can impact the tactic's feasibility/desirability, as can the expected weather conditions at the place of use. Essential are the steps, which are the actions the user will complete.
- *Goal 2*: That tactics-dependent criteria contain stage-appropriate detail. Some methods in the literature use criteria that are ambiguous (e.g., 'human desirability' (Lewrick et al., 2018)). This is a potential problem as Pugh (1991) observed that the use of ambiguous criteria can be interpreted differently by development team members. However, too much detail would be inappropriate for the conceptual stage of product development (Pahl and Beitz, 1996).
- *Goal 3*: That tactics-dependent criteria represent a broad range of impact categories. Some methods only focus on impacts on the user, such as *usability*. This is an incomplete evaluation as the tactics design can also have other impacts, such as impacts on the project, environment and technology. For example, the tactics design for a car could impact the comfort of the driver, the level of pollution produced by the driver's style of operating the car, the engineering development time and/or the reliability of the car.

As shown in Table 1, there are many methods in the literature related to the evaluation of tactics and technology concepts, but none that meets all three goals listed above. Note their inclusion or exclusion of explicit SOE, criteria or their fulfilment of the three goals listed above.

Table 1 Comparison of existing methods for evaluating tactics and technology during conceptual design from the literature. Note: Solid circles indicate *the presence of*, empty circles represent *the absence of*, while dotted circles indicate *somewhat present*

	Explicit representation of concept for:		*Explicit criteria for evaluation of:*		*Has information on actor, environment and steps for tactic (Goal 1)*	*Has tactics criteria with stage appropriate detail (Goal 2)*	*Has tactics criteria from a broad range of impact categories (Goal 3)*
Method Name	*Tec*	*Tac*	*Tec*	*Tac*			
Decision-matrix (Mattson and Sorensen, 2019; Ullman, 1992)	●	○	●	●	○	●	○
Task Analysis (Harvey et al., 2014)	○	●	○	○	○	○	○
Storyboards (Van der Lelie, 2006)	●	●	○	○	⊙	○	○
Role Plays (IDEO, 2003)	●	●	○	○	●	○	○
Bodystorming (Buchenau and Suri, 2000)	●	●	○	○	●	○	○
Scenarios (Suri and Marsh, 2000)	●	●	○	○	●	○	○

Table 1 Comparison of existing methods for evaluating tactics and technology during conceptual design from the literature. Note: Solid circles indicate *the presence of*, empty circles represent *the absence of*, while dotted circles indicate *somewhat present* (continued)

	Explicit representation of concept for:		*Explicit criteria for evaluation of:*		*Has information on actor, environment and steps for tactic (Goal 1)*	*Has tactics criteria with stage appropriate detail (Goal 2*	*Has tactics criteria from a broad range of impact categories (Goal 3)*
Method Name	*Tec*	*Tac*	*Tec*	*Tac*			
Empathic Walkthroughs (Gray et al., 2015)	●	●	○	○	●	○	○
Cognitive Walkthroughs (Wharton et al., 1994)	●	●	○	●	●	○	○
Journey Maps (Journey mapping 101, 2021)	●	●	○	○	●	○	○
Service Engineering (Sakao and Shimomura, 2007)	⦿	●	●	●	●	●	○
Service Blueprints (Shostack, 1982; Lewrick et al., 2018)	○	●	○	●	○	●	○
Extended Service Blueprint (Sakao and Lindahl, 2009)	○	●	●	●	○	●	○
Bertoni (2019)	●	●	●	●	○	●	●
Maussang et al. (2009)	⦿	●	●	●	⦿	●	○
Proposed Method	●	●	●	●	●	●	●

To summarise the findings presented in Table 1, the challenges of the methods found in the literature for tactics evaluation are that some methods are informal, but those which might be considered formal either 1) focus only on a subset of the criteria, 2) have ambiguous criteria and/or 3) the tactics representations are missing key information which is necessary in an evaluation. In short, there is a lack of methods in the literature for the formal and simultaneous evaluation of both concept technology and tactics in conceptual design.

The objective of this paper is to build on appropriate methods in the literature to create a method for simultaneously and formally evaluating technology and tactics during the early stages of product development, which meets all three goals previously iterated.

To achieve this objective, two main questions must first be answered:

1 How can a tactics concept be represented?

2 What stage-appropriate criteria can be used to evaluate the tactics concept?

A method for the formal and simultaneous evaluation of tactics and technology can then be created by combining the tactics representation and tactics-dependent criteria with a representation of the technology concept and technology-dependent criteria. An important, but more straightforward, part of a formal evaluation method is the presentation of evaluation results to team members to facilitate further ideation. In this paper, we choose to present the results using common radar charts.

The remainder of this paper is organised as follows: In Section 2, we provide a brief review of the literature related to the representation of tactics concepts, and tactics-dependent criteria. In Section 3, theoretical developments and the proposed method are presented and in Section 4, a demonstration of the method's use in a design project is provided.

2 Literature survey

In this section we review the literature as it relates to the development of the proposed method. We specifically review the state of the art in: 1) representations of tactics and 2) tactics-dependent criteria.

2.1 Representations of tactics

As shown in Table 1, various methods exist for representing tactics concepts. Each is described in more detail in this section.

Bodystorming (Buchenau and Suri, 2000) and empathic walkthroughs (Gray et al., 2015) both provide different approaches to tactics representation. In bodystorming, designers carry out the steps needed to interact with a product, and in place of a product use a prop or simply their imagination. Thus, the tactics representation is the user's actual movements. A limitation of this representation of tactics is that it is not easily stored by, shared with, or evaluated by dispersed teams, since its stored form (video), though information-rich, can be time-intensive to review or give feedback on (Breimer et al., 2012).

In empathic walkthroughs, the designer imagines the use of the product by talking aloud. The subject of the evaluation in this case is the audible words describing the tactic. Just as in bodystorming, this representation of the tactic is beneficial because the design is no longer in the stage of a vague idea. However, reviewing the verbal dictations of many concepts while carrying out an evaluation can be prohibitively expensive (Tabbers et al., 2004).

Storyboards represent tactics by a series of drawings or photos which provide chronological snapshots of a product's use (Van der Lelie, 2006). While this representation can be easily used later, it is less detailed and not typically as information-rich as bodystorming. Further it may not be quickly constructed during ideation (Garmendia et al., 2007).

Contextual inquiry (2021) and co-creation workshops (2021) are examples of methods which allow the tactic to be represented not by the designer, but by the user themselves. In contextual inquiry, the design team observes the user as they carry out the current tactic in their workplace. Co-creation workshops allow the design team to see the actual user act out the tactics concepts. User participation provides obvious benefits, but also requires significant resources which make these representations ill-suited for use in impromptu ideation that often is needed throughout the product development process.

A journey mapping (2021) described actions in various phases of product use, plus the user goals, emotions and mindsets which can explain those actions. Although the described series of actions represent the tactical design well, the high level of detail present related to user motivations and emotions make such a method difficult to use quickly when representing many concepts.

Two service design methods are service engineering and blueprints (Maussang et al., 2009). The service engineering method (Tomiyama, 2001) proposes that a service is an activity, where an activity is a series of actions performed by the people involved. The method (Sakao and Shimomura, 2007) involves considering deeply the characteristics of the user and the series of steps the user takes in interacting with the Product Service System (PSS). The steps take the form of a sequential list of written steps. The characteristics of the environment however are not formally defined.

Shostack (1982) presented the blueprint as a way to represent a service during the service design process. A blueprint represents steps using a flow chart with execution times to represent the service, and provides a means for denoting when a step is performed by the consumer rather than the service provider. Others have also made use of the blueprint in developing PSS (Boughnim and Yannou, 2005). While the blueprint represents the user steps and distinguishes between steps taken by different actors, it does not detail the actor skills/knowledge nor the environmental characteristics.

A task analysis is a tactics representation from the field of human factors (Harvey et al., 2014). It fills at least two functions: It helps the ergonomist discover the steps currently taken to complete a task, and it presents the list of steps for future reference. To create a task analysis, the designer begins with a task and decomposes it into a series of steps, which take the form of an ordered list (Harvey et al., 2014; Salvendy, 2012; Kirwan and Ainsworth, 1992).

One difficulty associated with task analysis is determining how far to decompose a task. Some ergonomists decompose the task until a useful point of detail is reached, while others determine a stopping point by using a $P \times C$ criterion, where P is the probability of failure at that task, and C is the consequences of that failure (Harvey et al., 2014). Note however that this is not usually carried out by a formal calculation, but rather a mental guideline for the ergonomist (Harvey et al., 2014). With or without a $P \times C$ criterion, it can be difficult for those who do not have experience with task analyses to know how far to decompose the task. This can ultimately result in an excessively detailed list, which is difficult for a novice in task analysis to use.

When representing the technology and tactics concepts, we believe it is important that a similar level of detail should be used when describing each. It could be problematic for example to represent the technology in high detail and the tactics in minimal detail, or vice-versa (Reich and Subrahmanian, 2020).

Despite these difficulties, the task analysis does represent a series of steps in a way that is relatively easy for the designer to review, and is relatively inexpensive to create, share and get feedback on. A task analysis alone, however, is inadequate to describe a tactic concept prior to evaluation. It is clear, i.e., that the difficulty of a series of steps would be different depending upon the characteristics of the human carrying them out, or depending upon the environment within which the tasks would be carried out. Because a task analysis does not include these details, a task analysis alone is an insufficient SOE to use for tactics when the goal is to evaluate the tactics design.

We see that while each of the existing tactics representation methods have their own strengths, they also have drawbacks that make their application to the conceptual design stage problematic. Noted drawbacks include ease of creation, ease of transferability, time to review and amount/type of information captured.

As a final note, Bracewell et al. (2009) and Ganeshan et al. (1994) indicated a potential connection between the notion of formally defining user tactics and capturing design rationale. An intended user tactic may be the rationale behind particular technology concepts, e.g., the placement of knob or other user interface to promote a particular tactic. In this way, a formal representation of user tactics, in a way captures design rationale.

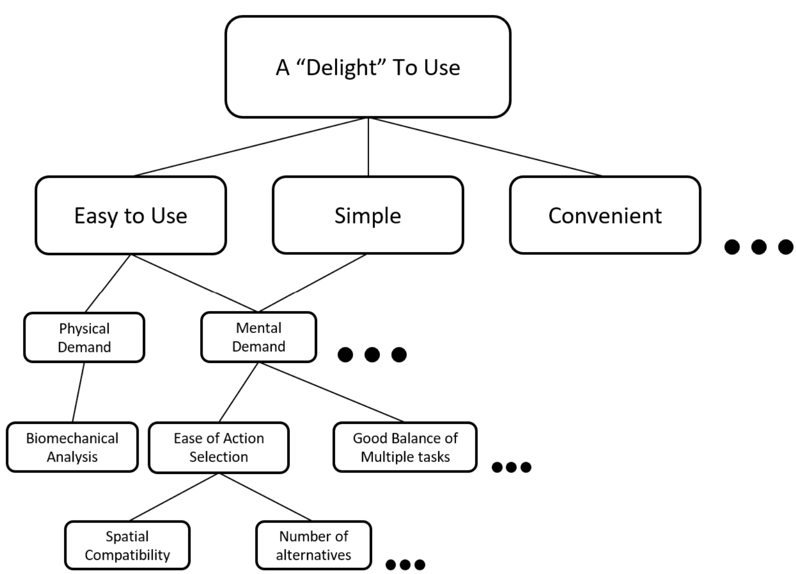
2.2 Tactics-dependent criteria

As noted in Table 1, evaluation criteria are not always stated explicitly in the published evaluation methods. Existing methods such as scenarios (Suri and Marsh, 2000), storyboards (Van der Lelie, 2006), bodystorming (Buchenau and Suri, 2000) and cognitive walkthroughs (Gray et al., 2015) all represent the tactic in a way that is believed to make weaknesses apparent to the development team. Evaluations made using these techniques are not necessarily made on explicitly stated tactics-dependent criteria; rather the product's use is evaluated against the designer's mental model for a usable product.

This can be problematic because it relies on the design team having expertise in the intended use-case, and/or being able to empathise effectively with stakeholders. Technology-based evaluations don't rely on the design team having these traits, instead they rely on explicit criteria derived from customers.

Other methods do, however, evaluate the product against specific tactics-dependent criteria (Brooke, 1996; Salvendy, 2012; Sanders and McCormick, 1998; Cushman and Rosenberg, 1991; Hart and Staveland, 1988; Reid and Nygren, 1988). In order to review these criteria, consider the *Tactics-Dependent Criteria Decomposition Tree*, referred to hereafter as *the criteria tree*, in Figure 2. The decomposition suggests that the most abstracted and general tactics-dependent criterion is whether or not a product is a delight to use. One layer down in this decomposition includes criteria such as *Easy to use* and *Simple*, and so on.

Figure 2 The *Tactics-Dependent Criteria Decomposition Tree*. Methods exist at every level in the tree that utilise tactics-dependent criteria to evaluate products



Many methods exist that use criteria at the second level of the criteria tree. One example of a method at this level is the System Usability Scale (SUS) (Brooke et al., 1996). The SUS is a widely accepted ten-item user survey for determining the usability of products and services. Two points in the survey are: ‘I found the system unnecessarily complex’. and ‘I thought the system was easy to use’. Criteria at this level in the tree present difficulties to teams carrying out evaluations in the conceptual design stage because there is no physical technology for potential users to evaluate. Further, Pugh observed that the use of ambiguous criteria in the Pugh matrix can lead to a less productive evaluation, since these criteria can be interpreted very differently by development team members (Pugh, 1991).

Other methods exist that use criteria at lower levels of the criteria tree, but they too have limitations when applying them to conceptual design. Human factors and ergonomics has examined closely what makes a product easy to use. For instance, the effects of spatial compatibility and number of alternatives on the ease of action selection have been examined (Salvendy, 2012) (see Figure 2). Other decompositions have been carried out in this field, such as studying what makes a movement physically difficult for a human, as in biomechanical analysis (Salvendy, 2012; Sanders and McCormick, 1998; Cushman and Rosenberg, 1991). A problem with using criteria deep in the criteria tree is that they require more information and therefore are inappropriate to use in the conceptual stage when relatively little information about the design exists.

Stage-appropriate criteria do exist and are often situated in the middle portion of the criteria tree. Mental demand, physical demand (Hart and Staveland, 1988), psychological stress load (Reid and Nygren, 1988) and cost of operation (Dieter et al., 2009) e.g., are criteria that are quickly understood and are also more specific than the criteria higher in the tree. The difficulty with these mid-level criteria is simply that they are scattered across multiple areas of research, making engineers less likely to be aware of and use them because of the associated acquisition cost.

In summary, many tactics-dependent criteria exist and are currently used by practitioners to evaluate products, however they are not readily applicable by design engineers in the conceptual stage. This is because criteria lower in the tree require more information than is available in the conceptual design stage, criteria higher in the tree tend to be ambiguous and criteria in the middle portion of the tree are scattered across many areas of research and practice.

3 Theoretical developments

This section provides a detailed description of our proposed approach to represent a tactics concept, our proposed criteria for considering tactics during concept evaluation and a basic, but adequate, approach to present the concept evaluation results to teams.

3.1 Representing a tactics concept

We propose that a tactic can be adequately described in the conceptual design stage by a simple written description including the following three things, which are illustrated in Figure 3:

- *The actor*: The actor is one or more people who carry out the tactic. A brief description of the actor is sufficient, when it is focused on actor characteristics that affect the actor's ability to carry out the tactic. This is a key component missing from the task analysis discussed in Section 2. As shown in Figure 3, the description can be simple. For example, the actor is an experienced able-bodied warehouse worker of typical stature and strength.
- *The environment*: The environment is the location(s) where the tactic will take place. A brief description is sufficient when it is focused on the characteristics of the environment that affect that actor's ability to carry out the tactic, or the technology's ability to perform (this may include weather, noise, hazards, etc.). This element is also absent from the task analysis in Section 2. For example, the environment is a temporary warehouse for receiving and distributing aid supplies to Afghans in a military conflict zone.
- *The sequence of steps*: The sequence of steps is simply a list of what the actor would do to carry out the tactic, as shown in Figure 3.

Figure 3 A tactics concept for a product can be represented in a written form with descriptions of the actor, environment and sequence of steps

Tactics Concept Name: *Pull sliding door and lever*

Actor

An able-bodied warehouse worker of typical stature and strength.

Environment

A temporary warehouse for receiving and distributing aid supplies. Warehouse is located in a middle-eastern conflict zone

User Actions

- *Grasp handle of garage door*
- *Pull door to open position, keeping body behind the door in the process*
- *Pull lever to drop external barrier*
- *Attend to vehicle as normal*

One other piece of information included in the tactics representation is the name of the tactics concept. This simply facilitates organisation and discussion later in the design process.

The sequence of steps is the most substantial part of representing a tactics concept. A *task analysis* (Harvey et al., 2014) is an effective means for representing a sequence of steps during conceptual design because it can be created and edited quickly, information is captured and is not subject to loss and information can be reviewed relatively quickly during an evaluation.

As described in Section 2, one challenge of task analysis is knowing when to stop decomposing the task. We propose that the designer decompose tasks until the tasks describe whole body movements and part placement. These two items are inspired by the work of Boothroyd and Dewhurst (Boothroyd, 1994), where they present time predictions based on two categories of actions: 1) part acquisition and orientation and 2) part insertion. We have found that this guideline helps avoid confusion over how far to decompose a tactic, and allows for more uniform creation of tactics concepts. This guideline also has the quality of guarding against the over-decomposition of tasks which is also a function of the $P \times C$ criterion. The task would never be decomposed so far such that P, the probability of failure is nearly zero (e.g., Human looks at the handle. Extend human arm towards handle.). By basing decomposition on whole body movement and part placement, such over decomposition is avoided and since whole body movements and part placement are easily comprehensible guidelines, they are more accessible to novices at task analysis.

Boothroyd and Dewhurst's categories are used here because they are effective in describing user interactions of a physical nature. Although other types of user interaction exist, we do not make them a focus of this paper. While the Boothroyd and Dewhurst approach is certainly relevant in the detailed design stages of product development, the principles behind the method can be applied in the conceptual stage. This is evident since some tactics-representation methods which are used in the conceptual stage (e.g., Empathic Walkthroughs (Gray et al., 2015)) represent the steps the user would take to use a product on a level of detail similar to Boothroyd's approach. As an example of the use of these categories, the task analysis for opening a door would be: Walk to the door (major body movement), open the door (part placement).

It should be noted that this form of a tactics concept is meant to be used when the concept set contains fewer than 20 concepts. If the set were much larger, a significant amount of time would be required to create tactics representations for each concept.

This form of a tactics concept – a written description of the actor, environment and steps – does entail certain drawbacks. For example, it is not as information-rich as other representation methods such as bodystorming, and although the proposed decomposition guideline reduces confusion, it can still be difficult to know how far to decompose an action. Despite these drawbacks, this form of a tactics concept addresses many of the weaknesses identified in existing tactics concept representations which are important in conceptual design. Specifically, it can be created relatively quickly, it can be reviewed and shared relatively quickly and unlike task analysis alone, this method articulates who the actor is and the environment, which facilitates meaningful evaluation.

3.2 Tactics-dependent criteria

We recommend that for development teams wishing to formally consider tactics during product concept evaluation, the set of stage-appropriate tactics-dependent criteria in Table 2 should be considered by the team as a requirements checklist (Pahl and Beitz, 1996). The list serves to alert engineers of potentially useful criteria that the team can consider as they choose final tactics-dependent criteria for their specific project.

Table 2 A list of tactics-dependent criteria. The performance of a product in a criterion on this list is sometimes dependent upon the tactics design. Therefore, it is wise to consider tactics when evaluating a product relative to these criteria

Units	*Criterion*	*Description*
	Impact on project	
Time	Time to reach milestones	Key project deadlines
$	Cost for development	Financial cost to design the product.
$	Target product Cost	Intended market price for product
$/Time	Rate of return on investment	Expected financial performance considering revenues and expenses
$, time	Resources for developing user documentation	Resources required to develop documentation necessary for user to be capable of carrying out product steps.
$ spent on fines	Degree of intellectual property infringement	Resources spent on patent and intellectual property infringements. For example, new use patents.
	Impact on user	
n/a	Boredom and monotony	User boredom and monotony while using the product
$	Cost of operation	The financial cost to the user to operate.
$	Opportunity Cost	The financial cost of forgone opportunities.
n/a	Human comfort	Human comfort while using the product
n/a	User acceptance	User acceptance of the sequence of steps necessary to use the product. Historical, cultural and other factors may impact acceptance.
n/a	Favourable working environment for human performance	Characteristics of the service environment that support successful human performance. For example, Light, temperature, etc.
n/a	Fatigue and physical stress	Human fatigue and physical stress
n/a	Ease of use	Ease of using a product.
Time	Losses of time	Losses of user time during product use.
#/time	Frequency of errors	Rate of human errors. May be specified to be error rate for errors with a specific degree of consequence severity.
Time	User training necessary	Time user must spend in receiving training necessary to carry out product steps.
#	Manpower	The number of people required to use a product.

Table 2 A list of tactics-dependent criteria. The performance of a product in a criterion on this list is sometimes dependent upon the tactics design. Therefore, it is wise to consider tactics when evaluating a product relative to these criteria (continued)

Units	*Criterion*	*Description*
n/a	Personnel	The aptitudes, experiences and other human characteristics necessary to achieve optimal system performance
n/a	Mental demand	Extent of mental and perceptual activity required (e.g., thinking, deciding, calculating, remembering, looking, searching etc.). Level of concentration and complexity.
n/a	Physical demand	Extent of physical activity required (e.g., pushing, pulling, turning, controlling, activating, etc.).
n/a	Temporal demand	Pressure due to the rate at which the tasks occurred. (For example, slow or fanatic). Frequency of spare time and occurrence of interruptions or activity overlap.
n/a	Human performance	Extent to which the human successfully carried out the main goal of the task.
n/a	Psychological stress load	Level of stress due to confusion, frustration, insecurity, discouragement or anxiety.
$Prob._{hazard}$	Safety (Hazard assessment)	Probability of hazards to human safety that arise from product use. May be specified to be probability of hazards with a specific degree of severity.
	Impact on technology	
Time	Life in service	Service life of technology.
Time	Time to unacceptable wear	Wear on technological components.
Time	Mean time to failures	Mean time to technological failures.
$	Cost of equipment losses	Losses of technology due to human use.
Various	Functional Performance	Functional performance of the technology.
Various	Key performance targets	Key performance targets of the technology.
	Impact on environment	
m_{CO2} / m_{fuel}, m_{NO} / m_{fuel}, etc.	Environmental impact resulting from use	Impact on environment as a result of product use. (e.g., Pollutants, noise, production of waste, use of natural resources)

To help teams with the process of choosing criteria from Table 1, we provide the following guidelines:

- Choose criteria that different product concepts will perform differently in. For example, *manpower* would not be a helpful criterion to use if all of the proposed concepts in a set use only 1 person to carry out the tactics.
- Choose criteria that are important given the specifics of the project. Each design problem is different and so necessitates the prioritisation of certain criteria over others.

The first guideline is given based on the rationale that it is not effective to use a criterion which does not highlight any differences in concept performance since a main purpose of an evaluation of concepts is to comprehend the strengths and weaknesses among the set. The second guideline is supported in Pahl and Beitz (1996). The criteria in Table 2 aim to address the challenges associated with the criteria discussed in the literature survey, namely, that criteria can either be ambiguous or require more information than is available during conceptual design.

3.2.1 Methodology for creating and using Table 2

The approach for deriving the list of tactics-dependent criteria in Table 2 can be summarised in three major steps. First, potential tactics-dependent criteria were gathered from the literature into a master list. Second, the list was consolidated by removing redundancies. Third, the tactics-dependent criteria were identified from the consolidated list. In what follows, each of the three processes will be described, one at a time. Finally, guidelines are provided for teams who wish to determine dependencies of criteria for their specific project.

Gathering criteria into master list: Criteria were gathered in two ways. First, tactics-dependent criteria at a middle level of detail in the Criteria Tree (see Section 2) were sought out and added to the master list. Second, sets of general product criteria from the mechanical design literature were added. This was done because such sets of requirements tend towards comprehensiveness, which is helpful in ensuring that the list of tactics-dependent criteria cover the breadth of ways that tactics can affect the results of a product evaluation.

Stage-appropriate tactics-dependent criteria from three methods – NASA TLX (Hart and Staveland, 1988), SWAT (Reid and Nygren, 1988) and MANPRINT (Booher, 2003) – and one requirements set (Chapanis, 1996) in the field of human factors were added to the list. Criteria lists from the field of product service system design were also considered (Bertoni et al., 2017; Bertoni, 2019; Chou et al., 2015; Isaksson et al., 2013).

Four lists of general product criteria were used from the mechanical design Ullman (1992); Pugh (1991); Dieter et al. (2009) and Pahl and Beitz (1996). Ullman (1992); Pahl and Beitz (1996) and Dieter et al. (2009) used headings to organise requirements. While general phrases were used as headings, on occasion authors used more specific phrases as headings such that the headings themselves could be considered semi-detailed criteria. Two headings were deemed to be specific enough to be considered criteria: functional performance (Ullman, 1992) and key project deadlines (Dieter et al., 2009). The initial list of compiled criteria, excluding the 25 headings, contained 157 items.

Consolidating the master list: The first step in consolidating the master list was to ascertain meanings behind the criteria by examining each source. This not only enabled the elimination of redundant entries, but also led to a clear understanding of the criteria for future analysis. As an example of this consolidation step, Pugh's criterion *environment* is similar in meaning to Dieter's *service environment*, and both were consolidated into the same criterion, *effect of service environment on product performance*.

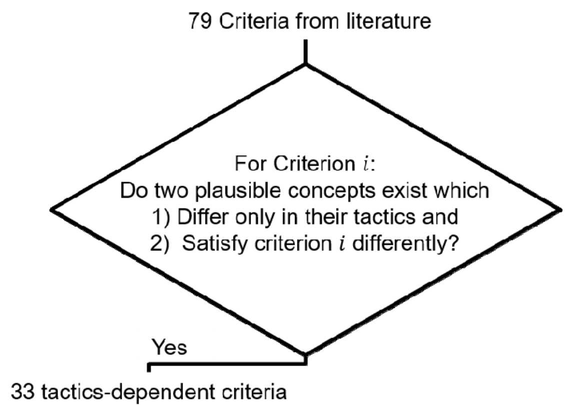
Four criteria were omitted from further analysis: *Soldier survivability* (Booher, 2003), *product name* (Dieter et al., 2009), *customer* (Pugh, 1991) and *competition* (Pugh, 1991). *Customer* and *competition* suggest that the design team understand the competition and the customer in creating requirements. These were omitted because they suggest a process for gathering requirements, and are not criteria for product evaluation. *Soldier survivability* was omitted because of its multifaceted nature, and *product name* because of the lack of importance in conceptual design.

At the end of this step, 79 criteria remained, (see Owens (2022) for this full list of criteria). The resulting list was considered to be a suitable starting set of criteria from which tactics-dependent criteria could be identified.

Identifying tactic-dependent criteria from the consolidated list: The basis behind the approach for identifying tactics-dependent criteria is depicted in Figure 4 and can be summarised in the following principle:

If two products exist that 1) differ only in their tactics and 2) satisfy criterion i differently, then the satisfaction of criterion i is dependent upon the tactics. Following this principle, we can test if a criterion is dependent upon the tactics by determining if two plausible product concepts exist that 1) satisfy the criterion differently and 2) have different tactics but the same technology. As will be seen later, it is instructive to also identify technology-dependent criteria, and a similar test can be carried out to determine those criteria.

Figure 4 Process used to determine if an evaluation criterion is dependent on tactics



In summary, tactics-dependent criteria and technology-dependent criteria can be identified by carrying out the following tests: *Tactics test*: Determine if two plausible product concepts exist that 1) satisfy criterion i differently and 2) have different tactics but the same technology. *Technology test*: Determine if two plausible product concepts exist that 1) satisfy criterion i differently and 2) have different technology but the same tactics

The list in Table 2 is tactics-dependent criteria that resulted from the tactics test. (See Owens (2022) for the product concepts used to justify the inclusion of each criterion and the reasoning used). The results of the technology test were that almost all criteria are technology-dependent criteria. Only two criteria were found to not be dependent upon the technology: *Manpower* and *personnel*. *Manpower* is the number of people needed to carry out a tactic, and *personnel* is the aptitudes, experiences and other human characteristics necessary to achieve optimal system performance. Because these criteria relate to the actor, which is a characteristic of the tactic, a concept where the tactics remained the same and the performance in the criterion changed was not found.

Therefore, all criteria in Table 1 except *manpower* and *personnel* were classified as being both tactics-dependent and technology-dependent. *Manpower* and *personnel* were classified as only being tactics-dependent.

Using an affinity diagramming approach (Kiran, 2016), the list was then organised into similar groups, and headings were given to each group. The following four headings resulted from this process: Impact on the project, impact on the user, impact on the technology and impact on the environment, where environment here refers to the earth's environment.

3.2.2 Team guidelines for project-specific criteria classification

Clearly, more criteria may be classified as tactics-dependent or technology-dependent than have been given here. In addition, some criteria presented here as dependent may be independent when applied to projects with certain characteristics.

Therefore, while the list in Table 2 functions well as an initial checklist, it may be helpful for design teams to add to or subtract from this list after considering the details of their specific design project. To do this, we recommend that design teams simply carry out the tactics and technology tests themselves in order to classify criteria as tactics and/or technology-dependent. These tests require the team to find two plausible concepts with certain characteristics (see Sub-section 3.2.1). We provide the following guidelines to help teams with the process of finding two plausible concepts:

- Clearly state the design objective that the two product concepts must achieve. The objective should be achievable by both product concepts.
- Try to find product concepts whose tactics and technology differ significantly for the tactics and technology tests, respectively. For example, for the tactics test, seek significant changes in the user actions. For the technology test, seek significant geometry or material changes.
- Find concepts that could plausibly be generated by a design team during an ideation session. It is therefore not necessary that each concept be free of flaws or be fully defined.

These guidelines represent the lessons learned while carrying out the process described in Sub-section 3.2.1. During that process, it was apparent that without clearly stating the design objective, it was easy to unintentionally generate two concepts that do not achieve the same objective and are therefore two fundamentally different ideas which violated the requirements of the tests listed in Sub-section 3.2.1. It was also apparent that another pitfall was making a very minor change to technology or tactic, e.g., changing a screw. While this technically satisfies the requirements of the tests, it does not satisfy the purpose of the test. The last pitfall was that one might be tempted to require high quality ideas when in practice, ideas are not required to be high quality in an ideation session.

To summarise, there are at least two ways to use the list in Table 1. First, teams can use the list directly by simply accepting the presented classifications of criteria as being tactics-dependent or both tactics and technology-dependent. Second, teams can use the list in Table 1 as a starting point and classify the criteria themselves in light of the details of their specific project. The first approach has the benefit of being faster, but it may be that certain criteria are imperfectly classified for their particular project. The second approach is slower, but has the advantage of more accurate classifications. The advantages of having criteria classified is discussed in the next section.

3.2.3 Criteria organisation

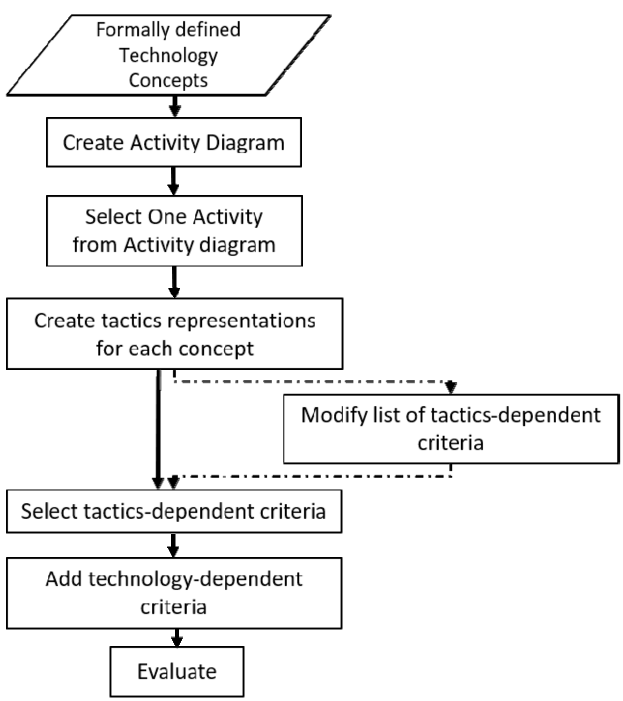
After the design team has chosen tactics-dependent criteria, we recommend that design teams organise their chosen set of evaluation criteria into three possible classes: Criteria that are only dependent on tactics, criteria that are only dependent on technology and criteria that are dependent on both tactics and technology.

Such an organisation is helpful in several ways. First, it reminds engineers when tactics may impact a certain criterion. This signals to the team that evaluating without an evolved form of the tactics as part of the SOE may lead to a less accurate evaluation. Second, it gives engineers a starting point for the idea generation process that often follows an evaluation. For example, if it is desirable to improve a product's performance in a particular criterion, which is dependent upon both tactics and technology, then the performance can be improved by changing the tactics, the technology or both. A third way this classification is helpful is it can save time during evaluations. Traditionally, teams often review the product concept being evaluated before making a judgement about its performance in a certain criterion. By knowing the criterion's dependencies, the team can skip reviewing any concept that does not impact its performance.

3.3 Description of full evaluation method

This section's aim is to combine the previously described elements and demonstrate how they would be used in a method for the formal and simultaneous evaluation of tactics and technology concepts. The illustration of this overall method is found in Figure 5.

Figure 5 The overall evaluation method using the tools proposed in this paper. Note that although in this paper it is assumed the team begins with technology concepts, this is not the only valid starting point



Suppose that a development team has generated a set of product concepts, and that those concepts contain technologies that have evolved to the point of a sketch, and tactics which are only vaguely defined. We do not suggest that this state of evolution is the most common or the best state of evolution for a set of ideas. Instead, we begin at this point purely to illustrate the creation of the proposed written form for tactics concepts.

In order to consider the tactics during evaluation, the designer must first narrow the scope of the tactic to one appropriate for the desired evaluation. A user can carry out many different activities with a product; they purchase it at the store, unbox it, stow it, retrieve it, use it, clean it, and more. The full scope of the activities a user engages in with the product is illustrated well by Otto and Wood's Activity Diagram (Otto et al., 2003). With awareness of the extent of possible activities, the first step is to choose one or more activities to analyse.

Having chosen an activity, the development team begins representing the tactics concept by stating the actor and environment. As part of specifying the environment, it can be useful at this point to specify the initial relative positions of the product and human for the activity or activities being analysed. For example, the battery-powered drill is in a protective case inside the bottom drawer of the tool chest, and the user is in front of the tool chest. Then, the steps for carrying out the tactic are stated in the form of a list of user actions.

With this completed for each product concept, each product concept now has a representation of tactics and technology that contains enough detail such that an evaluation can be carried out, and tactics-dependent criteria can be chosen from the list in Table 2. As an option, the team may choose to modify this list using the guidelines in Sub-section 3.2.2.

After adding in any other technology-dependent criteria that the team sees fit, the criteria are then used to evaluate all product concepts, e.g., in a concept scoring matrix. A subsequent discussion can then be carried out in which the development team carefully considers the strengths and weaknesses of each product concept, and both the tactics and the technology can be considered as design variables to enable the improvement and combination of concepts.

4 Demonstration

As a demonstration of the method, we present the results of a team of undergraduate engineers who are designing a machine that can create broom bristles from 2L plastic bottles (see Figure 6), and is meant to be used in Amazon region of Brazil as a sustainable means for producing household brooms. Prior to carrying out the method, the team had created many technology concepts in the form of annotated sketches but had not yet considered tactics deliberately during product concept evaluation. The first sub-section that follows will present how the team used the method during conceptual design. The second will discuss the more and less effective ways the team used the components of the method, and the third will discuss what the team could do next with the results of the method.

Figure 6 A broom whose bristles are made from 2L plastic bottles

4.1 *Results from team's use of method*

First, the team created a user activity diagram (defined in Sub-section 3.3) for the bristle machine (see Figure 7). After selecting the *use machine to produce bristles* activity, the team created tactics representations for each technology concept in the set (see Figure 8).

Figure 7 An activity diagram for a machine which converts 2L bottles into broom bristles

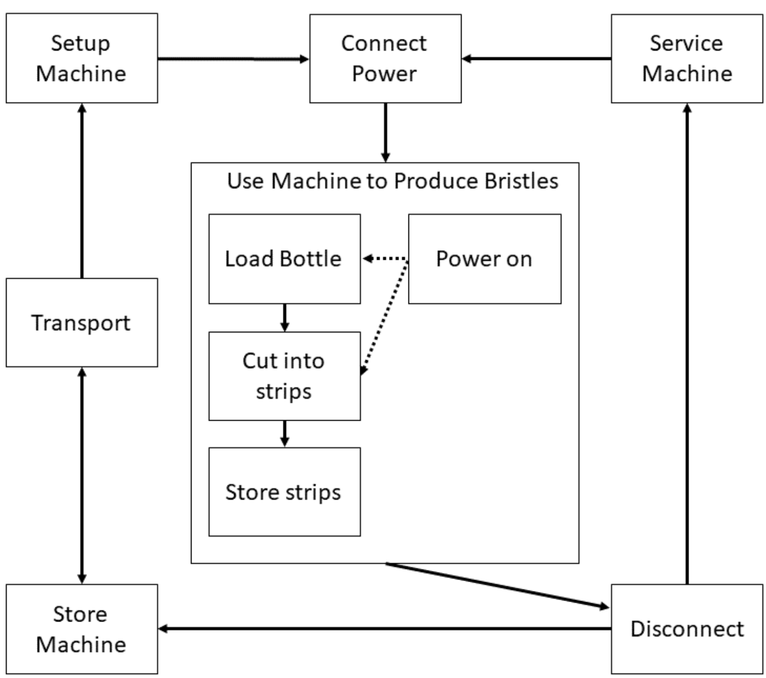
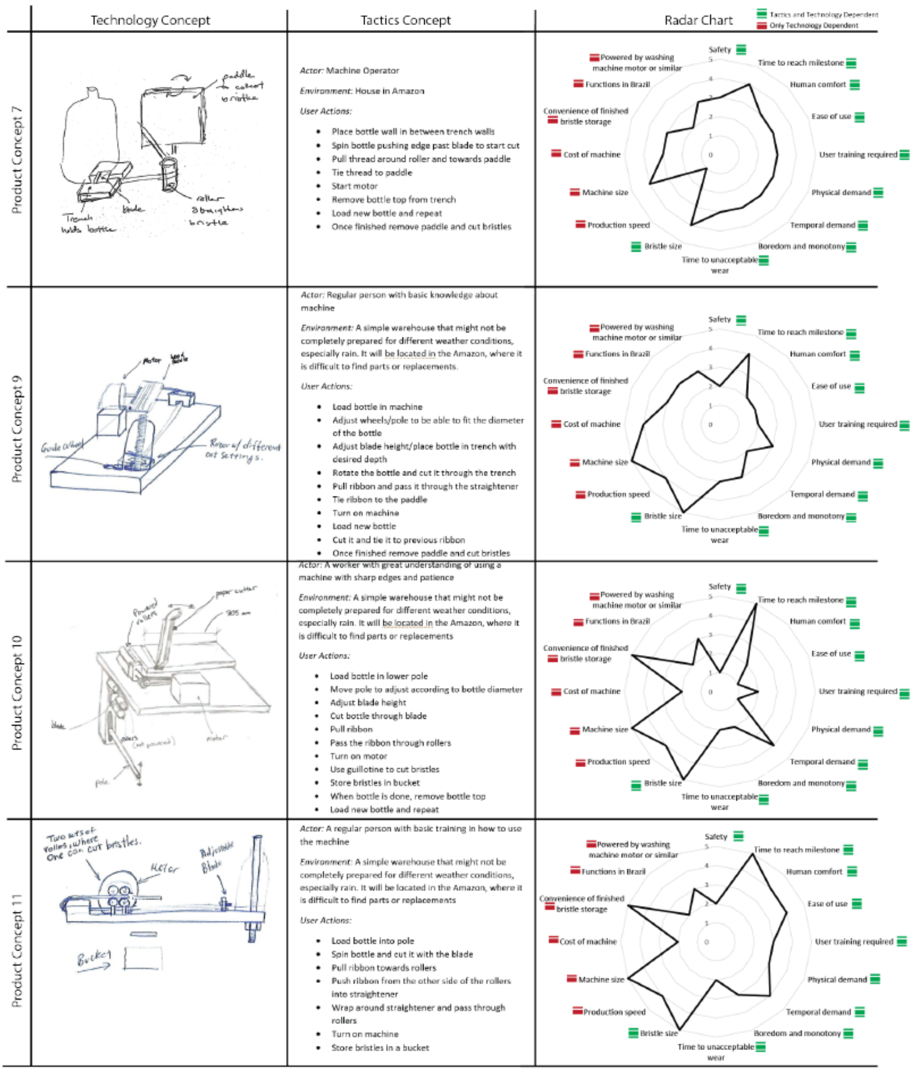


Figure 8 Product concepts for a machine that turns 2L plastic bottles into broom bristles. Each product concept has an associated Technology and Tactics concept, as well as a radar chart



The list of user actions gave the development team a deeper understanding for what each tactic entailed as they wrote out each step and envisioned the process of product use. Whereas before the tactics were only implicitly defined, the tactic now had a written form and could be communicated to others as well as referenced during the following evaluation.

The next step was for the team to select tactics-dependent criteria to use during product concept evaluation. After following the guidelines for criteria selection in Sub-section 3.2, the team chose nine criteria from Table 2, and these criteria are labelled as 1 through 9 in Table 3. Seven other technology-dependent evaluation criteria were of interest to the team, and these are labelled as 10 through 16 in Table 3.

Table 3 Evaluation criteria chosen for the broom bristle project. *Tac* and *tec* denote tactics-dependency and technology dependency, respectively

#	*Criterion*	*Tac*	*Tec*
1	Safety	✓	✓
2	Time to reach milestone	✓	✓
3	Human comfort	✓	✓
4	Ease of use	✓	✓
5	User training necessary	✓	✓
6	Physical demand	✓	✓
7	Temporal demand	✓	✓
8	Boredom and monotony	✓	✓
9	Time to unacceptable wear	✓	✓
10	Bristle size	✓	✓
11	Machine is powered by washing machine motor or similar		✓
12	Machine is functional in Brazil		✓
13	Convenience of finished bristle storage		✓
14	Cost of machine		✓
15	Machine size		✓
16	Production speed		✓

In this case, the criteria were classified in light of project-specific details as described in Sub-section 3.2.2. The classifications found are given in Table 3. Note that in this case, all of the classifications from Table 2 remained the same. As an example of when this might not have been the case, consider a concept set in which all concepts include an automated cutting system. In this case, the 'Bristle size' criterion would be only technology dependent, whereas in the current concept set concepts exist where the bristle size is dependent upon the user tactics (e.g., product concept 10 in Figure 8). In addition, bristle size was determined to be tactics-dependent. This was due to product concept 10, in which the user must cut each bristle to size individually.

With both technology and tactics concepts as part of the SOE, and tactics-dependent criteria being used for the evaluation, the team was ready to proceed with a product concept evaluation that considered tactics.

Note that there are many methods for carrying out the next step of the evaluation. Some heuristic methods are commonly used in conceptual design, such as the concept scoring matrix or Pugh's matrix. Other methods like VIKOR and TOPSIS (Thakkar, 2021) take a numerical approach for identifying the best alternatives. If desired, criteria can be weighted subjectively as in traditional decision matrix methods (Mattson and Sorensen, 2019), or their weightings could be informed by a numerical approach like DEMATEL (Thakkar, 2021). All of these are valid ways to continue the evaluation. In this demonstration we choose to use a concept scoring matrix without criteria weights and evaluate each product concept on a 5-point scale, using a baseline product (see (Owens, 2022) for baseline concept) as reference. When using a 5-point scale, a 3 represents ‘same as baseline’, while 4 and 5 represent better and much better than baseline, respectively (Ulrich and Eppinger, 1988).

After scores were assigned for each product concept and for each criterion, these scores were used to create radar charts of the evaluation information. In this case, only two categories of criteria were present in the plots: Technology-dependent criteria and both tactics and technology-dependent criteria (see Figure 8). This is because the team had no criteria that were only tactics-dependent.

This demonstration has thus far illustrated how the method works when used on an actual design project by engineers who were previously unfamiliar with the research. In the next section, the results of the team will be discussed in relation to how they illustrate more and less effective ways of applying them.

4.2 More and less effective use of the method

Poor use of the *actor* component of the tactics representation is illustrated in product concept 7, where ‘Machine operator’ was the written description of the actor. Clearly, this description provides minimal additional detail beyond the word actor itself. Better use of the *actor* component can be seen in product concept 10: ‘A worker with great understanding of using a machine with sharp edges and patience’. This description provides specific characteristics about the user that affect his/her ability to use the product; in this case, one of the characteristics provided is experience handling a machine with sharp edges.

Poor use of the *environment* component can be seen in product concept 7: ‘House in Amazon’. This description leaves many questions unanswered which may impact the nature of the user interaction with the product. Better use of *environment* is given in product concept 9, ‘A simple warehouse that might not be completely prepared for different weather conditions, especially rain. It will be located in the Amazon, where it is difficult to find parts or replacements’. With more specifics defined about the environment, it is more likely that the design team will have a common understanding of the environment so that a more uniform evaluation can be carried out.

Poor use of the *user actions* list is demonstrated in concept 11, where the use of the technology is described, but only for using one bottle to create bristles. This is problematic as the actual use of the technology will involve creating bristles from many bottles, one after another. Therefore, only a portion of the actual tactic has been described with this representation, which may leave the engineer with an inaccurate understanding of what the tactic is before proceeding with the evaluation. Better use of the *user actions* is demonstrated in product concept 7, where the simple statement ‘load new bottle and repeat’ demonstrates that the engineer was cognizant of the range of user actions needed to use the product.

Another illustration of the more and less effective uses of the user actions is evident in the decomposition of tasks. As an example of poor decomposition, consider the user action ‘store bristles in bucket’. This action doesn’t specify what the user must do to store the bristles. For example, do the bristles simply drop into the bucket, and the user must collect and order the bristles? Or does the user bundle the bristles and drop them into the bucket already ordered? This is unclear. Many examples can be found in the tactics concepts of better uses of the user actions. For example ‘wrap around straightener and pass through rollers’ in product concept 11 gives a clear picture of what the user must do.

4.3 Future steps for the team

As a next step, the team should now view the presented results found in the radar charts in Figure 8 to identify strengths and weaknesses that will inform the combination, improvement, and elimination of concepts.

For example, it is immediately clear that product concept 11 may be a promising candidate for future consideration as it performs better than the baseline concept in many criteria. However, it appears to have notable weaknesses in the *cost of the machine*, *functionality in Brazil*, and the *time to unacceptable wear* criteria. As an approach to improvement of concept 11, the team could use the tactics and technology dependencies to guide their ideation. For example, to improve in the *functions in Brazil* and *cost of machine* criteria, the team can note that these criteria are solely dependent on the technology and can therefore focus on technology improvements. In the case of the *time to unacceptable wear* criterion, it is dependent on both the tactics and the technology, and the team can therefore try to imagine a way to improve the product concept in this criterion by only changing the tactics. For example, if the product may wear more quickly because of the user using the blade adjustment mechanism roughly, it is possible that the team can create documentation to instruct the user in proper handling. The team could also guide ideation by trying to imagine a way to improve the product by changing only the technology, or by changing both the tactics and technology.

5 Concluding remarks

In this paper we have proposed 1) a means for formally representing tactics concepts, 2) a set of tactics-dependent criteria that can be used to evaluate products while considering tactics in conceptual design and 3) a method which makes use of 1) and 2) to formally and simultaneously evaluate tactics and technology in conceptual design. The contributions in this paper together offer a practical method to simultaneously consider a product concept's tactics and technology which ultimately can facilitate the design team's creation of improved concepts by changing the tactics, the technology, or both.

To be more specific, this paper presented a tactics concept representation that can be quickly created and reviewed, is transferable, and contains descriptions necessary to make an evaluation that considers tactics. It also presented a list of stage-appropriate tactics-dependent criteria from a broad range of impact categories that originated from the literature but have not previously been presented in a compiled, ordered form that is ready for use by engineers. The proposed method meets all the goals identified in Table 1 unlike the existing methods from the literature.

We believe that designers who apply the proposed method, in full or in part, will benefit from the examples in Section 4 to improve their ability to create tactics representations with sufficient detail and to effectively consider tactics during product concept evaluation. Further, we believe that using Table 2 as a checklist will broaden the thinking of a typical engineering team about tactical requirements, and that by separating evaluation criteria into groups based on their dependence on tactics or technology will help engineers be mindful of the role of tactics in determining a concept's success. Finally, we believe that teams who are rigorous about the evaluation of both the technology and tactics during the conceptual stage of design are likely to develop better, more desirable products.

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