Feelings and Physics: Emotional, Psychological, and Other Soft Human Requirements, by Model-Based Systems Engineering

William D. Schindel
ICTT, Inc., and System Sciences, LLC
100 East Campus Drive, Terre Haute, IN 47802
812-232-2062 schindel@ictt.com

Abstract. Traditionally, engineering encourages requirements statements that are objective, testable, quantitative, atomic descriptions of system technical behavior. But what about "soft" requirements? When products deliver psychologically or emotionally-based human experiences, subjective descriptions may frustrate engineers. This challenge is important for products appealing to senses of style, enjoyment, fulfillment, stimulation, power, safety, awareness, comfort, or similar emotional or psychological factors. Automobiles, buildings, consumer products, packaging, graphic user interfaces, airline passenger compartments and flight decks, and hospital equipment provide typical examples. This paper shows how Model-Based Systems Engineering helps solve three related problems: (1) integrating models of "soft" human experience with hard technical product requirements; (2) describing how to score traditional "hard" technology products in terms of "fuzzier" business and competitive marketplace issues; and (3) coordinating marketing communication and promotion with the design process. The resulting framework integrates the diverse perspectives of engineers, stylists, industrial designers, human factors experts, and marketing professionals.

"SOFT" HUMAN REQUIREMENTS: THE ENGINEER'S CHALLENGE

Human-Experienced Qualities. Traditional engineering methods encourage us to write requirements statements that are objective, testable, quantitative, atomic descriptions of desired system technical behavior. It has been shown (Schindel 2005) that such requirements prose may be directly generated by model-based methods. This paper explores the opposite direction: Requirements for products and systems that interact with people are frequently expressed in terms of human-experienced qualities. For some system products (e.g., aircraft passenger compartments, furniture, tools, entertainment systems, clothing), these may be among their most important requirements. For other products (e.g., control systems, manufacturing processes, buildings), these requirements can be at least a critical subset of the total requirements.

The descriptions of such "soft" qualities often use nomenclature and ideas of psychology, emotion, and other human-based terminology, and may originate from non-technical laymen, or from technical specialists who study human nature instead of engineering and physics. This can leave the engineer writing technical product or system engineering specifications in a dilemma. How does one treat seemingly "soft" requirements of this type seriously, link them to technical designs, and subject them to formal and effective validation and verification?

The Challenge to Engineers. These questions frequently lead to uncertainty or frustration on the part of the engineer, or a sense that requirements of this sort cannot be treated the same as “hard technical” requirements, such as one finds in interactions between non-human systems. How is an engineering-trained designer to accommodate requests that a product should make its human user “excited”, “fulfilled”, “undistracted”, or “uplifted”? How can engineers in such cases feel that their work is conducted in a technically sound, systematic, and optimized fashion?

Human-based requirements of this sort are essential in the design of consumer products, military and commercial aircraft and vehicles (which interact with pilots and operators), therapeutic devices and systems, and many other products. Techniques such as Quality Function Deployment (QFD) (Clausing et al 1988) and Axiomatic Design (Suh, 2001) express certain relationships about soft requirements, but may do so without fully communicating the human factors specialist’s understanding, and their full integration into model-based systems engineering processes is not always clear.

Industrial Designers and Architects. The technical design community is not without success in the design of human-oriented systems. The work of Raymond Loewy (Loewy 1998), Henry Dreyfuss (Flinchum 1997), Louis Sullivan (Sullivan 1956), Frank Lloyd Wright (Pfeiffer 1993), and other industrial designers and architects reveals a rich heritage of design for human experience. The work of these pioneers illustrates intuitive genius but may not fully reveal a systematic process joining human experiential needs with technical requirements and designs. How does the systems engineer make this connection?

Contributors from Other Fields. The systematic study of human-experienced qualities and related behaviors is the domain of other disciplines originating outside engineering. The modern analytical expression of human psychological systems dates back to at least William James (James 1950), Sigmund Freud (Hutchins 1952), Carl Jung (DeLaszlo 1993), and their followers, with the introduction of the logical system concepts such as the Unconscious and Conscious, or Ego and Id, etc. For these pioneers, the systems described did not necessarily have a claimed physical basis--in the terminology of methods described herein, they were “logical” systems not “physical” systems. With the eventual emergence of the disciplines of neuroscience and cognitive psychology in the late twentieth century, researchers such as (Domasio 1994), (Crick 1994), (Edelman 1989), and others explored more deeply the possible physical mechanisms for consciousness, emotion, and their connection to cognitive processes. Studies of the physical basis of human consciousness, emotion, and cognition have most recently moved to the center stage of hard-science sub-disciplines of neuroscience. Arguments about these kinds of logical-physical system associations in humankind are much older. They include the mind-body problem, debated by Descartes (Gaukroger 1995) and others as one of Philosophy’s central questions. Fortunately for the product design engineer on a commercial schedule, we need not answer these questions of the ages to practice an effective system design approach.

Other related work may be found in Model-Based Systems Engineering (AP233 2004) (INCOSE MBSE 2004), (SysML Partners 2004), Quality Function Deployment (QFD) (Clausing et al 1988), Axiomatic Design (Suh 2001), and Fuzzy Set Theory (Zadeh 1965). The framework described here acknowledges and relates these and other conceptual ancestors.

THE APPROACH IN A NUTSHELL

This approach describes an integrated model-based conceptual framework in which product engineers, human factors experts, marketing communication specialists and product planners can work productively together as a team, linking and coordinating their various needs and solutions with improved consistency—while still using different perspectives, tools, and concepts natural to their specialties. We will summarize how "soft" requirements of actual or promoted human experience can be formally described in Model Based Systems Engineering (MBSE) models, using a specific systems engineering methodology (Schindel et al 2002).

This approach uses the MBSE concept of logical systems to represent behavior-based knowledge of softer human dimensions, avoiding the conundrums of the physical basis of mind and experience. The very same MBSE tools are also used to describe the "hard" behavioral requirements of the engineered product with which the human interacts. These two model segments are brought together in a single interacting system domain model, to reveal their inter-dependencies, consistencies, and inconsistencies. Marketing and human factors specialists can "own" the human part of this model, and product engineers can "own" the technical product part of the model. The resulting unified framework provides a more productive means for these two different professional groups to work together to reach a common understanding of product requirements and opportunities to meet human perceived experience objectives.

In further extensions also described here, the same principles are additionally shown to address other types of "soft" problems that apply even to "hard" technical products: competitive choice, marketable features, product positioning, and promotional programs.

INTRODUCTORY PRINCIPLES AND MODELING TECHNIQUES

Modelling Interacting Systems. The perspective here is that requirements of all types ultimately connect to external physical interactions between systems (Schindel 2005). We say that systems "interact" when they can impact each others' (physical) states, through the (physical) exchange of energy, mass, force, or information (all of which are modeled as "Input-Outputs").

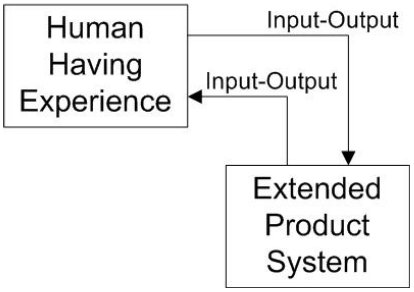


Figure 1: The Perspective of Human-Product Interaction

Such a "physics-like" interaction perspective is summarized at the most abstract level by Figure 1, in which the interacting systems are defined as follows:

1. Extended Product System: Includes the subject system, for which we will specify requirements and design. It may be a manufactured product, a service-providing system, or any system. It is called "extended" because it also includes other systems in the product's domain (environment), with which the human and/or product also interacts.

2. Human Having Experience: This is a human being that interacts with the Extended Product System, for whom we want certain experience-based outcomes to occur.

Modelling "Soft" Qualities of Human Experience. This "physics" oriented model-based strategy for the technical product is extended to soft human experience issues by taking advantage of two key observations:

1. To understand "soft" product requirements based on human emotional or psychological experiences, we must model the *human*, not just the *product*.
2. These models are about externally-observed human behavior, not the internal physical basis of that behavior—we don't have to understand the physical basis of mind to get the practical results needed for the development process.

This methodology uses the concept of Logical Systems to model externally visible behavior—including human behavior as well as engineered systems behavior. This approach allows the introduction and use of concepts familiar to the psychologist, but usually considered by the engineer to be "soft" in nature when applied to humans. It then allows these to be linked in an unbroken model chain to hard technical requirements on engineered product interactions.

The following definition is provided by the referenced methodology: A logical system is a system that is defined based upon its externally visible behavior, not its physical identity. "Externally visible behavior" means that which can be "seen" by other systems through physical interactions with an observed system. This means that we can model logical systems without knowing their physical implementation, much as early psychologists (e.g., Freud) described theories of human psychological structure without need to describe their physical basis. Figure 2 shows a simplistic model illustrating this approach.

Freud was not required to explain the physical basis of Id and Ego in order to use these concepts to advance the description of human psychology. The point here is not whether Freud's early models were "correct" (the reader can substitute a favored model), but rather that these models could be described and externally tested without having to allocate the logical systems of the model to particular physical mechanisms. Such models express the logical architecture of behavior by partitioning that behavior into interacting logical subsystems that are nothing more than components of externally verifiable behavior.

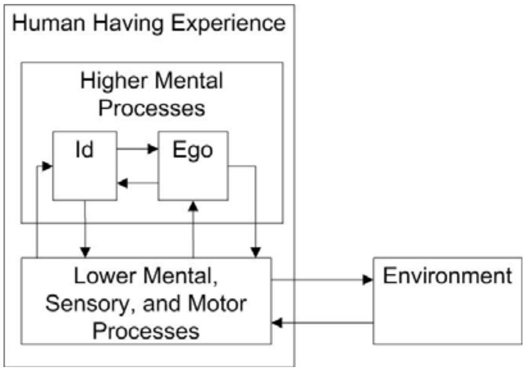


Figure 2: Logical Subsystems Organize Externally Visible Behavior

For example, Figure 3 represents the relatively more elaborate ideas that behavior can be partitioned to include:

1. Hierarchical behaviors concerned with basic functioning, higher level planning, aspirations and values (hierarchy of needs was described by (Maslow 1962));
2. Attention-focusing systems that regulate the application of finite information processing resources to priority issues (LaBerge 1995);
3. Emotional systems that span multiple levels to regulate behavior globally (Damasio 1994)
4. One's own image of oneself, as well as one's environment—also including how one thinks of the product and one's own use of it. (Trout et al 1981).

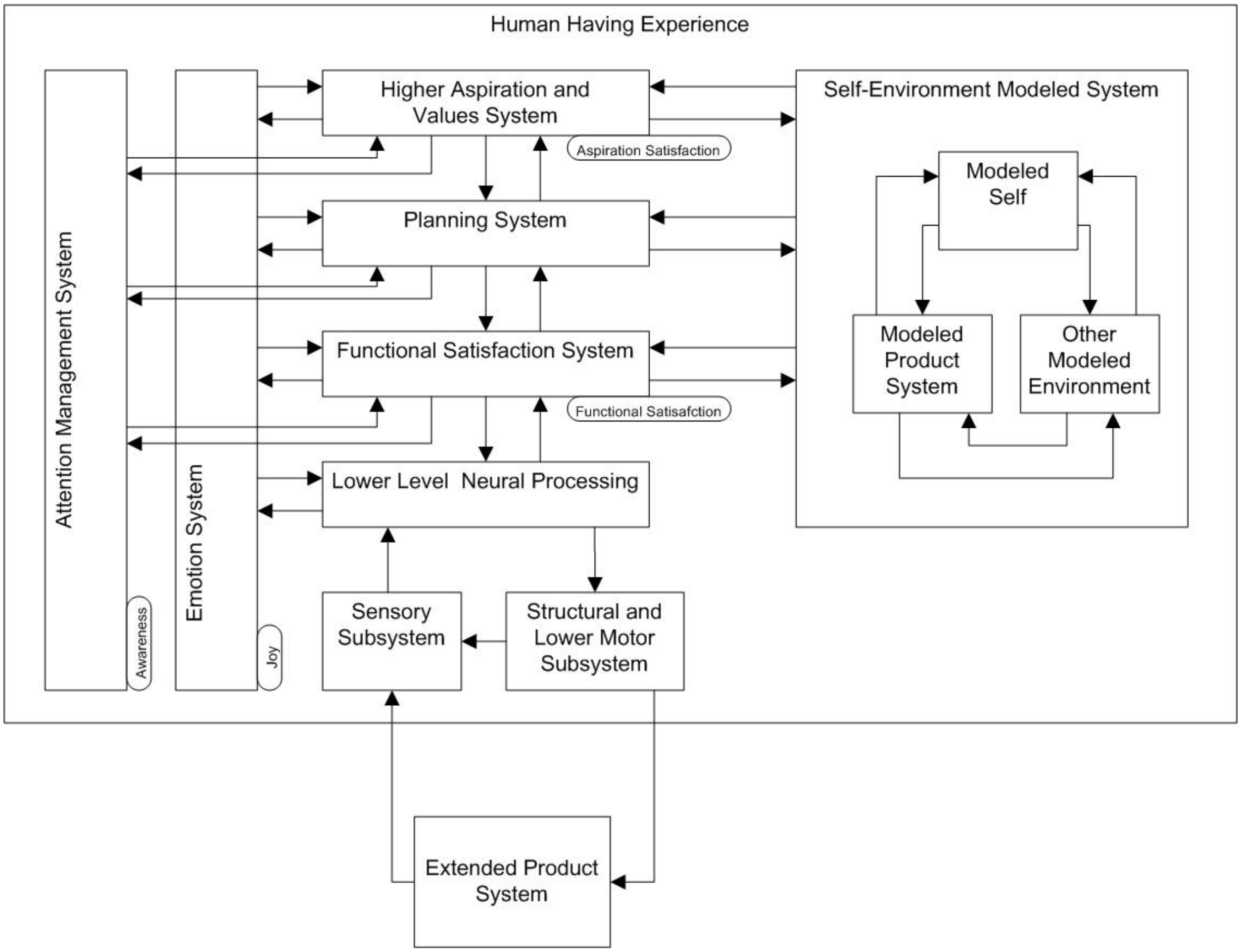


Figure 3: More Elaborate Logical Behavioral Models May Be Constructed

The logical systems shown in Figure 3 accordingly model the following components of externally visible behavior:

1. Sensory Subsystem: Converts "hard" external physical interaction inputs into other representations.
2. Structural and Lower Motor Subsystem: Converts internal signals in the nervous system into external physical output motions or dynamic or static forces.

3. Self-Environment Modeled System: Maintains an internally-perceived model of the self (the human's perception of self) and of its interactions with its environment. This environment includes in particular the Product System. These logical systems are called "modeled" to differentiate them from the "real" external systems—they are the human's constructed, subjective perceptions of those systems and the self. For some products, the modeled attributes of the Self-Environment Modeled System of Figure 3 include some of the most important customer satisfaction attributes to be supported by the hard technology of the Product System.
4. Lower Level Neural Processing: Performs unconscious processing important for regulating bodily processes, survival, and other base functions.
5. Emotion System: Interacts with all levels of conscious and unconscious processes to provide for overall regulation of same.
6. Attention Management System: Manages the resources of conscious level processing to direct limited attention capacity to the highest value perceived situations.

The specific model used above is not the main point—those expert in current or specialized psychological models can replace the example shown with their own logical constructs fit to local needs. The key point here is modeling of human behavioural components for integration with product performance—all in a single integrated framework that enables different professionals to work together more successfully.

By the time interactions are shown between the Human User and the Product System, they include representation of physical Input-Outputs:

- Information:
    - Visual (Appearance)
    - Tactile (Feel)
    - Olfactory (Smell)
    - Audible (Sound)
    - Thermal (Heat and Cold)
    - Informative Forces (Orientation, Pressure, Acceleration)
- Forces (Physical Manipulation)
- Mass Transfer (Ingestion or Secretion / Excretion of Mass)
- Thermal Energy (Heat Transfer)

Modeling the Behavior of the Product

A similar approach is used to model the logical architecture of behavior of the product, including its logical subsystems, as shown in Figure 4. It can be seen that Figures 3 and 4 alternatively "telescope" the product versus human behavioral models, ready for integration together.

The model of the product and human behaviors consist of more than just collaboration diagrams of their logical systems. Other parts of the associated meta-model include Features, (Functional) Interactions, States, and Interfaces. For purposes of this paper, we will focus on the subset of the meta-model concerned with describing the quantitative relationships between the attributes of the person, engineered system, and environment. This requires an understanding of models of

Functional Interactions, their logical Roles, and the quantitative coupling relationships between the attributes that parameterize these roles, discussed in the next section.

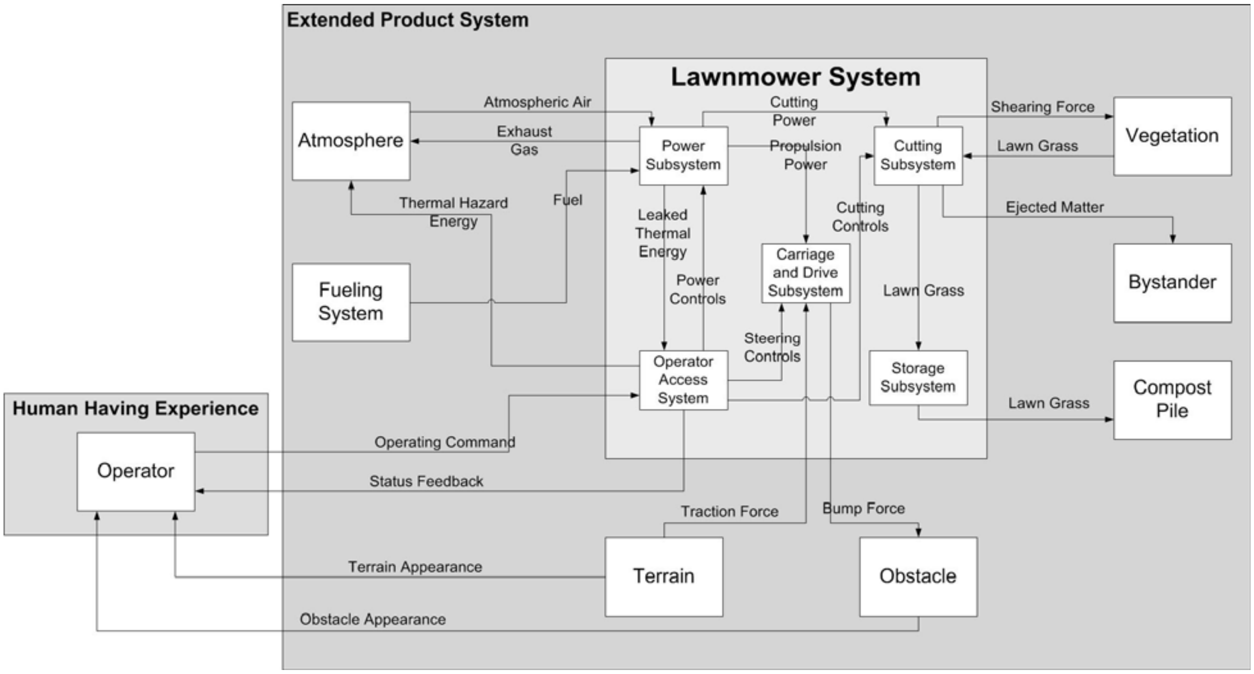


Figure 4: Product System Domain and Logical Architecture

ATTRIBUTE COUPLINGS: MODELS OF INTER-DEPENDENCIES

Integrating the two parts of the model now enables more fully expressing how the structure of "soft" requirements on the product is dependent upon the structure of the human behavior model. For a human directly interacting with the product (see later herein for indirect cases), the chain of dependencies is as follows:

1. Feature and Feature Attributes: The "soft" requirements are imposed by the human experienced (subjective, psychological, emotional) outcomes we seek to optimize by the behavior of the product. The most "outcome oriented" of these characteristics important to product stakeholders will eventually be modeled as the Features and Feature Attributes of the product—even though they describe human experienced outcome states. (See Figures 5 and 6.) This is because the product's attributes express how well it satisfies associated soft human requirements. All features and feature attributes are associated with feature stakeholders, and are always described in the language of their stakeholders, not the technical requirements language of designers. Soft human requirements therefore are described in the language of the human stakeholder or specialists in human studies.
2. Functional Roles and Role Attributes: The Features are associated with the Functional Interactions through which they are experienced. These are physical interactions of the human and product for the cases discussed here, during which physical Input-Outputs are exchanged between the human and product. These Functional Interactions are the systems engineering "glue" that ties together the human and product subsystems. These interactions are in turn broken into multiple Functional Roles that are allocated

individually to the human and product (or to other domain systems involved in the interaction). These roles are the logical systems described earlier—the blocks in Figures 3 and 4. These roles represent the transformation of inputs into outputs, shown in those diagrams. The input-output transformations can be quantitatively described by prose statements, empirical graphs or tables from experience, by equations, by rules of thumb, results of focus groups or surveys, or other transformation descriptions, shown as Requirements Statements in Figure 5. These transformation descriptions are parameterized by attributes of the Roles shown in Figures 3 and 4. These are "knobs" on the transformations that "tune" their input-output characteristics. The roles they parameterize serve to package, organize, and express the development team's best available (hopefully advancing) current knowledge, whether empirical or otherwise, as explicit intellectual assets (IP). *The coupling of Feature to Functional Interaction to Functional Role spans and integrates the two worlds of soft human experienced qualities and hard technical requirements.*

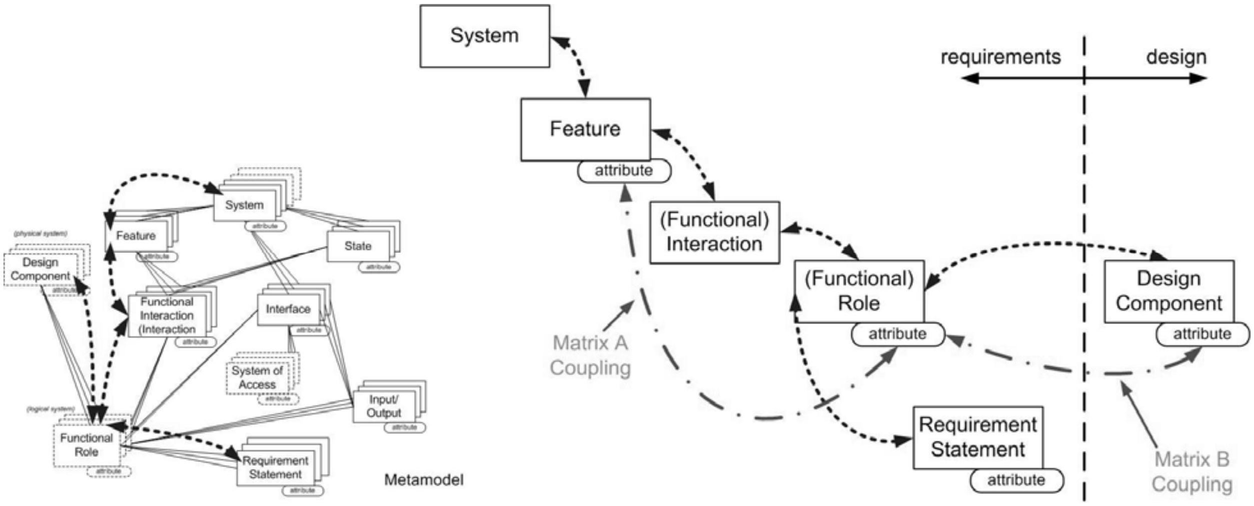


Figure 5: Tracing A Subset of the Metamodel

3. Design Components and Design Attributes: The architecture of the product design is expressed by the (Physical) Design Components and their physical relationships, onto which are allocated the Functional Roles (behaviors). The design is further parameterized by the Attributes of the (Physical) Design Components, themselves tuned to best meet the role-based behavioral requirements.

4. Attribute Couplings: The dependencies of the three types of attributes shown in Figure 5 are expressed by Attribute Couplings, also summarized there. Design Component attribute values are chosen to satisfy technical requirements expressed through Functional Role attribute values. These role attribute values are in turn chosen to satisfy Feature attribute values that express stakeholder needs. These couplings express the dependency of hard technical requirements (as well as design) upon soft human experienced aspects. This also shows how to embed techniques such as QFD (Clausing et al 1988) in the larger framework of Model-Based Systems Engineering. It explains the ideas behind the parametric requirements models supported by SysML (SysML Partners 2004).

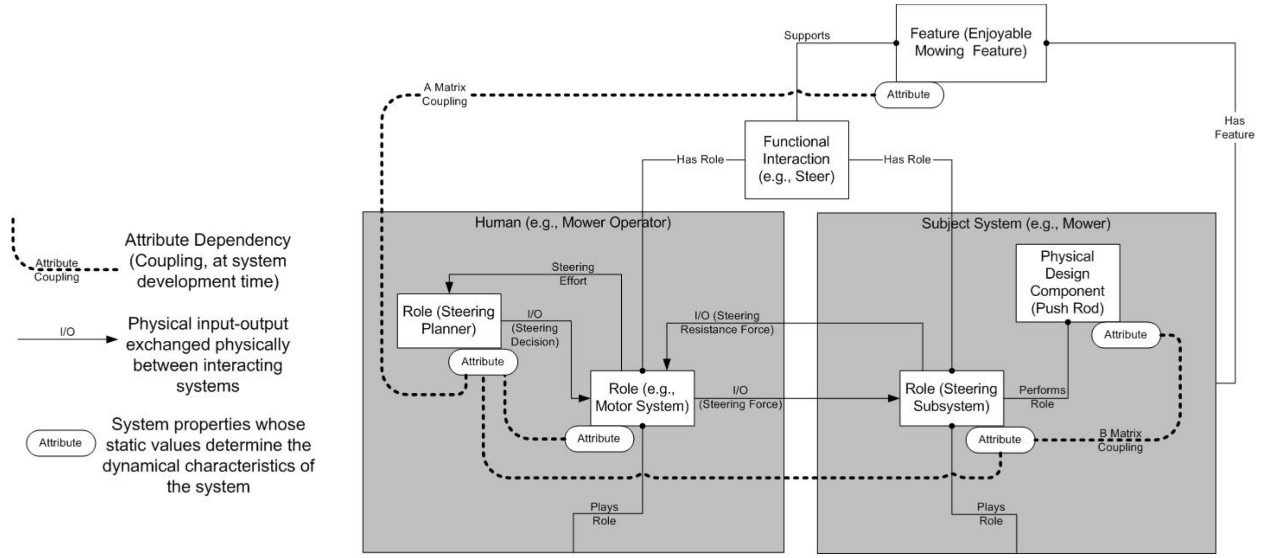


Figure 6: Attribute Coupling Framework

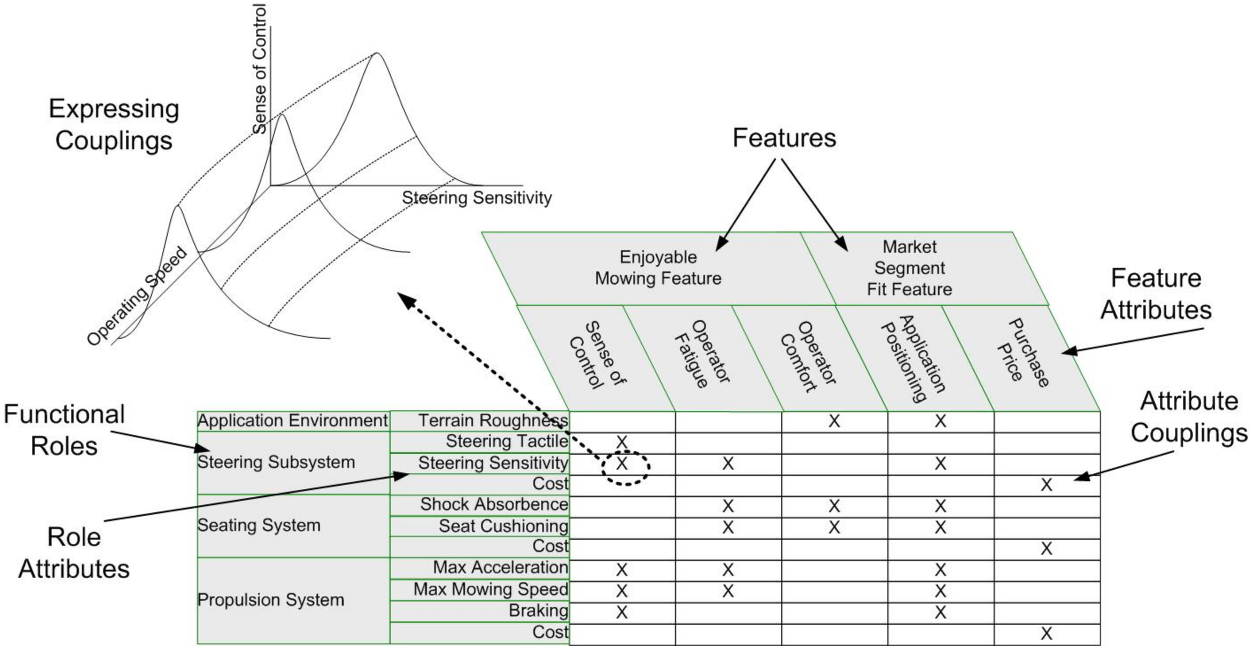
A SIMPLIFIED EXAMPLE

This process ultimately leads to some quantitative expression of the organization's best known (whether empirical, analytical, rule of thumb, or other form of) knowledge about the coupling of subjective Feature Attribute outcomes to technical Role Attribute values. As a simple example, the "A Matrix" of Figure 7 (see also 5 and 6) expresses the organization's knowledge that a number of subjective human operator Feature Attributes for a Lawnmower System are coupled to more technical Role Attributes describing that product's hard technical behaviour. The "X" indications in this matrix represent knowledge of couplings. This may include several levels of knowledge:

1. The simple (binary--yes or no) awareness that there is any significant coupling at all;
2. Awareness of the strength of the coupling;
3. More quantitative knowledge of the coupling (graphs, prose, simulations, tables, field surveys, rules of thumb, standards, etc.—in each case relating the coupled attributes)

In this example, a graph expresses knowledge of the relationship between the lawnmower operator's subjective sense of control (a "feeling") and the steering sensitivity and operating speed of the mower. Instead of a graph as shown, a table of values might have appeared. Still another possibility might have been a reference to a past study or to a person known by the organization to be the current expert on the subject. No matter what the form of the representation of the quantitative coupling relationship, the same framework can be used: couplings of attributes on stakeholder features (including soft/subjective human experience outcomes) to technical role requirements attributes--a universal (and QFD-like) paradigm.

The actual prose form (input-outputs, attributes, relationships) of associated model-based requirements statements(s) is described in detail in (Schindel 2005)—the current paper shows how such prose requirements apply when models describe psychological or human factors, improving requirements effectiveness. As shown in that reference publication, requirements in this form are less ambiguous, easier to inspect for completeness, and easier to test, because they are embedded in and a part of explicit semantic models. This extends the use of prose-only glossaries to "explicate" the meaning of requirements statements using more descriptive models.



		Enjoyable Mowing Feature			Market Segment Fit Feature	
		Sense of Control	Operator Fatigue	Operator Comfort	Application Positioning	Purchase Price
Application Environment	Terrain Roughness			X	X	
Steering Subsystem	Steering Tactile	X				
	Steering Sensitivity	X	X		X	
	Cost					X
Seating System	Shock Absorbence		X	X	X	
	Seat Cushioning		X	X	X	
	Cost					X
Propulsion System	Max Acceleration	X	X		X	
	Max Mowing Speed	X	X		X	
	Braking	X			X	
	Cost					X

Figure 7: Simple Example of Attribute Coupling Matrix A (Features-Roles)

This approach also enhances validation and verification of human-oriented aspects. The validation of the Feature-Role couplings summarized by the A Matrix checks our understanding of human behaviour—not that of the product, but still essential to validating its requirements—and can frequently be addressed through simulation (or prototyping or other approach) of the product to humans. The verification of the Logical Role-Design Component couplings summarized by the B Matrix verifies that a product design meets the technical input-output (black-box) requirements. Finally, an overall validation of a real designed product in the hands of the human combines these two in an end-to-end test. Separating them improves understanding of both the stakeholders and the product.

EXTENSIONS: ALL SYSTEMS ARE SOFT

It turns out that the above techniques are important for designers of all systems—not just those who design direct human-interaction types of products.

All Engineered Systems Have Human Stakeholders. Many products and systems don't have direct interactions with humans while performing their primary mission, thereby seeming to avoid the human experienced qualities challenges described above. A submersible pump in a deep well, an orbiting surveillance system, an undersea communication cable, and other even less isolated systems may conduct their primary missions without direct human interactions (notwithstanding the parts of their life cycles involving direct human interaction for fabrication, installation, or maintenance). Many such products primarily interact with other hard technology systems, instead of people, in performing their primary mission. The engineer may believe that the requirements of such systems are easier to specify than those that directly interact with humans, and their designers may be envied by the designer who must deal with more human-intensive systems. Indeed, prose form technical requirements for these systems may be generated by physical interaction model-based means (Schindel 2005).

However, to claim that this avoids human factors challenges is to overlook a critical commercial fact of life. All engineered systems are created for some intended purpose, and on behalf of some human stakeholder, even if the stakeholder is not a direct user of the system. Stakeholders represent a form of market for the system to be designed. Stakeholders or their representatives may include purchasers, shareholders, financiers, general managers, sales organizations, customers of customers, regulators, and others. The "markets" they populate value those systems on a relative scale, ranking some products over others. The difference in these valuations can spell the difference between commercial success and failure in competitive markets. The engineering organizations of these businesses will eventually discover that the judgments rendered by such markets are themselves something other than the objective stuff of physics. The *perceived value* of a pump, satellite, or cable includes *subjective judgments* made by humans. The *relative utility* of these systems is the subject of utility theory (Bell et al 1988), (Keeney et al 1993), (Nash 1950), (von Neumann et al 1953) which is itself embedded in the study of human psychology and mathematics. Every engineered system, no matter how technical, is ultimately subject to "soft" human judgments, and these are overlooked at the peril of the designer.

All Engineered Systems Require "Life Cycle Marketing Support". Whether sold into commercial markets or defended to institutional administrators, every engineered system requires marketing support over its life cycle, including connecting its engineering process to the "marketplace" for that system. The marketplace description and advertising of commercial consumer and industrial product and service offerings have evolved in sophistication through over a century of modern practice. Today, products are subject to "positioning" by planners, to occupy certain "mental spaces" in the marketplace, with respect to perceptions of competition, the buyer's self-image, and other factors (Trout et al 1981). Although one result of this positioning effort is the content of product advertising and promotional campaigns, we are frequently reminded that our actual engineered products need to back up (or drive!) the claims of advertising with real performance that is consistent with those claims. We need assurance that our promotional programs and product designs will reinforce each other for an optimum use of the assets employed. However, they are described in the languages of very different professions and organizations. As a result of this built-in disconnection of perspective, the disparity between "what Engineering designed", "what Marketing sold" and "what the Customer wanted" has become the subject of popular cartoons. When product positioning promotes various images of a psychological nature using the power of suggestion and association, how does the product design engineer practically incorporate these "requirements" into the actual technical specification and design of the product? We again have a case of "soft versus hard" requirements.

All Product Stakeholders Eventually Interact at Least Indirectly with the Product. In systems engineering terms, it may seem a long way indeed from the physical aircraft to the aircraft company's shareholder, but their (indirect) physical interaction is very real and important. Without it, there would be no relationship whatsoever between the price of company shares and the performance of the aircraft. Investors will indeed debate how "real" this coupling is when they see peculiar share price performance in comparison to the product. But this equity market complexity only serves to underline the points of this paper concerning "soft" requirements. Were a stakeholder to be totally isolated from even indirect interaction with the product, then by definition they would have no stake in that product—a contradiction proving the point.

We can now return to Figure 1, add to it as Figure 8, and re-interpret it more generally, to extend the methods described in this paper:

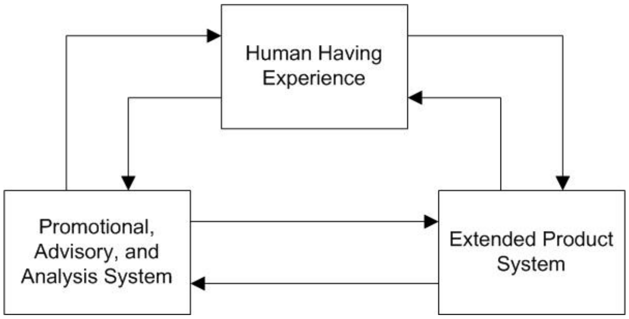


Figure 8: Extensions to the Abstract Model of Figure 1

2. Human Having Experience: This is a human being that interacts *even indirectly (i.e. through intermediate people or other systems)* with the subject system within the Extended Product System, for whom we want certain experience-based outcomes.
3. Promotional, Advisory, and Analysis System: This is a system that communicates product-related usage information to and from the Human User and Product System (either one or both). This is intended by the supplier of the Product System to (a) cause selection and purchase of the Product System or the services it provides, (b) communicate advice on how to use or interact with the Product System, and (c) collect and analyze information on how the User thinks about, selects, or interacts with the Product System. (This "system" need not be high technology in nature—it could be based on mail telephone surveys, focus groups, consumer observation, or more sophisticated web sites or built-in monitoring technologies.)

All human Stakeholders in the subject system are therefore included in this definition. Every such Stakeholder is associated with Features of the subject system that represent the value-centric outcomes that the Stakeholder seeks from the subject system. These are subject to the same models and model coupling methods as described earlier above.

The informational "messages" produced by the Promotional and Advisory System and consumed by the Human User are meant to establish the preliminary models of the Self-Environment Modeled System even before experience with the Product System. The physical interactions with the Product System are required to reinforce those same models.

PATTERNS: LEVERAGING EXPERTISE ACROSS PRODUCT LINES

Understanding the soft requirements of human stakeholders and how they imply technical product requirements is highly valuable to a competitive organization, and not lightly accomplished. The resulting knowledge represents some of the most valuable intellectual assets of the organization. Preserving this information for repeated use across different configurations of products or systems in a large product line enterprise is highly desirable. The models described in this paper can be made to be configurable across product lines or system families, to meet differing market segment or application requirements. (Refer to Figure 9.) This leverages the knowledge of the most expert players and makes it available across the organization.

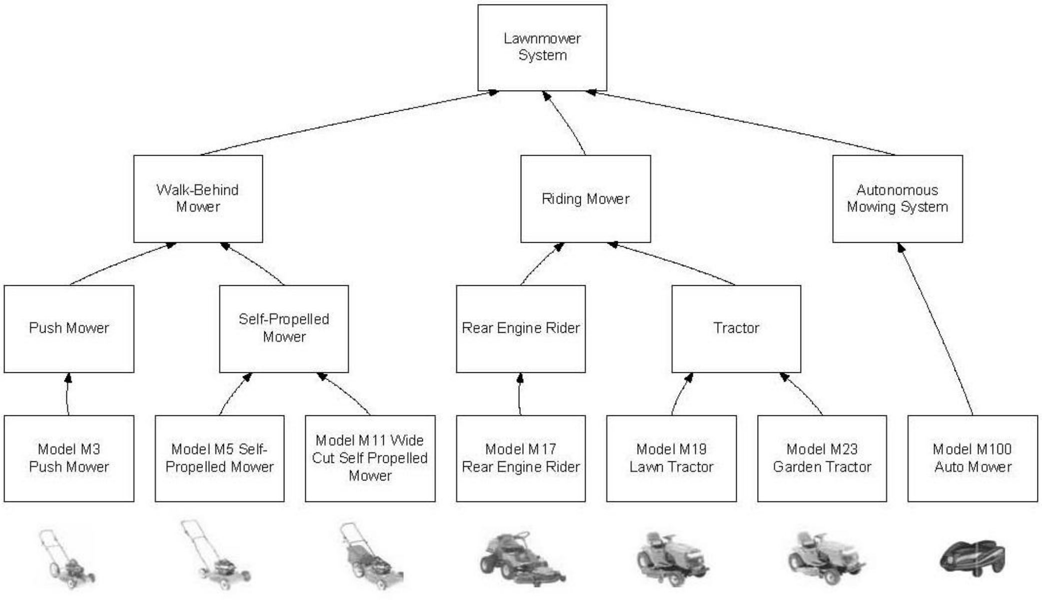


Figure 9: Patterns of Soft and Hard Requirements, Configurable Across Product Lines

CONCLUSIONS AND RESULTS

Summarizing the results and conclusions:

1. Decomposed as described in this paper, “soft” requirements can be expressed in the form best-suited to the human experienced disciplines in which these arise (human factors, marketing, psychology, consumer research, cognitive science), but directly coupled to “hard” engineering requirements without loss of fidelity. This aids both forms, and unifies traditional disciplines for soft requirements with both technical requirements writing and model-based development
2. The shared understanding of multi-disciplinary teams can be improved, by better understanding the origin of hard requirements in soft human factors, and the form of their inter-dependent coupling.
3. Expressing couplings to other stakeholders, the same techniques can be used to express <u>all</u> stakeholder requirements, improving the understanding of stakeholder perspectives by the technical design team.

4. This improves the ability to write, understand, inspect, and use hard requirements, and improves the usual discipline of writing requirements statements, while maintaining traditional principles of requirements.
5. This approach also improves the ability to create requirements patterns—libraries of configurable, re-usable requirements, improving the performance of the engineering process across larger product line and COTS enterprises.
6. The treatment of soft requirements by methods such as QFD and Axiomatic Design can be unified with the total development process.
7. Automated modelling and requirements tools can increase in their capabilities using this paradigm. We have applied this approach using the systems engineering and modelling tools of a number of tools suppliers.
8. Less experienced engineers can apply these concepts to improve their requirements writing and modelling. We have successfully taught this approach to undergraduate and graduate engineering students, as well as practicing engineers in commercial and mil-aero organizations.

REFERENCES

1. AP233 (ISO 10303) Web Site, http://step.jpl.nasa.gov/AP233/ , 2004.
2. Barberà, Salvador; Hammond, Peter; Seidl, Christian (Eds.), *Handbook of Utility Theory*, 2004, ISBN: 1-4020-7965-6
3. Bell, D. E., Raiffa, H., & Tversky, A. (Eds.). (1988). *Decision Making: Descriptive, Normative, and Prescriptive Interactions*. New York: Cambridge University Press.
4. Clausing, D., and Hauser, R., “The House of Quality", *Harvard Business Review*, May-June, 1988.
5. Crick, Francis J., *The Astonishing Hypothesis*, Charles Scribners, 1994.
6. Damasio, Antonio R., *Descartes’ Error: Emotion, Reason, and the Human Brain*, Putnam, 1994.
7. De Laszlo, Violet S. (ed.), *The Basic Writings of C. G. Jung*, New York: Random House, 1993.
8. Edelman, Gerald M., *The Remembered Present: A Biological Theory of Consciousness*, Basic Books, 1989.
9. Flinchum, Russell, *Henry Dreyfuss, Industrial Designer: The Man In The Brown Suit*, New York: Rizzoli International Publications, 1997.
10. Gaukroger, S., *Descartes: An Intellectual Biography*, Oxford: Clarendon Press, 1995.
11. Hutchins, Robert M., editor, *The Major Works of Sigmund Freud*, Great Books of the Western World, Vol. 54, William Benton, Publisher, 1952.
12. INCOSE MBSE, INCOSE Model Driven System Design Working Group web site, `http://www.incose.org/practice/techactivities/modelingtools/mdsdwg.aspx` , 2004.

13. James, William, *The Principles of Psychology*, Volumes 1-2, Dover Publications, 1950.
14. Keeney, R. L., & Raiffa, H. (1993). *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*, New York: Cambridge University Press.
15. LaBerge, David, *Attentional Processing: The Brain's Art of Mindfulness*, Cambridge, MA: Harvard U. Press, 1995.
16. Loewy, Raymond, *Industrial Design*, Overlook TP, 1998.
17. Maslow, Abraham H., *Toward a Psychology of Being*, D. Van Nostrand Company, 1962.
18. Nash Jr., John F. "The Bargaining Problem". *Econometrica* 18:155 1950.
19. Pfeiffer, Bruce B. (ed.), *Frank Lloyd Wright: Collected Writings*, New York: Rizzoli International Publications, 1993.
20. Piaget, Jean, *Biology and Knowledge: An Essay on the Relations Between Organic Regulations and Cognitive Processes*, The University of Chicago Press, 1971.
21. Schindel, W., and Smith, V., "Results of Applying a Families-of-Systems Approach to Systems Engineering of Product Line Families", SAE International, Technical Report 2002-01-3086, November, 2002.
22. Schindel, William D., "Requirements Statements Are Transfer Functions: An Insight from Model-Based Systems Engineering", *Proceedings of INCOSE 2005 Symposium*, July, 2005.
23. Sullivan, Louis H., *The Autobiography of an Idea*, Dover edition, New York: Dover, 1956.
24. Suh, Nam P., *Axiomatic Design: Advances and Applications*, NY: Oxford U. Press, 2001.
25. SysML Partners Web Site, `http://www.sysml.org/, 2004.`
26. Trout, Jack and Ries, Al, *Positioning: The Battle for Your Mind*, McGraw-Hill, 1981.
27. von Neumann, J., Morgenstern, O., *Theory of Games and Economic Behavior*, 1953 edition, Princeton, NJ: Princeton University Press.
28. Zadeh, L. A., "Fuzzy Sets" *Information and Control*, vol. 8, 1965, pp 338-353.

Biography

William D. Schindel is president of ICTT, Inc., a systems engineering company, and developer of the Systematica™ Methodology for model and pattern-based systems engineering. His 36-year engineering career began in mil/aero systems with IBM Federal Systems, Owego, NY, included service as a faculty member of Rose-Hulman Institute of Technology, and founding of three commercial systems-based enterprises. He has consulted on improvement of engineering processes within automotive, medical/health care, telecommunications, aerospace, and consumer products businesses. Schindel earned the BS and MS in Mathematics, and was awarded the Hon. D.Eng by Rose-Hulman Institute of Technology for his systems engineering work.

V1.2.7