Developing Specifications as Goals for the Engineering Design Process

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Goal of these slides:

Describe the procedures that engineers use to convert customer requirements to engineering specifications.

Terminology

Equivalent terms:
Market requirements
Customer requirements
Customer needs

Equivalent terms:
Performance measures
Performance specifications
Engineering requirements

Opportunity development phase requires

1. Identifying the market requirements
2. Determining appropriate performance measures
3. Mapping market requirements to performance measures

The textbook by Mattson and Sorensen use the terms “Market requirements” and “Performance measures”.

Market requirements and performance measures

Market requirements

- Are characteristics of a desirable product or process
- May be expressed quantitatively or qualitatively

Performance measures

- Provide concrete metrics (measures of success) used in the engineering design process
- Ideally are measurable performance goals

In addition to obtaining lists of market requirements and performance measures, we need to specify the relationships between market requirements and performance measures.

Specification = metric + value

metric
(noun) technical: a system or standard of measurement

Concise Oxford English Dictionary, Revised 10th ed., 2002, Oxford University Press

Examples of metrics

Temperature of water bath

Weight of seat assembly

Time to close door

Velocity at impact

Force necessary to latch

Standards by which performance is measured.

Not the values of the metrics or the means of obtaining the performance.

Note

- Metrics will have associated values, but metrics are a *category of performance*, *not the value itself*
- Metrics are *independent* of the design implementation

Metrics are used to measure performance

What, not how:

- Metrics define the way that an engineering requirement will be measured
- Metrics do **not** specify **how** a need is met
  - Metrics *do not specify* the *implementation*
  - Example: A weight metric may be met by a choice of material, a reduction in structural components (for a given material), by a change in how structure is supported. The metric does not choose the method.
- Metrics do **not** specify **whether** a need is met
- Metrics allow design options to be compared

Metrics should be dependent variables

A designer's choices determine how well the design meets requirements as measured by metrics.

- Metrics are outcomes from design choices.
- Designers make choices: Those choices result in values for metrics.

Example

An engineer chooses to make a part out of aluminum instead of steel:

- Choice leads to a value of weight metric
- Choice leads to a value of deflection metric

Recommendations for Metrics

1. Metrics should be complete
   - All market requirements should be covered
   - Any market requirement can correspond to one or more metric
2. Metrics should be dependent variables
   - Goal is to use design choices to satisfy performance requirements that are measured by metrics
   - Metrics reflect an outcome of design choices
3. Metrics should be practical
   - Relevant to the object or process being designed
   - Measurable with resource available to the team

Karl. T. Ulrich and Steven D. Eppinger, Product Design and Development, 5th ed., 2012, McGraw-Hill, Chapter 6

Recommendations for Metrics

4. Qualitative metrics are OK, though more challenging to evaluate
    - Example: Easy-to-use
    - Example: “cool”, “modern”, “sporty”
    - Don’t absolutely avoid qualitative metrics. If possible, find less subjective surrogates.
5. Metrics should reflect common criteria for the marketplace
    - Example: Fuel efficiency in MPG
    - Example: Camera resolution in megapixels

Karl. T. Ulrich and Steven D. Eppinger, Product Design and Development, 5th ed., 2012, McGraw-Hill, Chapter 6

Qualitative or Subjective Metrics

Remember that the **goal** is to create a product that is **desirable** in the market.

How do you quantify “cool”, “fashionable”, “comfortable”, “easy-to-use”?

Qualitative metrics should rely on additional measurements of customer satisfaction

- User testing with prototypes or existing products
- Comparison to competitive benchmarks
- Surveys and other market research

Specification = metric + value

Ways of specifying values for metrics

At least X

- A minimal acceptable value
- higher is better

At most X

- Maximum acceptable value
- Lower is better

Between X and Y

- Anywhere in the range is acceptable

Exactly X

- Avoid if possible

A set of discrete values (e.g. pipe sizes)

Karl. T. Ulrich and Steven D. Eppinger, Product Design and Development, 5th ed., 2012, McGraw-Hill, Chapter 6

Values of metrics can take on continuous or restricted values

Many conventional engineering quantities have continuous values and obvious units

- Mass (kg), force(N), temperature (°C), velocity (m/s)

Some metrics can only take on discrete values

- Common when requirement is to be compatible with some other feature
- Examples: Pipe diameter, tire sizes, bolts

Some metrics will have yes/no values

- “has adjustable height”
- “meets mil-spec”

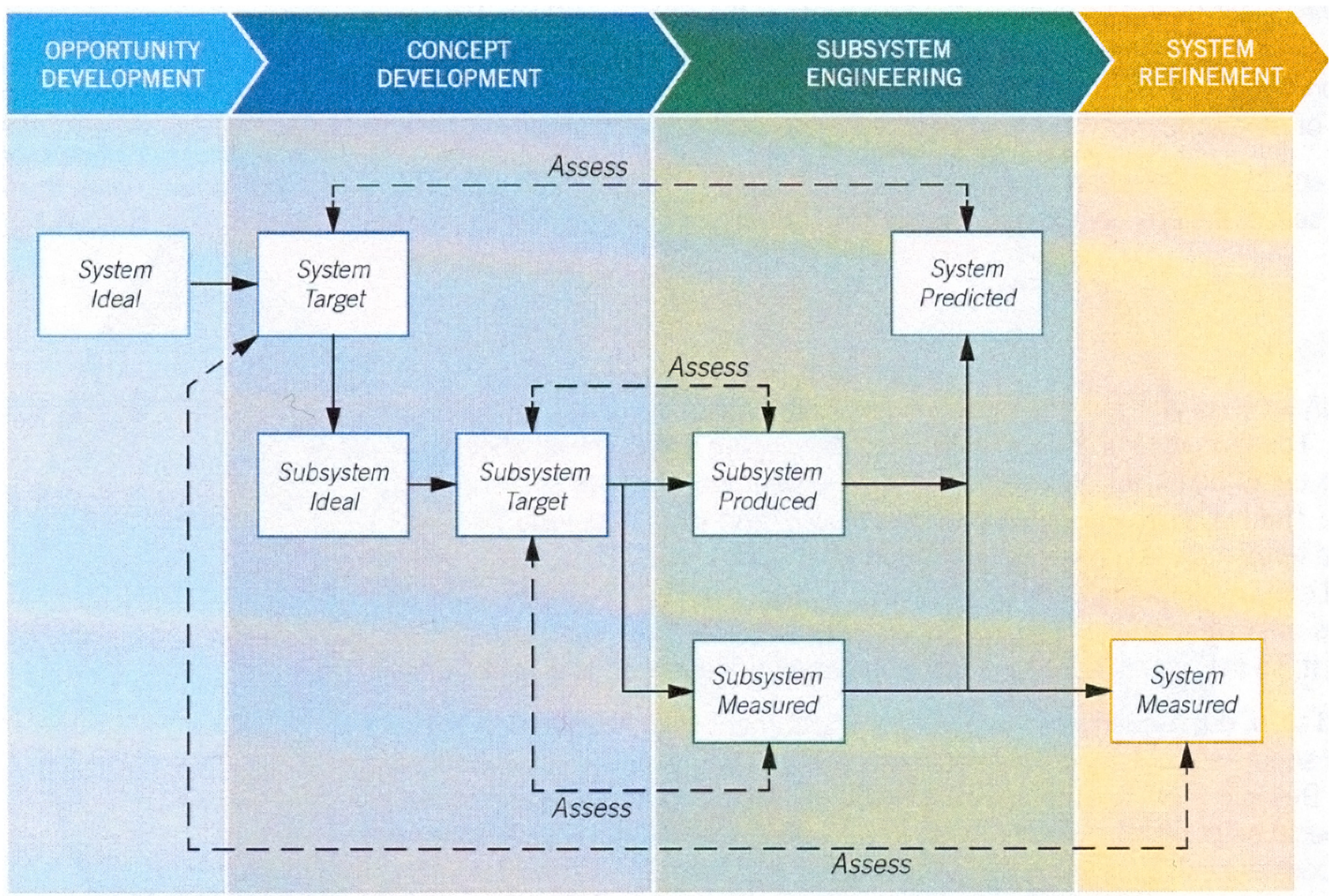
Two-stage process for establishing specifications

Stage 1: Set ideal and marginal target values

- Occurs after listing and prioritizing customer requirements
- Team decides (guesses) what will best satisfy customer requirements
- Iteration may be required
- Goal is to enable conceptual design

Stage 2: Revisit specifications after completing conceptual design

Mattson and Sorensen show how performance measures evolve



Real values for the performance measures evolve during product development. Target values for systems and subsystems are identified during concept development. Predicted values for the system, and measured and predicted values for subsystems, are obtained during subsystem engineering, and are assessed by comparing with the appropriate target values. During system refinement, measured values for the system are obtained and compared with the targets. As the design continues to evolve, measured and/or predicted values will likely change as well. Each time they change, they should be compared with the target.

Image from p. 289 of *Fundamentals of Product Development*, 5th ed., 2017, by Christopher A. Mattson and Carl D. Sorensen

Case Study: Human-powered well drilling device

Mattson and Sorensen present a detailed case study of a human-powered well drilling device in the textbook for this class. See Section 4.2 for a summary of market requirements, performance measures and the presentation of a Requirements-matrix.

Christopher A. Mattson and Carl D. Sorensen, *Fundamentals of Product Development*, 4th ed. 2016, Brigham Young University

Case Study: Bicycle Fork

Ulrich and Eppinger present a case study of developing performance specifications for a front suspension of a mountain bicycle.

Karl. T. Ulrich and Steven D. Eppinger, Product Design and Development, 5th ed., 2012, McGraw-Hill, Chapter 6

Condensed list of customer needs for suspension system of a mountain bicycle

EXHIBIT 6-2
Customer needs for the suspension fork and their relative importance (shown in a convenient spreadsheet format).

No.	Need		Imp.
1	The suspension	reduces vibration to the hands.	3
2	The suspension	allows easy traversal of slow, difficult terrain.	2
3	The suspension	enables high-speed descents on bumpy trails.	5
4	The suspension	allows sensitivity adjustment.	3
5	The suspension	preserves the steering characteristics of the bike.	4
6	The suspension	remains rigid during hard cornering.	4
7	The suspension	is lightweight.	4
8	The suspension	provides stiff mounting points for the brakes.	2
9	The suspension	fits a wide variety of bikes, wheels, and tires.	5
10	The suspension	is easy to install.	1
11	The suspension	works with fenders.	1
12	The suspension	instills pride.	5
13	The suspension	is affordable for an amateur enthusiast.	5
14	The suspension	is not contaminated by water.	5
15	The suspension	is not contaminated by grunge.	5
16	The suspension	can be easily accessed for maintenance.	3
17	The suspension	allows easy replacement of worn parts.	1
18	The suspension	can be maintained with readily available tools.	3
19	The suspension	lasts a long time.	5
20	The suspension	is safe in a crash.	5

Karl. T. Ulrich and Steven D. Eppinger, Product Design and Development, 5th ed., 2012, McGraw-Hill, Chapter 6

Performance metrics for suspension system of a mountain bicycle

Metric No.	Need Nos.	Metric	Imp.	Units
1	1, 3	Attenuation from dropout to handlebar at 10 Hz	3	dB
2	2, 6	Spring preload	3	N
3	1, 3	Maximum value from the Monster	5	g
4	1, 3	Minimum descent time on test track	5	s
5	4	Damping coefficient adjustment range	3	N-s/m
6	5	Maximum travel (26-in. wheel)	3	mm
7	5	Rake offset	3	mm
8	6	Lateral stiffness at the tip	3	kN/m
9	7	Total mass	4	kg
10	8	Lateral stiffness at brake pivots	2	kN/m
11	9	Headset sizes	5	in.
12	9	Steertube length	5	mm
13	9	Wheel sizes	5	List
14	9	Maximum tire width	5	in.
15	10	Time to assemble to frame	1	s
16	11	Fender compatibility	1	List
17	12	Instills pride	5	Subj.
18	13	Unit manufacturing cost	5	US$
19	14	Time in spray chamber without water entry	5	s
20	15	Cycles in mud chamber without contamination	5	k-cycles
21	16, 17	Time to disassemble/assemble for maintenance	3	s
22	17, 18	Special tools required for maintenance	3	List
23	19	UV test duration to degrade rubber parts	5	hr
24	19	Monster cycles to failure	5	Cycles
25	20	Japan Industrial Standards test	5	Binary
26	20	Bending strength (frontal loading)	5	kN

EXHIBIT 6-4 List of metrics for the suspension. The relative importance of each metric and the units for the metric are also shown. "Subj." is an abbreviation indicating that a metric is subjective.

Karl. T. Ulrich and Steven D. Eppinger, Product Design and Development, 5th ed., 2012, McGraw-Hill, Chapter 6

Needs-metrics matrix for suspension system of a mountain bicycle. See Requirements Matrix in textbook by Mattson and Sorensen

	Need	1 Attenuation from dropout to handlebar at 10 Hz	2 Spring preload	3 Maximum value from the Monster	4 Minimum descent time on test track	5 Damping coefficient adjustment range	6 Maximum travel (26-in. wheel)	7 Rake offset	8 Lateral stiffness at the tip	9 Total mass	10 Lateral stiffness at brake pivots	11 Headset sizes	12 Steertube length	13 Wheel sizes	14 Maximum tire width	15 Time to assemble to frame	16 Fender compatibility	17 Instills pride	18 Unit manufacturing cost	19 Time in spray chamber without water entry	20 Cycles in mud chamber without contamination	21 Time to disassemble/assemble for maintenance	22 Special tools required for maintenance	23 UV test duration to degrade rubber parts	24 Monster cycles to failure	25 Japan Industrial Standards test	26 Bending strength (frontal loading)
1	Reduces vibration to the hands	•		•	•																						
2	Allows easy traversal of slow, difficult terrain		•																								
3	Enables high-speed descents on bumpy trails	•		•	•																						
4	Allows sensitivity adjustment					•																					
5	Preserves the steering characteristics of the bike						•	•																			
6	Remains rigid during hard cornering		•						•																		
7	Is lightweight									•																	
8	Provides stiff mounting points for the brakes										•																
9	Fits a wide variety of bikes, wheels, and tires											•	•	•	•												
10	Is easy to install															•											
11	Works with fenders																•										
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13	Is affordable for an amateur enthusiast																		•								
14	Is not contaminated by water																			•							
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18	Can be maintained with readily available tools																						•				
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20	Is safe in a crash																									•	•

EXHIBIT 6-5 The needs-metrics matrix.

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Reading in the textbook by Mattson and Sorensen

Chapter 4: Opportunity Development

Developing market requirements

- Interviews, pp. 252-253
- Observational studies, pp. 262-263
- Surveys

Performance Measures & Market Requirements

- Quality function deployment, pp. 276-277
- Requirements matrix, pp. 284-287

References

1. Christopher A. Mattson and Carl D. Sorensen, 2016, *Fundamentals of Product Development*, 4th ed., Brigham Young University, Chapter 4 and Part 2
2. Karl. T. Ulrich and Steven D. Eppinger, Product Design and Development, 5th ed., 2012, McGraw-Hill, Chapter 6.