WORLD-CLASS MANUFACTURING

current advances in the digital revolution have made it possible

- To do business,
- Develop a new product,
- Instantaneously with almost any other people across the world.

World-class manufacturing is achieved by those companies which are best in the field at each of the competitive priorities such as

- Quality,
- Price,
- Delivery speed,
- Delivery reliability,
- Flexibility,
- Innovation.

PRODUCT PROTOTYPING AND ITS IMPACT

PROTOTYPE DESIGN AND INNOVATION

- Product prototyping can be used as an evaluation tool in the engineering design process.
- Prototyping plays a key role in product innovation.
- Prototyping helps to quickly develop a product by providing a good tool for problem solving and can validate a concept.

Issues That Cause Product Innovation Failures

Rank/Issues	Role	Causes	Comments
1. Market obstacles	Major	Missing demands	Need
		Product pricing	Cost
		Late-to-market	Time
2. Management issues	Medium	Poor market analysis	Need
		Understaffing	Time/cost
		Lack of capital resources	Cost
3. Technology issues	Minor	Dated technical approach	Performance Quality
		Design problems	Performance Quality
		Poor quality	Quality
4. Others	Minor		Other

IMPACT ON COST,QUALITY, AND TIME

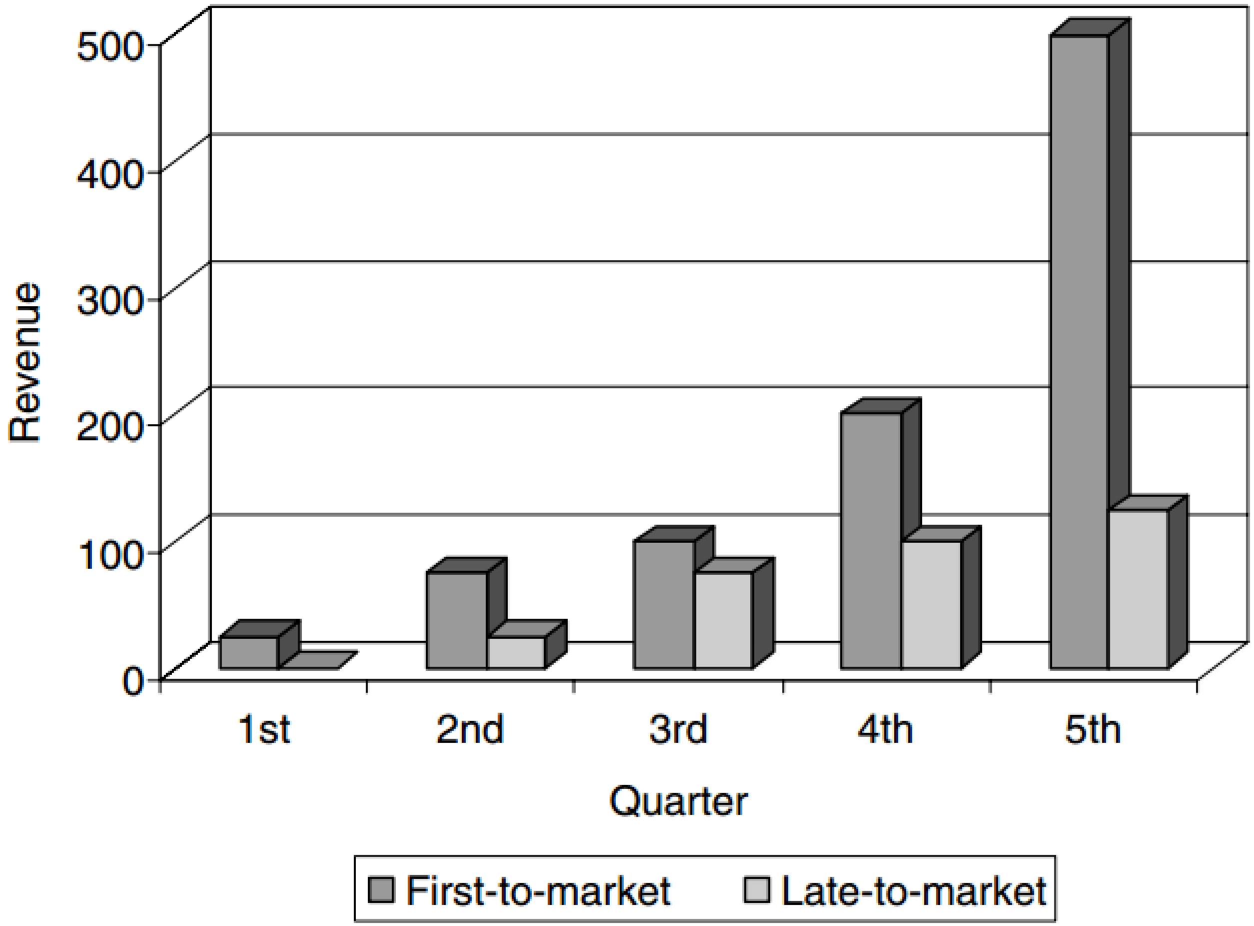
The direct impact of a shorter product development time includes the opportunity to sell the product at **premium prices early in the life cycle**, and **enjoy longer market life cycle.**

The benefits include faster breakeven on development investment and lower financial risk, which leads to greater overall profits and higher return on investment (ROI).

The ROI of the a product can be estimated as

$$\text{Net profit}/[(\text{Development cost}) \times (\text{Time-to-market})]$$

Time-to-market can significantly impact product development cost and can even be more critical to the ROI.



The impact of an example of timing to market on product revenue.

KEY PROCESS REQUIREMENTS FOR RAPID PROTOTYPING

Traditional design ideologies require that engineers construct a variety of **physical prototypes to test and evaluate design concepts.**
The design and analysis of new products can become very time-consuming and expensive.

New technologies involving rapid and virtual prototyping are revolutionizing the way products are designed.

Virtual prototyping, for example, **integrates digital technologies such as computer-aided design (CAD), computer-aided engineering (CAE), and computer-aided manufacturing (CAM) data**, into a single visual environment for viewing and analysis.

when companies are **building large assemblies**, they face a **bigger challenge** in the managing of their products, **and virtual prototyping technologies have proven to be very effective.**

For example, the **Boeing 777 airplane consists of 3 million parts**, and the fabrication involved **545 suppliers, and 22,900 composites**.

Thousands of engineers participated in the activities, using 100% digital product definition for digital preassembly.

The 777 was designed by cross-functional teams using thousands of terminals and a computer-aided, 3-D interactive application (CATIA) system that allowed engineers to simulate the assembly for the 777 without resorting to physical prototypes.

Rapid prototyping which can rapidly create physical prototypes along with virtual prototyping can be very effective in accelerating the product development process.

It can increase visualization capability during the early phases of design by using rapid physical models.

It can test and improve design before the manufacture of tooling.

PRODUCT PROTOTYPING AND PRODUCT DEVELOPMENT

PROTOTYPING

The complexity of the global market environment not only makes the **product cheaper, better, faster to the consumers,** but also **increases severe competition** for product producers.

The trend in industry is

- **To use simulation technologies in all design phases** from the concept to the final implementation.
- **To minimize prototype tests on actual full-size systems** by improving virtual modeling technologies.
- **To use automatic code generation technologies for rapid prototyping**.

These simulations**, virtual prototyping, and rapid prototyping activities** are all part of the **product prototyping activities**.

Prototyping has huge implications **on product cost, quality, and time**.

To select a **prototyping process** that not only serves the **prototype's purpose**, but also keeps **cost low**.

Material and process criteria for every prototype are important.

Prototyping can help everyone visualize the same end result so that there is no ambiguity, and everyone is on the same track.

Depending on various prototyping applications, **prototyping methods** can be classified into **physical or analytical methods**.
For example, **simulation approach is an analytical method**,
clay mock-up is a physical prototype.

From a different angle, prototypes can also be classified as **comprehensive or focused prototypes**.

For example, when a prototype is used to test **the "look" of a product**, this prototype may be **made from foam** for the purpose, and thus it is a look **focused prototype**.

On the contrary, a full vehicle **prototype built to test** its full functions would be a **comprehensive prototype**.

Within traditional prototyping methods, engineers created new products by using techniques, very different from **today’s cost-effective, faster, and quality-based processes**, which demonstrate the following features:

- **Traditional prototyping methods allowed the engineers to create only a static mock-up of what the interface looked like**. It was not a dynamic process and the prototypes were not alive enough to enable the designer to test the real world usage of the product.

- **Engineers had to use manual tools to create prototypes but since these tools were manual, it is difficult to show all user requirements with a single prototype**. That is why the designers, most of the time, had **to develop separate prototypes for the same end product** to be able to see various user requirements.

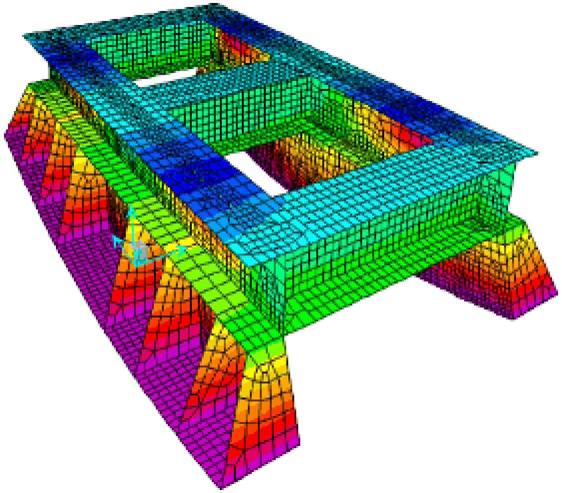
- Since the traditional prototyping methods **did not allow the designer to reflect all user expectations with one prototype**, the process became very costly and time-consuming.

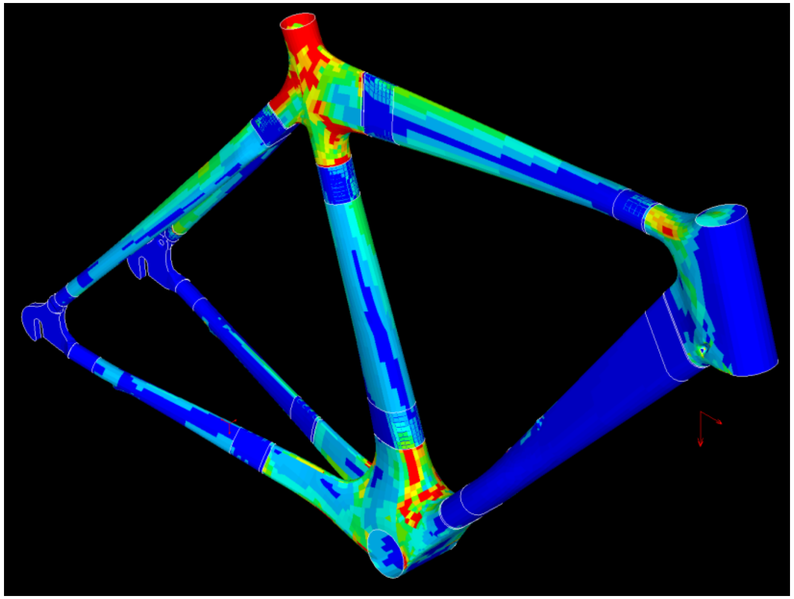
VIRTUAL PROTOTYPING IN PRODUCT DEVELOPMENT

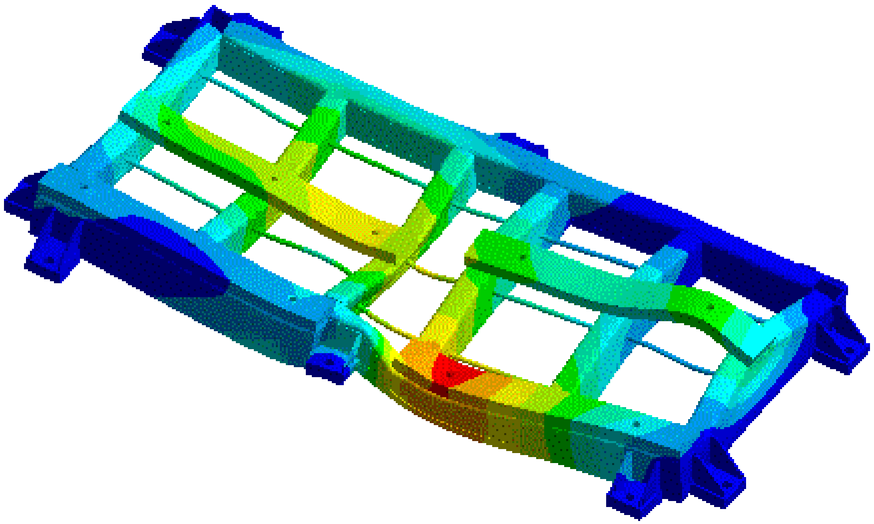
A **virtual prototype is an analytical model** of some aspect of a design.
It allows the engineer to **predict with some confidence the design's behavior,** without **building expensive, inflexible, physical prototypes**.

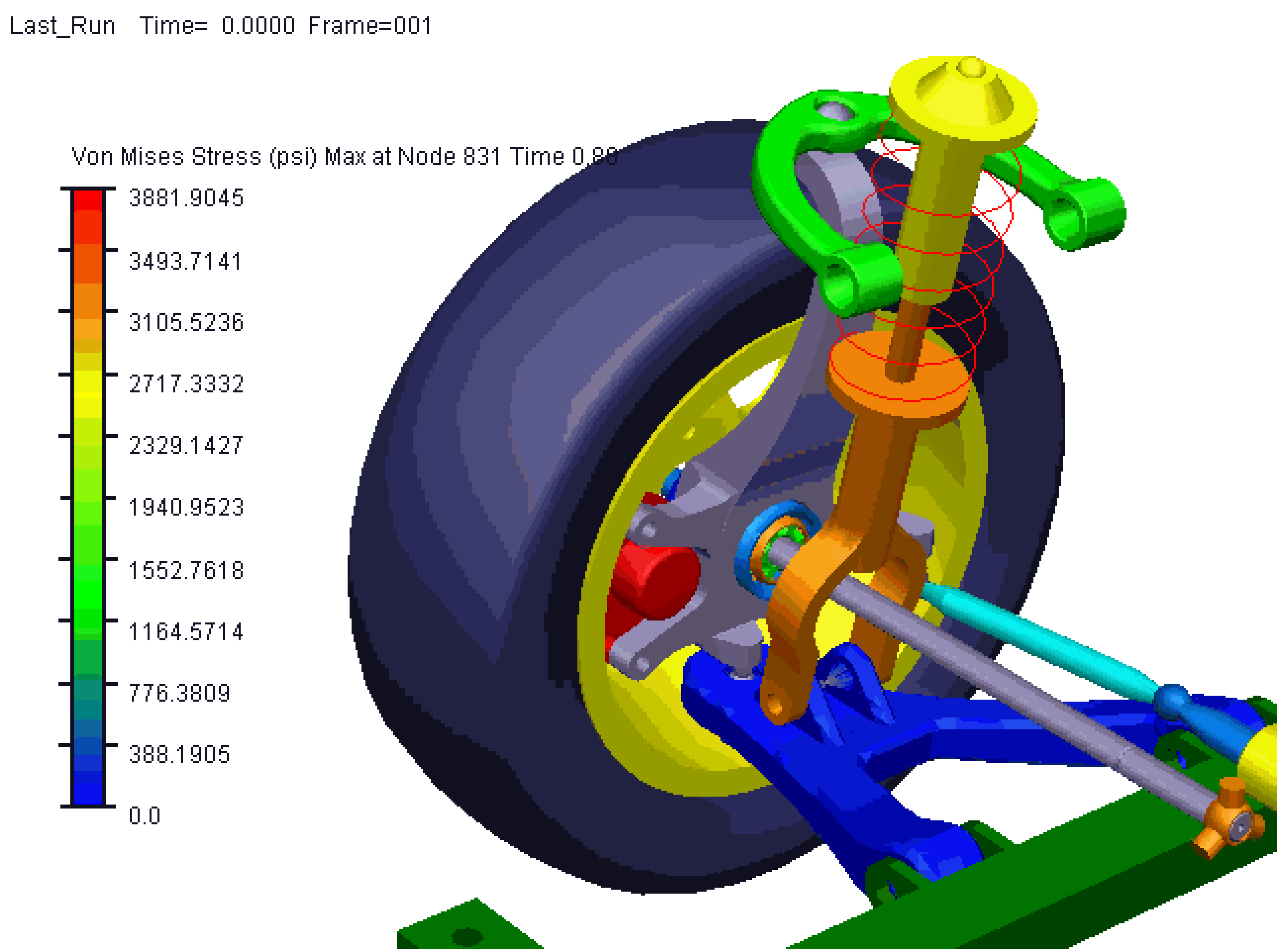
There are many **different computational approaches** to address different aspects in the design process, These are all analytical prototyping methods.

- FEA
- Kinematics and multi-body dynamics
- Electronic circuit design
- CAD immersive design
- Virtual reality topological modeling





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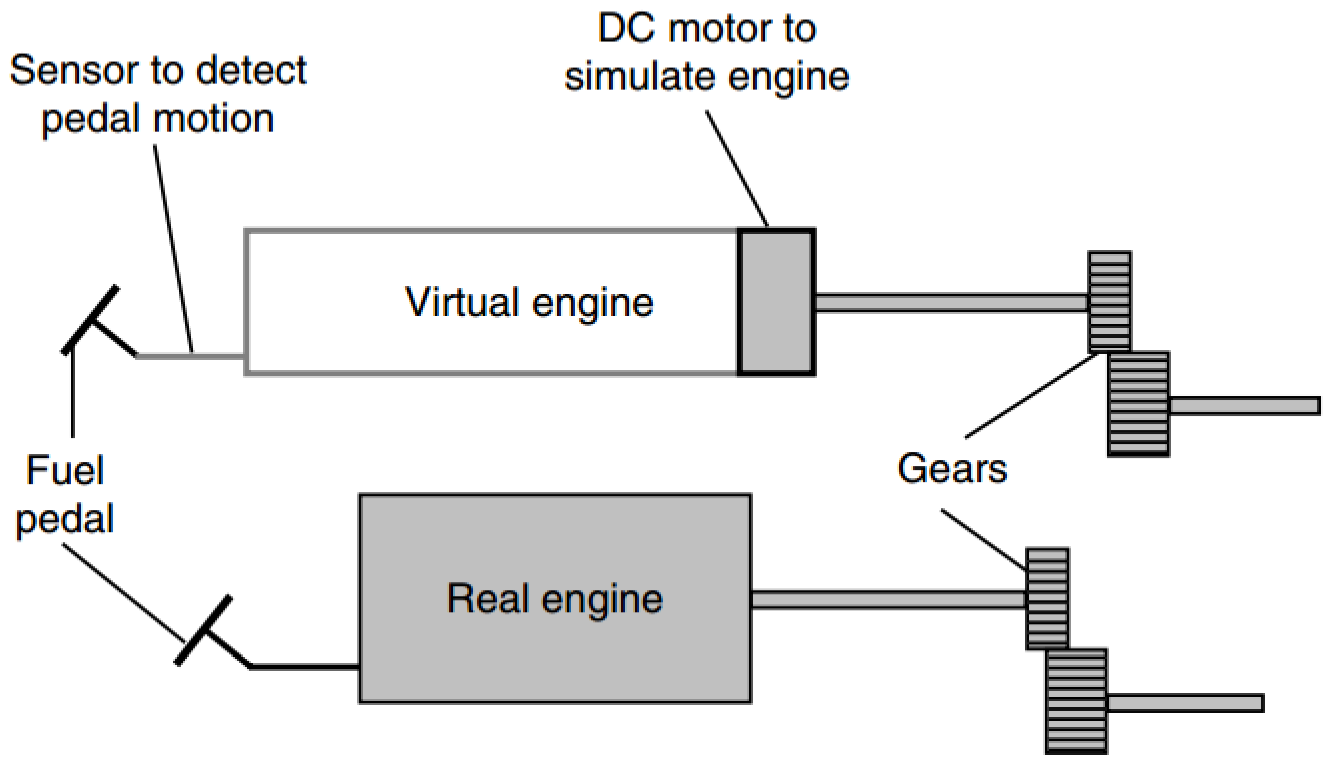


An example of mixing virtual and physical components together to evaluate a prototype.

RAPID PROTOTYPING IN PRODUCT DEVELOPMENT

Often **virtual prototyping** may **not be able to evaluate the ultimate performance** of a product.

Physical prototyping enables the exploration, optimization, and validation of mechanical hardware.

Physical prototyping is traditionally a very time-consuming process.

Recently **rapid prototyping (RP)** has become a new trend to produce a physical prototype for testing.

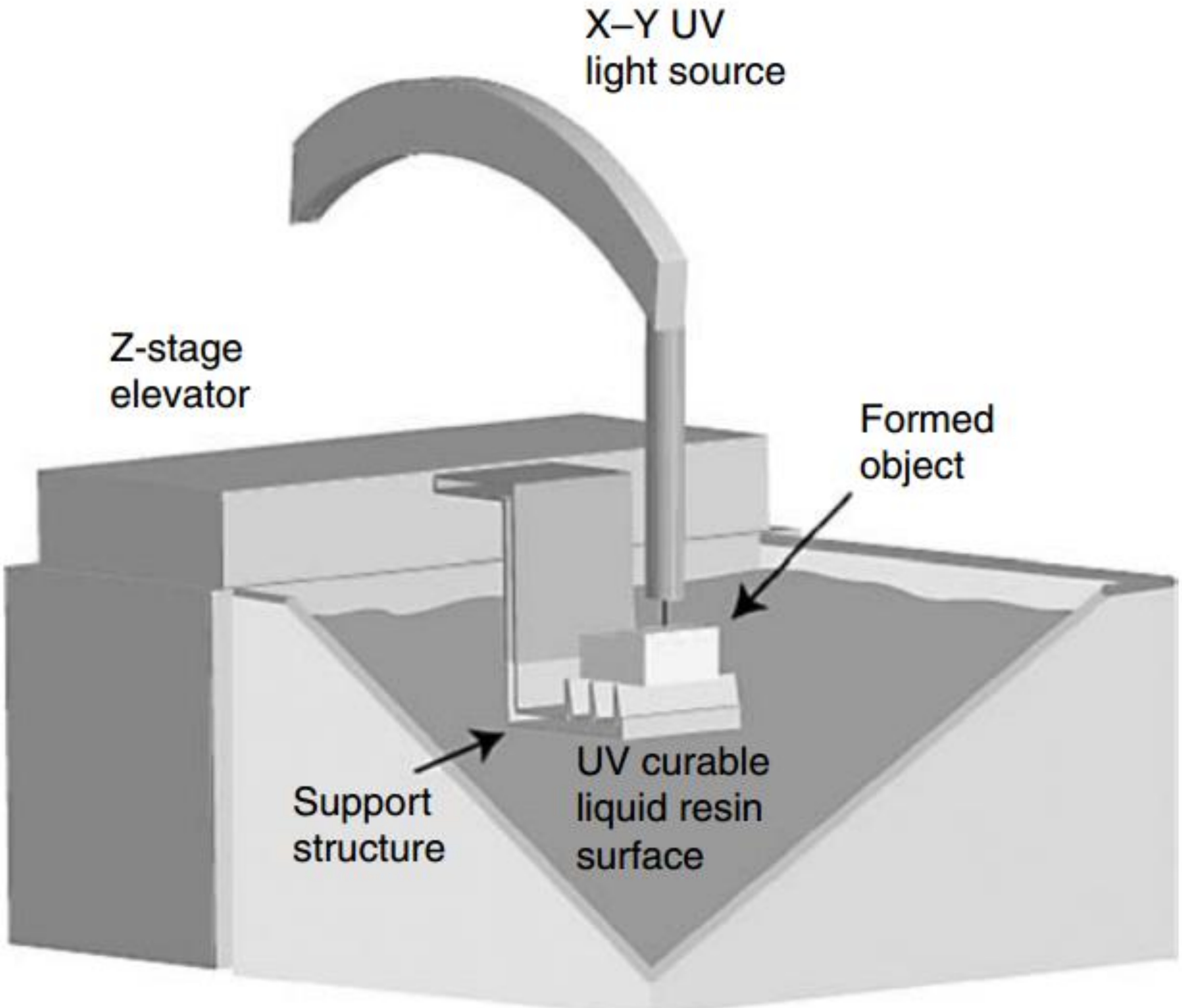
RP is based on layered manufacturing, which builds a part in a layered fashion—typically from the bottom up.

A layer of material is printed or laid down on a substrate with careful control. When various layers are stacked together, it forms a 3-D object.

A prototype can be used

- To test the fitting for product packaging,
- Styling
- Ergonomics

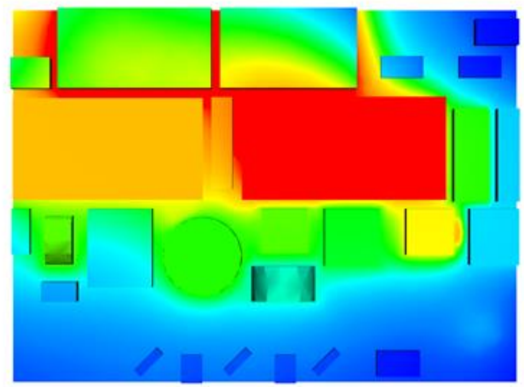
The first commercial RP system is called stereolithographic apparatus (SLA)

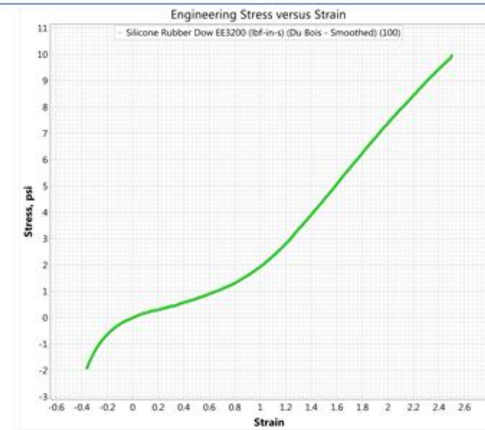


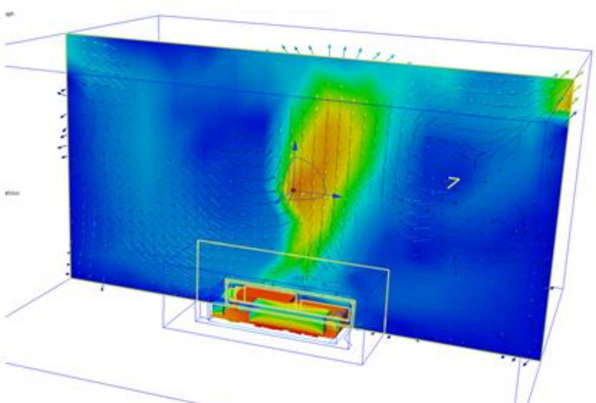
Schematics of a stereolithographic apparatus (SLA).

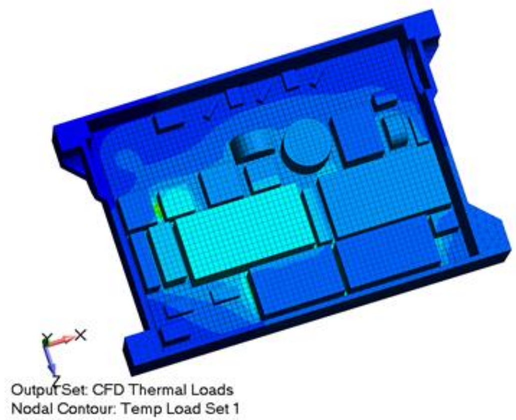
Thermal-Stress Analysis of Potted DC-AC Invertor and other Electronic Devices

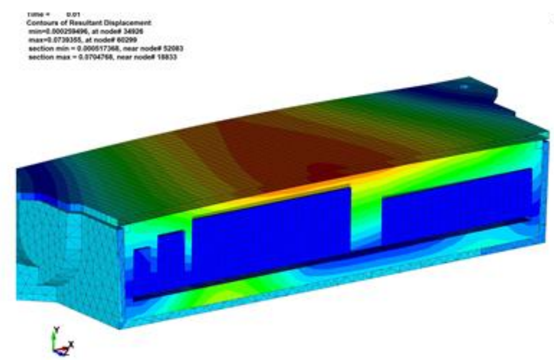
Thermal Analysis of DC-AC Invertor in Ambient Air (Convection / Radiation)	CFD to FEA Temperature Mapping	Thermal-Stress Analysis (LS-DYNA) with Silicon Pottant











Product Prototyping.

Prototyping is a quick way to incorporate direct feedback from (real) users into a design.

A prototype can be created for the purpose of

- How it will look?
- How it will feel?
- How it will Function?
- Where to get it made?
- How to make sure it will turn out the way one wants it?

WHEN IS PROTOTYPING NEEDED

A prototype can be used for many purposes, such as

- Gather initial user requirements
- Show proof of concept to senior management
- Validate system specifications
- Explore solutions to specific usability or design problems
- Deliver early proof of concept
- Resolve fuzziness in early stages of design
- Manage change requests
- Validate evolving user requirements
- Increase constructive user participation
- Customer acceptance
- Product invisibility
- Quality assurance
- marketing demo

Cost and Risk Effects to Prototyping

	Cost of Comprehensive Prototype	
Technical Risk	**Low Cost**	**High Cost**
Low risk	One prototype may be built for verification, e.g., printed goods	Few or no comprehensive prototypes built, e.g., commercial buildings, ships
High risk	Many comprehensive prototypes built, e.g., software, consumer products	Analytical prototypes used extensively. Carefully planned comprehensive prototypes, e.g., airplanes, satellites, automobiles

Commonly seen mistakes in the prototyping process include

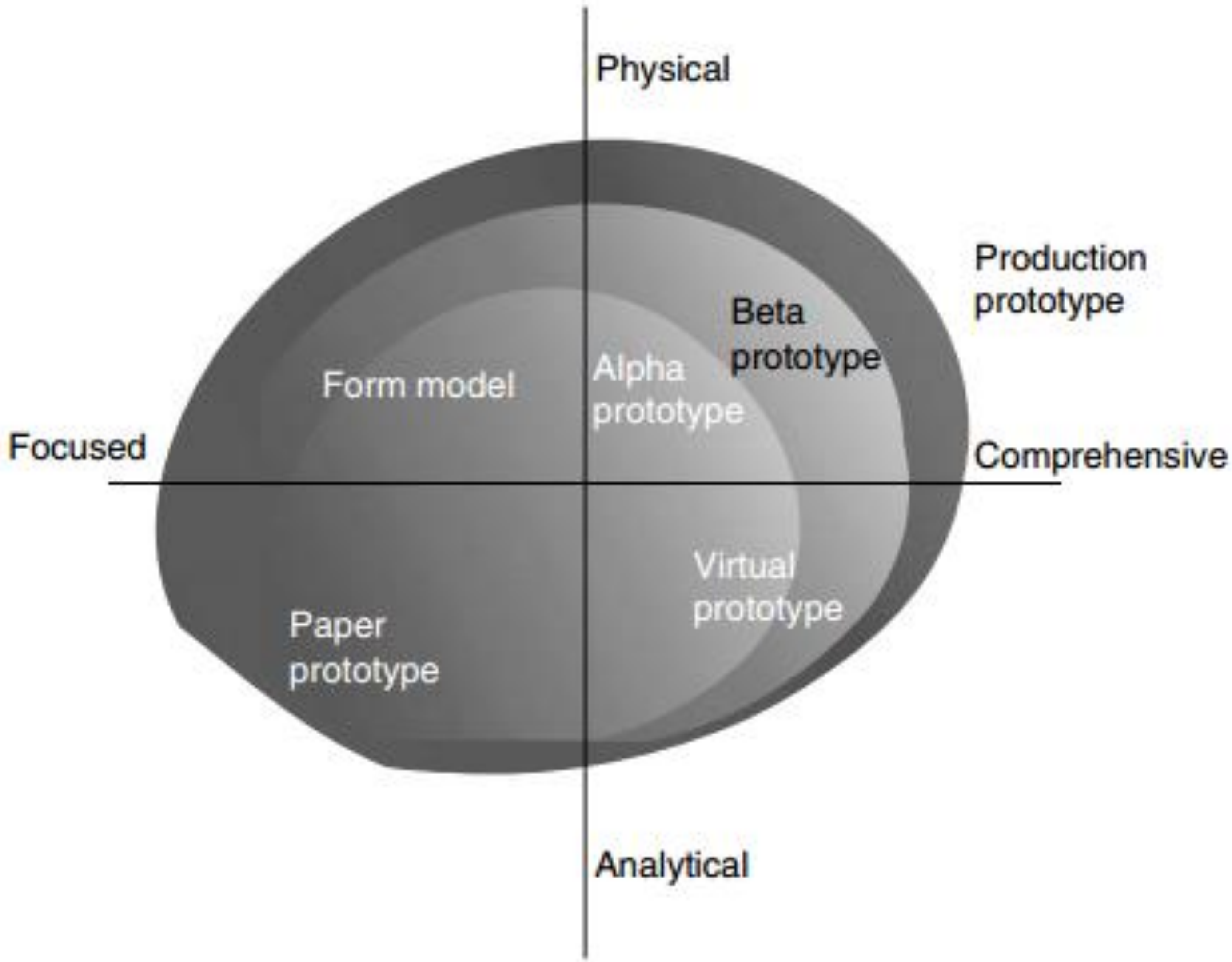
(1) Commitment too early to a particular design

(2) Gaining a false view of how long the system will take to complete based on the time taken to prototype

(3) Too many design iterations that could lead to maintenance and or operational problems associated with previous versions

(4) The performance characteristics of prototypes misled the customer

(5) Utilizing materials or methods that do not reflect the final design, leading to erroneous performance data.



Prototype classifications.

General principles of prototyping

. Analytical prototypes are generally more flexible than physical prototypes

. Analytical prototypes can be used to narrow the range of feasible parameters

. Physical prototypes can be used to fine-tune or confirm the design

.A prototype may reduce the risk of costly iterations

. Benefits of a prototype may be weighted against time and money

.A prototype may expedite other development steps

.A prototype may restructure task dependencies

Before constructing a physical prototype the following items are kept in mind:

- Purpose
- Development time of prototype
- Possible forms
- Types of tests to perform
- Risk of constructing prototype

PHYSICAL PROTOTYPE DESIGN PROCEDURE

Step 1. Prototype Conceptual Design

Customer requirements and include a vision and market opportunity analysis.

Step 2. Configuration Design of Prototype Parts and Components

Involves selecting the types or classes such as motor (DC, AC, stepper), spring (leaf, beam, helical),

Step 3. Parametric Design

This task defines major dimensions and tolerance information

Step 4. Detailed Design

This task supplies remaining dimensions, tolerances, and material information for engineering drawings.

PROTOTYPE PLANNING AND MANAGEMENT

A good project vision should be SMART:

- Specific
- Measurable
- Achievable
- Relevant
- Time dimensioned

Good project management includes

- **Good communication**

This task includes sufficient planning for each meeting, project status reports, Listserv and Web site, show and tell activities, and e-mail communication.

- **Mentoring and Brainstorming**

This task has team members help each other and solve project problems.

- **Resource allocation**

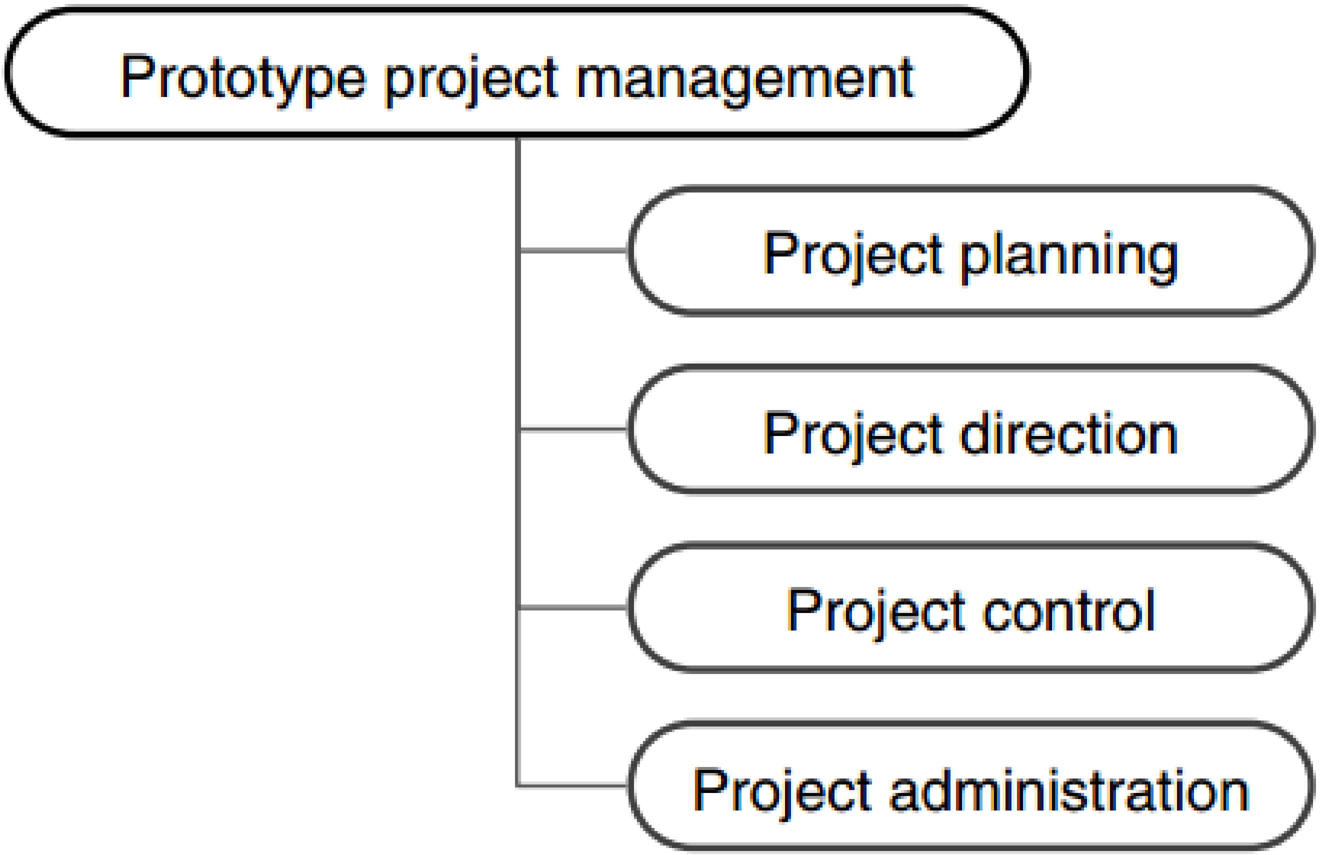
This task needs to define who should work on what task, how to avoid overload.

- **Tracking and measurement**

This task requires tracking task completion, deadlines, and budgets.

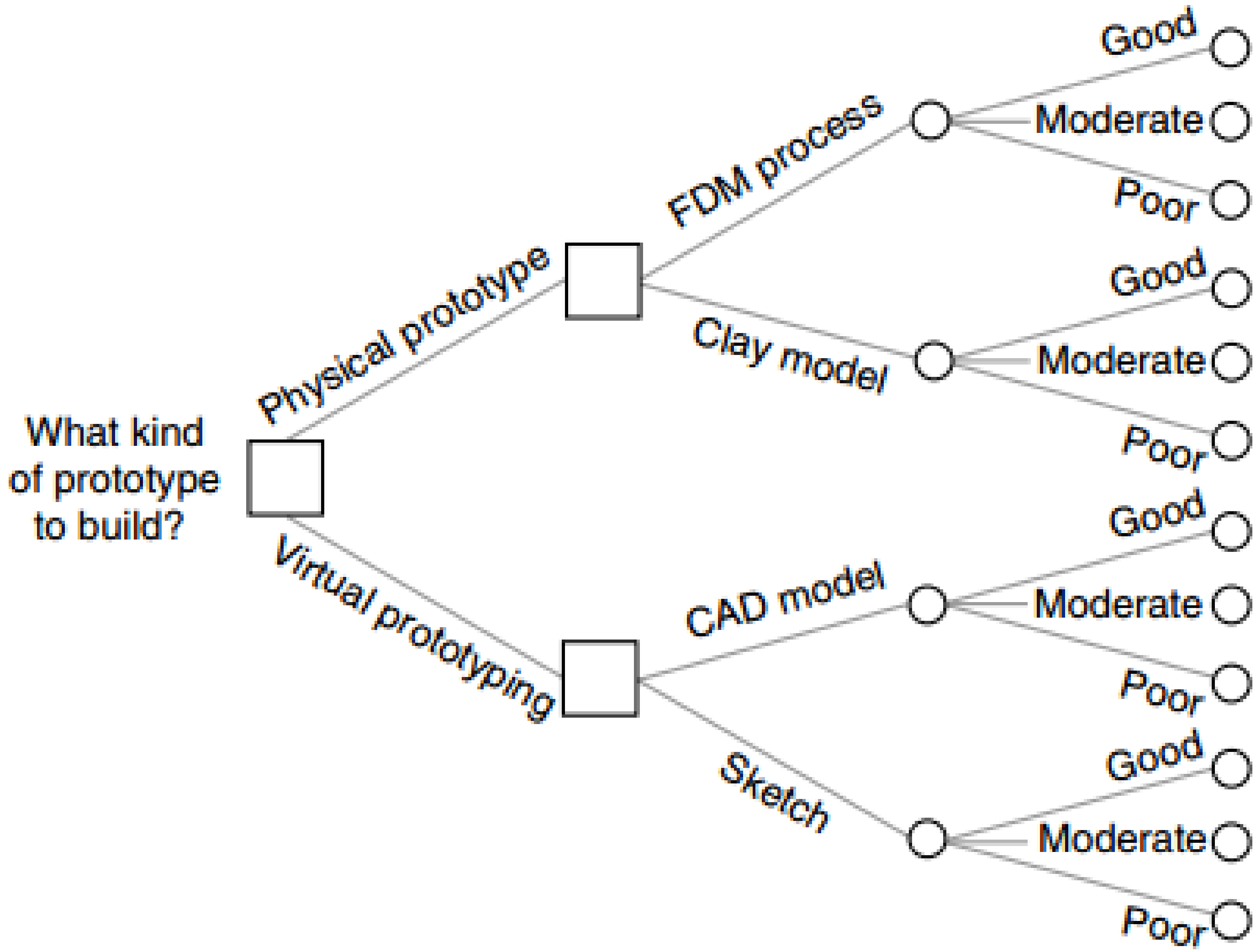
- **A good project manager**

He or she should have technical skill, people skill, and business skill.



Prototype project management.

PROJECT RISK MANAGEMENT



Decision tree.

0.8 (probability good outcome) × \$5000 (value) = \$4000
0.1 (probability moderate outcome) × \$2000 (value) = \$200
0.1 (probability poor outcome) × 0 (value) = \$0
The total expected value = +\$4200 − \$1000 (FDM process cost) = \$3200

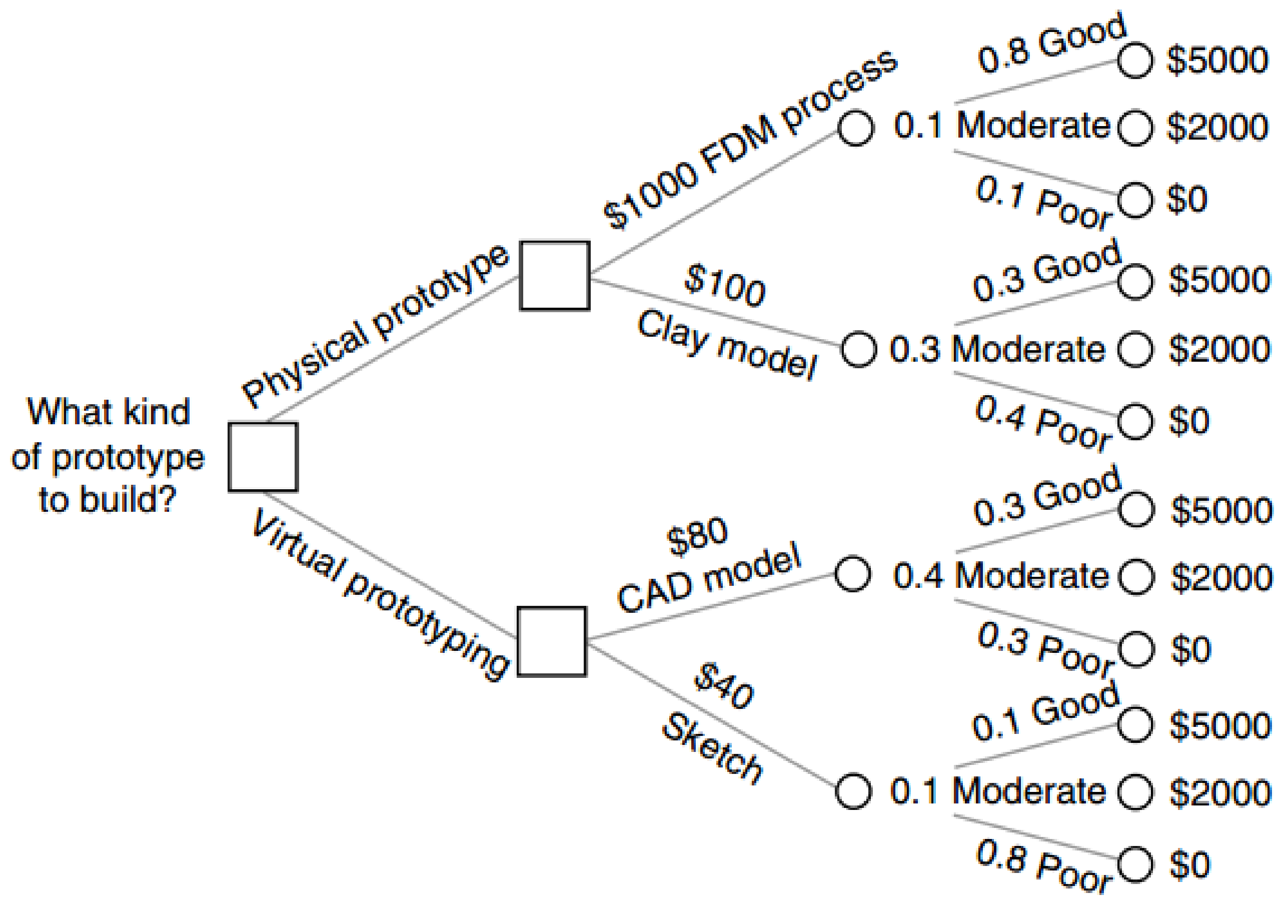
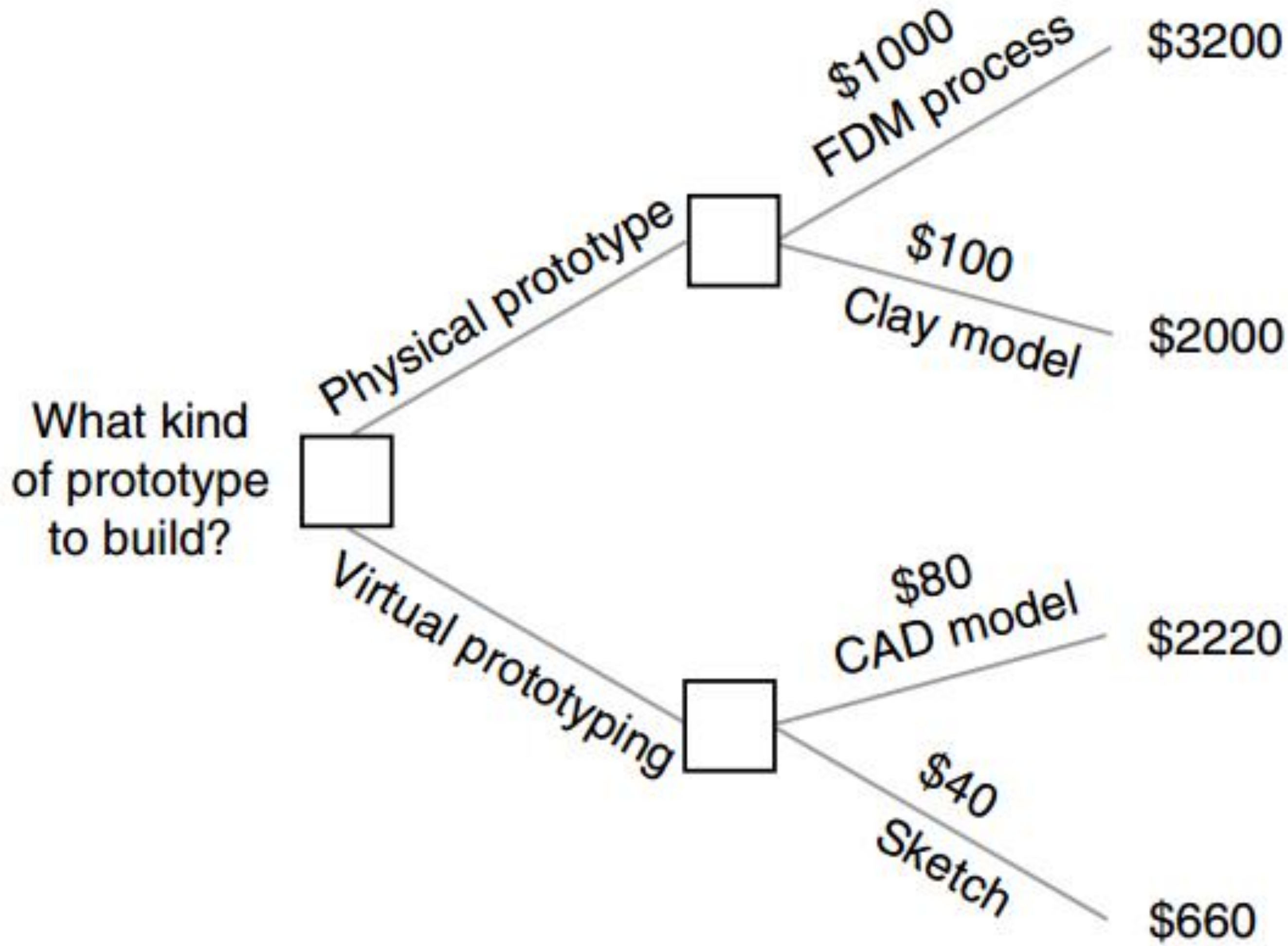


FIGURE 2.6 Further developed decision tree.



Making decisions based on expected cash values.

PRODUCT AND PROTOTYPE COST ESTIMATION

Good cost-estimate practices should include the following:

(1) Uses best available data

(2) Adjusts data for definitions, accounting changes, time,

unit number of production

(3) Applies appropriate estimating techniques

(4) Addresses risk and uncertainty

(5) Is well documented.

There are several cost estimation methods

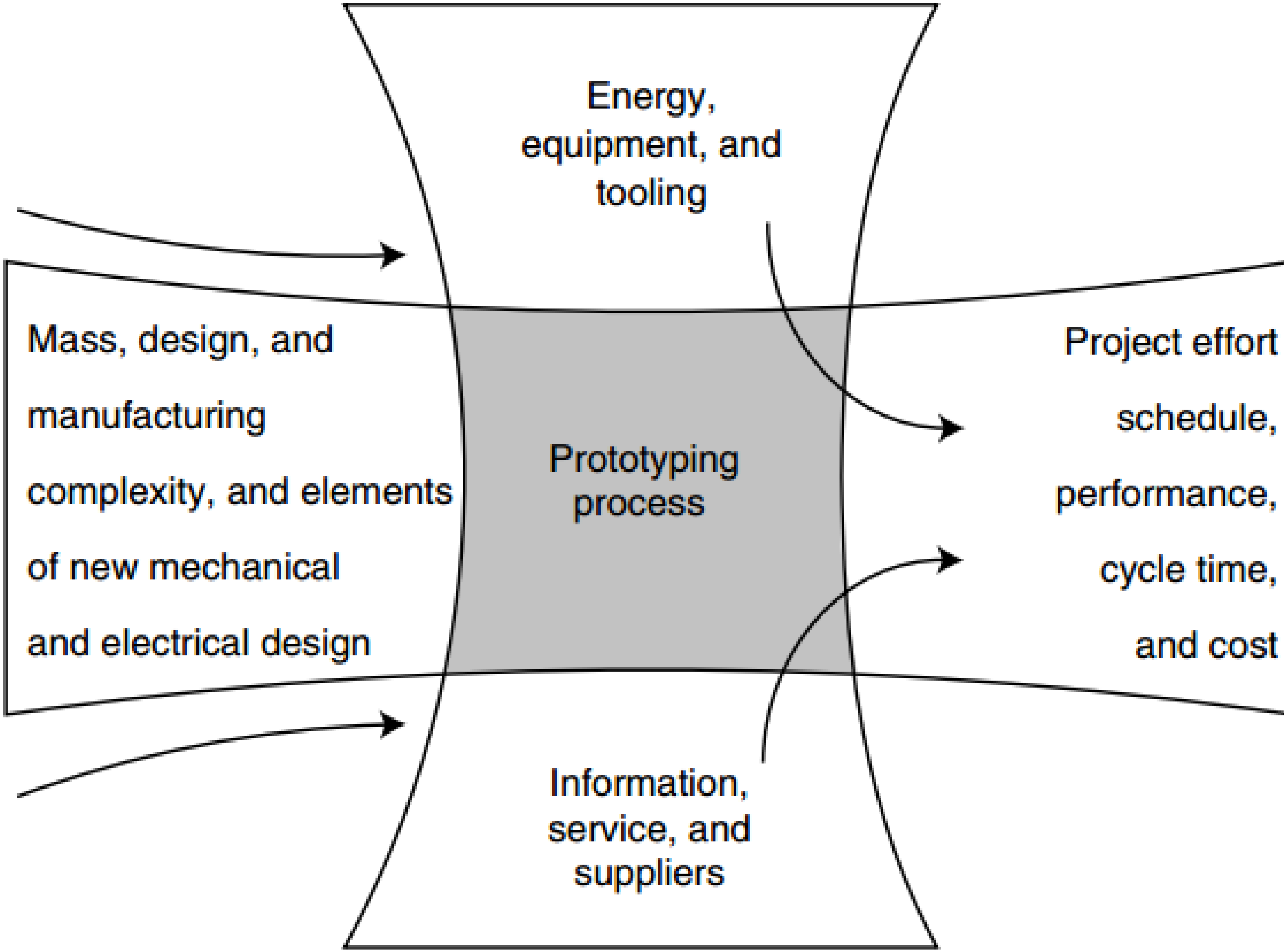
Estimation by analogy: This method relies on comparison to a similar available system and ability to normalize cost data.
For example, one can use DC-8 aircraft to estimate the larger DC-10 since they are similar types of aircraft.

Bottom–up estimation: System is broken up into lower-level components and costs rolled up. This method adds up the sum of the cost of each individual component of the product.

Top–down estimation: The cost is established by considering the overall functionality of the product and how that functionality is provided by interacting sub-functions.

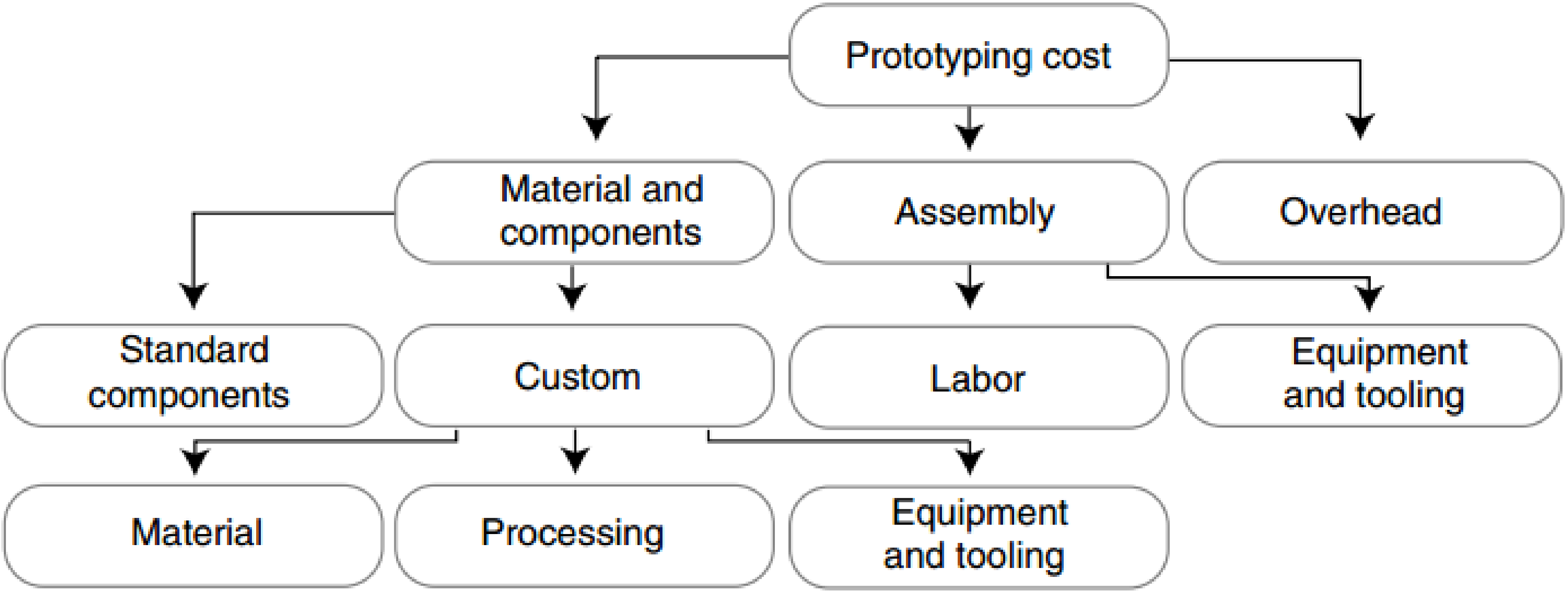
Expert judgment: This method uses one or more experts in both system development and the application domain to predict development costs.

Pricing to win: This method is commonly used in cost estimation for winning the biding process. The project costs whatever the customer has to spend on it. The cost will be fixed by the customer and the product must be manufactured within that cost.



An estimating model for prototyping.

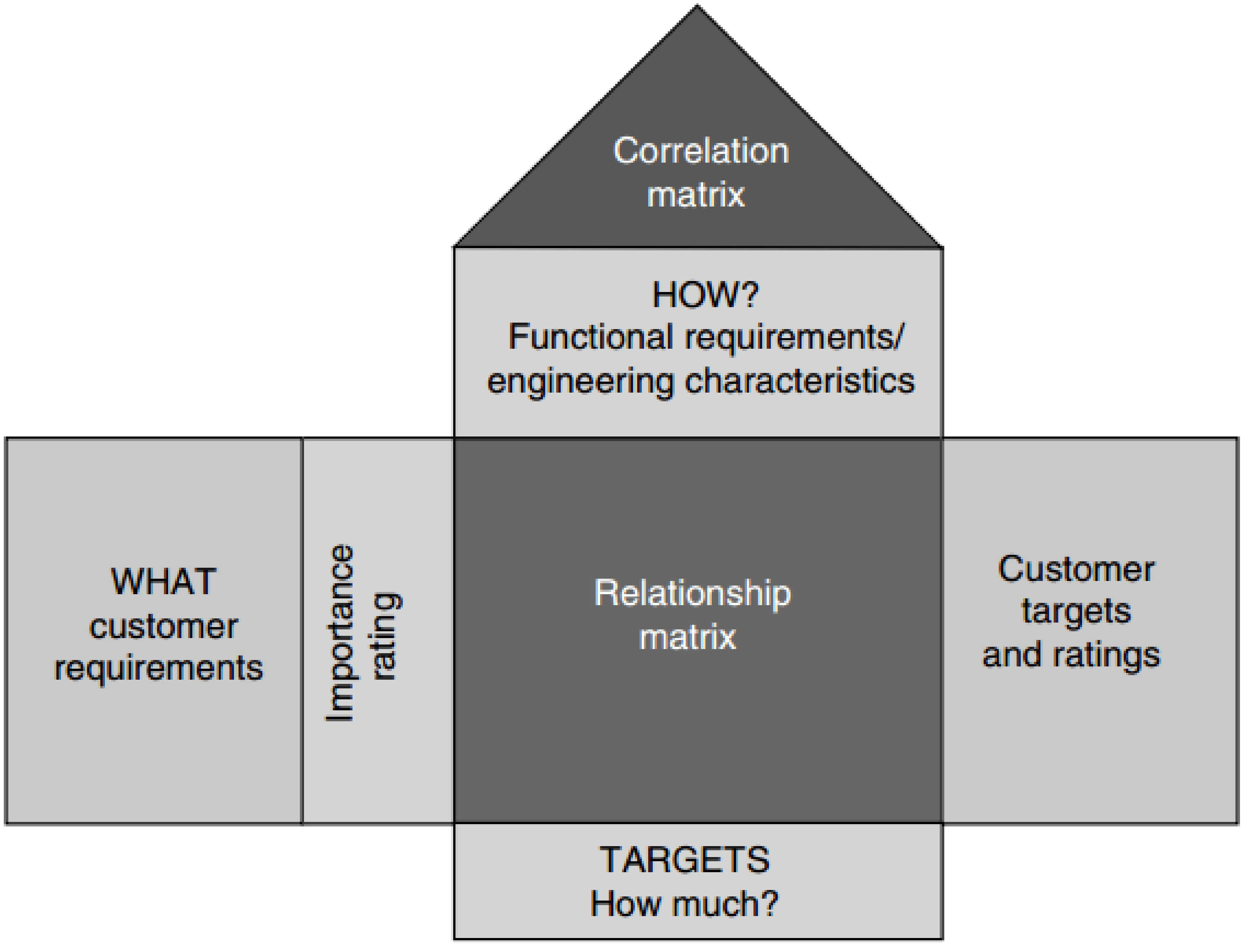
Prototyping cost breakdowns.



PROTOTYPE DESIGN METHODS

PROTOTYPE DESIGN PRINCIPLES

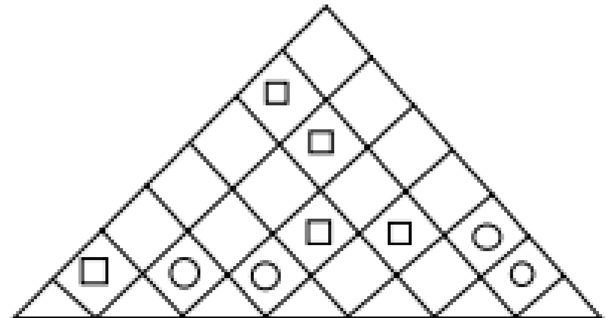
1. **Simplicity:** keep it simple for success. This is due to the fact that cost correlates with size, mass and complexity, number of parts.
2. **Clarity:** is the function of the machine, product or component clear for all to see.
3. **Safety:** is the machine inherently safe. A product should be designed to be safe for all people who will encounter it during its life. Is it reliable.



House of quality.

O = Negative/trade-off
□ = Positive/supporting

H = 5
M = 3
L = 1



Compliant microrobot arm				Engineering characteristics						
				Durability		Provides forward movement		Manufacturing		
			Importance (60 pts total)	Vibration resistant	Long lasting	High speed	Precise movement	Low no. of piezostrips	Small/simple shape	Large-scale etching
Customer attributes	Handling	Easily placed	7		L				M	
	Functionality	Withstand up to 1 mg	12		M				M	
		Low bulk	10			M	L	H	H	
		Requires less piezostrips	15			L		H	H	
		Durable	5	M	H				L	
	Miscellaneous	Cheap	11					H	L	H
	Abs. importance		60	15	68	45	10	180	198	55
	Rel. importance (%)		9.5	2.4	10.8	7.1	1.6	28.5	31.4	8.7

FIGURE 2.17 The house of quality of designing a compliant microrobot.

PRODUCT DESIGN SPECIFICATIONS

- Performance: the basic need or expectation of the user
- Environment: range of temperature, pressure, humidity, dirt, dust, corrosive environments, shock loading, vibration, etc.
- Service life: expected service life and duty cycle
- Maintenance and logistics: specify ease of access to components, spares, tools and test equipment, operator and maintenance manuals, and training
- Target product cost: experience shows that almost all target costs are unrealistically low
- Competition: future and existing
- Shipping: size of boxcar doors, cargo hatches, weight, limits on truck trailers, shipping costs

- Packing: storage, corrosion, or shock loading
- Quantity: cost per unit, the methods of production, and the manufacturing cost
- Manufacturing facility: whether the product is to be produced in an existing plant or whether a new plant will be built
- Aesthetics: visual appearance of a product, color, shape, form, and texture of finish
- Materials: performance and manufacturing
- Product life span: whether the product is likely to remain marketable for 3 or 30 years
- Standards and specifications: SI or U.S. units and existing standards and specifications
- Ergonomics: human–machine interface requirements
- Quality and reliability: high-risk areas should be identified
- Shelf life in storage: batteries or bake goods, construction site, spare parts
- Company constraints
- Market constraints
- Testing and inspection: acceptance testing and quality requirements
- Safety: critical parts should be identified. Warning labels should be devised and operating manuals should clearly spell out abusive use of the product
- Patents: prevent a costly patent infringement suit
- Social and political factors: EPA, FDA, or NRC

PROTOTYPE DESIGN TOOLS

EVALUATING ALTERNATIVES

Comparison between Factors for Importance

	A	B	C	D	E	Total
A	—	1	0	0	1	2
B	0	—	1	1	1	3
C	1	0	—	0	0	1
D	1	0	1	—	1	3
E	0	0	1	0	—	1
					Total	10

Assigning Weights Based on Intuitions and Engineering Judgment

10	9	8	7	6	5	4	3	2	1	0
B	D		A					E	C	

Decision Factors

Factor	Processor (CPU)	Total Memory	Hard Drive	Display	Graphics	Battery
Symbol	A	B	C	D	E	F
Factor	**Exterior**	**Cost**	**Weight**	**Volume**	**Reliability**	**Guarantee**
Symbol	G	H	I	J	K	L

Step 1: Each factor is listed as compared to other factors, two at a time.

	A	B	C	D	E	F	G	H	I	J	K	L	Total
A	—	1	1	1	1	1	1	1	1	1	1	1	11
B	0	—	1	1	1	1	1	1	1	1	1	1	10
C	0	0	—	1	1	1	1	1	0	1	1	1	8
D	0	0	0	—	1	1	1	0	0	1	0	1	5
E	0	0	0	0	—	1	1	0	0	1	0	1	4
F	0	0	0	0	0	—	1	0	0	0	0	0	1
G	0	0	0	0	0	0	—	0	0	1	0	0	1
H	0	0	0	1	1	1	1	—	1	1	1	1	8
I	0	0	1	1	1	1	1	0	—	1	1	1	8
J	0	0	0	0	0	1	0	0	0	—	0	0	1
K	0	0	0	1	1	1	1	0	0	1	—	1	6
L	0	0	0	0	0	1	1	0	0	1	0	—	3

Step 2: Weight of each factor is calculated.

$$N = I_A + I_B + I_C + I_D + I_E + I_F + I_G + I_H + I_I + I_J + I_K + I_L$$
$$= 11 + 10 + 8 + 5 + 4 + 1 + 1 + 8 + 8 + 1 + 6 + 3 = 66.$$

$W_A = 0.167$, $W_B = 0.152$, $W_C = 0.121$, $W_D = 0.076$, $W_E = 0.061$, $W_F = 0.015$, $W_G = 0.015$, $W_H = 0.121$, $W_I = 0.121$, $W_J = 0.015$, $W_K = 0.091$, $W_L = 0.045$.

Step 3: Distribute 100 points among the factors.

A	B	C	D	E	F	G	H	I	J	K	L
17	15	12	8	6	1.5	1.5	12	12	1.5	9	4.5

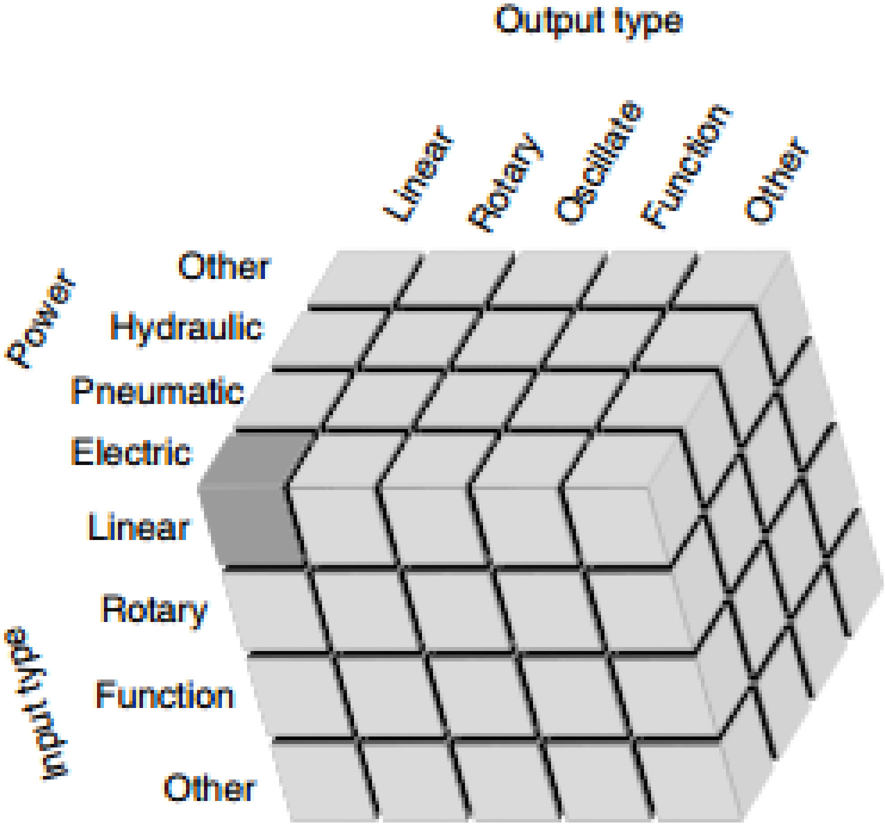
RESULTS:

$W_A = 17$, $W_B = 15$, $W_C = 12$, $W_D = 8$, $W_E = 6$, $W_F = 1.5$, $W_G = 1.5$, $W_H = 12$, $W_I = 12$, $W_J = 1.5$, $W_K = 9$, $W_L = 4.5$.

Morphological Analysis

morphological analysis can be used to uncover combinations of factors to create a new design.

Robotic mechanism



An example of morphological analysis.

Learning from Nature

Nature's blueprints are logical principles of how the Earth creates and maintains life, principals that could give new shape and meaning to human endeavor.

There are design elements in nature that may be learned when a new product or prototype is developed:

. Runs on sunlight
. Uses only the energy it needs
. Fits form to function

Emulation Level 1: Form

Kingfisher beak shape inspired shinkansen train tip.

Form can be seen with your eye, something you can measure (kingfisher beak shape for a train tip.)