Modeling, Systems, Teamwork and Quality

Supplemental Notes for

Designing Engineers

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Modeling, systems, teamwork and quality are at the heart of this course on designing engineers as they are in the practice of engineering. These notes define, elaborate on, and provide examples of the relationship between modeling, teamwork, quality and engineering and engineering systems.

Contents

Background

Deming associate and engineering educator, Myron Tribus summarized the purpose of engineering schools as follows (Tribus, 1995):

> The purpose of a School of Engineering is to teach students to create value through the design of high quality products and systems of production, and services, and to organize and lead people in the continuous improvement of these designs.

Notice that in Tribus' statement, management is considered a part of, not apart from, engineering. He also elaborates on the importance of group work for learning to engineer:

> The main tool for teaching wisdom and character is the group project. Experiences with group activities, in which the members of the groups are required to exhibit honesty, integrity, perseverance, creativity and cooperation, provide the basis for critical review by both students and teachers. Teachers will need to learn to function more as coaches and resources and less as givers of knowledge.

Changes occurring in how engineers work in business and industry, summarized in the following table, have serious implications for how we prepare engineering graduates for working in the 21st century.

A Paradigm Shift: Manufacturing 2002 (1992)

Old Paradigm	New Paradigm
Inspectors responsible for quality	Worker responsible for quality
One worker at a machine	Self-directed work teams at machines
Static job assignments	Worker empowerment
"Management thinks, you do"	"Management and worker think and do"
Quantity over quality	Quality over quantity
Price and supply	Quality and customer service
Competition	Collaboration
Collusion/antitrust	Manufacturer networks
Individual incentives	Group incentives
"Let the buyer beware"	External and internal customers
Local orientation	Global orientation
Single-job skills	Job clusters/skill families
Muscle power	Smart machinery
Individual efforts	Partnerships
Sporadic training	Constant training
"Degree" education	Lifelong or competency-based learning

Similar changes are outlined in numerous references. Byrne (1992) and Weisbord (1987) are two of my favorites. Many of these changes have direct implications for engineering education. The changes that are occurring in business and industry suggest that we should consider changes in engineering education to prepare our graduates to function effectively in the "new paradigm" companies. The "Made in America" study (Dertouzos, Lester & Solow, 1989) recommended the following changes for MIT:

1. Broaden its educational approach in the sciences, in technology, and in the humanities and should educate students to be more sensitive to productivity, to practical problems, to teamwork, and to the cultures, institutions, and business practices of other countries.
2. Create a new cadre of students and faculty characterized by (1) interest in, and knowledge of, real problems and their societal, economic, and political context; (2) an ability to function effectively as members of a team creating new products, processes, and systems; (3) an ability to operate effectively beyond the confines of a single discipline; and (4) an integration of a deep understanding of science and technology with practical knowledge, a hands-on orientation, and experimental skills and insight.
3. Revise subjects to include team projects, practical problems, and exposure to international cultures. Encourage student teaching to instill a stronger appreciation of lifelong learning and the teaching of others. Reinstitute a foreign-language requirement in the undergraduate admissions process.

The nature of change is described by Katzenbach and Smith (1993) by a "whitewater raft ride" metaphor.

They also list behavioral changes that are demanded by the changes.

> Major change, by its nature, is intentionally disruptive and largely unprogrammable. In comparing the management of major versus normal change, one top executive said, "It used to be like I-75. You'd lay it out from Toledo to Tampa. Now it's more like a whitewater raft ride. You try to get the right people in the raft and do the best you can to steer it. But you never know what's just around the bend."

Behavioral Changes Demanded by Performance in the 1990s and Beyond

FROM	TO
Individual accountability	Mutual support, joint accountability, and trust-based relationships *in addition* to individual accountability
Dividing those who think and decide from those who work and do	Expecting everyone to think, work, and do
Building functional excellence through each person executing a narrow set of tasks ever more efficiently	Encouraging people to play multiple roles and work together interchangeably on continuous improvement
Relying on managerial control	Getting people to buy into meaningful purpose, to help shape direction, and to learn
A fair day's pay for a fair day's work	Aspiring to personal growth that expands as well as exploits each person's capabilities

Systems Approach

A system is a network of interdependent components that work together to try to accomplish the aim of the system. (Deming, 1993). Systems are made up of sets of components that work together for the overall objective of the whole. The systems approach is simply a way of thinking about these total systems and their components. Five basic considerations that must be kept in mind when thinking about the meaning of a system: (1) the total system objectives and, more specifically, the performance measures of the whole system; (2) the system's environment: the fixed constraints; (3) the resources of the system; (4) the components of the system, their activities, goals, and measures of performance; and (5) the management of the system (Churchman, 1968). Systems thinking is a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static "snapshots." It is a set of principles and a set of specific tools and techniques (Senge, 1990). An implication of the systems approach is the importance of getting everybody involved to improve whole systems (Weisbord, 1987). The systems approach is commonly operationalized through learning organizations.

The Art & Practice of the Learning Organization
Peter Senge (In Ray & Rinzler, 1993)

1. *Building Shared Vision*. The idea of *building* shared vision stresses that you never quite finish it--it's an ongoing process.
2. *Personal Mastery*. Learning organizations must be fully committed to the development of each individual's personal mastery--each individual's capacity to create their life the way they truly want.
3. *Mental Models*. Our vision of current reality has everything to do with the third discipline--*mental*

models--because what we really have in our lives is constructions, internal pictures that we continually use of interpret and make sense out of the world.

4. *Team Learning*. Individual learning, no matter how wonderful it is or how great it makes us feel, if fundamentally irrelevant to organizations, because virtually all important decisions occur in groups. The learning unit of organizations are "teams," groups of people who need one another to act.
5. *Systems Thinking*. The last discipline, the one that ties them all together, is *systems thinking*.

What Will Be Different in the Learning Organization
(Watkins & Marsick, 1993)

From	*To*
Individual	
Learning that is canned, sporadic, and faddish	Learning that is continuous, strategically tied to future organizational needs
Learning that is not coherently integrated or sequential	Learning that is developmental
Learned helplessness	Personal mastery, learning to challenge assumptions and to inquire
Team	
Learning that is focused on task accomplishment with no attention to process	Learning that is focused on group development and on building collaborative skills
Rewards for individuals, not teams	Rewards for teams, whole divisions
Compartmentalization	Cross-functional, self-directed work teams
Organizational	
Learning that is superficial and unconnected to previous skills, truncated learning	Learning that builds over time on previous skill attainment
Learning through structural reorganization without regard to learning barriers created; structural rigidity	Creation of flexible structures to enhance learning for everyone
Societal	
Unawareness of impact on society of policies, tunnel vision	Acknowledgment of interdependence and work to improve society generally
Attempts to control societal influence	Constant scanning and projecting of future trends while working to build a desirable future

Some Heuristics for Building a System (Rechtin, 1992)

Specifically refers to a computer system, but heuristics are applicable to other systems, too.

The conceptual phase:

- The choice between architecture may well depend upon which set of drawbacks the client can handle

best.
- Extreme requirements should remain under challenge throughout system design, implementation, and operation.
- Don't assume that the original statement of the problem is necessarily the best or even the right one.
- No complex system can be optimum to all parties concerned, nor all functions optimized.
- A model is not reality.
- Complex systems will develop and evolve within an overall architecture much more rapidly if there are stable intermediate forms than if there are not.
- Build in and maintain options as long as possible.
- Don't make an architecture too smart for its own good.

The build and test phases:
- The product and process must match.
- An element good enough in a small system is unlikely to be good enough in a more complex one.
- Within the same class of products and processes, the failure rate of a product is linearly proportional to its cost.
- High-quality, reliable systems are produced by high-quality architecting, engineering, design, and manufacture, not by inspection, test, and rework.
- Regardless of what has gone before, the acceptance criteria determine what is actually built.
- To be tested, a system must be designed to be tested.
- Qualification and acceptance tests must be both definitive and passable.
- The cost to find and fix a failed part (or software bug) increases by an order of magnitude as that part is successively into higher levels in the system.

The operations phrase:
- Before the flight, it's opinion. After the flight, it's obvious.
- For every competitive system, there is a countersystem.
- Success is defined by the beholder, not the architect.
- There's nothing like being the first success.

Systems Engineering Checklist (Skytte, 1994)

Requirements phase
- Consult potential customers to ascertain their actual needs.
- Have a multidisciplinary project team take that statement of needs and use it to develop a detailed specification describing the product's functional requirements.

System-design phase
- Develop a system architecture that supports specified product requirements.
- Develop system-design specifications that document the system's architecture, systems-level performance specifications, and the functional requirements of each subsystem and component.
- If necessary, use simulations and other analytical techniques to verify that top-level design concepts support all specified product requirements.
- Define the system's life-cycle cost model.

Detailed design phase
- Design the hardware and software as described in the system-design specifications.
- Schedule several detail-design reviews to make quite sure that the hardware and software meet the specifications.
- Build and test each component to verify that the design objectives have been met.
- Develop plans for integrating the components and subsystems into the entire system, and for testing the system.
- Compare the actual costs of designing the hardware and software with the cost estimates to verify that cost objectives are being met.

System integration phase

- Integrate the components and subsystems into a prototype system and verify its functionality.

Design verification and optimization phase

- Verify that all performance specifications are met over all specified operating conditions.
- Optimize the system's design by minimizing any differences found between expected and measured performance.

System validation phase

- Evaluate the final product's configuration to ensure that it complies with the original functional-requirements specification.

Modeling, Heuristics and Engineering

Modeling in its broadest sense is the cost-effective use of something in place of something else for some cognitive purpose (Rothenberg, 1989). A model represents reality for the given purpose; the model is an abstraction of reality in the sense that it cannot represent all aspects of reality.

Any model is characterized by three essential attributes: (1) *Reference*: It is *of* something (its "*referent*"); (2) *Purpose*: It has an intended cognitive *purpose* with respect to its referent; (3) *Cost-effectiveness:* It is more *cost-effective* to use the model for this purpose than to use the referent itself.

An essential aspect of modeling is the use of heuristics (Starfield, Smith & Bleloch, 1994). Although difficult to define, heuristics are relatively easy to identify using the characteristics listed by Koen (1985): (1) Heuristics do not guarantee a solution; (2) Two heuristics may contradict or give different answers to the same question and still be useful; (3) Heuristics permit the solving of unsolvable problems or reduce the search time to a satisfactory solution; (4) The heuristic depends on the immediate context instead of absolute truth as a standard of validity. A heuristic is anything that provides a plausible aid or direction in the solution of a problem but is in the final analysis unjustified, incapable of justification, and fallible. It is used to guide, to discover, and to reveal. Heuristics are also a key part of the Koen's definition of the engineering method: *The engineering method is the use of heuristics to cause the best change in a poorly understood situation within the available resources* (p. 70). Typical engineering heuristics include: (1) Rules of thumb and orders of magnitude; (2) Factors of safety; (3) Heuristics that determine the engineer's attitude toward his or her work; (4) Heuristics that engineers use to keep risk within acceptable bounds; and (5) Rules of thumb that are important in resource allocation.

A superb collection of modeling heuristics was presented by Ravindran, Phillips, and Solberg (1987):

1. Do not build a complicated model when a simple one will suffice.
2. Beware of molding the problem to fit the technique.
3. The deduction phase of modeling must be conducted rigorously.
4. Models should be validated prior to implementation.
5. A model should never be taken too literally.
6. A model should neither be pressed to do, nor criticized for failing to do, that for which it was never intended.
7. Beware of overselling a model.
8. Some of the primary benefits of modeling are associated with the process of developing the model.
9. A model cannot be any better than the information that goes into it.
10. Models cannot replace decision makers.

Teamwork

Tribus stressed the importance of project work and I would advocate that teamwork is crucial in engineering. You may have been asking then, or are probably wondering now, "What does he mean by the term 'Teamwork'?" My favorite definition was developed by Katzenbach & Smith (1993). They wrote

> *A team is a* ***small number*** *of people with* ***complementary skills*** *who are committed to a* ***common purpose****,* ***performance goals****, and* ***approach*** *for which they hold themselves* ***mutually accountable****.*

The importance of teamwork in business and industry is embedded in the concepts of concurrent (or simultaneous) engineering and total quality management. Two recent citations elaborate on this point:

> In concurrent engineering (CE), the key ingredient is teamwork. People from many departments collaborate over the life of a product--from idea to obsolescence--to ensure that it reflects customers' needs and desires. . .Since the very start of CE, product development must involve all parts of an organization, effective teamwork depends upon sharing ideas and goals beyond immediate assignments and departmental loyalties. Such behavior is not typically taught in the engineering schools of U.S. colleges and universities. For CE to succeed, teamwork and sharing must be valued just as highly as the traditional attributes of technical competence and creativity, and they must be rewarded by making them an integral part of the engineer's performance evaluation (Shina, 1991).

> Team development must precede all other kinds of improvement initiatives and teams, more than executive leadership, cultural change, TQM training, or any other strategy, account for most major improvements in organizations. Team development must be strategically placed at the very center of TQM and must form the hub around which all other elements of TQM (customer satisfaction, supplier performance, measurement and assessment, and so on) must revolve... Teams are the primary units of performance in organizations. They are, inevitably, the most direct sources of continuous improvement (Kinlaw, 1992).

Not All Groups Are Teams: How to Tell the Difference
(Katzenback & Smith, 1993)

Working Group	Team
Strong, clearly focussed leader	Shared leadership roles
Individual accountability	Individual and mutual accountability
The group's purpose is the same as the broader organizational mission	Specific team purpose that the team itself delivers
Individual work-products	Collective work-products
Runs efficient meetings	Encourages open-ended discussion and active problem-solving meetings
Measures its effectiveness indirectly by its influence on others	Measures performance directly by assessing collective work-products
Discusses, decides, and delegates	Discusses, decides, and does real work together

Effective teamwork is not easy to accomplish. Engineering professor Douglas J. Wilde said "It's the soft stuff that's hard, the hard stuff is easy." Larry Leifer, Director or the Stanford Center for Design Research, reports "Design team failure is usually due to failed team dynamics."

Quality and Beyond

W. Edwards Deming is probably the most influencial person in the quality area. He is well know for his "Fourteen Points."

Deming's Fourteen Points
(Deming, 1986, 1993; Walton, 1986; Roberts & Sergesketter, 1993):

1. Create a constancy of purpose toward improvement of product or service with the aim to become competitive and to stay in business and to provide jobs.
2 Adopt the new philosophy. We are in a new economic age. Western management must awaken to the challenge, must learn their responsibilities, and take on leadership for change.
3. Cease dependence on inspection to improve quality. Eliminate the need for inspection on a mass basis by building quality into the product (service) in the first place.
4. End the practice of awarding business on price tag. Instead, minimize total costs. Move toward a single supplier for any one item on a long-term relationship of loyalty and trust.
5. Improve constantly and forever the system of production and service to improve quality and productivity and thus constantly reduce costs.
6. Institute training on the job.
7. Institute leadership. The aim of leadership should be to help people and machines and gadgets to do a better job. Leadership of management is in need of overhaul as well as leadership of production workers.
8. Drive out fear so that everyone may work effectively for the company.
9. Break down barriers between departments. People in research, design, sales, and production must work as a team to foresee problems of production and use that may be encountered with the product or service.
10. Eliminate slogans, exhortations, and targets for the work force asking for zero defects and new levels of productivity.
11a. Eliminate work standards (quotas) on the factory floor.
11b. Eliminate management by objective. Eliminate management by numbers, numerical goals. Substitute leadership.
12a. Remove barriers the rob the hourly worker of his right to pride of workmanship. The responsibility of supervisors must be changed from sheer numbers to quality.
12b. Remove barriers that rob people in management and in engineering of their right to pride of workmanship. This means inter alia abolishment of the annual or merit rating and of management by objective, management by the numbers.
13. Institute a vigorous program of education and self-improvement.
14. Put everybody in the company to work to accomplish the transformation. The transformation is everybody's job.

...and Deming's **The Seven Deadly Diseases**

1. Lack of constancy of purpose. A company that is without constancy of purpose has no long-range plans for staying in business. Management is insecure, and so are employees.
2. Emphasis on short-term profits. Looking to increase the quarterly dividend undermines quality and productivity.
3. Evaluation by performance, merit rating, or annual review of performance. The effects of these are devastating--teamwork is destroyed, rivalry is nurtured. Performance ratings build fear, and leave people bitter, despondent, and beaten. They also encourage mobility of management.
4. Mobility of management. Job-hopping managers never understand the companies that they work for and are never there long enough to follow through on long-term changes that are necessary for quality and productivity.

5. Running a company of visible figures alone. The most important figures are unknown and unknowable--the multiplier effect of a happy customer, for example.
6. Excessive medical costs. [Pertinent in the United States].
7. Excessive costs of warranty, fueled by lawyers that work on contingency fees. [Pertinent in the United States].

Thinking About Quality
(Dobyns & Crawford-Mason. 1994

Old	**New**
Competition motivates people to do better work	Cooperation helps people do more effective work
For every winner there's a loser	Everyone can win
Please your boss	Please your customer
Scapegoating pinpoints problems	Improve the system
Focus improvements on individual processes	Focus on the purpose of the overall system, and how the processes can be improved to serve it better
Find the cause and fix the problem	First, acknowledge there is variation in all things and people. See if the problem falls in or outside the system
The job is complete if specifications have been met	Continual improvement is an unending journey
Inspection and measurement ensure quality	A capable process, shared vision and aim, good leadership and training are major factors in creating quality
Risks and mistakes are bad	Risks are necessary and some mistakes inevitable when you practice continual improvement
You can complete your education	Everyone is a lifelong learner
Bosses command and control	Bosses help workers learn and make improvements
Bosses have to know everything	The team with a good leader knows and can do more
Short-term profits are best	Significant achievement in a complex world takes time
You don't have to be aware of your basic beliefs	You must be conscious of your beliefs and constantly examine and test them to see if they continue to be true
Do it now	Think first, then act

Beyond Quality

The Ten Commandments of Continuous Improvement
*(*Bowles & Hammond, 1991).

1. *Put the customer first.* Without customers, there is no business. Companies must focus first and foremost on fulfilling the ever-changing expectations of the marketplace in such a manner that they earn and keep the trust of their customers.
2. *Innovate constantly*. But do not emphasize product innovation over process innovation. Breakthroughs are important, but incremental improvements to succeeding generations of products and services are just as important.
3. *Design quality into products and services*; plan for prevention. Stopping defects before they happen is more productive and cost-effective than detecting them after the fact. By anticipating problems, you can avoid time and costs associated with "inspecting them out" and rework.
4. *Improve everything continually*; quality improvement never ends. All work is part of a process; every process can be improved, no matter how good it is today. An emphasis on continuous improvement fosters creativity and breakthroughs.
5. *Create and support a safe and open work environment* that seeks out, nurtures, rewards, and celebrates the contribution of each employee.
6. *Do not shoot the messenger*. Overcome the barriers to quality and productivity: discuss the undiscussibles.
7. *Stop imitating the Japanese*. Heed this Japanese proverb: The crow, imitating the cormorant, drowns in the water.
8. *Use time wisely*. Speeding up production or delivery cuts costs, accelerates new product development, and improves quality. The fastest was to get something done is to do the right things right the first time.
9. *Do not sacrifice long-term improvements for short-term profits.*
10. *Quality is not enough.*

The Seven Habits of Highly Effective People

(Stephen Covey, 1990)

1. Be Pro-Active: Take the initiative and the responsibility to make things happen. Focus on a "circle of influence" and produce tangible results rather than react poorly, place blame, point fingers, and make excuses in the name of your boss, the bureaucracy, your spouse or other forces over which you have little or no control.

2. Begin With an End in Mind: Start with a clear destination to understand where you are now, where you're going, and what you value most. Identify mission and values before setting goals. Seek unity between means and ends.

3. Put First Things First: Manage yourself. Organize and execute around priorities. Manage your time and resources in ways than keep you focussed on key roles and goals, thereby reducing crisis management and increasing productive time through more high-leverage activities.

4. Think Win/Win: See life as a cooperative, not a competitive arena where success is not achieved at the expense or exclusion of the success of others. Negotiate agreements from a tough-minded, "win-win or no deal" perspective, resulting in more mutual satisfaction.

5. Seek First to Understand: Understand then be understood to build the skills of empathic listening that inspires openness and trust. Enhance relationships with family members and business, reduce

interdepartmental rivalry and build teamwork through seeking first to understand.

6. Synergize: Apply the principles of cooperative creativity and value differences. Valuing differences helps people work together more effectively which results in higher quality decisions. Get beyond the either/or traps and explore third-alternative solutions.

7. Renewal: Preserving and enhancing your greatest asset, yourself, by renewing the physical, spiritual, mental and social/emotional dimensions of your nature. Develop and implement a total fitness program that rejuvenates the mind and body, provides for personal value review, and enhances capabilities.

Conclusions

The emphasis in these notes on systems, teamwork, quality, problem formulation and modeling is based on the observation that the world is moving too fast for experts, and old-fashioned "problem-solving" no longer works. Productive work has been moving away from problem solving toward whole-systems improvement as the secret for solving great handfuls of problems at once. Furthermore, effective work has been moving away from getting experts to fix systems toward having experts join everyone else in learning how to make improvements (Weisbord, 1992). It is becoming clearer and clearer that knowledge and skill can't be pumped into people the way traditional schools have done it. They can be mastered only by applying theory directly on the job, to real problems, here and now. That requires the learner's direct involvement. Once again this change cries out for a different environment--one of cooperation, interdependence, and accountability. We learn and change as we have face-to-face contact with others and get new information. We change when we listen and respond in new ways, when we genuinely interact with others and when we listen to our inner voices.

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