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Education Approach in Japan for Management and Engineering of Systems

by

David S. Cochran and Makoto Kawada

Abstract

Designing and managing systems that are sustainable requires a new approach to thinking and learning about the management and engineering of systems. This paper describes a university curriculum in Japan that embodies a new approach to education about enterprises systems (and specifically knowledge about the Toyota Production System (lean)). Referred to as Collective System Design, the new learning approach emphasizes the tone of the system participants and a language for system design to codify the understanding gained during a system design and learning process.

Introduction

Collective System Design (CSD) is an enterprise and manufacturing system design, implementation and management methodology. CSD is being developed in response to problems that many enterprises face in implementing and sustaining the Toyota Production System, Lean and Lean-Six Sigma. Evidence in the application of lean as it is being taught and implemented today is that "lean" is sustained in just five percent of the applications after three years [1, 2].

The lessons learned in developing the CSD approach are the result of many years of systems engineering, implementation and management experience. Enterprise and manufacturing system design is an emerging discipline as it addresses the thoughts and actions of people internal to a system to provide a service or product to people outside of the system boundary [3, 4].

The CSD methodology provides a framework to incorporate systems solutions from the Toyota Production System (TPS) [5, 6, 7], Six-Sigma, Lean-Six Sigma, Drum-Buffer-Rope and other methodologies, and the relationships in systems implementations expressed mathematically as Factory Physics and Principles of Systems [8,9] and others. CSD incorporate physical solutions as it works as a tool to codify, "the thinking" by first expressing system purpose, stated as non-numerical, non-financial system design functional requirements, and then identifying physical solutions to achieve the specified purpose [10].

The open framework of CSD enables a team to identify a new system purpose based on a new customer need, which is then stated as a Functional Requirement (FR) and a related Physical Solution (PS) for the system to achieve the FR. Each PS is treated as a hypothesis to achieve an FR. The team starts with a set of FRs, but at that point does not necessarily know or even understand the PSs [11]. An important lesson from working with students in Japan is that the PSs of the system do not have to be understood at all prior to the system design exercise. The students must first understand and agree on system purpose, expressed as system design Functional Requirements (FRs) as part of a system design exercise.

The purpose of this paper is to describe the educational methodology, course sequence and the system design simulation used in the learning process at Meijo University in Japan.

Educational Methodology

Meijo University is located in midland Japan, the center of Japan's manufacturing industry, including Toyota. Meijo University established the "Manufacturing Management Systems Course" in the Graduate School of Business in 2003 as part of the "Practical Process Management Study" curriculum. The students who participate in the course are Meijo graduate students from Japan, China and many places in Southeast Asia (e.g., Vietnam or Sri Lanka) and sometimes in South America, particularly, Uruguay. In addition, class members include Business Leaders, Engineering Managers, Accountants, Production Control and Purchasing Agents, Team Leaders and other practitioners from Japanese Manufacturing Industry. This course is the most popular in the Practical Process Management Study curriculum.

The course is taught in English but is translated to Japanese simultaneously. The learning objective about the design of the Toyota Production System is the same in Japan as it is at Southern Methodist University (SMU) in the U.S., namely that to understand how a team of people must work in a system and manage its operation to deliver a product or service, requires collective or shared understanding of system purpose (FRs) and shared understanding of how physical work methods (PSs) are used to achieve system purpose. To facilitate this understanding, the system design education simulation is used as part of the course sequence.

Collective System Design: Course Syllabus

The course syllabus summarizes course content and learning points. The program defined here summarizes the learning based on eight years of experience of teaching in Japan and the USA.

1. The Assumptions of Traditional Management Accounting. Traditional management accounting asserts that the total system cost is reduced by first reducing the unit cost of an operation. This approach is incorrect in that it does not reduce the system cost (or the cost of the process according to Shingo and many others.) [12]. The key points of this section of the course are:

- The application of traditional management accounting results in improving cost of the operation and not of the system (process).
- Define an operation versus a system, and contrast operation improvement versus system improvement.
- Illustration of traditional management accounting gone bad with pictures of a factory with a 3600 unit / hour cup line and a video of product flow in a factory (that travels over five miles) in a departmental-layout based company that evolved in this particular way because of the application of traditional management accounting.
- Discussion of The Unit Cost Equation, which is the foundation of traditional management accounting. See Appendix A for the equations.
- Explain the System Design Language of CSD (Figures 1, 2 and 3) and describe the implied FRs of traditional management accounting and the corresponding PSs (Figure 4).

The System Design Language expresses "the thinking" about the design by defining the relationship of a set of PSs that are hypothesized to achieve a set of FRs. This relationship connects and defines the hypothesized physical means (PS) to achieve the system purpose, which is expressed by the system FRs. The design team expresses both the PSs and the FRs. Also, the design team seeks to understand how each PS affects each FR.

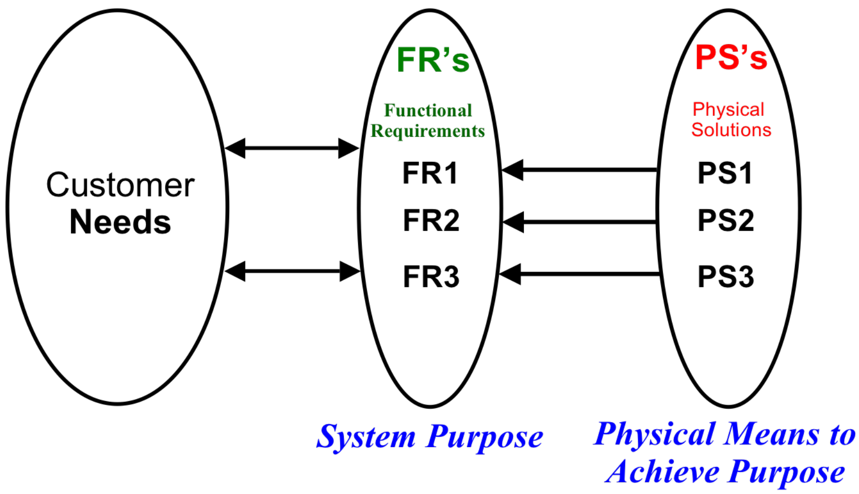


Figure 1. The System Design Language to Express the Group's Thinking

A design is considered most effective when a set of PSs independently achieve a set of FRs (Case 1, Figure 3) so that the manipulation of one PS only affects the FR that it is supposed to influence.

In most large and complex systems, like manufacturing, Case 2 (Figure 2) occurs, which is the case in which at least one PS affects more than one FR. This situation causes a condition in which the PSs must follow a pre-defined implementation sequence. This case is called a path-dependent design (Case 2) [13]. The construction of a house on slab illustrates the path-dependent (Case 2) design. Notice that the PSs in the following design (Figure 2) are physical entities or things. The FRs, in contrast, state the purpose for the user, without saying how to achieve purpose. For this reason, this format of a design's expression delineates the thinking about the design.

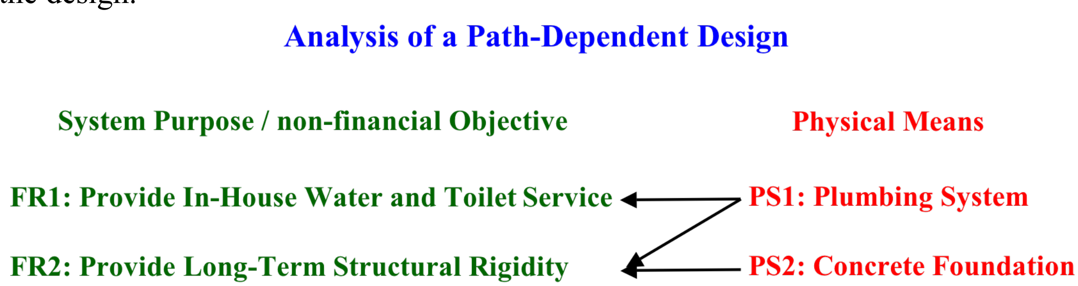


Figure 2. Example of Path Dependent (Case 2) System Design

For on-slab home construction, the plumbing lines must be laid before the concrete foundation is poured. In this case, the path dependency is PS1, then PS2 to achieve FR1 and FR2. However, if the concrete is poured first, PS2, then installing the plumbing, PS1, requires using a jack hammer to dig up the concrete, undo PS2, then install the plumbing lines, PS1, and then to re-pour the concrete PS2. This implementation sequence results in waste and excessive cost since it is: PS2, undo PS2, PS1 and then PS2.

A design that is not acceptable does not achieve the FRs. An inter-dependent or coupled design occurs when PS1 and PS2 must be iterated, over and over again, perhaps ad infinitum (Case 3, Figure 3). This case leads to optimization methods and a great deal of expense to determine how a set of PSs affects a set of FRs; it is not a preferred design as it is costly. Most optimization problems in engineering deal with this type of design. The idea is to avoid it, if possible, in the first place [14]. Figure 3 illustrates the design cases introduced so far and also illustrates the incomplete design case (Case 4) when not enough PSs are chosen to achieve the FRs and the redundant design case (Case 5), which adds cost by using more than one PS to achieve an FR.

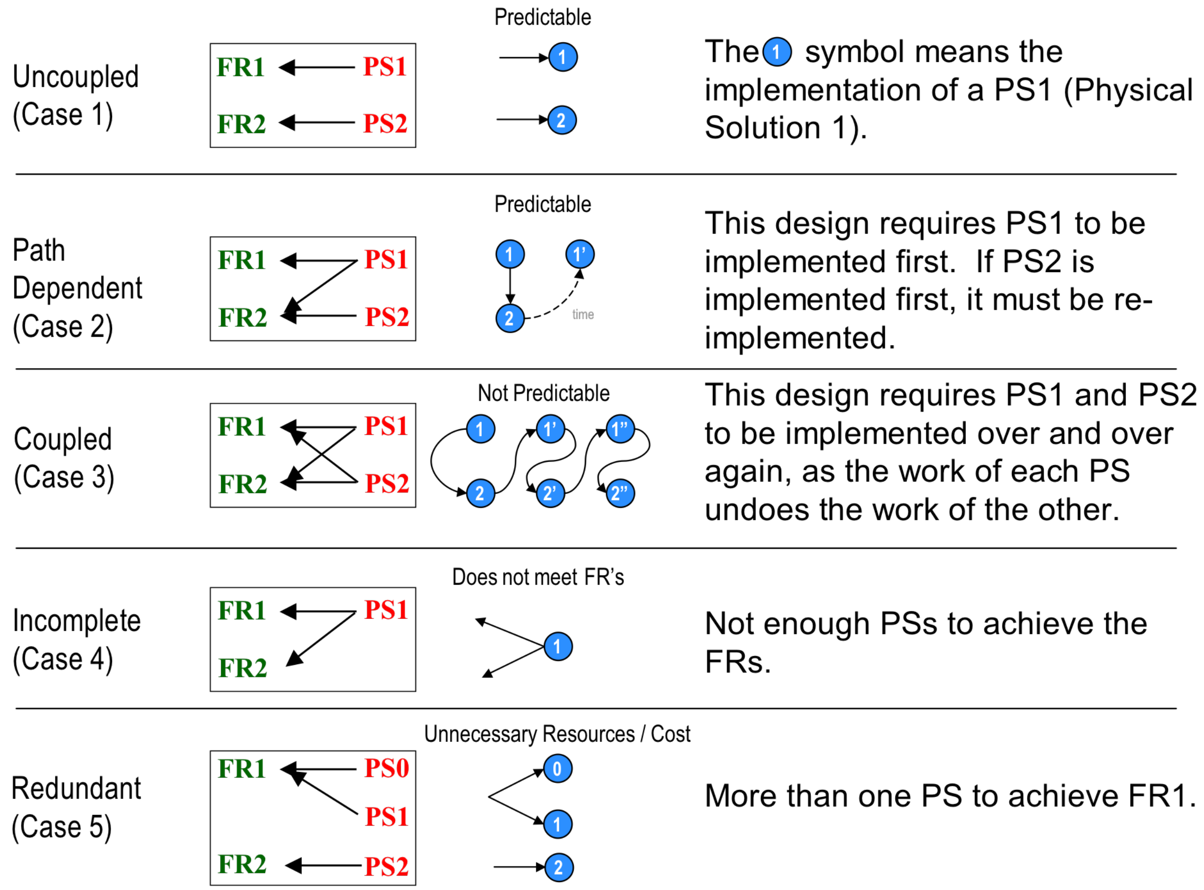


Figure 3. System Design Cases

After a discussion of the unit cost equations (Eq. 1, 2, and 3) presented in Appendix A, the System Design Language is used to discover the FRs and PSs that are implied (or built into) the unit cost equations that are applied by traditional management accounting. Eq. 2 states that the unit cost ($/unit) at a single production operation decreases as the number of units produced (N) is increased [15]. There is no boundary condition placed on N. This implies that as $N \rightarrow \infty$, the unit cost of the operation, $UC(Op_i) \rightarrow 0$. The result of the unit cost equation's formulation is FR1, to increase the speed of the operation, as illustrated in Figure 4. The physical solution (PS1) is to build high-speed machines. In fact, the faster the machine, the better.

The diagonal arrows in Figure 4 only indicate negative inter-dependencies. A negative inter-dependency means that the application of PS has a negative impact on an FR. The PS1 to FR2 diagonal inter-dependency is negative, since a machine that is high speed, reduces the operation cycle time. A production facility with a line that produces 3600 units / hour illustrates this point. 3600 units / hour is an operation cycle time of 1 second / unit. This condition makes it impossible to do line balancing, since the goal of machine design is not overall system balance, but instead, is to build machines to work as fast possible. In addition, the high-speed machine induces repetitive work stress on team members.

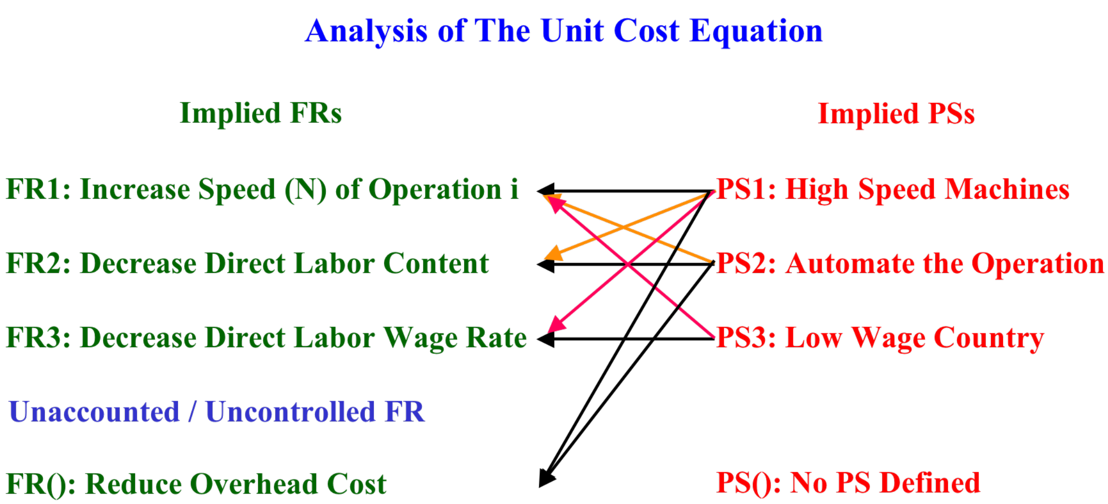


Figure 4. The Unit Cost Equation is Both a Coupled and Incomplete System Design

The design is both coupled (Case 3) and incomplete (Case 4). The design is incomplete, because there is no PS in place to reduce overhead cost. Overhead cost is increased since high-speed machines and automation are costly and require a higher, more costly skill set to maintain.

In addition, the design is coupled as highlighted by the orange (PS1 and PS2 relative to FR1 and FR2) and magenta crosses (PS1 and PS3 relative to FR1 and FR3). The orange cross indicates the negative impact on labor content due to inability to line balance and the difficulty that is associated with automated high-speed processes [16,17]. Looking at the PS1 to FR3 relationship of the magenta cross, the use of high-speed machines grouped in departmental layouts does not reduce overall system cost relative to systems that balance machine cycle time and standard work of team members to customer takt time [18]. The PS3 to FR1 line is a negative inter-dependency since the resources in low-wage countries typically are limited in dealing with high-speed, complex machines. One major auto company set up a factory by the strict application of the above formula and positioned a factory with high-speed, automated lines in a low-wage country.

2. Address the Question, "If TPS / Lean is so easy, why is it so hard to do?" Introduce the Flame Model of System Design as a solution to address this question. The flame model illustrates that a system consists of multiple layers that are inter-related that include Tone, Thinking, Structure, and Action (the work) [19].

3. Using Collective System Design to Define the Manufacturing System Design Problem. Collective System Design (CSD) uses the System Design Language (Figures 1-3) to express the thinking layer of a system design. A system design consists of four layers, according to CSD: the tone, the thinking, the business structure, and standard work/action. Any system design is hypothesized to emanate from the tone and mindset of the people that are present in a system. Tone can be positive or negative. The tone creates an inherent bias in a designer's viewpoint. Since the design of manufacturing systems includes people and their inherent thinking, bias is part of any system design endeavor. CSD acknowledges that the first step of a large system design that includes people in that system is to understand tone and to express tone in a positive manner. Collective System Design starts with the tone and moves to thinking, then structure and then codifies and lastly defines the actions / work to implement a system design in the form of standard work. The standard work is continuously improved and must define the content, sequence and timing of all work that is performed by all people in the system that is designed.

4. Describe the Tone Layer of the Flame Model of System Design. Emphasize the importance of human attitudes and the mindset that is pre-requisite for people in systems to learn and to work together.

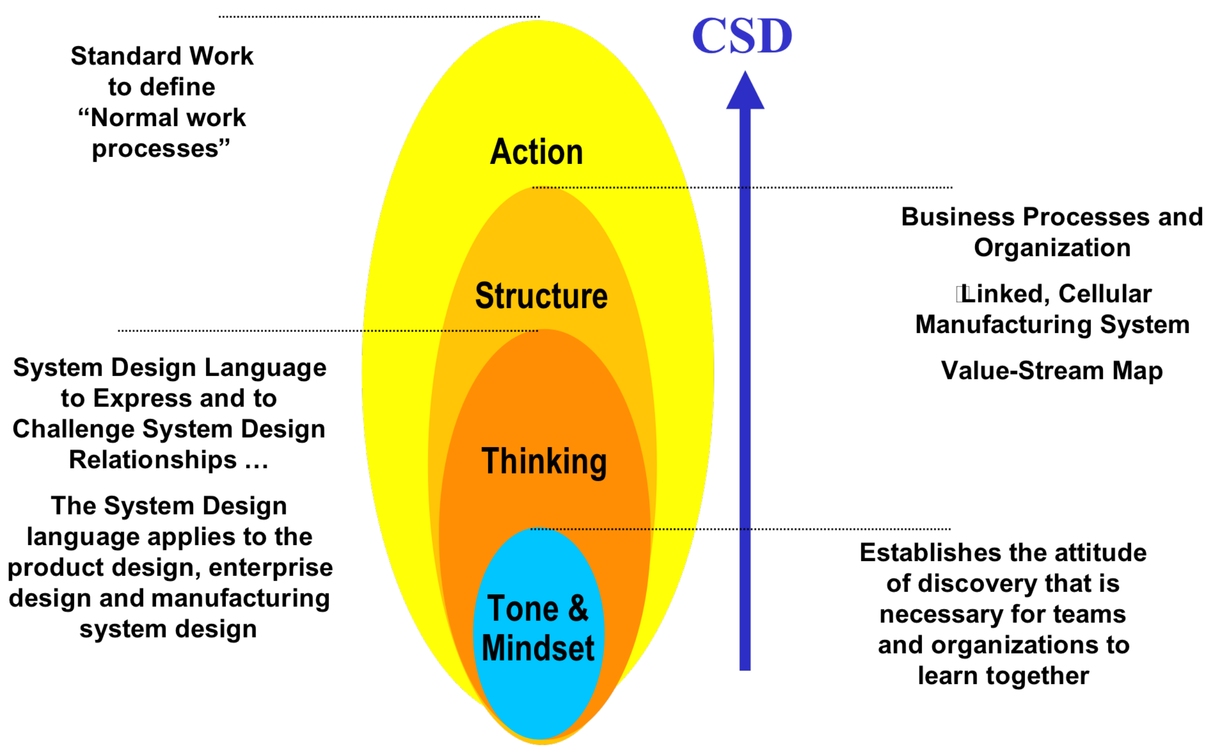


Figure 5. Collective System Design: Flame Model of Systems

The flame model illustrates that system design starts with people. Collective System Design requires people to have the tone and mindset needed to openly think about change together and to have the attitude that is needed to accept change to the existing system. The tone and mindset is about the way people work together. This concept applies to the people within the designated system boundary and to the tone and mindset of the people internal to the system relative to the people external to it. The flame model illustrates that innovation, discovery and improvement requires openness to other people's ideas. It is an adaptation of Chris Argyris' work, because of the addition of the thinking layer of system design and the use of the System Design Language to express the thinking in an unambiguous way [20,21]. The concept of tone is inspired by David Bohm's expression of dialogue [22]. A meaningful part of dialogue is to use "I" language… to realize that one's statement is one's own way of thinking and not necessarily the thinking of other people internal or external to the system boundary. The System Design Language provides a rigorous method to express the thinking about a system design. This thinking starts with the tone and mindset of the participants [23].

System discovery starts when the leaders in a group realize that they do not have all of the answers and that people who do the actual work in a system are more likely to know the answers. "I language" starts with, "I think," realizing that there is more than one possibility to any thought, even if it is not one's own way of thinking. Bohm's knowledge of physics no doubt influenced this approach, that the minds of people work as holographic generators to influence matter, energy and reality [24]. Collective understanding and agreement about system FRs, PSs and performance measures is the result when there is shared understanding, shared reality and shared energy among the people within a system. The purpose of giving the students the system design simulation exercise is to enable them to experience what shared learning and shared understanding really is.

System design moves progressively out of the flame. The System Design Language is used to clearly separate system purpose (stated by FRs) from the means of achieving the purpose (stated by PSs). FRs are most closely aligned with business strategy; while PSs are the tactics, and define a physical operation, "op," to achieve a strategy.

5. Describe the Thinking Layer of System Design. The Thinking Layer is presented to the students as an initial set of FRs for the design of a Manufacturing System. The following manufacturing FRs are derived from the TPS house model [25] and engineering principles for controllability and feedback in systems [26]:

Manufacturing System Design Functional Requirements (FRs)

FR1: Produce the customer-consumed quantity every shift (derived from Toyota House Model: JIT Pillar)

FR2: Produce the customer-consumed mix or product variety every shift (derived from Toyota House Model: JIT Pillar)

FR3: Ship perfect quality products to the final customer every shift (derived from Toyota House Model: Jidoka Pillar)

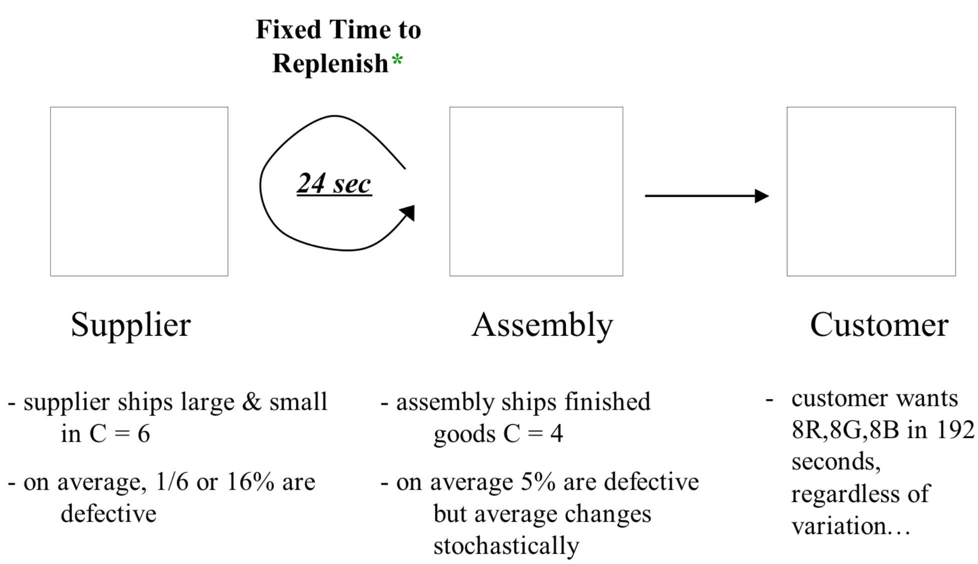
FR4: Achieve FR1, FR2 and FR3 in spite of operation variation (derived from Robust Design)

FR5: Identify immediately when a problem occurs in accomplishing FR1, FR2 or FR3, and respond in a pre-defined way (derived from Control Theory)

FR6: Provide a safe, clean, ergonomically sound work environment

Each layer of the flame model has an associated tool set. The System Design Language of CSD expresses the thinking layer of the flame. The structure layer of the flame relies on several tools, namely process or Value-Stream Mapping (VSM) [27], the linked-cellular manufacturing system (L-CMS) [28] and organization structure. Standard work and the standard operations routine sheet codify the action layer of the flame model.

6. Discuss the Supply Chain to be simulated. It consists of the final customer, mixed-model assembly of three product colors, and a supplier that is a simulated distance away from assembly. There are three nodes and two customer-supplier connections. The simulated system exaggerates the existence of variation in the supply chain in two ways: defects are sent from the supplier to assembly and assembly itself makes defects. Students assemble a very simple product that is made from Duplo® Legos®. The purpose of using a relatively simple manufacturing system is to emphasize two points: the system design itself leads to complexity and, secondly, that system success is the result of the way people work together.



*This is a fixed time, variable consumption quantity model…"milk run"

Figure 6. Manufacturing System Design Exercise Details

7. Initial Design and Operation. The students then design and run the simulation of factory operations. The simulated time for one eight-hour shift of production is less than 5 minutes. Then the students record their results for each simulation run. The students record whether each of the six FRs are achieved or not achieved. For example, if the final customer consumes just 10 blue products, this means that the system according to FR1 must replace the 10 products consumed by the customer. If, instead, the system makes 24 blue products, FR1 is not achieved because the system made too many products; FR1 is not achieved. It is important to note that the system is self-measuring. Performance information is <u>not</u> sent to an external group of managers.

Figure 7. Students in Japan Working Together on the Manufacturing System Design

8. Run and Re-Run Simulation Until the Team Achieves the System FRs. If, the system does not achieve the FRs, the students re-design and re-run their plant simulation, until the system achieves each of the 6 FRs. The approach is that the student teams invent the 6 PSs to achieve the 6 FRs. In addition students may add additional FRs to the initial set of 6 FRs.

9. Team Reflection and Coaching. After each simulation run, the students discuss their observations about the simulation run. The teacher helps students put into words their observations about the physical operation of the system and asks questions in a Socratic manner about what must be done to meet system FRs. Additionally, the teacher describes the issues encountered in terms of engineering and management principles and may explain the engineering and management issues that the students are dealing with in the broader context of industry implementation. Once one of the teams' system design simulation achieves all the FRs, the team will demonstrate their design to the other teams. Then the other teams continue working so that their design achieves all the system FRs.

Typically there are three to five student teams. The students *invent*, for themselves, a "pull" system which operates at takt time, and that minimizes the run size of production via some type of heijunka (leveling) box which is the physical integration of the information system that is necessary to pace production to takt time, identify when the system is not operating to takt time and to establish a fixed production run size.

10. Codify the System Design Relationships using the System Design Language. Codification requires the student teams to state a PS to achieve each FR. A learning organization seeks to create shared mental models. The approach is to cover two aspects of a shared mental model. The first mental model is the experience of physically designing and running a system until it succeeds. The second mental model is to use the system design language of FRs and PSs to put into words the physical solutions that each team invents to achieve the system FRs.

11. Discussion about Performance Measures for the System. CSD uses the system design language (Figure 8) to first identify system FRs, then PSs. Performance measures can be of two types. The first type of measure is placed on and is associated with the FR, which relates to the achievement of system purpose; these are called Purpose Measures (M_{FR}). The teams identify the fewest possible purpose measures to minimize complexity. The second type of measure is the Solution Measure (M_{PS}), which is typically a binary measure and asks whether or not the standard work that is associated with a physical solution is being done (yes or no) and whether it is being done correctly (yes or no). Solution measures deal with whether the work is being performed as designed. Since a PS is a hypothesis to achieve the desired FR, a solution measure does not measure whether an FR is achieved. The Solution Measure (M_{PS}) determines how well the work associated with a PS is performed / executed. Purpose Measures (M_{FR}) determine the extent of achievement of an FR or the growth and trend in achievement of an FR.

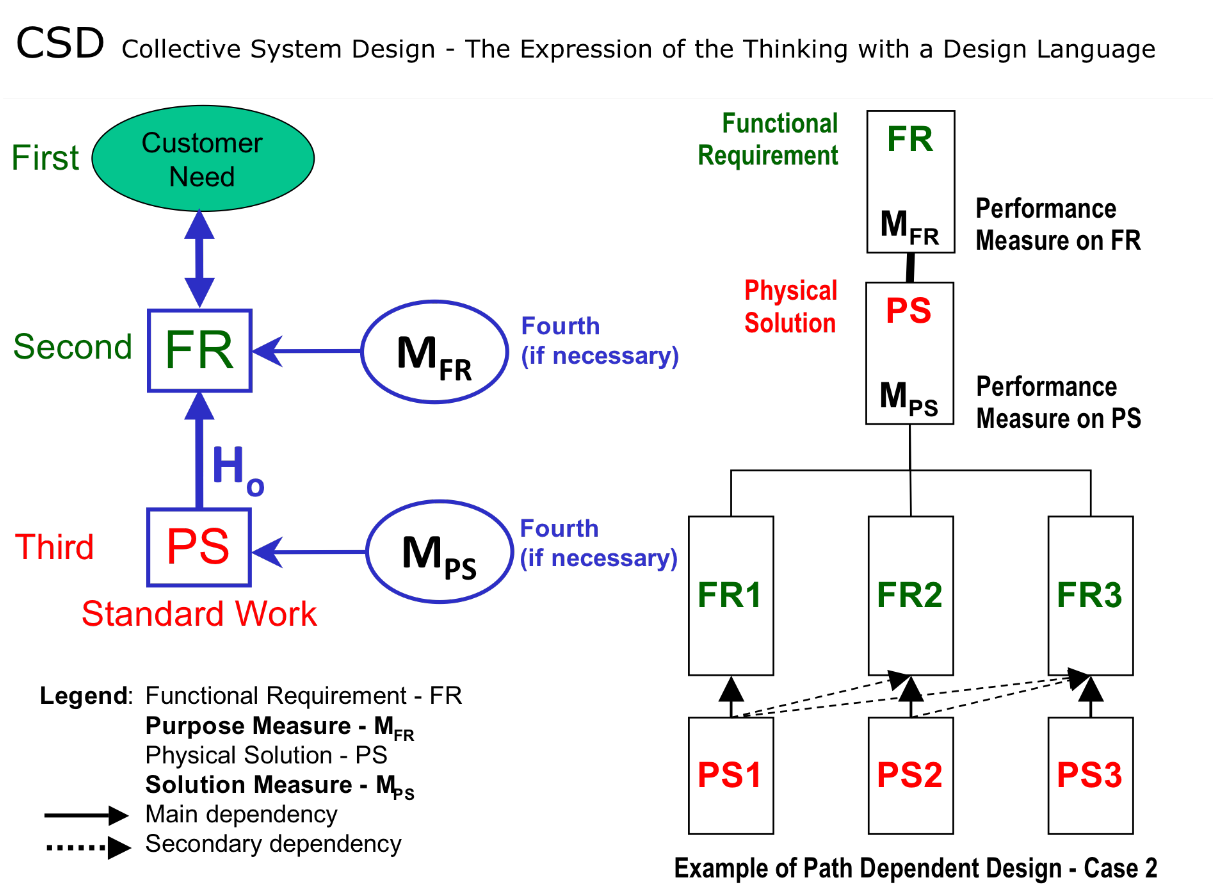


Figure 8. Each Performance Measure Must be Aligned with a System FR or PS

12. Discussion about Continuous Improvement and Sustainability. Continuous Improvement and kaizen in the context of the system design language applies to the PSs of the system. The PSs define the work that people must do to achieve system FRs. The teacher asserts that work must be continuously improved (i.e., kaizen) in the context of a system design; that kaizen done randomly and out-of-context of the overall system design is sub-optimal, at best. In Japan, this approach of putting in the system to achieving the system design, and then making small incremental improvements to the work done by people in the system is called, "tightening the rope" [29,30] and is Toyota's meaning in the desire to achieve "True North."

Sustainability deals with a larger scope than continuous improvement. Sustainability is the ability of a system to adapt to change, specifically to changes in internal and external customer needs. Since FRs are derived from customer needs, to add additional system FRs or to make changes in system FRs, as Figure 9 illustrates, is the challenge of system sustainability.

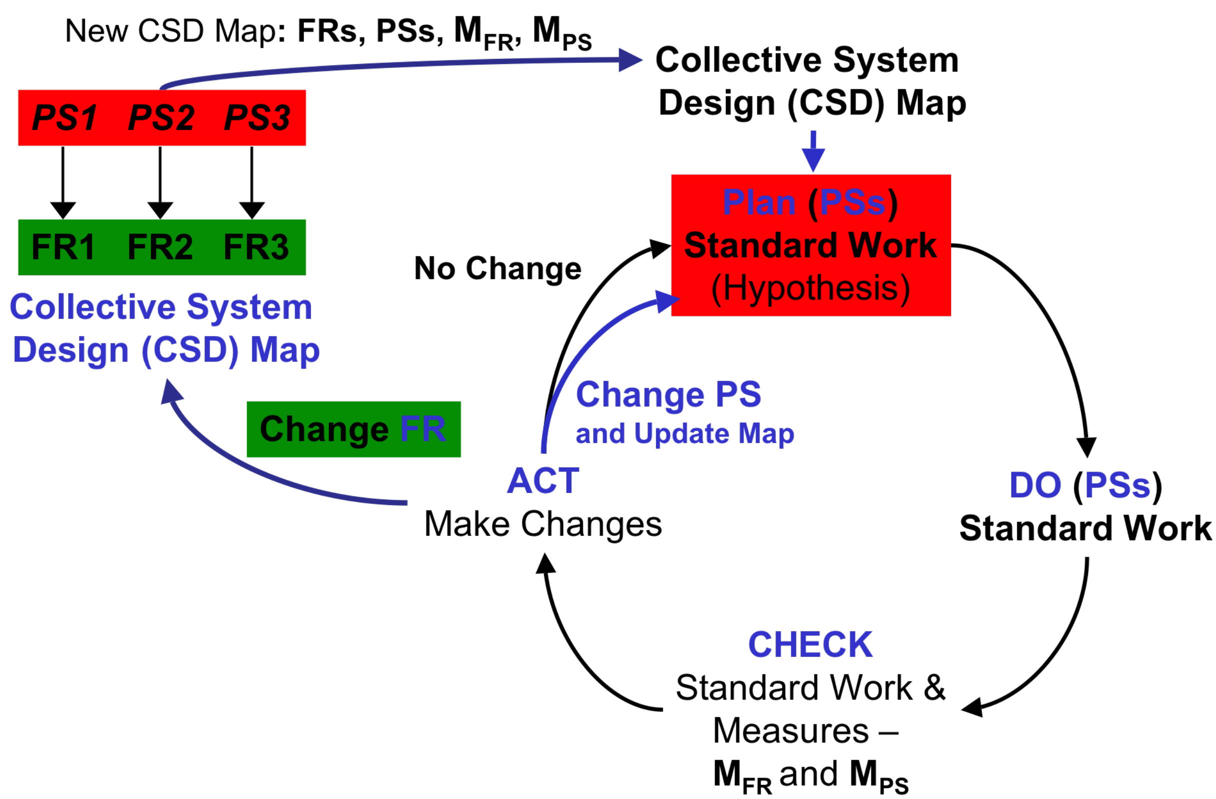


Figure 9. CSD uses a Combination of the System Design Map and PDCA Loop to Manage and Sustain Systems

The System Design Language of CSD describes the evolution of TPS / Lean as a PS in response to marketplace evolution in the form of customers wanting low cost, high product variety / flexibility, rapid and on-time delivery, and perfect quality. CSD describes this evolution as both an increase in system FRs and as a change in system FRs in the auto industry relative to the 1950s automotive marketplace [31].

Summary

The new teaching method of CSD provides a unique opportunity for students to learn about manufacturing system design. The use of Collective System Design (CSD) in the classroom strengthens the decision-making process in system design and provides rigorous, explainable results to the industrial participants.

Collective System Design provides clear advantages in defining problems and finding corresponding solutions in many different enterprise systems. Students learn that it is important to always consider system purpose / objectives (FRs) while seeking solutions (PSs) to problems and to reduce inter-dependencies.

Lessons Learned

- Not one right solution; know “why”(FR) then “how” (PS)… fosters a process of learning.
- It is critical to understand each Customer-Supplier Connection in large systems.
- The simulation of just 2 Customer-Supplier Connections provides a fractal of how to think about and deal with larger systems.
- Complexity is the result of the system design, not the number of products or the number of Customer-Supplier connections.
- The teams learn together to create a shared mental model of their manufacturing system that works equally well for learning, regardless of geographic boundary, language or culture.
- The use of the CSD language combined with building a physical system together, enables students to learn and to co-create systems that have the potential of sustainability.
- The System Design Language and CSD apply to any system: manufacturing, enterprise-wide, service or government system.

Profit Potential

Incremental sales increase must be realized with the less incremental inventory. This is the very principle TPS has continued to pursue for the past half century and finally overtook GM at the beginning of the 21st century. Prof. Kawada proposes here, based on hints gained from TPS, the notion of “Profit Potential (PP)” to support the *new* capitalism. In the *old* capitalism, only the Profit at the bottom line in the income statement was the focal point, but in the *new* (sustainable) capitalism, Profit Potential, which means the power to generate profit in the future, should be pursued. PP is measured as “operating profit (P) divided by inventory.”

$$\textbf{PP = P/ inventory = P/Sales} \times \textbf{Sales/ inventory}$$

The implication of the PP equation is to compare the amount of profit in the income statement with the inventory prepared for the next term operation, asking, “While acquiring sales and profit for this fiscal term, how much inventory had this company to prepare for the operation of the next term?" As the lead-time of a factory approaches zero, PP increases, thus representing the degree of operational evolution.

When the incremental inventory turnover is less than the incremental reporting profit, PP decreases. The incremental profit in this case should be blamed, not be praised, as the decline of PP value means the decline of operational profitability, and what is more, it means the waste of natural resources as well as more cash out. Profit increase by increasing inventory means the "negative" service both for the individual enterprise and for the society in the *new* capitalism.

Conclusions (Prof. Kawada)

Toyota Motor Corporation proclaimed after the Fukushima disaster in March 2011 that they will raise Tohoku (northern Japan) district as one of its three major production base in Japan along with Nagoya (Central Japan) and Kyushu (Southern Japan). Toyota's stance is evidently that of altruism instead of egotism as done in the 20th century laissez-faire economy. Production base, in this case, has the network of 'horizontal linkage' between assemblers and parts suppliers that is connected with the tool called *Kanban* at its core, and around it public, cultural, medical and other organizations combined the software network. It is a kind of emergent and autonomous industrial cluster as the typical 'innovation from the frontier' model, and the technical philosophy to support this cluster is the 'service science.'

In the 21st century, the fusion of the manufacturing industry and the service industry is going on. The first trigger for the fusion was the emergence of Toyota Production System (TPS) in manufacturing industry. To serve the requirements of the next process, or 'don't make more than the customer actually ordered' is its core principle, which Dr. Cochran teaches through CSD and the system design simulation exercise; where FR1 is achieved via PS1 of Takt time, and FR2 is achieved via PS2, *Heijunka* (leveling).

The second trigger of the fusion is the information technology, network and database that support the horizontal linkage to support the recent recovery of US manufacturing industry. The image of the service science society is the *new* capitalism led by the schema of horizontal linkage. The real problem we face is *how* to change the schema, or *Tone* in the management and engineering of systems.

Management by "fear" by strictly checking from outside and punishing more severely than before, like the Sarbanes–Oxley Act (SOX) enacted in 2002, cannot change the tone of the enterprise. Whereas, after the one-day intensive course of Dr. Cochran's CSD approach the students' tone changes.

Appendix A

The unit cost equation is broken down into three parts given by Eqs: 1, 2, and 3. This cost evaluation approach incorrectly assumes that Total Cost (TC) is the result of summing the minimum Unit Cost (UC) of each operation (OP_i), given in $/unit for each operation "i" in the supply chain.

$$\mathbf{TC} = \sum [UC(Op_i)] \text{ for } i = 1 \text{ to } n \text{ operations} \qquad \text{(Eq. 1)}$$

where,

TC = total cost of all operations "i"
UC(Opi) = minimum unit cost ($/unit) at operation "i"

and,

$$\mathbf{UC(Op_i)} = \frac{W*T(Op_i) + M(Op_i) + OC(Op_i)}{N} \qquad \text{(Eq. 2)}$$

where,

$UC(Op_i)$ = unit cost ($/unit) at operation "i"
W = wage rate in dollars per hour
$T(Op_i)$ = direct labor time at operation "i" in a period
$M(Op_i)$ = material cost at operation "i" in a period
$OC(Op_i)$ = overhead cost allocated to operation "i" in a period
N = number of units produced in a period

and,

$$\mathbf{OC(Op_i)} = T(Op_i)/\, T(Op_{ALL}) * O \qquad \text{(Eq. 3)}$$

where,

$OC(Op_i)$ = overhead cost allocated to operation "i" in a period
$T(Op_i)$ = direct labor time at operation "i" in a period
$T(Op_{ALL})$ = direct labor hours (time) for all operations in a period
O = total overhead cost for the facility

Notes about the Unit Cost Equation

1. "The more you make, the cheaper the unit cost becomes, even when it is not sold yet." This hypothesis was valid in the Ford Model T era, but not in today's economic environment.

2. Total elapsed time instead of mere operation "i" of the material flow must be taken into consideration in presetting overhead rate. Then the cost allocation method matches with the JIT environment.

3. Another problem is that profit in the income statement increases by increasing inventory, thus deferring indirect cost to the next fiscal term. Don't see mere profit, but see profit potential for the future. Profit should be divided by inventory, which Kawada calls Profit Potential, or PP.

$$\mathbf{PP = P/\ inventory = P/Sales \times Sales/\ inventory}$$

PP is a new message to the Wall Street, and could help revive American manufacturing industry.

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