**WORCESTER POLYTECHNIC INSTITUTE**

# The Design of Public Education

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By

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## Abstract

The purpose of this MQP was to design a public education system using manufacturing and industrial engineering principles. Using axiomatic design, a design was proposed that prepares students to attend high school at their own individual learning rates, while controlling the cost to operate the system. Through a financial analysis and a design matrix analysis, the proposed design of public education was shown to be cost controllable flexible for students completing their course work in preparation for high school.

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# Chapter 1 – Introduction

## 1.1 Objective

The objective of this project is to design a public education system that prepares students for high school at their respective learning rates by adding the most value to the student and controlling the cost of operating the school system.

## 1.2 Rationale

Education is a key component in today's society, with everyone participating in some form of both formal education and informal education. The main goal of education is for people to become productive members of society, preparing them for social interaction as well as employment. Ideally, all educational institutions should be able to create such individuals, capable of earning a living and existing with others.

Today, the topic of education is on everyone's mind through media and politics. Is there evidence that society is providing for gifted students? Is society giving support to students with inadequate home situations? Providing support for students who learn at different rates and styles? Are individuals who will thrive in society once they have graduated high school created? In light of these challenges, a need has arisen to review our education systems and see where shortcomings may lie. Society has a never-ending need to improve education. The government at all levels provides billions in funding annually to improve our current system. Nearly $4.6 billion has been awarded to states to kick-start their efforts to improve our nation's repeatedly lowest-achieving schools and also provide grants to support

plans to "personalize and deepen student learning, directly improve student achievement and educator effectiveness, close achievement gaps and prepare every student to succeed in college and in their careers" (Duncan 2013).

Applying manufacturing principles to public education is a clear choice because a system that takes students as inputs and outputs them as educated individuals is similar to a manufacturing system. Manufacturing is not generally thought of when designing humans systems, people have heartbeats, emotions, thoughts and opinions while manufacturing processes deal with non-living materials, the similarities are also evident. There are raw inputs, like materials, that go through some kind of process and are transformed into the desired output. Just as factories might need to make adjustments to a process, schools need to make accommodations in order to effectively maximize the amount of students successfully put through the system.

The idea of looking at an education system as a manufacturing system is easy to grasp, but how a school might actually affect change with this thought process is much more involved. Just as a manufacturing system has metrics to determine success, a school must also have metrics to gauge success. The main production questions that a school should be asking are (Towner 2013):

- How does the school know when it is adding value to the student?
- How can learning be quantified?
- How are delays in the learning production system eliminated?
- How will successful completion of the learning requirements be known?

Educational systems might be characterized by a mass production approach to educating students, independent of the individual's learning rate. This project will design for individual's rates of learning, and as such create the most value for the student.

## 1.3 State-of-the-art

### 1.3.1 Education

Education in the United States has undergone many stages of reform. Throughout the process there have been resounding success and failures. In colonial America, education was comprised of one-room schoolhouses, in which many different grade levels would be represented ranging from elementary school through what we would consider high school. Horace Mann considered by many to be one of the greatest figures in the development of education in the United States surfaced in the 1820 (Cremin 1957). Horace Mann instituted reform influenced from the Prussian education systems of the early 1800s. He argued that the small rural schoolhouse, untrained teachers, and limitations in education opportunities were not sufficient for the rapidly developing America. In 1848 Mann resigned as the Secretary of Education having built the foundations of the education in America. Education reform continued with the raise pragmatism, and progressive education philosophy from John Dewey (Early Childhood Today Editorial Staff 2000).

John Dewey argued that education and learning are social and interactive processes. In essence, Dewey believed that students learn best and thrive when they are allowed to interact and experience the curriculum. Additionally, Dewey believed the purpose of education should not be solely based on the ability to retain a certain

set of pre-determined skills, but allowing the student to realize their full potential. (Dewey 1897). Dewey's progressive thought was a revolutionary concept in education reform (Dewey 1897).  Dewey's ideas of progressivism were the pillars of education; however the rewards of World War II resulted in a profound impact on the American education system.

Following WWII teacher centric education philosophy quickly evolved to become creative and student centered instruction. This perspective has been dominant in the modern curriculum and teaching. It could be argued that the resulting product is a comparatively ill-informed student in relation the other developed nations. (Pearson 2012) According to the education firm Pearson, the United Stated ranks 17th in the developed world for education. This placement puts the USA just behind much smaller nations such as Belgium, and just before Hungry (Pearson 2012).  For this less than stellar result in 2008 the United States spent $10,995 per student on elementary and secondary education. This amount was 35% more than average of developed countries at $8,169 (Institute of Education Sciences 2012). To summarize, the United States spends more and get less.

There has been much speculation about why the United States spends more and gets less from its education system.  Many people and politicians have tried to curb the problem. The state of Wisconsin attempted to remedy the problem when it attempted to force the teachers union to lower the cost of public education. A major change in public education occurred in 2002 when President George W. Bush signed the No Child Left Behind Act (NCLB) in an attempt to make "make every student college bound". As one of the biggest sources of education reforms since WWII the

NCLB act implements standardized tests for all schools who receive federal funds. The act then awards or punishes schools based on their performance the standardized tests. In practice, little progress was made through the policies of NCLB. The American education system still processes students in much the same as what the school systems of Horace Mann when he removed the one room school house. The result may be characterized as manufacturing as a batch production technique.

Today's education system treats every student the same, as in batch production where every student should be learning at the same rate. A subject taught to all students in the class at the same time with the expectation that the students learn at similar speeds. The reality is that most students do not learn at the same rate. One study shows that there are large fluctuations in student performance (Lyon & Gettinger 1985). As a result of batch production teaching some students excel and others fall through the cracks and get left behind.  Along the same context, some students have the potential to progress quickly, but are slowed down, causing frustration for the student. The results of this frustration might be expressed in poor behavior and classroom disturbance (Patron 2011). Similar behavior can occur when students do not grasp the material at the pace of other students in the class.

The batched student classroom can overlook commonly known concepts of learning.  Students don't just learn at different rates, but students have different learning styles (Garcia et al. 2005). Teaching methods that address the student's learning style has been shown to be effective (Garcia et al. 2005). "It was found that students whose learning styles were matched with the corresponding teaching style

showed significantly greater improvement in reflection than those in the mismatched group" (Hsieh et al. 2011). A logical conclusion might be to minimize the amount of time and money it takes to educate students teaching should address the way the students learn individually. The prevailing teaching system has teachers using the same methods for all students. This is in contrast to the knowledge that the majority for the students do not learn as effectively with such teaching method.

## 1.4 Axiomatic Design

Nam Pyo Suh, former head of Mechanical Engineering at Massachusetts Institute of Technology and past president at KAIST, created axiomatic design in 1990 (Suh 1990). Dr. Suh's goal was to find out what all good designs have in common in order to improve the design process. Axiomatic design can be used for a number of designs, such as hardware, software, materials, manufacturing, and organizations. Axiomatic design is useful in the decision making process because the two axioms maximize the independence of the variables and minimize the information content. It can help improve designs, shorten lead times, improve quality, and address complex problems.

The axiomatic design approach provides axioms that lead to optimal solutions for design problems. The process involves applying the axioms to arrive at the best solutions for a given set of functional requirements. Axiomatic design consists of two axioms; the independence axiom, and the information axiom. For this project, the two top-level functional requirements were maximizing the value added to the student, and controlling the cost to the educational system.

When solving design problems, it is desirable to find a solution that is both effective in efficient manner. Maximizing the value added is important because the

overall goal of the design is accomplished. Creating a solution that maximizes the value-added brings the design closer to a robust and elegant solution. Minimizing the non-value-added time is important because wasteful activities do not contribute to fulfilling the functional requirements. Minimizing waste is a main goal of lean manufacturing.

Axiomatic design employs hierarchal design decomposition. Design decompositions exist in domains that respond to the goals of the design. The domains address the what and how of the design. The domains used in this project are customer domain, functional domain, physical domain, and process domain (Benavides 2012).

The customer domain relates the needs of the customer. These needs can be a product, a process, a system, a material, or anything else the customer needs. Customer satisfaction and fitness for use are the ultimate goals of any manufacturing process (Juran 1999). Customer satisfaction is important to successfully run a company. Customer needs should be met with every design and are used to determine functional requirements.

The functional domain is characterized by functional requirements (FRs) and constraints. The functional domain is how the designer interprets the problem given by the customer. Functional requirements are what the designer recognizes as the customer's needs to fulfill the design objectives. The hierarchal nature of axiomatic design requires that a functional requirement be decomposed into sub-functional requirements. Each sub-functional requirement must satisfy the original requirement. Each of these requirements must be unique and not duplicated or overlapped because they should satisfy the customer's needs independently. The best designs maintain the independence of the functional requirements. Designs have constraints that limit the functional requirements because they might impact a functional requirement's independence. Constraints,

however, do not have to be independent from each other. There are two types of constraints in axiomatic design; input constraints and system constraints. The input constraints have an effect on design conditions while system constraints have an effect on how the design operates.

The physical domain consists of design parameters (DPs). This domain is a breakdown of the FRs and constraints into physical properties. Design parameters are the "how" the design will fulfill the functional requirements. These parameters contribute to an item's cost or processes, its physical design, and its development through the design process.

The process domain consists of the details of the design parameters; they are the way design parameters can be made into a process, which satisfies the physical properties of a design. The process domain is used for the production of the design.

The independence axiom is used to avoid coupling between the FRs and DRS. If coupling is present in a design, the design can be difficult to adjust and control. Each functional requirement needs its own design parameter. The design equation stating the relationship between the FRs and DPS may be repeated in a matrix.

**Equation 1: Design Equation**

**FR = [X] * DP**

Matrix **X** is known as the design matrix. The design matrix states if the independence axiom is satisfied. If the design is uncoupled, all of the interactions between the FRs and DPs can be organized to be lower triangular or below the diagonal of the design matrix. This diagonal design means that each design parameter can satisfy its corresponding functional requirement independently without coupling. If the design matrix is lower triangular, then the design is considered decoupled, which means that it

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can satisfy the independence axiom if the order of adjustment is correctly chosen. When a design matrix is not diagonal or triangular, it is considered coupled. This means that no arrangement of FR DP matrix can satisfy the functional requirements independently. One way to fix the coupling issue is the generation of new functional requirements. Figure 1 shows an uncoupled design, Figure 2 shows a decoupled design and Figure 3 shows a coupled design.

$$\begin{bmatrix} FR1 \\ FR2 \\ FR3 \end{bmatrix} = \begin{bmatrix} X11 & 0 & 0 \\ 0 & X22 & 0 \\ 0 & 0 & X23 \end{bmatrix} * \begin{bmatrix} DP1 \\ DP2 \\ DP3 \end{bmatrix} \longrightarrow \begin{matrix} FR1 = X11 * DP1 \\ FR2 = X22 * DP2 \\ FR3 = X33 * DP3 \end{matrix}$$

**Figure 1: Uncoupled Design**

$$\begin{bmatrix} FR1 \\ FR2 \\ FR3 \end{bmatrix} = \begin{bmatrix} X11 & 0 & 0 \\ X21 & X22 & 0 \\ X31 & X32 & X23 \end{bmatrix} * \begin{bmatrix} DP1 \\ DP2 \\ DP3 \end{bmatrix} \longrightarrow \begin{matrix} FR1 = X11 * DP1 \\ FR2 = X21 * DP1 + X22 * DP2 \\ FR3 = X31 * DP1 + X32 * DP2 + X33 * DP3 \end{matrix}$$

**Figure 2: Decoupled Design**

$$\begin{bmatrix} FR1 \\ FR2 \\ FR3 \end{bmatrix} = \begin{bmatrix} X11 & X12 & X13 \\ X21 & X22 & X23 \\ X31 & X32 & X23 \end{bmatrix} * \begin{bmatrix} DP1 \\ DP2 \\ DP3 \end{bmatrix} \longrightarrow \begin{matrix} FR1 = X11 * DP1 + X12 * DP2 + X13 * DP3 \\ FR2 = X21 * DP1 + X22 * DP2 + X23 * DP3 \\ FR3 = X31 * DP1 + X32 * DP2 + X33 * DP3 \end{matrix}$$

**Figure 3: Coupled Design**

### 1.4.1 Design Software

The software used for this project is called Acclaro® DFSS, which was created by Axiomatic Design Solutions, Inc. It is used to manage design hierarchy. Acclaro® is able to show, at different levels of analysis, the functional requirements in a hierarchal form. Each functional requirement has a "child" or new row made up of sub-FRs. The design

matrix in Acclaro® shows an "X" to indicate each design parameter that interacts with a

functional requirement (Axiomatic Design Solutions INC. 2013).

# Chapter 2 - Design Decomposition

## 2.1 Statement of the highest level functional requirement - $FR_0$

The goal of the education system is to efficiently prepare students at their respective learning rates for high school.

## 2.2 Statement of the first level functional requirement $FR_1$

The goal of $FR_1$ is 'prepare a student for high school at their respective learning rates'. There are two key elements of this statement. The first is to prepare students for high school. This is important because to be prepared for high school, a student needs to demonstrate proficiency in the sub FR's. Lacking this proficiency, the functional requirement will not be met. In essence, the goal of the sub $FR_1$'s is to ensure that each will show demonstrated proficiency and that the student is prepared for high school.

The second element of this statement is preparing the student at his or her own respective learning rates. This is crucial because it allows the student to advance through the curriculum at their own speed so they may not affect other students in the system. To evaluate how well $FR_1$ is being satisfied, we have created the equation in Eq. 2.

$$VA = \sum_{0}^{n} \frac{M_n}{T_n}$$

Such that
$VA$ = value added
$M$ = measurement of student performance
$T$ = time taken to complete performance relative to standard time taken.
$N$ = specific parameter which is measured

**Equation 2: FR1 Measurement**

The relationship stated in the value-added equation lets the school know how they are doing in achieving their goals. The evaluation of each sub FR is taking into account in measuring the output of the education system.

## 2.3 List of the 2<sup>nd</sup> level of functional requirements for $FR_1$

These functional requirements were taken from the New Hampshire public school requirements. (New Hampshire Department of Education, 2010) This approach ensures that there is no difference between a student who is educated in the proposed system vs. the current system. The New Hampshire Department of Education lists the requirements of skills and abilities that a student is expected to have proficiency in to enter into high school. Every public school district in the nation is required to publish curriculum guidelines. There are also Common Core State Standards. Incorporated in the state standards are History/Social Studies, Science, Mathematics, English and Language Arts. To ensure these functional requirements were collectively exhaustive and mutually exclusive, the state standards were analyzed to derive the FR's necessary to fulfill the required guidelines. The FR's where analyzed to determine if collectively exhaustive and mutually exclusive. The functional requirements appear in Figure 4.

| [FR] Functional Requirements | | [DP] Design Parameters | |
|---|---|---|---|
| 0 FR | Efficiently prepare students at their respective learning rates for high school | DP | Public School Education System that prepares students at their respective learning rates for high school |
| 1 FR | Prepare students for high school at their respective learning rates | DP | System to prepare students for high school |
| 1.1 FR | Prepare student for high school level reading comprehension skill | DP | System for preparing student for high school level reading comprehension skill |
| 1.2 FR | Prepare student for high school level writing skill | DP | System for preparing student for high school level writing skill |
| 1.3 FR | Prepare student for high school level mathematics skill | DP | System for preparing student for high school level mathematics skill |
| 1.4 FR | Prepare student for high school level scientific skill set | DP | System for preparing student for high school level scientific skill set |
| 1.5 FR | Prepare student for high school level knowledge of civics | DP | System for preparing student for high school level knowledge of civics |
| 1.6 FR | Prepare student for high school level knowledge of social studies | DP | System for preparing student for high school level knowledge of social studies |
| 1.7 FR | Prepare student for high school level awarness of unified arts | DP | System for preparing student for high school level awarness of unified arts |
| 1.8 FR | Prepare student for high school level awarness of physical education | DP | System for preparing student for high school level awarness of physical education |
| 1.9 FR | Prepare student for high school level teamwork/collaboration skills | DP | System for preparing student for high school level teamwork/collaboration skills |
| 1.10 FR | Prepare student to work independently | DP | System for preparing student to work independently |
| 1.11 FR | Prepare student to follow written/verbal instructons | DP | System for preparing student to follow written/verbal instructons |
| 1.12 FR | Prepare student to make ethical decisions | DP | System for preparing student to make ethical decisions |

**Figure 4: Functional Requirements FR$_{1.1}$-FR$_{1.12}$**

Each of the sub-FRs is designed to ensure the student receives a well-rounded education and is prepared to attend high school. The following measurement was created to evaluate each of these standards individually and to ensure that the requirements of FR1 are met:

$$P_n = \frac{M_n}{T_n}$$

Such that:
*P*= Performance
*M*= measurement of student performance
*T* = time taken to complete performance relative to standard time taken.
*n* = specific parameter which is measured

**Equation 3: Performance Measurement**

The measurement of performance is to evaluate how a student is performing. This evaluation can be used for each of the subject areas in which a student has been taught. This equation currently manifests itself in another form in education systems as a Grade Point Average (GPA). However, because students are not allowed to learn at their respective rates, the variable that corresponds to the amount of time taken by a student to achieve proficiency levels relative to the standard time taken (*T)* is set to 1. By allowing students to learn at different rates, *T* is going to take on a value less than or equal to 1.

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With this allowance, students are able to demonstrate more than their proficiency in a subject area; they are able to show how quickly they can achieve proficiency. This is important because if a student can achieve proficiency in a shorter period of time, they are adding more value to themselves as per the equation stated in Eq. 3. While the ability to achieve proficiency at a faster pace is beneficial, we cannot say it is the only factor in evaluating a student's performance. That being said, for the purposes of our system, we are only using proficiency level and time required to attain said proficiency level as indicators of valued-added.

## 2.4 List of the 2$^{nd}$ level of functional requirements for FR$_2$

The functional requirements that were created to control the cost of creating a public school student were adapted from the seven lean wastes in manufacturing. The seven wastes were developed and used by Taiichi Ohno, who is credited with developing the Toyota Production System. The seven wastes in manufacturing are (Ohno 1988):

1. Overproduction
2. Inventory
3. Waiting
4. Transportation
5. Defects
6. Student movement
7. Unnecessary processing.

These wastes are used for seven of the nine functional requirements that satisfy FR$_2$. The two functional requirements that have been added to Ohno's original seven wastes are: wasted time due to scheduling; and wasted assets from not being fully

utilized. These two FRs needed to be included in the decomposition because they satisfy the needs of FR$_2$, and assist in making an education system more effective. All nine wastes comprise the education system's waste because they help minimize wasted time and money. These nine functional requirements help fulfill FR$_2$ in controlling the cost of a public school system. The sub-functional requirements of FR$_2$ are shown in Figure 5.

| 2 | FR | Control cost of public school student | DP | System to control cost of creating public school student |
|---|----|---|----|---|
| 2.1 | FR | Control overproduction from re-learning materials (plan) | DP | System to minimize overproduction |
| 2.2 | FR | Control unnecessary inventory from the batch style of learning (plan) | DP | System to minimize unnecessary inventory |
| 2.3 | FR | Control waiting from queues (plan) | DP | System to minimize waiting |
| 2.4 | FR | Control transportation waste from different locations of students (plan) | DP | System to minimize transportation waste |
| 2.5 | FR | Control defects from early advancement to more difficult subjects (plan) | DP | System to minimize defects |
| 2.6 | FR | Control student movement from incomplete lesson plans (plan) | DP | System to minimize staff/student movement |
| 2.7 | FR | Control unnecessary processing from irrelevant material (plan) | DP | System to minimize unnecessary processing |
| 2.8 | FR | Control wasted time from scheduling (plan) | DP | System to minimize wasted time from scheduling |
| 2.9 | FR | Control wasted assets of school (plan) | DP | System to minimize wasted assets of school |

**Figure 5: Functional Requirements 2.1-2.9**

## 2.5 Measurements

### 2.5.1 Metric for controlling the cost of educating a student

The cost of educating a student can be found by analyzing the total expenditures for the school and the number of students who have graduated. These numbers can be found in the financial statements located in the annual report of any school district. The equation of cost per student is shown in Eq. 4.

$$Cost\ per\ student = \frac{total\ expenditures}{\#\ of\ students\ educated}$$

**Equation 4: Cost per Student**

### 2.5.2 Metric for the waste of overproduction

The waste from overproduction can be associated with re-teaching material to students who already know the information that is associated with that subject. This issue

can be resolved by coordination of lesson plans with other teachers in all grade levels to make sure the students are learning new material. The overproduction waste ratio is shown in Eq. 5.

$$\% = \frac{Number\ of\ material\ tought\ more\ than\ once}{Total\ number\ of\ material\ tought}$$

<div align="center">Equation 5: Overproduction Waste Ratio</div>

### 2.5.3 Metric for the waste of unnecessary inventory

The waste from inventory is interpreted in our system as a student who is incapable of achieving proficiency at the minimum allowed rate. Little's law is used to find the average flow time of unnecessary inventory. The equation for inventory waste is shown below:

$$Average\ Flow\ Times = \frac{Avg\ Inventory}{Throughput\ Rate}$$

<div align="center">Equation 6: Inventory Waste</div>

### 2.5.4 Metric for the waste of waiting

The waste from waiting can be associated with the non-value added time during the student's learning process. This can be linked to any time that a student doesn't spend learning information within the education system. The equation for value added time is shown in Eq. 7.

<div align="center">Equation 7: Value Added Time Ratio</div>

$$Time\ Ratio = \sum \frac{\sum VA}{\sum VA + nonVA}$$

### 2.5.5 Metric for the waste of transportation

The waste from transportation can be found by analyzing the transportation of students and teachers to the same location. This is usually due to bussing students from

different locations to school. A way to avoid this would be to allow virtual attendance as well as physical attendance in the classroom. The transportation waste ratio is shown in Eq. 8.

$$\% = \frac{Number\ of\ students\ attending\ virtualy}{Total\ number\ of\ students\ attending}$$

Equation 8: Transportation Waste Ratio

### 2.5.6 Metric for the waste of defects

The waste from defects can be found when students continue on to tougher subjects when they are not prepared. This causes students to become a defect within the system because they are not equipped with the sufficient knowledge to complete the next stage of their learning process. Not only is a defect caused, but rework, which refers to the process of reeducating the student, also occurs. The defect ratio is shown in Eq. 9.

$$\% = \frac{Number\ of\ students\ first\ time\ pass}{Total\ number\ of\ students\ passed}$$

Equation 9: Defect Ratio

### 2.5.7 Metric for the waste of student movement

The waste due to student movement can be found by analyzing incomplete lesson plans. This waste could be produced when students have to spend time looking for information that should be included within lesson plans. The student movement ratio is shown in Eq. 10.

Equation 10: Student Movement Ratio

$$\% = \frac{Amount\ of\ incomplete\ course\ data}{Total\ amount\ of\ course\ data}$$

### 2.5.8 Metric for the waste of unnecessary processing

The waste due to unnecessary processing can be associated with material not specific to the subject taught to students. This waste is closely related to the overproduction waste, and can be minimized using the same approach of coordinating lesson plans. The unnecessary processing ratio is shown in Eq. 11:

$$\% = \frac{Number\ of\ irrelevant\ concepts}{Total\ number\ of\ concepts}$$

**Equation 11: Unnecessary Processing Ratio**

### 2.5.9 Metric for the waste of time scheduling

The waste due to time scheduling can be associated with un-leveraged time of educators. This is connected to the time and resources being used by teachers when they are not teaching, which can harm productivity. This can be avoided by relocating the use of time for faculty. The time scheduling ratio is shown below:

$$\% = \frac{Amount\ of\ value - added\ teacher\ time}{Total\ amount\ of\ teacher\ time\ allocated}$$

**Equation 12: Time Scheduling Ratio**

### 2.5.10 Metric for the waste from assets

The waste due to assets can be associated with the waste of fixed resources within the school. Energy consumption and other variable assets can be reduced but the maximization of the potential for fixed resources should also be considered, such as holding classes around the clock to maximize the use of that space. The wasted assets ratio is shown in Eq. 13:

$$\% = \frac{Amount\ of\ asset\ (capacity)used}{Total\ amount\ of\ asset\ (capacity)available}$$

**Equation 13: Wasted Assets Ratio**

## 2.6 Information Axiom

Information can be described as the probability of fulfilling a Functional Requirement. This equation is shown in Eq. 14:

$$I = \log\left(\frac{System\ range}{Common\ rage}\right)$$

Equation 14: Information Content

A table calculating the information for the first and second level FRs is shown in Table 1. Each FR is analyzed to determine information value. The information content is used to produce the probability of successfully fulfilling a FR. The information value can be used to compare system performance over time. This comparison can show any improvement in the system or if there is a lack in fulfilling the functional requirement.

| FR | Description | FR Measurement | System Range | Design Range | Success= Common Range / System Range | I= Log (system / common) |
|---|---|---|---|---|---|---|
| FR0 | Efficiently prepare students at their respective learning rates for high school | $$\sum_{0}^{n}\left(\frac{M_n}{T_n}*C\right)-C$$ | $0-$65,000 | $0-$65,000 | 100% | 6.64 |
| FR1 | Prepare students for high school at their respective learning rates | $VA=\sum_{0}^{n}\frac{M_n}{T_n}$ | 0% -100% | 70%-200% | 15% | 3.91 |
| FR1.1 | Prepare student for high school level reading comprehension skill | Measure students' reading comprehension | 0% -100% | 70% - 200% | 15% | 3.91 |
| FR1.2 | Prepare student for high school level writing skill | Measure students' writing skill | 0% -100% | 70% - 200% | 15% | 3.91 |
| FR1.3 | Prepare student for high school level mathematics skill | Measure students' mathematics skill | 0% -100% | 70% - 200% | 15% | 3.91 |
| FR1.4 | Prepare student for scientific process experimentation skill set | Measure students' experimentation skills | 0% -100% | 70% - 200% | 15% | 3.91 |
| FR1.5 | Prepare student for knowledge of civics | Measure students' knowledge of civics | 0% -100% | 70% - 200% | 15% | 3.91 |
| FR1.6 | Prepare student for of knowledge of social studies | Measure students' knowledge of social studies | 0% -100% | 70% - 200% | 15% | 3.91 |
| FR1.7 | Prepare student for awareness of unified arts | Measure students' awareness of arts | 0% -100% | 70% - 200% | 15% | 3.91 |

| FR1.8 | Prepare student for awareness of student physical education | Measure students' awareness of physical education | 0% -100% | 70% - 200% | 15% | 3.91 |
|---|---|---|---|---|---|---|
| FR1.9 | Prepare student for teamwork / collaboration skills | Measure students' teamwork/ collaboration skills | 0% -100% | 70% - 200% | 15% | 3.91 |
| FR1.10 | Prepare student for ability for student to work independently | Measure students' ability to work independently | 0% -100% | 70% - 200% | 15% | 3.91 |
| FR1.11 | Prepare student for ability to follow written/verbal instruction | Measure students' ability to follow written/verbal instruction | 0% -100% | 70% - 200% | 15% | 3.91 |
| FR1.12 | Prepare student for ability to make ethical decisions | Measure students' ability to make ethical decisions | 0% -100% | 70% - 200% | 15% | 3.91 |
| FR2 | Control cost of educating a student | $= \dfrac{total\ expendatures}{\#\ of\ students\ educated}$ | $0-$20,000 | $0-$16,000 | 80% | 5.90 |
| FR2.1 | Control overproduction from re-learning materials | $\% = \dfrac{Number\ of\ material\ tought\ more\ than\ once}{Total\ number\ of\ material\ tought}$ | 1% | .1 | 10% | 3.32 |
| FR2.2 | Control unnecessary inventory from the batch style of learning | Average Flow times = $\dfrac{Avg\ Inventory}{Throughput\ Rate}$ (Little's Law) | 0-40 students/ week | 0-200 students/week | 20% | 4.32 |
| FR2.3 | Control waiting from queues | Time Ratio $= \sum \dfrac{\sum VA}{\sum VA + nonVA}$ | 48% | 5% | 10.4% | 3.26 |
| FR2.4 | Control transportation waste from different locations of students | $\% = \dfrac{Number\ of\ students\ attending\ virtualy}{Total\ number\ of\ students\ attending}$ | 80% | 50% | 62.5% | .68 |

| | | | | | | |
|---|---|---|---|---|---|---|
| FR2.5 | Control defects from early advancement to more difficult subjects | $\% = \dfrac{Number\ of\ students\ first\ time\ pass}{Total\ number\ of\ students\ assed}$ | 10% | 1% | 10% | 3.32 |
| FR2.6 | Control student movement form incomplete lesson plans | $\% = \dfrac{Amount\ of\ incomplete\ course\ data}{Total\ amount\ of\ course\ data}$ | 1% | .1% | 10% | 3.32 |
| FR2.7 | Control unnecessary processing from irrelevant material | $\% = \dfrac{Number\ of\ irrelevant\ concepts}{Total\ number\ of\ concepts}$ | 1% | .1% | 10% | 3.32 |
| FR2.8 | Control wasted time from scheduling | $\% = \dfrac{Amount\ of\ value-added\ teacher\ time}{Total\ amount\ of\ teacher\ time\ allocated}$ | 30% | 5% | 16.7% | 2.58 |
| FR2.9 | Control wasted assets of school | $\% = \dfrac{Amount\ of\ asset\ (capacity)\ used}{Total\ amount\ of\ asset\ (capacity)\ available}$ | 30% | 5% | 16.7% | 2.58 |
| | | | | | Total information Content | 90.07 |

**Table 1: Information Content**

## 2.7 Completed Axiomatic Design Hierarchy

The completed decomposition is shown in two parts in Figure 6 and 7. It includes

all of the functional requirements and design parameters.

| # | [FR] Functional Requirements | [DP] Design Parameters |
|---|---|---|
| 0 FR | Efficiently prepare students at their respective learning rates for high school | [DP] Public School Education System that prepares students at their respective learning rates for high school |
| 1 FR | Prepare students for high school at their respective learning rates | DP System to prepare students for high school |
| 1.1 FR | Prepare student for high school level reading comprehension skill | DP System for preparing student for high school level reading comprehension skill |
| 1.1.1 FR | Teach reading comprehension methods | DP System for teaching reading comprehension methods |
| 1.1.2 FR | Measure students reading comprehension | DP System for measuring student's comprehension knowledge |
| 1.1.3 FR | Improve reading comprehension ability | DP System for improving reading comprehension |
| 1.1.3.1 FR | Improve students reading compreheion | DP System for improving student's reading comprehension |
| 1.1.3.2 FR | Improve teaching system | DP System for improving teaching system |
| 1.2 FR | Prepare student for high school level writing skill | DP System for preparing student for high school level writing skill |
| 1.2.1 FR | Teach writing skill | DP System for teaching writing skill |
| 1.2.2 FR | Measure writing skill | DP System for measuring student's writing skill |
| 1.2.3 FR | Improve writing ability | DP System for improving writing |
| 1.2.3.1 FR | Improve students writing skill | DP System for improving student's writing skill |
| 1.2.3.2 FR | Improve teaching system | DP System for improving teaching system |
| 1.3 FR | Prepare student for high school level mathematics skill | DP System for preparing student for high school level mathematics skill |
| 1.3.1 FR | Teach mathematics skill | DP System for teaching mathematics skill |
| 1.3.2 FR | Measure mathematics skill | DP System for measuring mathematics skill |
| 1.3.3 FR | Improve mathematics ability | DP System for improving matematics |
| 1.3.3.1 FR | Improve students writing skill | DP System for improving student's writing skill |
| 1.3.3.2 FR | Improve teaching system | DP System for improving teaching system |
| 1.4 FR | Prepare student for high school level scientific skill set | DP System for preparing student for high school level scientific skill set |
| 1.4.1 FR | Teach scientific process experimentation skill set | DP System for teaching scientific skill |
| 1.4.2 FR | Measure scientific process experimentation skill set | DP System for measuring scientific skill |
| 1.4.3 FR | Improve scientific process experimentation ability | DP System for improving science skills |
| 1.4.3.1 FR | Improve students scientific experimentation skill | DP System for improving student's scientific skill |
| 1.4.3.2 FR | Improve teaching system | DP System for improving teaching system |
| 1.5 FR | Prepare student for high school level knowledge of civics | DP System for preparing student for high school level knowledge of civics |
| 1.5.1 FR | Teach civics | DP System for teaching civics |
| 1.5.2 FR | Measure knowldedge of civics | DP System for measuring knowledge skill |
| 1.5.3 FR | Improve civics ability | DP System for improving civics |
| 1.5.3.1 FR | Improve students knowledge of civics | DP System for improving student's knowledge of civics |
| 1.5.3.2 FR | Improve teaching system | DP System for improving teaching system |
| 1.6 FR | Prepare student for high school level knowledge of social studies | DP System for preparing student for high school level knowledge of social studies |
| 1.6.1 FR | Teach social studies | DP System for teaching social studies |
| 1.6.2 FR | Measure knowledge of social studies | DP System for measuring knowledge of social studies |
| 1.6.3 FR | Improve social studies ability | DP System for improving social studies |
| 1.6.3.1 FR | Improve students knowledge of social studies | DP System for improving student's knowledge of social studies |
| 1.6.3.2 FR | Improve teaching system | DP System for improving teaching system |
| 1.7 FR | Prepare student for high school level awarness of unified arts | DP System for preparing student for high school level awarness of unified arts |
| 1.7.1 FR | Teach unified arts | DP System for teaching unified arts |
| 1.7.2 FR | Measure awareness of unified arts | DP System for measuring awareness of arts |
| 1.7.3 FR | Improve unified arts ability | DP System for improving unified arts |
| 1.7.3.1 FR | Improve students awareness of unified arts | DP System for improving student's knowledge of unified arts |
| 1.7.3.2 FR | Improve teaching system | DP System for improving teaching system |
| 1.8 FR | Prepare student for high school level awarness of physical education | DP System for preparing student for high school level awarness of physical education |
| 1.8.1 FR | Teach physical education | DP System for teaching physical education |
| 1.8.2 FR | Measure awareness of physical education | DP System for measuring physical education |
| 1.8.3 FR | Improve physical education ability | DP System for improving physical education |
| 1.8.3.1 FR | Improve students awareness of physical education | DP System for improving student's physical education |
| 1.8.3.2 FR | Improve teaching system | DP System for improving teaching system |

**Figure 6: Decomposition Part A**

| 1.9 FR | Prepare student for high school level teamwork/collaboration skills | DP | System for preparing student for high school level teamwork/collaboration skills |
|---|---|---|---|
| 1.9.1 FR | Teach teamwork/collaboration skills | DP | System for teaching teamwork/collaboration skills |
| 1.9.2 FR | Measure teamwork/collaboration skill | DP | System for measuring teamwork/collaboration skills |
| 1.9.3 FR | Improve teamwork/collaboration ability | DP | System for improving teamwork/collaboration skills |
| 1.9.3.1 FR | Improve students teamwork/collaboration skill | DP | System for improving student's teamwork/collaboration skills |
| 1.9.3.2 FR | Improve teaching system | DP | System for improving teaching system |
| 1.10 FR | Prepare student to work independently | DP | System for preparing student to work independently |
| 1.10.1 FR | Teach independence skill | DP | System for teaching students to work independently |
| 1.10.2 FR | Measure independence skill | DP | System to measure student's independence skill |
| 1.10.3 FR | Improve independence ability | DP | System to improve independence skill |
| 1.10.3.1 FR | Improve students ability to work independently | DP | System for improving student's independence skill |
| 1.10.3.2 FR | Improve teaching system | DP | System for improving teaching system |
| 1.11 FR | Prepare student to follow written/verbal instructons | DP | System for preparing student to follow written/verbal instructons |
| 1.11.1 FR | Teach ability to follow instructions | DP | System for teaching students to follow directions |
| 1.11.2 FR | Measure ability to follow instructions | DP | System for measuring the ability to follow directions |
| 1.11.3 FR | Improve ability to follow instructions | DP | System to improve the ability to follow directions |
| 1.11.3.1 FR | Improve students ability to follow instructions | DP | System for improving student's ability to follow directions |
| 1.11.3.2 FR | Improve teaching system | DP | System for improving teaching system |
| 1.12 FR | Prepare student to make ethical decisions | DP | System for preparing student to make ethical decisions |
| 1.12.1 FR | Teach ability to make ethical decisions | DP | System for teaching students to make ethical decisions |
| 1.12.2 FR | Measure ability to make ethical decisions | DP | System for measuring student's ability to make ethical decisions |
| 1.12.3 FR | Improve ability to make ethical decisions | DP | System for improving the ability to make ethical decisions |
| 1.12.3.1 FR | Improve students ability to make ethical decisions | DP | System for improving's student's ability to make ethical decisions |
| 1.12.3.2 FR | Improve teaching system | DP | System for improving teaching system |
| 2 FR | Control cost of public school student | DP | System to control cost of creating public school student |
| 2.1 FR | Control overproduction from re-learning materials (plan) | DP | System to minimize overproduction |
| 2.1.1 FR | Identify waste from overproduction (do) | DP | System to identify waste from overproduction |
| 2.1.2 FR | Measure waste from overproduction (check) | DP | System to measure waste from overproduction |
| 2.1.3 FR | Improve waste from overproduction (act) | DP | System to improve waste from overproduction |
| 2.2 FR | Control unnecessary inventory from the batch style of learning (plan) | DP | System to minimize unnecessary inventory |
| 2.2.1 FR | Identify waste from unnecessary inventory (do) | DP | System to identify waste from unnecessary inventory |
| 2.2.2 FR | Measure waste from unnecessary inventory (check) | DP | System to measure waste from unnecessary inventory |
| 2.2.3 FR | Improve waste from unnecessary inventory (act) | DP | System to improve waste from unnecessary inventory |
| 2.3 FR | Control waiting from queues (plan) | DP | System to minimize waiting |
| 2.3.1 FR | Identify waste from waiting (do) | DP | System to identify waste from waiting |
| 2.3.2 FR | Measure waste from waiting (check) | DP | System to measure waste from waiting |
| 2.3.3 FR | Improve waste from waiting (act) | DP | System to improve waste from waiting |
| 2.4 FR | Control transportation waste from different locations of students (plan) | DP | System to minimize transportation waste |
| 2.4.1 FR | Identify waste from transportation (do) | DP | System to identify waste from transportation |
| 2.4.2 FR | Measure waste from transportation (check) | DP | System to measure waste from transportation |
| 2.4.3 FR | Improve waste from transportation (act) | DP | System to improve waste from transportation |
| 2.5 FR | Control defects from early advancement to more difficult subjects (plan) | DP | System to minimize defects |
| 2.5.1 FR | Identify waste from defects (do) | DP | System to identify waste from defects |
| 2.5.2 FR | Measure waste from defects (check) | DP | System to measure waste from defects |
| 2.5.3 FR | Improve waste from defects (act) | DP | System to improve waste from defects |
| 2.6 FR | Control student movement from incomplete lesson plans (plan) | DP | System to minimize staff/student movement |
| 2.6.1 FR | Identify waste from student movement (do) | DP | System to identify waste from staff/student movement |
| 2.6.2 FR | Measure waste from student movement (check) | DP | System to measure waste from staff/student movement |
| 2.6.3 FR | Improve waste from student movement (act) | DP | System to improve waste from staff/student movement |
| 2.7 FR | Control unnecessary processing from irrelevant material (plan) | DP | System to minimize unnecessary processing |
| 2.7.1 FR | Identify waste from unnecessary processing (do) | DP | System to identify waste from unnecessary processing |
| 2.7.2 FR | Measure waste from unnecessary processing (check) | DP | System to measure waste from unnecessary processing |
| 2.7.3 FR | Improve waste from unnecessary processing (act) | DP | System to improve waste from unnecessary processing |
| 2.8 FR | Control wasted time from scheduling (plan) | DP | System to minimize wasted time from scheduling |
| 2.8.1 FR | Identify waste from scheduling (do) | DP | System to identify waste from scheduling |
| 2.8.2 FR | Measure waste from scheduling (check) | DP | System to measure waste from scheduling |
| 2.8.3 FR | Improve waste from scheduling (act) | DP | System to improve waste from scheduling |
| 2.9 FR | Control wasted assets of school (plan) | DP | System to minimize wasted assets of school |
| 2.9.1 FR | Identify wasted assets (do) | DP | System to identify wasted assets |
| 2.9.2 FR | Measure wasted assets (check) | DP | System to measure wasted assets |
| 2.9.3 FR | Improve wasted assets (act) | DP | System to improve wasted assets |

**Figure 7: Decomposition Part B**

## 2.8 Interactions between the top level DPs and FRs

To fulfill $FR_1$, the design should prepare students for high school at their respective learning rates. This FR is satisfied through $DP_1$ which is a system to prepare students for high school. To fulfill $FR_2$, the design needs to control the cost of the public school system. This is satisfied through $DP_2$ which is a system to control the cost of the public school.

$FR_1$ needs to be satisfied prior to $FR_2$ because if controlling the cost of the system was fulfilled first; the public school system would not exist, therefore eliminating the possibility of fulfilling $FR_1$. This association is known as coupling.



**Figure 8: Interactions between top level FRs**

## 2.9 Interactions between the 2$^{nd}$ level FR$_1$ and its corresponding DPs

FR$_1$ has much less coupling than might be expected; however, students cannot advance without being able to read and communicate effectively. This causes coupling in some instances, but because reading comprehension is the first functional requirement listed within FR$_1$'s sub-FRs, the design is decoupled.

DP0: Public School Education System that prepares students at their respective learning rates for high school
DP1: System to prepare students for high school
DP1.1: System for preparing student for high school level reading comprehension skill
DP1.2: System for preparing student for high school level writing skill
DP1.3: System for preparing student for high school level mathematics skill
DP1.4: System for preparing student for high school level scientific skill set
DP1.5: System for preparing student for high school level knowledge of civics
DP1.6: System for preparing student for high school level knowledge of social studies
DP1.7: System for preparing student for high school level awarness of unified arts
DP1.8: System for preparing student for high school level awarness of physical education
DP1.9: System for preparing student for high school level teamwork/collaboration skills
DP1.10: System for preparing student to work independently
DP1.11: System for preparing student to follow written/verbal instructons
DP1.12: System for preparing student to make ethical decisions
DP2: System to control cost of creating public school student

FR0: Efficiently prepare students at their respective learning rates for high school
FR1: Prepare students for high school at their respective learning rates
FR1.1: Prepare student for high school level reading comprehension skill
FR1.2: Prepare student for high school level writing skill
FR1.3: Prepare student for high school level mathematics skill
FR1.4: Prepare student for high school level scientific skill set
FR1.5: Prepare student for high school level knowledge of civics
FR1.6: Prepare student for high school level knowledge of social studies
FR1.7: Prepare student for high school level awarness of unified arts
FR1.8: Prepare student for high school level awarness of physical education
FR1.9: Prepare student for high school level teamwork/collaboration skills
FR1.10: Prepare student to work independently
FR1.11: Prepare student to follow written/verbal instructons
FR1.12: Prepare student to make ethical decisions
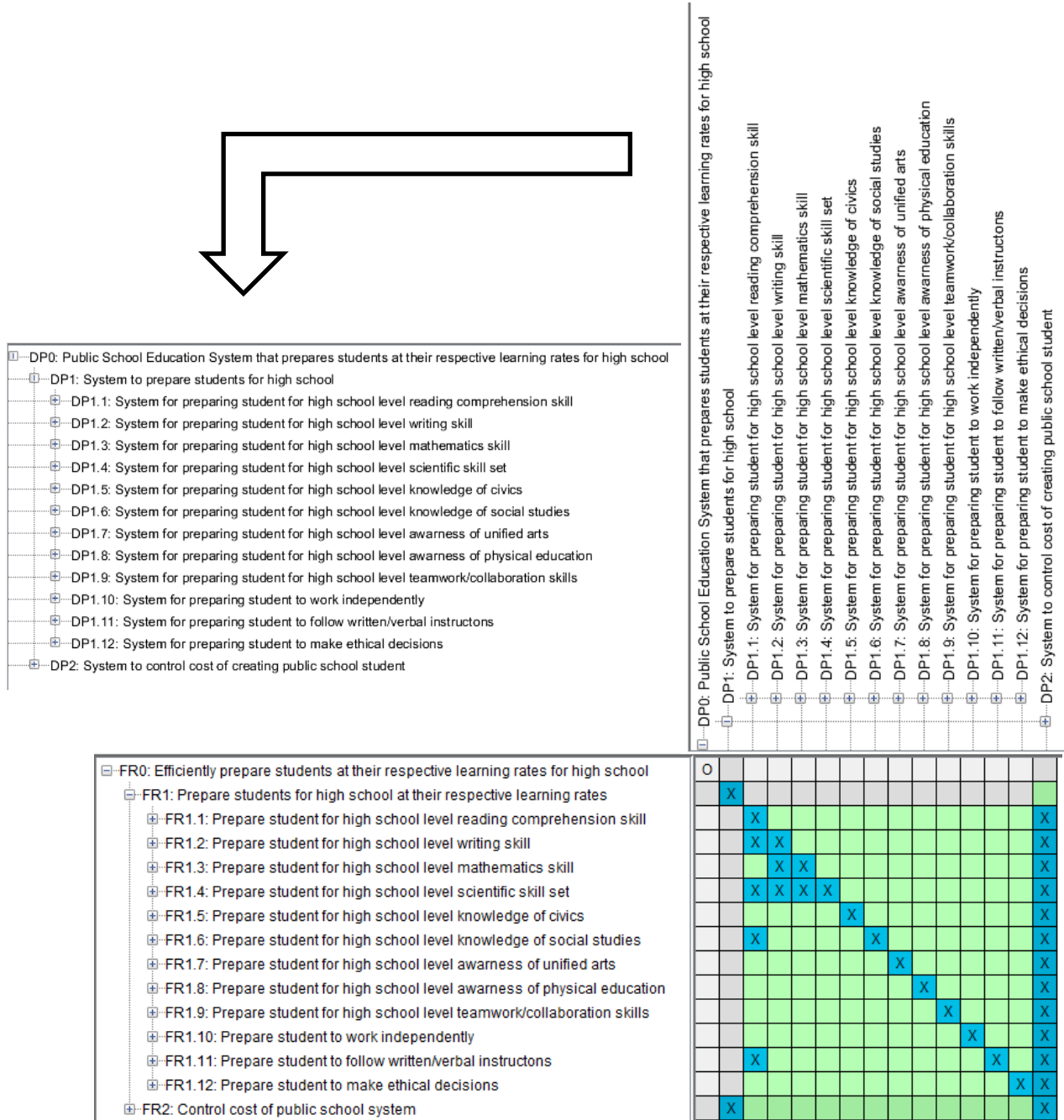FR2: Control cost of public school system

**Figure 9: Interactions between the 2nd level FR$_1$ its corresponding DPs**

## 2.10 Interactions between the 2nd level $FR_2$ and its corresponding DPs

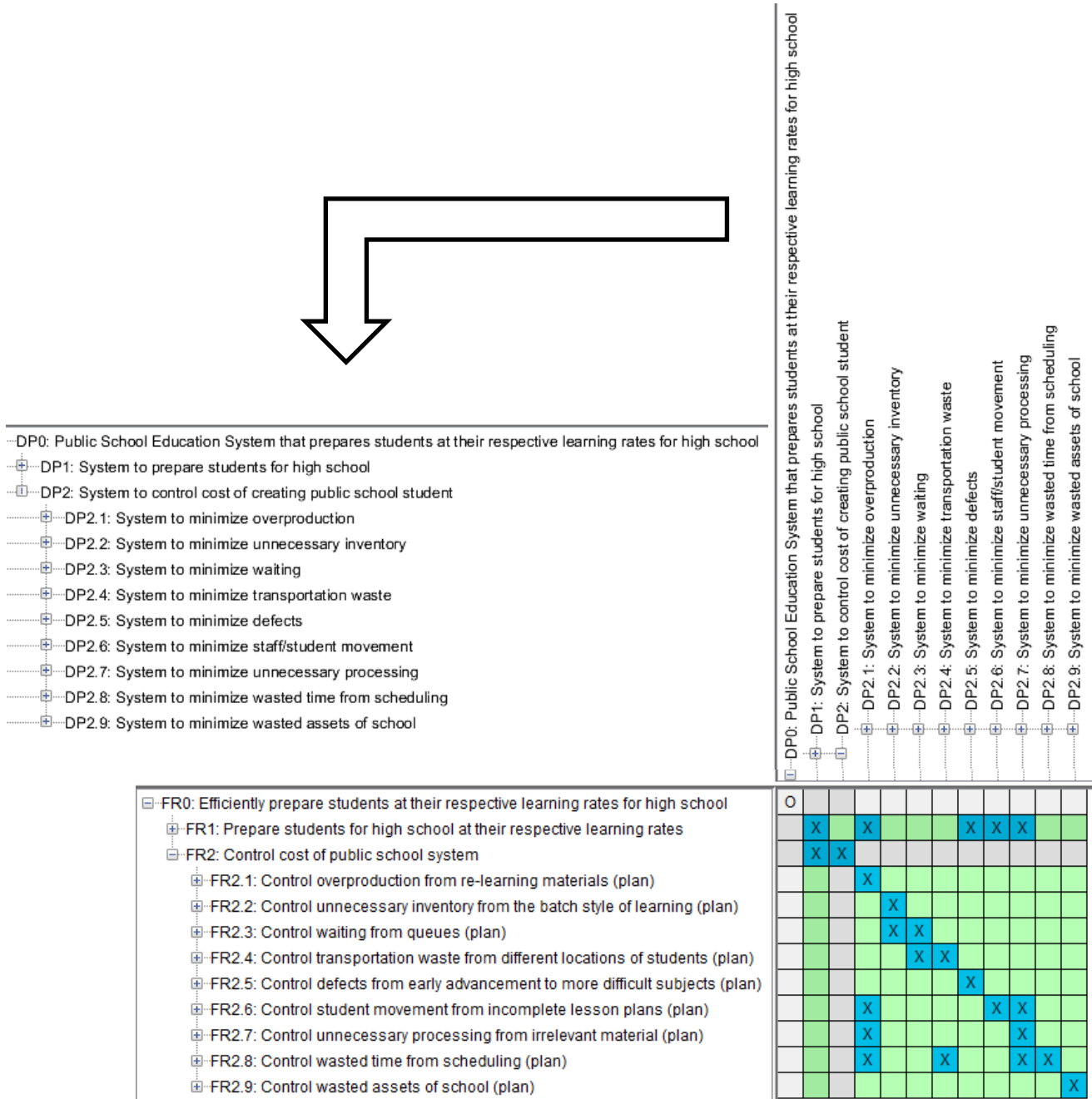$FR_2$ has more coupling taking place than $FR_1$ due to the interactions of the DPs and FRs.

DP0: Public School Education System that prepares students at their respective learning rates for high school
- DP1: System to prepare students for high school
- DP2: System to control cost of creating public school student
  - DP2.1: System to minimize overproduction
  - DP2.2: System to minimize unnecessary inventory
  - DP2.3: System to minimize waiting
  - DP2.4: System to minimize transportation waste
  - DP2.5: System to minimize defects
  - DP2.6: System to minimize staff/student movement
  - DP2.7: System to minimize unnecessary processing
  - DP2.8: System to minimize wasted time from scheduling
  - DP2.9: System to minimize wasted assets of school

| FR \ DP | DP0 | DP1 | DP2 | DP2.1 | DP2.2 | DP2.3 | DP2.4 | DP2.5 | DP2.6 | DP2.7 | DP2.8 | DP2.9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FR0: Efficiently prepare students at their respective learning rates for high school | O | | | | | | | | | | | |
| FR1: Prepare students for high school at their respective learning rates | | X | | X | | | | | X | X | X | |
| FR2: Control cost of public school system | | X | X | | | | | | | | | |
| FR2.1: Control overproduction from re-learning materials (plan) | | | | X | | | | | | | | |
| FR2.2: Control unnecessary inventory from the batch style of learning (plan) | | | | | X | | | | | | | |
| FR2.3: Control waiting from queues (plan) | | | | | X | X | | | | | | |
| FR2.4: Control transportation waste from different locations of students (plan) | | | | | | X | X | | | | | |
| FR2.5: Control defects from early advancement to more difficult subjects (plan) | | | | | | | | X | | | | |
| FR2.6: Control student movement from incomplete lesson plans (plan) | | | | X | | | | | X | X | | |
| FR2.7: Control unnecessary processing from irrelevant material (plan) | | | | X | | | | | | X | | |
| FR2.8: Control wasted time from scheduling (plan) | | | | X | | | X | | | | X | X |
| FR2.9: Control wasted assets of school (plan) | | | | | | | | | | | | X |

Figure 10: Interactions between the 2nd level $FR_2$ and its corresponding DPs

## 2.11 Complete Design Matrix



Figure 11: Complete Design Matrix

# Chapter 3 – Testing of the Final Design

## 3.1 Value Stream Map

The value stream mapping process was chosen because it is easy to show the value-added activities in a process. The value stream map's purpose is to show the flow of a service or product by identifying which steps create value so they can be improved. As an example the teaching of mathematics to students to fulfill the functional requirements was performed. Similar maps could be used to describe other education competency functional requirements, such as writing or science. The overall goal of using value stream mapping was to note the processing steps and determine if the functional requirements were independent of each other.
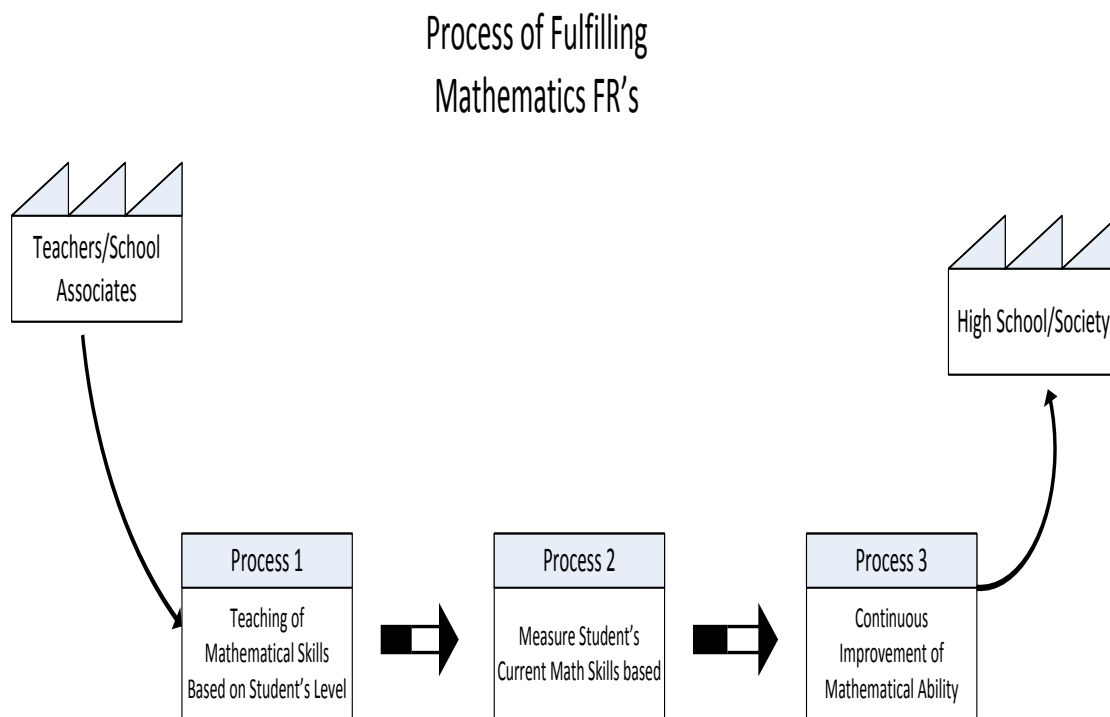
**Process of Fulfilling Mathematics FR's**

Teachers/School Associates

High School/Society

**Process 1**
Teaching of Mathematical Skills Based on Student's Level

**Process 2**
Measure Student's Current Math Skills based

**Process 3**
Continuous Improvement of Mathematical Ability

**Figure 12: Value Stream Map**

## 3.2 Financial Results

A financial analysis was performed on the proposed design. Metrics on $FR_0$ allowed evaluation to show the economic return relative to the cost incurred to educate the student. The $FR_0$ metric was first used to measure students who learned at different rates. This was necessary to calculate $T_n$ which is defined as, 'time taken to complete relative to standard time taken', or simply equated as $T_n = \frac{T_a}{T_s}$. A standard time of four years was used in the calculation. This was then evaluated relative to the measured performance $M_n$ of the overall GPA on a 100% scale. A minimum $M_n$ of 70% and maximum of 100% were evaluated with a mean of 85%. The results show the measurement of overall performance $P_n = \frac{M_n}{T_n}$. $FR_1$ is shown in Table 2.

Table 2: Performance Table

| Tn = Ta / Ts, where Ta = time actual, Ts = time standard (assume 4 years) | Mn = Overall GPA (100% scale) | Mn / Tn |
|---|---|---|
| | 70 | 70% |
| 4 years = 1.0 | 85 | 85% |
| | 100 | 100% |
| | 70 | 80% |
| 3.5 years = 0.865 | 85 | 98% |
| | 100 | 115% |
| | 70 | 93% |
| 3 years = 0.75 | 85 | 113% |
| | 100 | 133% |

To evaluate the non-fluctuation cost of a single year of school, the Hopkinton New Hampshire Public School Financial Statement was used to evaluate the average cost to educate a student for a year. To calculate this figure, the total expenses of the

school were divided by the total number of students in the school to establish an average cost per student per year. The average cost per student per year was shown to be $16,329. This is shown in Table 3.

| Total Expenses | $ | 15,627,371 |
|---|---|---|
| Total Students | | 957 |
| Expenses / Student | $ | 16,329 |

Table 3: Average Expenses per Student

The cost to educate a student for four years was evaluated relative to a student who can be educated in less time. The values are $65,318 for four years, $57,153 for three and half years, and $48,988 for a student who can complete the education in 3 years. The school's return on investment (ROI) is calculated by multiplying the overall performance $P_n$ by the total incurred cost of education. This is shown in Table 4.

| School's ROI = Mn/Tn * Total Tuition Cost | |
|---|---|
| $ | 45,722 |
| $ | 55,520 |
| $ | 65,318 |
| $ | 46,251 |
| $ | 56,162 |
| $ | 66,073 |
| $ | 45,722 |
| $ | 55,520 |
| $ | 65,318 |

Table 4: School's Return on Investment

Finally, the student's ROI can be found by calculating the difference between the total tuition from the schools ROI. The resulting values show the loss or gain on the student as a result. This is shown in Table 5.

| Tn = Ta / Ts, where Ta = time actual, Ts = time standard (assume 4 years) | Mn = Overall GPA (100% scale) | Mn / Tn | Student's ROI = Schools' ROI - Total Tuition |
|---|---|---|---|
| 4 years = 1.0 | 70 | 70% | $(19,595.45) |
|  | 85 | 85% | $(9,797.72) |
|  | 100 | 100% | $- |
| 3.5 years = .865.0 | 70 | 81% | $(10,902.09) |
|  | 85 | 98% | $(991.10) |
|  | 100 | 116% | $8,919.89 |
| 3 years = .75.0 | 70 | 93% | $(3,265.91) |
|  | 85 | 113% | $6,531.82 |
|  | 100 | 133% | $16,329.54 |

Table 5: Student's Return on Investment

By analyzing this information it can be shown how waste accumulates in the current system. To achieve a net gain of zero, which would signify that all the resources spent to educate a student where used effectively, the student in question would have to achieve a perfect GPA of 100% over the four years spend to educate them. Few students are able to achieve this standard.  The standard average of a C or 70% wastes 30% of the investment because the student could not demonstrate the skills or knowledge from all the information taught. In comparison, should a student be allowed and able to finish their requirements in three and half years while maintaining an average of 85% the resources spent in relation to the value received nearly break even, and only 1.5% of the equivalent education cost was lost. This

demonstrates a noticeable improvement in money spent relative to education

received in the current system's configuration.

# Chapter 4 – Discussion

## 4.1 Results

The fundamental goal of this project was to design an effective public education system that allows students to learn at their own pace. This design was able to satisfy our highest level functional requirement of creating a student who is prepared to enter high school, at their own respective learning rate, while controlling the cost of the system. This was accomplished by complying with the two axioms, maximize independence of the functional elements and minimize the information content in the design. The functional requirements are collectively exhaustive and mutually exclusive allowing for a design that is adjustable and controllable.

The design matrix shows the dependency of one student competency on another. The design matrix displays a lower triangular pattern, indicating the functional requirements are decoupled. The decoupled lower triangular matrix states that there is a specific order in which some competencies need to be accomplished. For example, knowledge of writing is needed prior to writing a lab report.

By re-designing public education, the issue of how much it costs to educate students in the public education system was addressed. The operating budget for school systems comes from grants and taxes. Schools spend a large amount per student, and it is important to minimize this amount when possible. The financial analysis stated that a student could progress through the system at their own

individual respective learning rate. If this were the case, there would be a savings

for the school, as well as a return on investment for the student.

## 4.2 Design Method

The premise of this project was that a system for public education could be

designed to better prepare students for high school at their own learning raters and

examine wastes in the system. Using the axiomatic design method, the objected was

met and fulfilled the requirements of the design. The first iteration of the system,

however, was coupled but could be reordered to be decoupled. A second iteration of

the design would reorder requirements and analyze the interactions cause by the

design parameters.

## 4.3 Constraints

Current deficiencies in public education are far reaching (Stotsky 2010). The

cost of primary and secondary education has been on a steady incline, while student

performance has remained stagnant (Gates 2011). Education systems have an

ongoing need to improve. New and innovative approaches to assess student

performance while limiting cost are important in support of the success of the

nation. The proposed design evaluated an approach to both student performance

and cost of education and proposed ways to control costs respond to improving

student performance to prepare them for high school.

The current performance measurement used for determining student

progress is a value from 0-100%. This value is meant to reflect a student's skills and

knowledge at a certain point in time. The problem which arises from this is the one

dimensional nature of the measurement. The broadly used measurement looks at a

student's current performance and ignores their ability to acquire knowledge. There is no method to recognize the capability of a student to achieve proficiency in their subjects at a faster rate. For example, two different students are both able to achieve the same score of 85% in mathematics; however, one of the students can achieve this proficiency level in half of the time. There is no way to currently recognize the efficiency of the rate at which one student can obtain knowledge. As such, the performance of the student who can achieve proficiency in half of the time is undervalued. Functional requirement ($FR_1$) directly addresses this.

The second dimension of education, which the proposed design addresses, is the issue of cost constraint was taken based on the seven sources of waste in manufacturing proposed by Taiichi Ohno (Ohno 1988). By evaluating the education system as a production system, these seven wastes can be used to lower the cost of education without impacting the quality of education. Manufacturing has many examples of using lean thinking and the seven wastes tool with success. Toyota is just one example. This can be reapplied to education as well.

## Chapter 5 – Conclusion

This project showed that public education could be designed using manufacturing and industrial engineering principles because certain aspects of education systems function like manufacturing systems.

The results show:

- A system was designed that prepares students to attend high school at their own individual learning rates, while controlling the cost to operate the system.

- The resulting design matrix exhibited a lower triangular pattern, indicating it is decoupled. This means that the design can be adjusted or controlled.

- Justification of the proposed design's validity was accomplished by analyzing the finances of a school system. The financial outcomes associated with student performance and learning rates was analyzed.

The proposed design of public education was shown to be cost controllable and flexible for students completing their course work in preparation for high school.

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