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Using Statistical Productivity Improvement to Enhance Performance of Construction Labor

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1. SPI Overview

a. Introduction

This paper is intended to serve as an introduction for the application of Statistical Productivity Improvement in the construction/maintenance environment.

b. Definition

Statistical Productivity Improvement or SPI is a methodology intended to provide its users with a productivity measurement and improvement tool aimed at identifying and correcting negative trends and excessive variation in construction labor performance.

c. Basis

SPI is grounded in both Total Quality Management (TQM) and Statistical Process Control (SPC) philosophies. Those philosophies infer a number of assumptions and guidelines for SPI application. First, applying the Pareto principle to work process improvement opportunities, it is assumed that 80% of the opportunities to improve productivity can be found in 20% of the work processes. It is believed these "vital few" work processes involve the delivery of key resources to the craft. From Construction Industry Institute (CII) Research; "The key to motivating construction craftsmen and foremen appears to be organizing the project and its resources to let individuals be productive. More than anything else, this promotes job satisfaction and provides an incentive for individuals to increase their productivity." Using these principles as guidelines, SPI focuses on the 80% category and assumes that for the most part, the craft workforce WANTS to be productive. The 20% category boils down to whether a company's workforce possesses the skills (technical skills), will (motivation), and access (availability of human resources). While this category is not a focus of SPI and represents a smaller portion of the opportunities to improve performance, significant shortfalls in skills, will, and access can have a devastating effect on productivity and thus should not be ignored. Craft skills training, recognition, and creative compensation/recruiting strategies are effective tools to combat shortfalls in the 20% category. Finally, the data collection methods of SPI ensure a 95% statistical confidence in the results of the process. This ensures that information to be acted upon from SPI can be analyzed with confidence even if other traditional productivity measures contradict the results.

d. SPI vs. Traditional Productivity Measurement

The basic definition of productivity is output compared to input. However, in the construction/maintenance environment, the definition is not as black and white. Traditional methods employ the use of Productivity Ratios or Factors that compare performance against a predetermined estimate of how much labor should be required to complete the subject task. These estimates are based on historical data of actual performance from past projects. The estimates employ the use of "unit rates" to forecast how many labor hours should be required to install a unit of the material or equipment. For example, historical data may indicate it takes 3.5 labor hours per linear foot of pipe to install it. Traditional Productivity Measurements utilize these unit rates to determine "earned" values. From the example, if 100 feet of pipe was installed, 350 hours (100 LF x 3.5 hours/LF) have been earned. The ratio of the earned value to the actual hours expended to install the 100LF of pipe is how traditional Productivity Ratios or Factors are calculated. Due to the changing nature of construction/maintenance work, many times unique variables enter the equation that were not present when the historical data was collected and may not present themselves again. To illustrate this point, consider a project that has estimated a unit rate of 4 labor hours per ton of steel installed. Historically, the steel to be installed arrives at the jobsite with faceplates already installed. The project's estimate accounts for this in the unit rates; however, the steel arrives from the fabrication shop without the faceplates installed. As a result, the Ironworkers are averaging 6 labor hours per ton attaching the faceplates and installing the steel members. Because the estimate did not account for this added work, the Productivity Ratio for Ironworkers shows very poor productivity, when in actuality, they may be performing productively. For this reason, Productivity Factors or Ratios are more a measure of estimate accuracy than they are of actual productivity. This is not to suggest that Productivity Ratios are not meaningful. Accurate estimates are critical to the budgeting process for owners and to the bidding process for contractors. Further, changes in productivity performance on a given project will normally be reflected by corresponding rises and falls in the calculated ratio. The point is that another tool that measures and improves productivity regardless of estimated values should be used in concert with traditional methods to ensure an "apples to apples" look at productivity from project to project. SPI measurements are based on definitions of craft activity that are constant from location-to-location and project-to-project.

e. How SPI Works

Within the 80% category, SPI focuses on inefficiencies in 4 Key Resource Processes or KRPs. These KRPs are the set of work processes responsible for delivering the ***tools, materials, equipment, and information*** the craft workforce needs in order to be productive. To accomplish this, SPI employs statistical observation and categorization of craft activity. Trained observers collect the information by making multiple rounds of observations and categorizing them as follows:

- **Direct Activity** – Craft activity that directly advances the schedule.
- **Support Activity** – Craft activity that is required for Direct Activity to take place but does not directly advance the schedule. Examples would include traveling to get tools and materials and waiting at tool stores.
- **Delay** – Waiting for tools, materials, equipment, or information. Also included are personal delays such as smoking and restroom breaks.

To ensure at least 95% confidence in the information collected, observers must collect over 1500 observations at each level of work to be analyzed. It is also important to achieve a balance of observations across the shift to ensure the information reflects a profile across the entire workday.

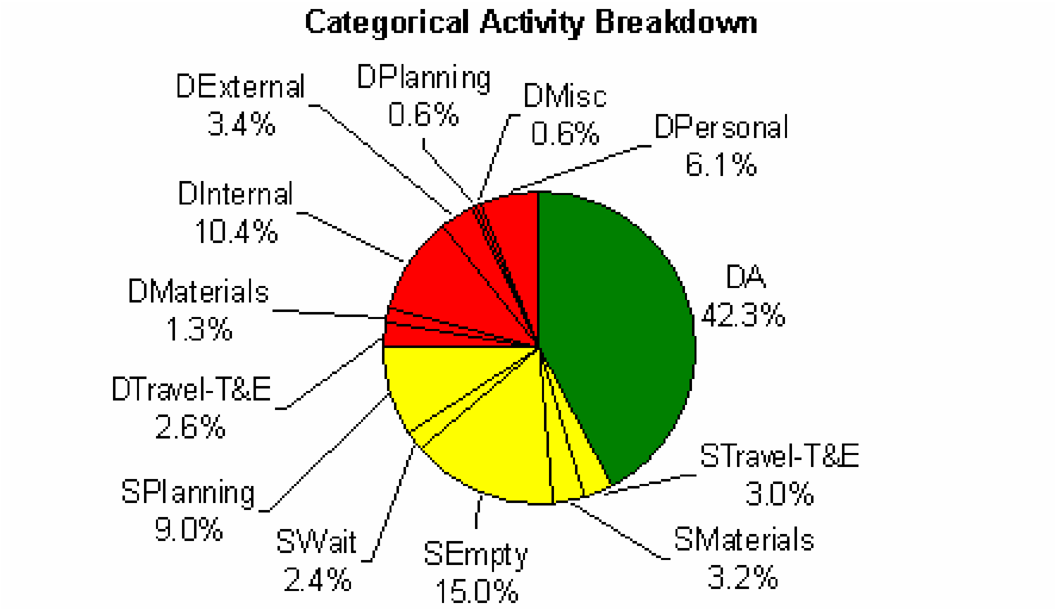
Within the Support and Delay categories are subcategories intended to identify the nature of the activity (or inactivity) more precisely. The subcategories for Support and Delay are as follows:

- **Support Activity Subcategories**
  - *Tool & Equipment Travel* – Transporting (walking or riding) tools or equipment or gathering / transporting tools or equipment outside the work area.
  - *Material Travel* – Transporting (walking or riding) parts, materials, or consumables outside the immediate work area.
  - *Empty Travel* – Walking or riding (as a passenger) empty-handed outside the work area.
  - *Waiting at Tool Stores* – Waiting at a store room or tool room/crib for parts, materials, tools or supplies not available in work areas or at point of assembly.
  - *Planning*
    - Studying drawings, diagrams, manuals or notes to obtain-job related information (outside work area).
    - Performing calculations (outside the work area).
    - Job-related discussion between craft members.
    - Making sketches.
    - Using paging systems, phones, or walkie-talkies for information.

- **Delay Subcategories**
  - *Tool & Equipment Delay* – Ready to work but on hold due to the immediate unavailability of tools or equipment.
  - *Material Delay* – Ready to work but on hold due to the immediate unavailability of parts, materials, or consumables.
  - *Planning Delay* – Ready to work but on hold due to waiting for instructions, drawings, or information.
  - Internal Delay – Examples:
    - Delayed due to scheduling conflicts within a crew(s).
    - Crew members' idle time attributed to over-manning of a job task.
  - External Delay – Examples:
    - Waiting on a crew to finish a task that must be completed before your work can be resumed (i.e. a pipefitter waiting on scaffold builders to modify a scaffold in order to access a flange)
    - Delays caused by poor coordination / scheduling between crews and / or crafts (i.e. more than one crew / craft scheduled to work in a specific area with limited space at the same time).
  - *Miscellaneous Delay* – All unexplained non-utilization or idle time.
  - *Personal Delay* – All delays due to personal reasons such as restroom breaks, water cooler breaks, etc.

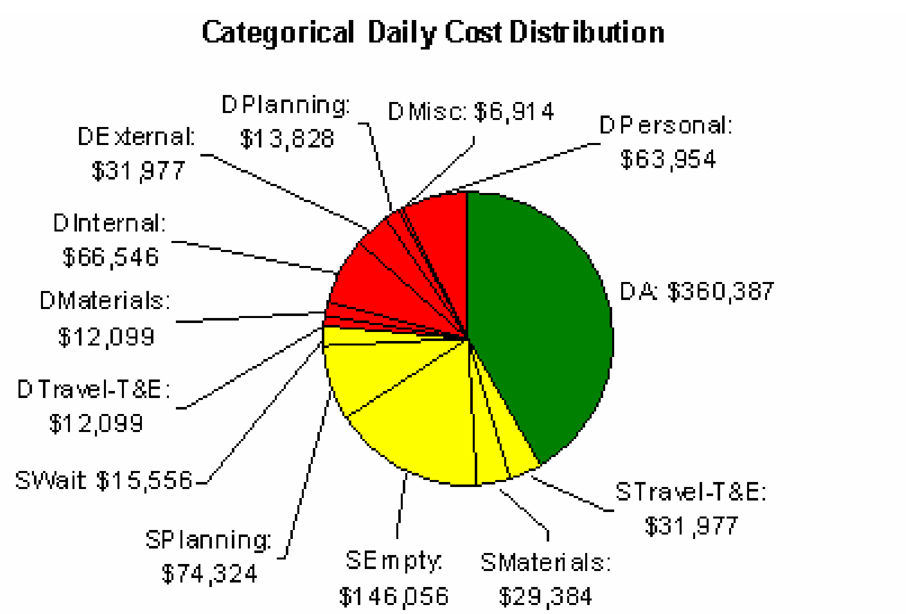
These definitions can be modified to fit a specific application's unique characteristics and purposes. This information is collected by area, craft, contractor, time of day, and other variables that facilitate in-depth analysis. An example of this measurement is shown below in Figure 1.1.

Figure 1.1 … Category Measurement Example



This information represents a snapshot profile of workforce productivity. To communicate the magnitude of this profile, information on manpower and average rates are applied to the percentages to show how much of the direct field cost can be associated with each category. An example of this type of chart is shown in Figure 1.2.

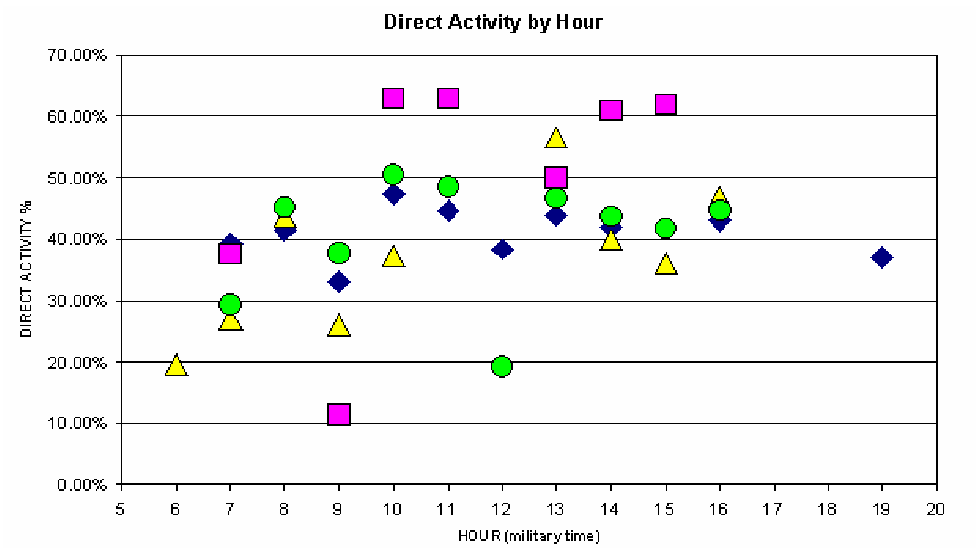
Figure 1.2 … Example of Daily Activity Cost Measurement



In this example, the analyst can see that over $200,000 is being spent on craft travel during a given workday. This type of analysis reinforces the fact that even small reductions in support activity and delays can result in huge gains in craft efficiency. One possibility to improve this situation that can be explored is adding break areas and material lay-down areas in closer proximity to the areas where work is being performed.

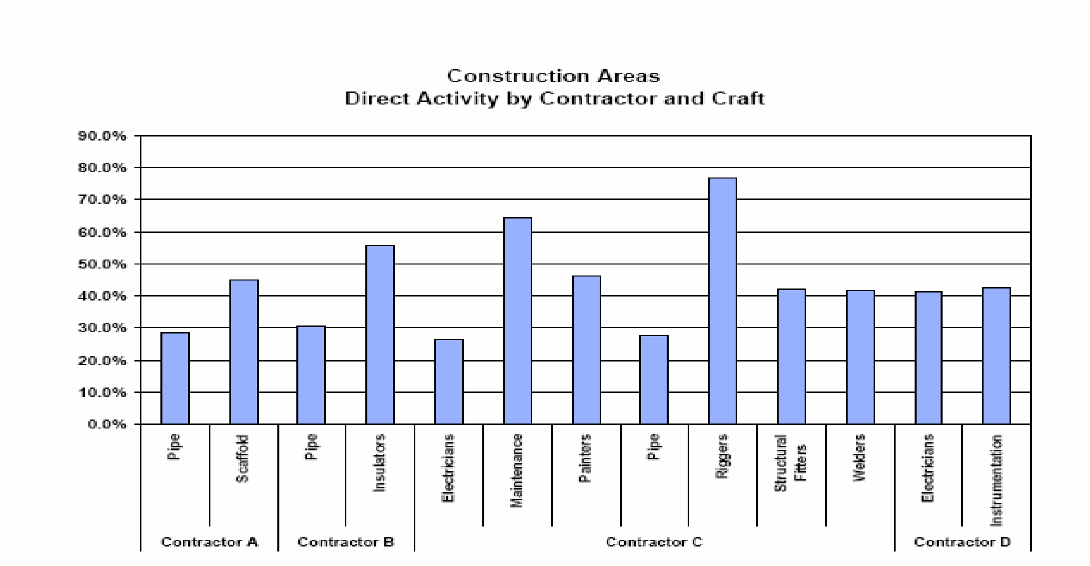
Because of the many parameters in which data is collected, it is also possible to analyze performance by many other variables such as time of day and by subcontractor. Examples of these charts are contained in Figures 1.3 and 1.4.

Figure 1.3 … Example of Direct Activity by Hour



This chart demonstrates the level of variation experienced from area to area and from hour to hour during the workday. Variation control is an advanced strategy within SPI that many customers evolve to over time. Borrowing lessons from Six Sigma® and Lean Construction, it has been shown that increasing the predictability of process outcomes will have a significant positive effect on craft productivity. In addition to looking at trends in performance, variation analysis and control is an effective strategy to improve craft productivity.

Figure 1.4 … Example of Contractor Comparison Measure



In order to fully leverage the potential of this mountain of information, it is necessary to take advantage of available data management technologies to provide the user with an efficient way to capture and analyze the data. Technologies are available to both collect the data and to store and analyze it from remote locations via the internet. The use of PocketPCs (shown in Figure 1.5), programmed with an interface file, allows the observer to efficiently and effectively capture the data, then wirelessly upload it to a database where it is instantly accessible and sortable.

These devices replace the clipboard or tape recorders used in traditional work sampling methods. It improves efficiency and effectiveness by reducing the number of times data is captured and entered into a spreadsheet. It also has the capability to capture voice notes from the observer, which can be critical to effective analysis. Some models have expansion slots where a digital camera can be added to capture a graphic illustration of the issue(s) being observed.

Figure 1.5 … Typical PocketPC Used in Collection of Field Productivity Data

Once captured, the data is then transferred wirelessly to a desktop or laptop computer connected to the internet. The information is uploaded to an "ftp" site where it is reviewed for validity before final transfer into the database.

Once the data is in the database, the analyst can then download the information into an Excel spreadsheet and sort it by multiple parameters. The potential of what is revealed by the data is limited only by the skills and experience of the analyst. Opportunities may surface that impact one area of the facility, or one craft, or only in a certain range of dates, etc. It is important to use all the information available to the analyst to get a full picture of the situation before actions are taken in response.

f. <u>Implementation</u>

Implementation is the key to the whole SPI Process. Without effective and appropriate implementation, all the effort to capture and analyze the information brings very little return. The manager should consider the following in deciding which actions to take:

- What will the change effect? When making a change, it is possible the change will impact other work processes that were intended to be left alone.
- Will the benefit be worth the cost of the change in the long run? Cost/Benefit analysis is a key variable in deciding what changes to implement.
- Who will be impacted? Sometimes the human effect of a work process change is not worth the efficiency gain. For example, banning smoking from a worksite because there is a high level of personal delay associated with smoke breaks

may result in a negative reaction from the craft. It may be better to build smoke areas closer to where the delays are happening to accommodate the smokers.

It is also important to attack a small number of opportunities at one time. Overloading your improvement efforts can lead to ineffective implementation and employee frustration. It is better to focus on a few at a time and get them right before moving on to the next opportunity for improvement.

Below is a case study from a major contractor who has successfully used SPI in their business. The case is from a major fabrication and assembly operation on the Gulf Coast. While SPI was applied successfully throughout the entire operation, this case focuses on the fabrication area of the application to most effectively demonstrate the use of the process and its results.

2. **Case Study**

a. Statistical Productivity Improvement Facility Implementation

The Statistical Productivity Improvement (SPI) process was implemented at J. Ray McDermott (JRM) by facility management in order to baseline current performance levels, improve productivity and meaningfully quantify subsequent improvements. The SPI process was implemented across the entire facility, encompassing seven pipe and steel fabrication areas and four major construction projects. While the entire facility benefited from the SPI process, one area in particular, Structural Fabrication, achieved and sustained a notable, dramatic improvement during the application of the SPI process. Because of the dramatic improvement in this one area, the case study focuses on the Structural Fabrication area exclusively.

Facility implementation of the SPI process was initiated through program orientation with facility management, project management, union representatives, and front line supervision (general foremen and foremen) for all areas. This crucial step was essential for communicating the purpose of the study and the basic methodology of the process to the craft personnel to assure their cooperation. All craft personnel that were included in the SPI study were identified by colored hard hats unique to each craft discipline.

Prior to any observation rounds being completed in the facility, the observation team completed interviews with key JRM personnel regarding the four Key Resource Processes (tools, equipment, material, and information) to determine management's perception of the areas evaluated by the SPI process. The development of effective improvement initiatives during the SPI process is contingent upon the plans being based on statistically valid data that address the perceptions of management regarding applicable Key Resource Processes.

The Structural Fabrication area of the JRM facility was an open-ended, double-production-line shop built on a concrete slab. Activity in this area consisted of both manual and automated welding processes. Typical craft demographics for this area consisted of welders, structural fitters, maintenance personnel, and equipment operators/riggers. For the duration of the SPI study in this area, there was around-the-clock activity with a day-shift and a night-shift working in this area. All data collected in this area was representative of activity observed on the day shift only.

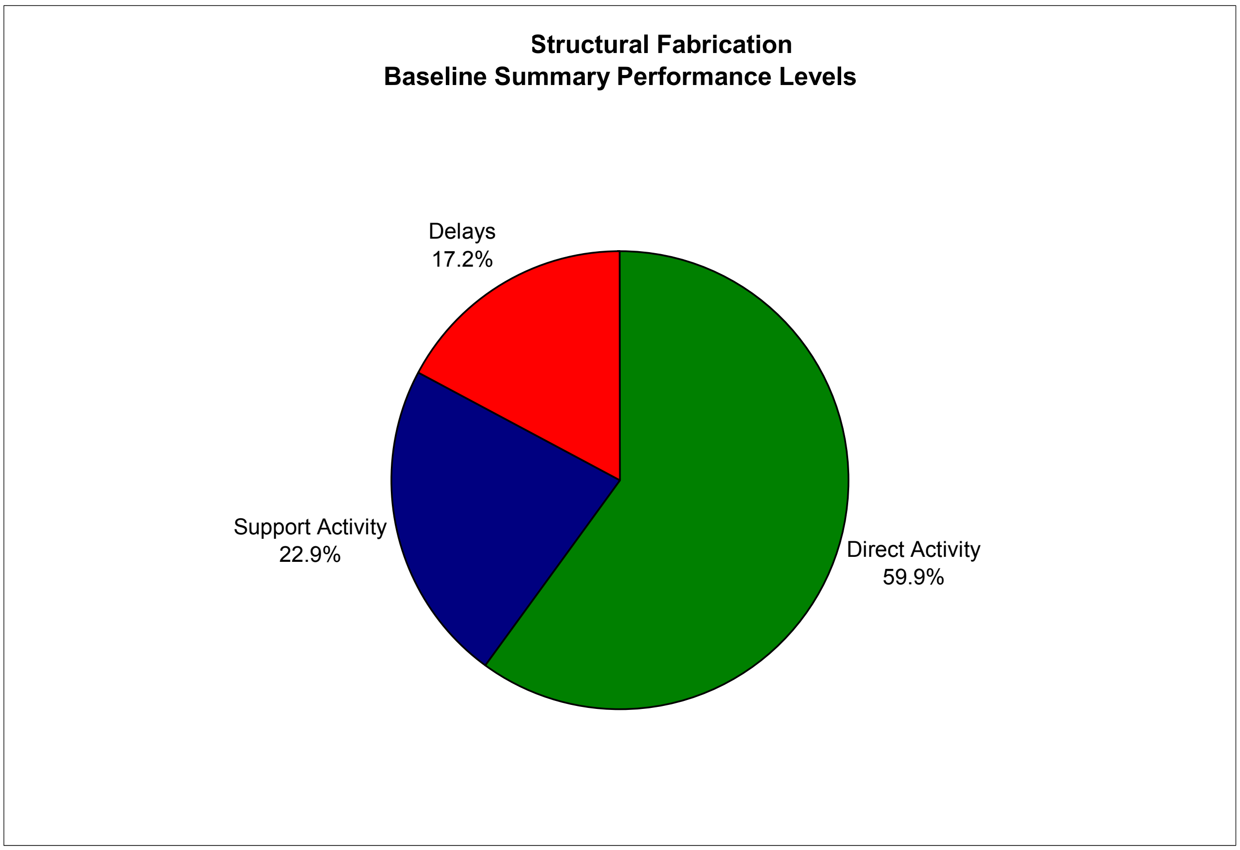
b. Baseline Study

The Baseline Study at the JRM facility spanned ten (10) weeks. The purpose of the Baseline Study was to establish a benchmark of current productivity levels, evaluating current performance levels and establishing a “yard stick” by which the effectiveness of future improvement initiatives could be measured.

Observations for the Baseline Study were captured by a team of three individuals. The established observation route was completed both forward and backward with random start times within each hour of the work schedule. Observations were distributed throughout the day proportionally to the number of productive minutes available on a ten (10) hour shift.

Figure 2.1 represents the summary results (Direct Activity, Support, and Delays) of the Baseline for the Structural Fabrication area of the JRM facility.

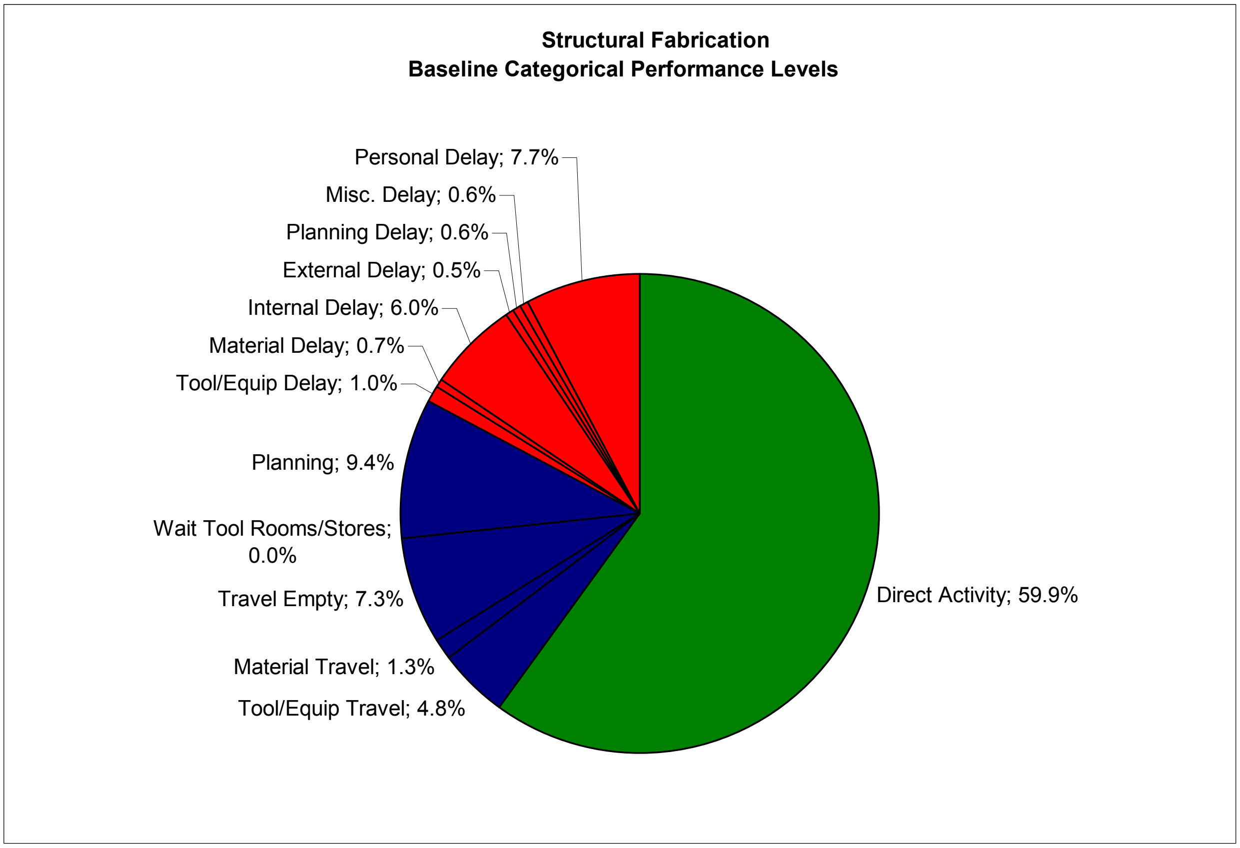
Figure 2.1 … JRM Structural Fabrication Baseline Summary Performance Levels



At the conclusion of the baseline study, Structural Fabrication was operating at 59.9% Direct Activity, Total Support was 22.9% and the Total Delays were 17.2%. This Direct Activity level identified this area as a high productivity area in the facility and was operating at a moderately efficient level. However, the Structural Fabrication management team felt that a higher productivity level could be achieved in this area. In order to determine the work activity categories that were candidates for improvement, the Total Support and Total Delay categories were examined at a categorical level.

Figure 2.2 represents the categorical breakdown of the Total Support and Total Delays categories and Direct Activity.

Figure 2.2 … JRM Structural Fabrication Baseline Categorical Performance Levels



At the conclusion of the baseline study, the most prominent negative performance levels became the Focus Areas for the Structural Fabrication's management team. The activity categories qualifying as Improvement Opportunities were determined to be:

- Travel Empty
- Planning
- Material Delay
- Internal Delay
- Personal Delay

c. Focus Area Improvement Plan Development

Following the completion of the baseline study, each of the identified focus areas was individually addressed by the Structural Fabrication management team. For each Focus Area, management spent time observing the behavior in the work area and conducting root cause analysis. This enabled the management team to develop effective, appropriate improvement plans that addressed the Focus Area without negatively impacting productivity and/or causing collateral damage in the Structural Fabrication area.

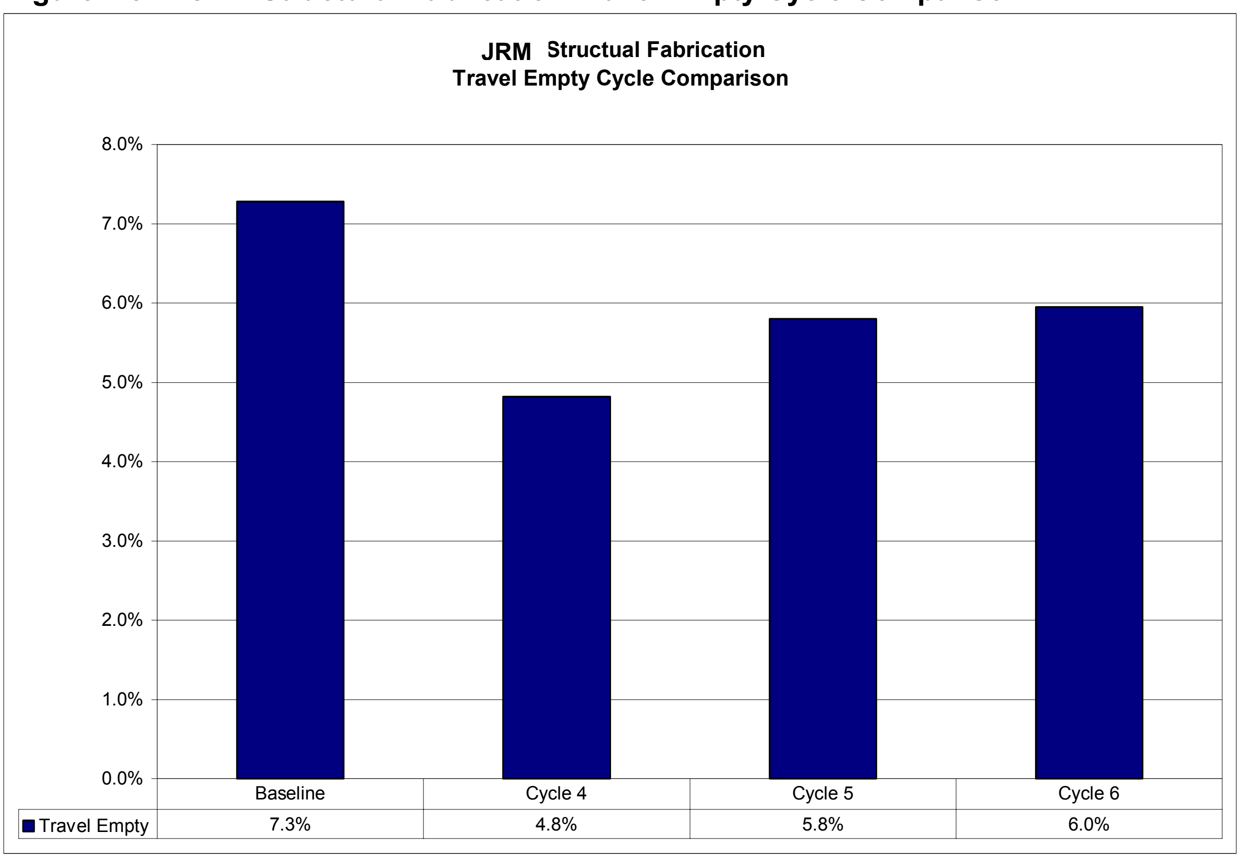
Three cycles of data were collected in Structural Fabrication following the Baseline Study to monitor the progress of any implemented improvement initiatives. For each of the sections below, graphical representations depict subsequent cycle activity levels for each category in comparison to the Baseline Study.

Travel Empty

Elevated levels of Travel Empty were mainly attributed to excessive travel for personal breaks. First, all of the restrooms for the Structural Fabrication area were located outside of the shop area. On most construction projects, portable restrooms are utilized because they can easily be relocated to high traffic areas. The restrooms at Structural Fabrication were permanent facilities at JRM, and could not be relocated closer to the immediate work area. Management increased visibility on the shop floor and more strictly enforced break times in order to minimize the amount of travel associated with personal breaks as there was no logistical solution. Second, water stations were distributed more frequently throughout the shop. Last, in order to minimize travel, craft personnel were allowed to take their breaks and lunch in their immediate work area.

At the end of the Cycle 6 Study following the Baseline Study, these three simple initiatives reduced Travel Empty in Structural Fabrication by 17.8% or 1.3 percentage points (see figure 2.3). This translates into a reduction of approximately seven (7) minutes per day, per worker that was no longer spent engaged in Travel Empty.

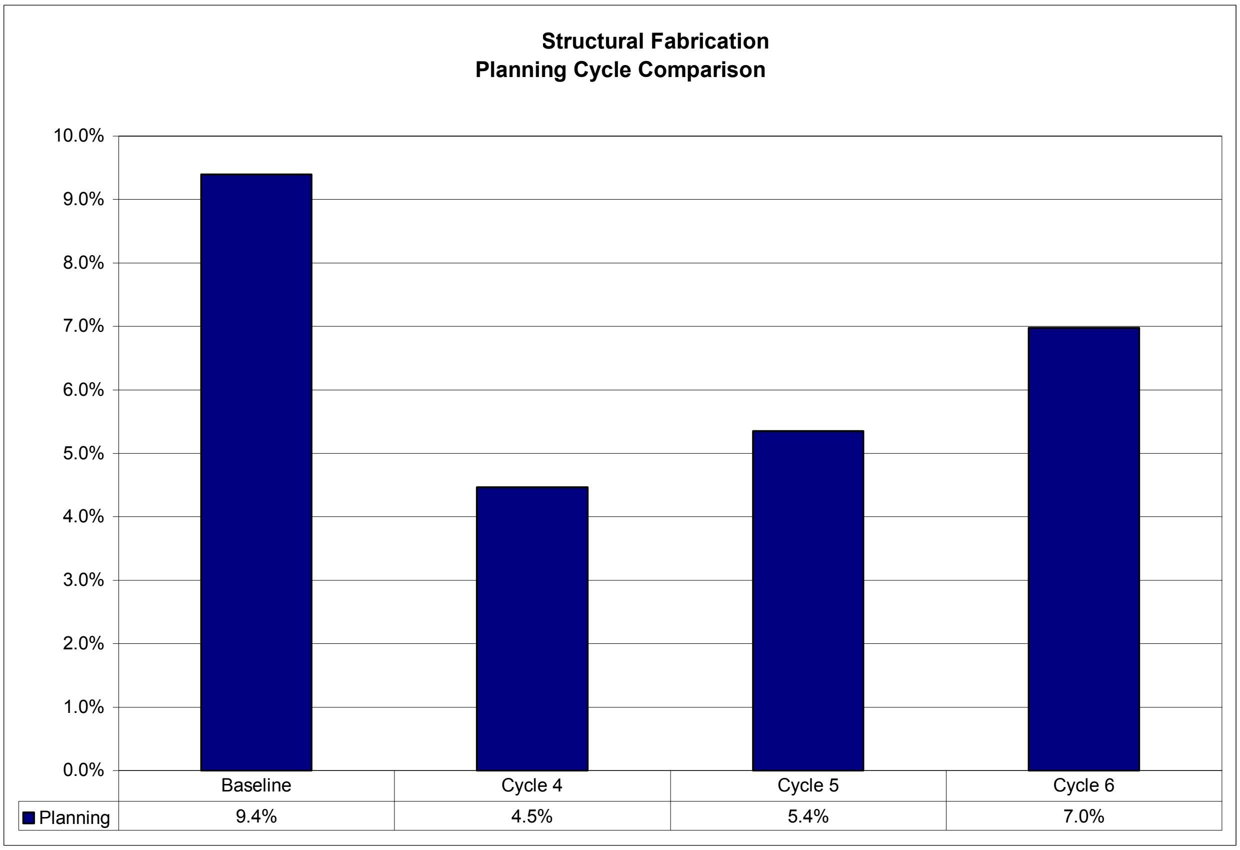
Figure 2.3 … JRM Structural Fabrication Travel Empty Cycle Comparison



Planning and Material Delay

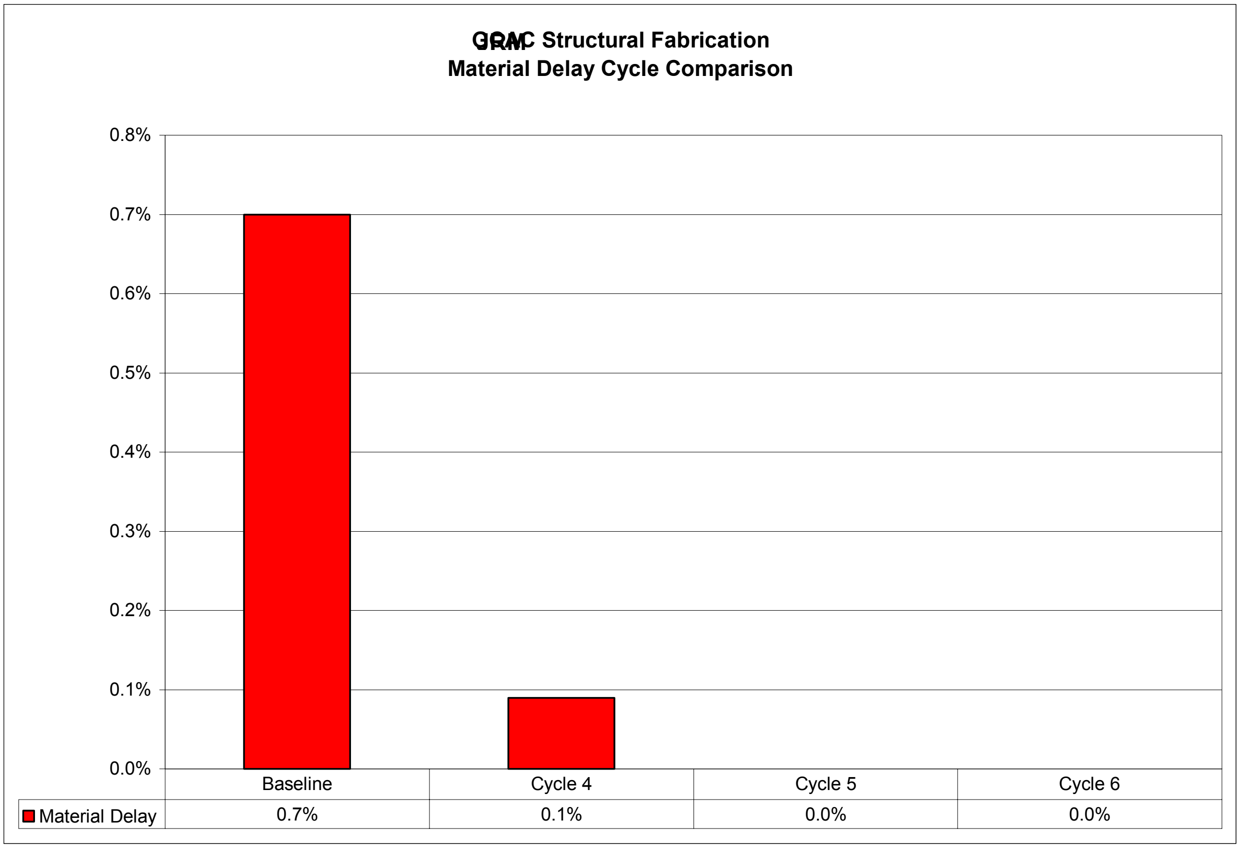
Planning and Material Delays were addressed with the same improvement initiative. Excessive planning in the work area is usually indicative of incomplete or unclear instructions that are given when craft personnel are assigned tasks at the start of shift. Thorough preparation by the field supervision prior to assigning task to craft personnel can eliminate the need for continuous consultation throughout the shift. Through more effective supervisor planning and thorough shift start assignments, Structural Fabrication reduced planning by 2.4 percentage points for the duration of this study (see Figure 2.4).

Figure 2.4 … JRM Structural Fabrication Planning Cycle Comparison



In the Structural Fabrication environment there should be little or no cause for Material Delay if the shift supervisor has effectively staged the work area for tasks to be completed. In a fabrication/shop environment, craft personnel typically are assigned to work in a designated area on a single assignment for the majority of a shift. Because of the steadiness of this type of work, management set the goal of 0.0% for Material Delays. By the end of this study, they had achieved that goal (see Figure 2.5).

Figure 2.5 … JRM Structural Fabrication Material Delay Cycle Comparison



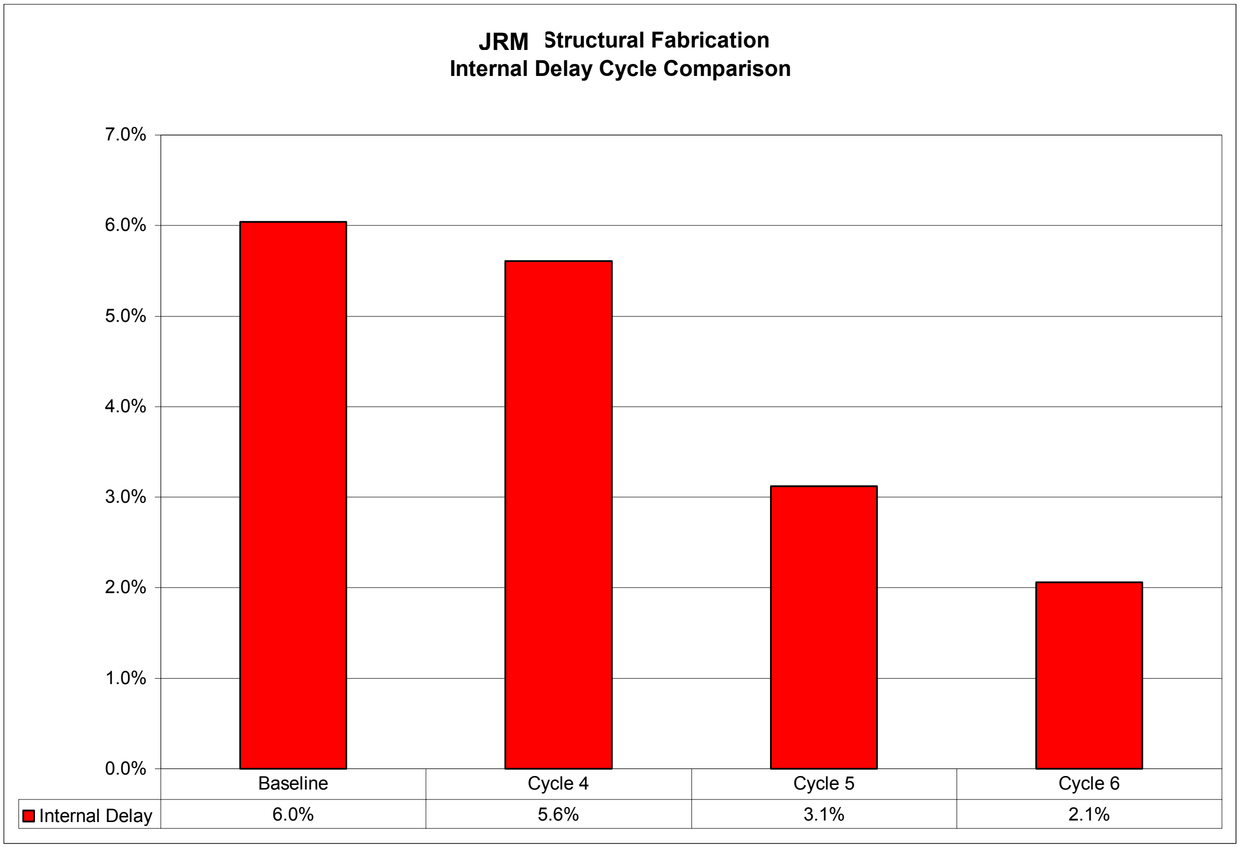
Internal Delay

The nature of the work in the Structural Fabrication area commands a higher level of Internal Delay than what is typically observed in a work area due to the nature of the work being completed there. High volumes of alternate welding and fitting leaves one member of a crew (a structural fitter and a welder working together) waiting on a task to be completed before they can move on to their next assignment. If the craft personnel are working in crews of 2, the work process essentially becomes a “switch-off” job. Only one member of the crew can be working at a time. This is particularly true in the JRM Structural Fabrication area as a result of the size of welds that must be completed. Most welding in this area takes place on pipe that is in excess of eight (8) ft. ID.

Restructuring the crew ratios and work process to enable each crew member to experience more productive time alleviates most of the Internal Delays experienced during task completion. For example, crews can be restructured to consist of one structural fitter and two welders. With both welders working after a fit has been made, the amount of time required to complete the weld is reduced, along with downtime (Internal Delay) experienced by the structural fitter. When the welders begin their current weld, the structural fitter can begin the prepping the next fit for the welders, concurrently with their task completion.

Using this approach, Internal Delays were significantly reduced at JRM Structural Fabrication. There was a 65% decrease (3.9 percentage points) from the baseline percentage to the Cycle 6 Report (see Figure 2.6).

Figure 2.6 … JRM Structural Fabrication Internal Delay Cycle Comparison



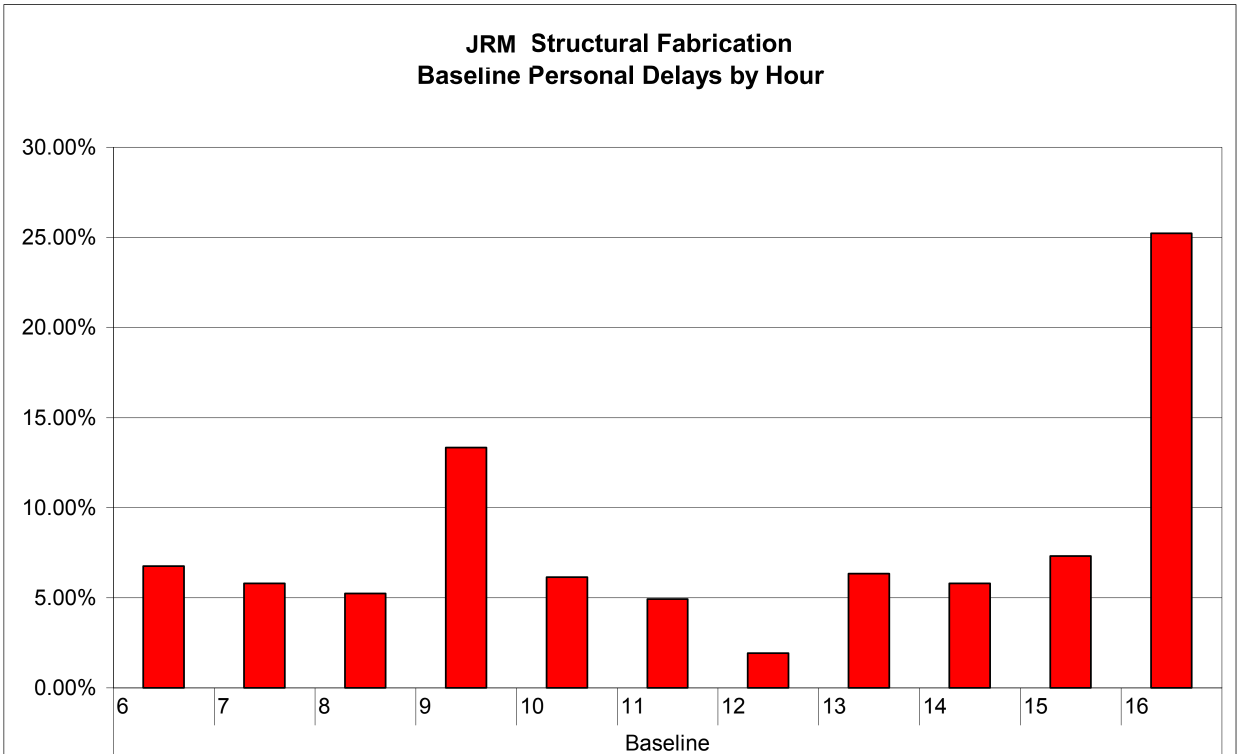
Personal Delay

Personal Delays in the Structural Fabrication area were at a somewhat elevated level at the completion of the Baseline Study. Although the levels of Personal Delay in this area fell within the 5-7% range that is typically observed during this type of study, based on logistics and performance indicators, this was not the optimum level for this category in Structural Fabrication at JRM.

Craft personnel had two (2) established breaks (a morning and an afternoon break). The 7.7% Personal Delay identified in the Baseline Study was time in addition to that designated by the work schedule. No observations were recorded during designated breaks or lunch times. Based on the Baseline percentage and a ten (10) hour work day, JRM was paying for approximately 42 minutes of Personal Delay per employee, per shift, in addition to the 20 minutes of designated breaks per shift.

Personal Delays were reduced primarily through two courses of action. First, supervisors more strictly enforced start and stop times of designated breaks. Most of the elevated levels of Personal Delays were the result of personnel either quitting early to start a break or lingering after the break time had concluded. Craft personnel were also cleaning up their work areas prematurely at shift end. The effects of this behavior are seen in Figure 2.7. Spikes at 0900, 1500, and 1600 indicate the early quits and late starts that led to higher Personal Delay Activity Levels.

Figure 2.7 … JRM Structural Fabrication Baseline Personal Delays by Hour

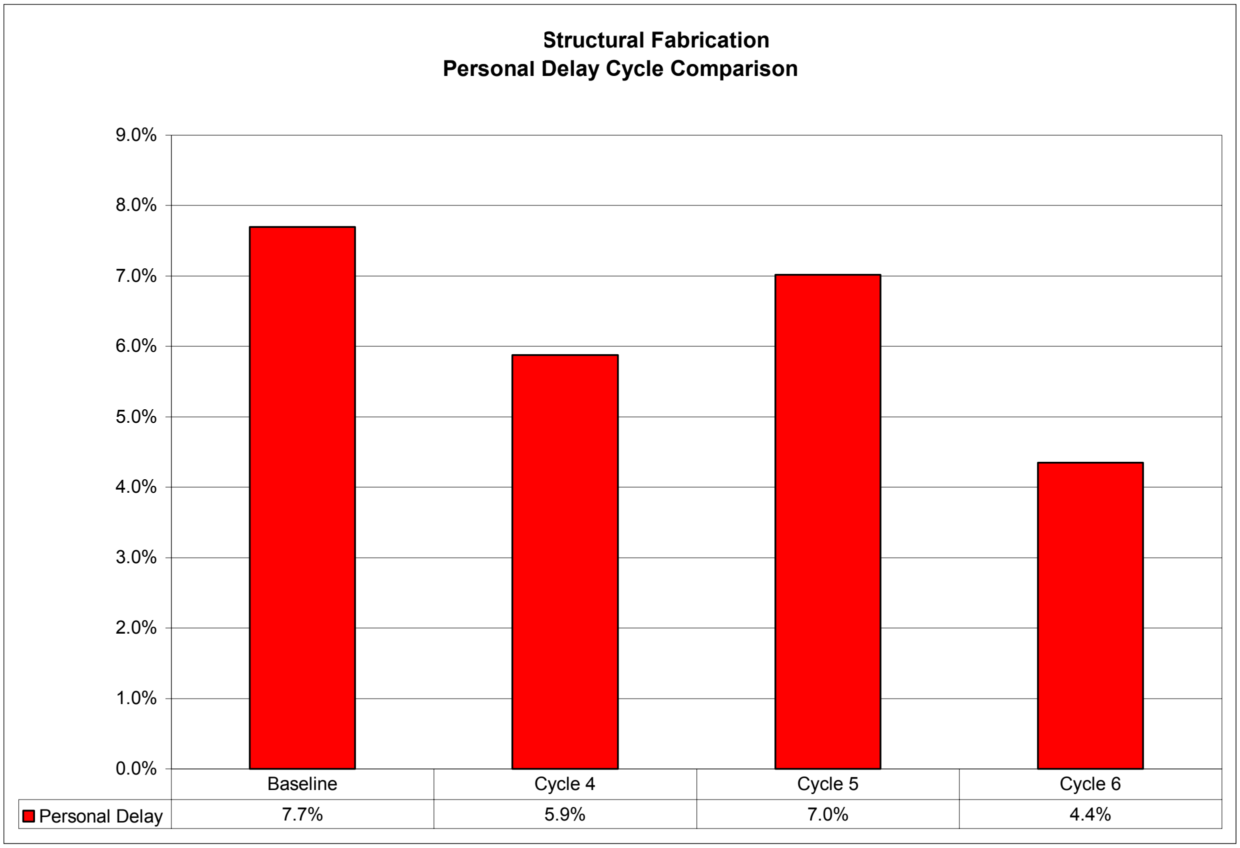


	6	7	8	9	10	11	12	13	14	15	16
Total	6.76%	5.80%	5.25%	13.33%	6.13%	4.92%	1.92%	6.33%	5.81%	7.31%	25.23%

After a root cause study, it was determined that a portion of the Personal Delays observed in the last hour of the shift were attributed to second shift personnel entering into the work areas before the first shift had officially ended. Often, second shift individuals would enter the shop, begin putting their lunches and other personal items away while the first shift was wrapping up for the day. Having the second shift personnel in the work place before the first shift had ended drove up early quits on the first shift. As the second shift personnel got to the work areas, many of the first shift personnel would simply stop working. Management implemented a new policy that all second shift personnel must remain outside the shop until the shift-end whistle blew for first-shift personnel. After the end of the day had been signaled, second-shift personnel were allowed to enter the work area and begin setting up for their upcoming shift.

The issuance of the Cycle 6 Report marked a 3.3 percentage point drop in Personal Delay from the activity level reported in the Baseline Report (see Figure 2.8). This significant improvement is indicative of how small changes in the work process can have great impacts on productivity.

Figure 2.8 … JRM Structural Fabrication Personal Delay Cycle Comparison



d. <u>Overall Improvement</u>

Structural Fabrication management drove a phenomenal improvement in Direct Activity over the course of the Baseline Study and all subsequent cycles of data reported (see Table 2.1)

Table 2.1 Structural Fabrication Activity Summary Cycle Comparison

Direct Activity	59.9%	73.3%	73.8%	73.7%
Support Activity	22.9%	12.7%	15.1%	17.1%
Delays	17.2%	14.0%	11.2%	9.3%

There was a 13.8 percentage point (or 23%) increase in Direct Activity from the Baseline Study to the conclusion of Cycle 6. Structural Fabrication also realized a corresponding 7.9 percentage point (or 46%) decrease in Delays.

An improvement in Direct Activity can be financially quantified using Potential Savings Opportunity or PSO. Enhancements to Direct Activity and resulting declines in delays represent an increased level of craft labor efficiency. Unless management responds to the improved efficiency by managing the human resource requirement appropriately, those efficiency gains will not result in savings. Therefore, improvements to Direct

Activity are quantified as PSOs to estimate the efficiency gain management is presented with to manage the human resource requirements on the site. It is then up to management to translate the PSOs into true savings. Table 2.2 estimates the PSO for the Structural Fabrication area. It assumes a craft workforce level in Structural Fabrication of 75 and an all-in average rate of $45 per hour. The savings amount represents the daily savings potential that corresponds to the improved efficiency gain.

Table 2.2 Structural Fabrication Potential Savings Opportunity (PSO)

Area	Baseline Direct Activity	Actual Daily Spending	Cycle 6 Direct Activity	Cycle 6 Daily Spending	Daily Potential Savings Opportunity
Structural Fabrication	59.90%	$20,216	73.70%	$24,874	$4,658

The SPI process enabled management to objectively evaluate their performance levels at a categorical activity level for easy data analysis. Categorical data analysis facilitates easy identification of improvement opportunities, and enables management to rank each opportunity by order of magnitude and impact on overall productivity.

By utilizing this feature of the SPI process, the JRM Structural Fabrication management team addressed root causes of productivity losses with effective improvement initiatives for sustained improvement.

3. Conclusion

The methodology used by the Statistical Productivity Improvement Process represents a statistically-based construction application of a Total Quality Management Program. Understanding the impact of construction resource (tools, materials, equipment, & information) processes on construction labor performance allows the user to make proactive, data-based decisions that will fundamentally improve craft productivity at a facility. The flexibility of the application allows effective implementation on small, "one-off" projects as well as across a multi-site operation. The methodology is equally as valuable for outages/turnarounds as it is for major construction projects.

The information above is intended to give the reader a basic understanding of the Statistical Productivity Improvement Process and to provide a real example of how a facility owner used the process to significantly improve performance at their facility. A user should consult an SPI service provider for specific guidance on implementation. Some firms offer SPI services only, others offer training to build internal resources for long-term implementation, and some firms offer both. Regardless of the path chosen, the SPI Process offers its users a systematic approach to long-term improvement at their facilities that will continue to provide value long after implementation is complete.

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