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Development of an Intellectual Framework for Schedule Control

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Abstract

Construction control systems provide a means to monitor progress, predict future status, and act to influence the outcome. Functions fundamental can be used to describe control systems and are: *define, measure, compare, predict*, and *act*. It is the ability to predict a likely future project status that allows appropriate action to be taken to control the project outcome. Schedule control systems are cyclic systems that serve to monitor and predict progress in terms of the construction schedule so that appropriate actions may be taken to promote on-time completion. The functions fundamental to schedule control are described as: *plan and schedule, monitor, track and report, forecast,* and *control.* The intellectual framework for schedule control developed bridges the gap between the well established progress monitoring techniques and the necessary forecasting function to provide a means for initiating appropriate action.

Development of an Intellectual Framework for Schedule Control

Introduction

Academic development of control systems in the construction industry appears to have reached a plateau in terms of the advancement of literature. Barrie and Paulson [1984] summarize familiar knowledge on the subject:

> Throughout the project, the control system quantitatively measures actual performance against the plan and acts as an early warning system to diagnose major problems while management action can still be effective in achieving solutions. Development and application of a practical control system to measure progress and costs are among the most important contributions of the professional construction manager.

It is clear that there is a need for a control system, and that the function of a control system is to compare the actual versus planned, which should in turn give a warning of future problems. Too often is this casual link made – that an uncomplicated comparison of actual and planned work provides the most efficient and effective early warning system; there is no mention of a forecast or prediction that provides the early warning. A dissection of construction control systems into base components is not readily available. Control systems in general can be broken down into five stages, used to maintain a desired output, which are:

1. Define
2. Measure
3. Compare
4. Predict
5. Act

The first three stages (*define*, *measure*, and *compare*) form a subset that are the basis for *progress monitoring*. From this grouping, the three major stages of control systems are:

1. Monitor Progress to Determine Current State
2. Predict Possible Future States
3. Act to Achieve a Desired Future State

These minor and major stages are directly applicable to the construction industry, and more specifically for this research, to project scheduling. To explain the need for a "control system" as opposed to a "monitoring system", the following sections discuss how monitoring systems are only a piece, albeit an integral one, of control systems.

Monitor Progress to Determine Current State

Forming the foundation of a control system is a progress monitoring system, which as stated before, consists of the steps of *define, measure*, and *compare*. Progress monitoring is essential in the control process in that you need to know where you are before you know where you are going. Knowing "where you are" is the practice of defining where you want to be, measuring where you are, and making a comparison between the two to determine where you are with respect to where you planned to be. The following diagram depicts progress monitoring in scheduling.

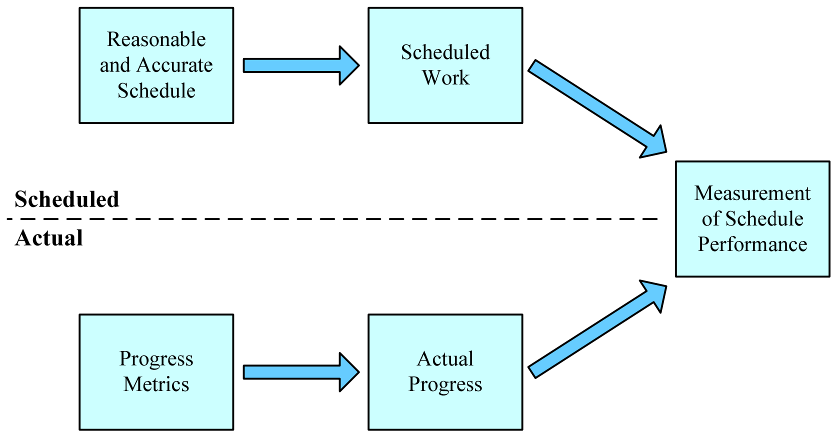

Figure 1: Progress Monitoring System

The diagram is divided vertically into scheduled work and actual work performed. On the *Scheduled* half of the diagram, once a reasonable and accurate schedule is approved (the schedule of record), there is a plan of attack for how construction will take place, comprised of scheduled work. This scheduled work serves as a datum or baseline of the actual work as it takes place. Examples of standards for measurement include CPM schedules, control budgets, procurement schedules, quality control specifications, and construction working drawings [Paulson 1976]. On the *Actual* half of the diagram, predefined progress metrics are used to track actual progress of construction. The *Measurement of Schedule Performance* takes place when *Scheduled Work* is compared with *Actual Progress*. With the measurement of schedule performance, it can be determined how close to, or how far off, actual construction is to the schedule. This quantifiable measurement provides information for the following steps of schedule control systems – predicting and acting, which in terms of project scheduling, need further understanding and definition.

<u>Predict Possible Future States</u>

A *prediction* is synonymous with a *forecast*, which serves as a necessary step in bridging the gap between monitoring progress, and taking action. According to Barrie and Paulson [1984], a *forecast* defined: "based on the best knowledge at hand, what is expected to happen to the project and its elements in the future." Forecasts require reliable progress measurement in order to project the future, for you cannot properly initiate action without valid predictions. Improving the validity of projections will provide strong grounds for improving actions. This being said, what actually *is* a "forecast" – what is it based on. Are forecasts based on tracking data (trends in current project data), historical data (trends in data from previous projects, applied to the current project), or both? Is forecasting taking the production to date and superimposing on the future? In reference to the definition above, what is the "best knowledge at hand" – the construction industry has clearly defined its concept of what a forecast is, but it is difficult to define what that "best knowledge" is.

Act to Achieve a Desired Future State

The final stage in a schedule control system is *acting*, which relies on predictions to produce actionable information in a format that allows action to be taken, if needed, in order to end up where you want to be. This stage shifts predictions into the "so what?" area – what does the forecast mean. It is documented that ominous forecasts necessitate that a decision must be made concerning what corrective action, if any, is required [Clough et al. 2000]. However, lacking is a good understanding of what the middle ground is between a poor forecast and corrective action – what type of indicator signals action to be taken. To further analyze problems associated with *acting*, the indicator is symbolized using a smoke alarm analogy.

Smoke alarms ring when they detect smoke, or in scheduling terms, an alarm to take action occurs when a forecast warrants action. A smoke alarm, when ringing, grabs your attention – which is exactly what is needed in construction scheduling, an alarm that raises awareness of a situation with the potential to cause schedule slippage. There are two different types of smoke alarms: 1) an alarm that requires you to check things out and inspect if all is OK, and 2) an alarm that warns that things are wrong. The second alarm differs in that it has detected something is definitely wrong and there is a need for corrective action. Associating a smoke alarm with forecasts puts the urgency on acting, which may be a change in method, sequence or other corrective action of the dismal prediction.

Structure of Control Systems

There is a clear understanding of progress monitoring systems, which are comprised of defining a plan or schedule, measuring actual work as it occurs, and tracking and reporting a comparison between planned and actual work. The same cannot be said, however, for intellectual framework that encompasses the *predict* and *act* stages of schedule controls systems. While it is known that a reliable forecast is needed for control systems, the links between progress monitoring and forecasts, and forecasts and control, are not thoroughly developed. As mentioned above, a prediction that causes action is what is described as an early warning system. Early warning systems that utilize a "smoke alarm" serve as the major component of schedule control systems, signaling an alarm to call attention and possibly take corrective action. The following diagram attempts to structure schedule control systems:

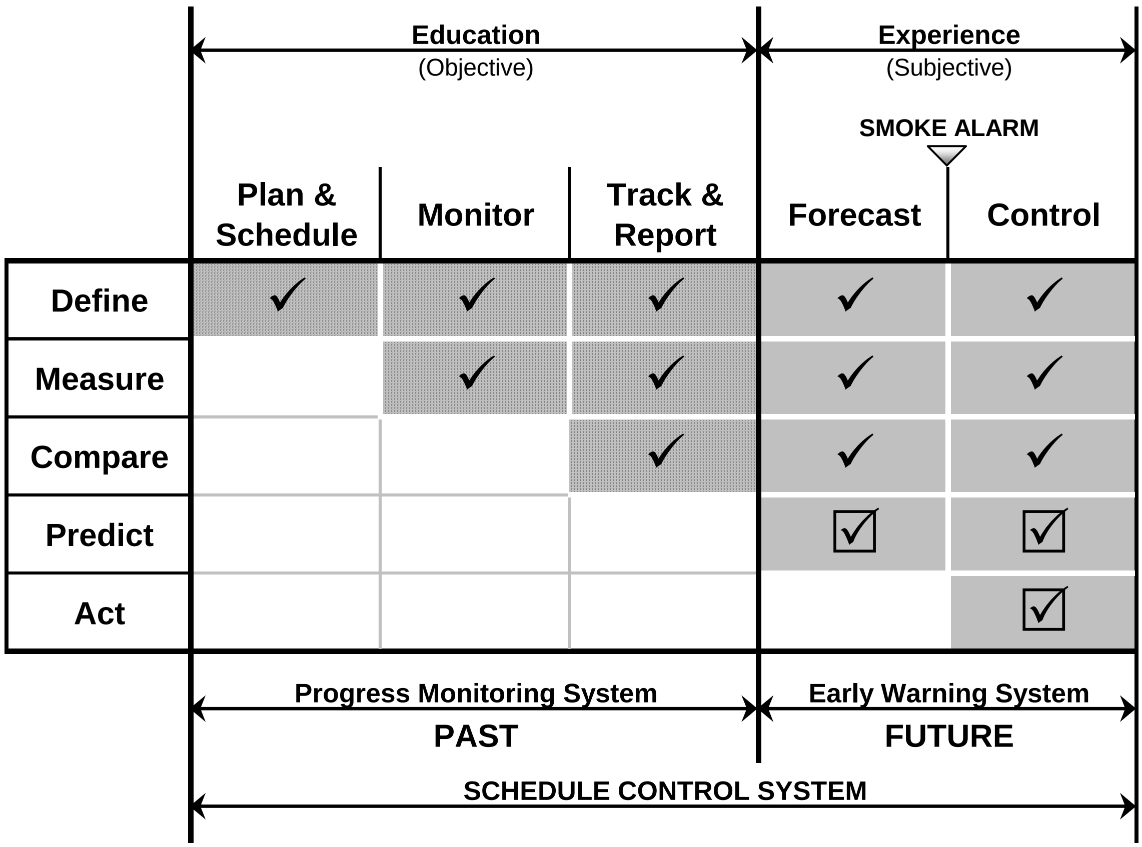

Figure 2: Structure of a Schedule Control System

Schedule control systems, as shown in the diagram, are divided into two major components: 1) a *Progress Monitoring System* that is a historical representation of the first three stages (*define, measure, compare*), and 2) an *Early Warning System* that looks towards the future by using the final two stages (*predict, act*). Bordering the top of the diagram, the five stages are matched with their project scheduling counterpart. Each project scheduling component has checkmarks across from the stages included in that component, e.g. *Track & Report* requires the stages of *define, measure, and compare*. These project scheduling components are the intellectual framework for schedule control that needs further development, as is described in Chapter 3.

Further distinguishing between progress monitoring and early warning, progress monitoring is generally of objective matter – tracking and reporting measurements of actual versus planned, which can be learned through an education of progress monitoring. On the other hand, early warning systems are more of subjective matter, where experience is required to determine what type of smoke alarm is needed, as well as how to fine-tune the smoke alarm to go off when it should go off. To develop an alarm, there must be a valid prediction of where the project is headed.

Given the information above on “schedule control,” there is an understandable distinction between progress monitoring systems and schedule control systems. Based on the notion that schedule control requires reliable forecasts that produce an action, there is not readily available information on quantitative indicators that say when the smoke alarm should go off. For example, remedial stages are suggested when project activities are “appreciably behind”, there are “substantial delays”, or durations have been “materially underestimated” [Clough et al. 2000]. All of these terms are laced with subjectivity and require experience for quantification.

With the clear need for a good understanding and intellectual framework for schedule control, the following section communicates the need for actual forms of schedule control systems.

Intellectual Framework for Schedule Control

In the domain of project scheduling, the intellectual framework for predictions and taking action are not as prevalent as those for progress measurement. Routine and reliable predictions that provide an early warning of schedule slippage, and in turn support action being taken, provide a control system that aids in minimizing the potential for late project completion. This is reason to further develop the intellectual framework for schedule control.

Researching and developing schedule control builds the philosophical and intellectual differences between progress monitoring systems and early warning systems. The research seeks valuable insight on the concept of triggers and their relation to warranting action, in terms of how quantifiable, if at all, these triggers are. Given that the concepts of progress monitoring are well known and accepted, the focus is on the relationships between progress monitoring, predicting, and taking action.

Literature Review

Control systems can be categorized as either absolute or cyclic. Absolute systems are appropriate for use when the desired result does not vary as a result of performance. When it is necessary to redefine the desired result due to actual performance, it is appropriate to apply cyclic systems.

Absolute Control Systems

Absolute control systems follow the general framework of control systems, yet are distinct in that the control system is not a circular process; there is no feedback loop that always links the *act* stage back to the *define* stage. This is very important to note, for in construction safety and construction quality the standards are constant and absolute. Whatever happens during the control process, it will not affect the goals of these elements. For example, the safety objective is to have no future injuries or accidents on the project. Yet, should an injury or accident occur, the safety objective is not changed – the goal is still to have no future mishaps on the project. The same goes for quality control: the goal is to produce an acceptable product. If substandard work should occur, there is no compromise in the established standard of acceptability.

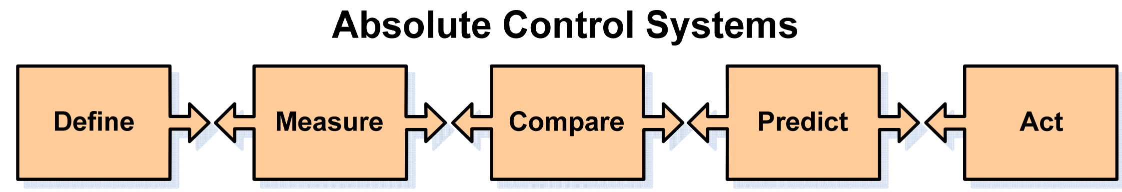

Figure 3: Absolute Control Systems

Safety and quality control systems lacking the feedback loop is attributed to the high-risk nature of the construction industry. If safety or quality are negotiated and a less regimented standard of acceptance is developed, lives are at risk – both those on site during construction, as well as civilians that will use these facilities.

While absolute controls systems are not one-in-the-same as cyclic control systems, there is great value in analyzing the components of how they define, measure, compare, predict, and act. Absolute control systems provide a strong emphasis on the *define* stage, which is demonstrated in the following sections on safety and cost control.

Safety Control

"Safety control is a person's perception of the ability or opportunity to manage work situations to avoid injuries and accidents" [Huang et al. 2006], a tool used for controlling the wellbeing of a project, free of risk or dangers. There has been added emphasis on how project management can improve site safety [Cheng et al. 2004], leading to a development of advanced safety control systems. This section details how each stage of general control systems is unique to safety control, as will be developed later for quality control, cost control, and ultimately schedule control.

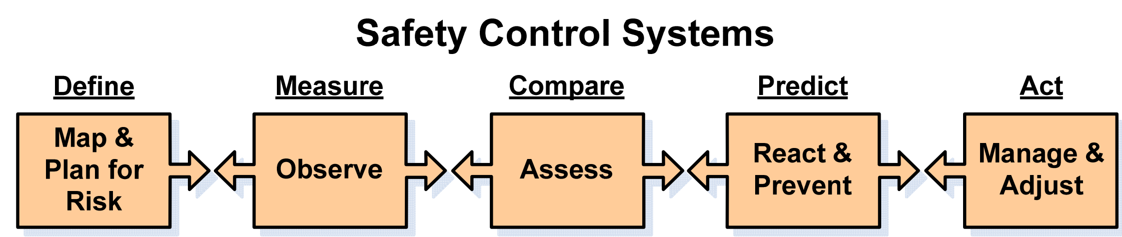

Figure 4: Safety Control Systems

Define: As noted before, the objective of every project is to be injury and accident-free. To achieve this, there is a strong emphasis on the initial stage of control, the *define* stage. Theoretically, an unlimited number of safety precautions, using an unlimited number of safety equipment, prepared by an unlimited amount of safety planning, eliminates any possible dangers in construction. This very well may be true. However, doing so puts construction costs at unreasonable and undesirable levels. Therefore, while "injury and accident-free" is the goal, efficient safety control should only cost a small (slightly over 1%) portion of total contract costs – this factoring in the cost of injuries and accident to an organization [Son and Melchers, 2000].

Based on this, limits are established for the cost of prevention, as well as the assumed damages for potential shortcomings. There are both direct and indirect costs, but the ultimate goal is to minimize the overall expected total cost for safety [Son and Melchers, 2000]. Statistical data of accident rates, the direct costs of damage and loss per worker, and the number of workers per accident provide a formula that helps management determine what safety expenditures they have to properly plan [Terrero and Yates 1997].

When considering the appropriate allocations for safety planning, keep in mind of the three stages of planning: 1) long-term planning, 2) medium-term (look-ahead), and 3) short-term. Throughout all stages, define proactive metrics that eventually provide feedback to safety planning of future tasks [Saurin et al. 2005]. Safety metrics tracked include number of accidents per man-hours worked, percentage of total project cost, hours lost to accidents per hours worked, unsafe acts, and near misses. Safety managers use this feedback to coordinate with schedulers to prevent hazardous environments and ensure that risk is spread over the entirety of the project [Yi and Langford, 2006]. Additional details defined during the initial planning stage include mandatory safety standards set by government regulations [Kerridge 1994], new employee orientation to safety standards, training, and the development of incentive programs [Huang and Hinze, 2006].

Measure: The importance of defining limits, regulations, and risks in safety control raises the question of how to measure all this. Safety management is a dynamic process operating in a constant state of change [Wilson and Koehn 2000], in which some safety problems can be only identified through careful and frequent observations of site activities [Saurin et al. 2005]. Because the slightest mishap in safety procedures can result in immediate injury or accident, reliable and continuing feedback is made through observation [Ai Lin Teo and Yean Yng Ling 2006]. Through constant observation, the aforementioned safety metrics are documented and reported to safety managers.

Watching the “action” of construction is not the only observations that need to be made – equipment should be inspected for repairs and preventative maintenance [Terrero and Yates 1997]. Just as important, work-in-place also requires thorough inspection to ensure safety.

Compare: The *compare* stage weighs the planned safety system against the actual safety system as it took place. One common source for black-and-white comparisons are through hazard logs and safety reports, such as the percentage of safe work packages that checks the written safety plans against the actual work performed [Saurin et al. 2005]. Assessing the climate is taking a “snapshot” comparison of the state of safety at a discreet point in time [Huang et al. 2006]. If the planned does not match up with the actual, there is recognition of a high-risk atmosphere. While constant observation is needed to prevent possible accidents, reporting and feedback are not as frequent.

Seeking feedback through scheduled safety meetings and interviews with supervisors, project managers, foremen, and workers is another source of comparison [Terrero et al. 1997, Saurin et al. 2005]. This communication ensures that all potential hazards and concern are known throughout all levels of command on a project. Weekly meetings provide management with the feedback needed to make changes, although “open door” policies allow for constant communication of potential hazardous environments.

Predict: The power of predicting in construction safety control systems saves lives every day. A useful predicting tool is the “near miss”, or “unplanned events that could potentially cause human injury or property damage,” which are “valuable, but inexpensive, warnings of unsafe trends on site” [Huang and Hinze 2006]. Near misses recognize an unsafe environment that may be a precursor of an accident; the near misses forecast potential harm. Also used for predicting are all warning signs that arise during the comparison stage, whether from data comparison or through communication and hazard recognition.

Beyond current project data and near misses, the most important predicting tool is that which takes place during the planning stage – taking preventative measures based on accident history and statistics [Mohan and Zech 2005, Terrero and Yates 1997]. Visualizing and predicting unsafe environments at the beginning of the project is the best predictor that the construction industry has, preventing accidents, rather than reacting to them.

Act: As previously noted, there generally is not redefinition of safety objectives – the goal is to be injury and accident-free from “this point forward”. That said, evaluation of safety performance provides opportunity to check the status of safety boundaries (crossed, not crossed, or not defined) and to reinforce the respect for them. If boundaries are crossed and there have been near misses, action can be taken by eliminating the root cause of the near miss [Saurin et al. 2005]. The action represents a “time-out” in the work, recognition of an accident or hazardous environment, analysis of the root cause of the accident, and the formulation and execution of remedial action. Failure to take action and adjust in response to a constraint in the environment is a potential work hazard [Huang and Hinze 2006].

A summary of the main components of safety control systems, as well as quality and cost control systems is provided in Table 2.1, presented after these three controls systems have been developed.

Quality Control

The second absolute control system in construction covered is quality control. A quality control system defined is “that system by which an organization achieves and maintains the fitness for use of its products or services” [Bishop 1974]. “By doing it right the first time, competitors add value to their products/services and exceed customers’ expectations, under budget and ahead of schedule.” [Calder 1997] This section discusses how quality control systems attempt to achieve and maintain a quality product the first time around.

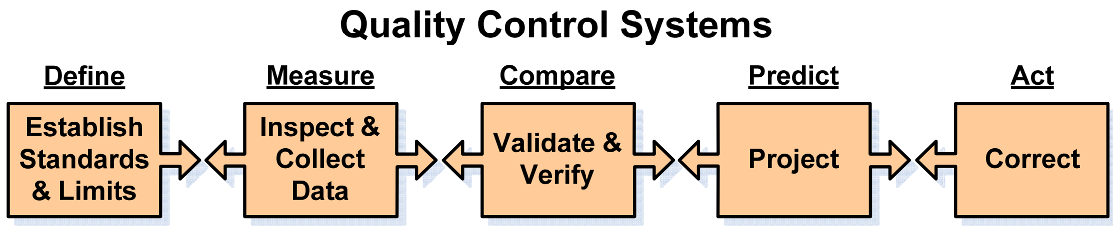

Figure 5: Quality Control Systems

Define: As an absolute control system, quality control is also very reliant on the *define* stage. The first step in a quality control system is to determine what metrics will be used to measure quality (performance, features, reliability, etc.) [Schniederjans and Karuppan 1995], followed by the establishment of standards for what is "acceptable" for these metrics – in terms of raw material, work in progress, and finished product [Bishop 1974]. Acceptability can be further defined into establishing limits for what is deemed acceptable – a control chart with a center (optimum) line and two surrounding lines that define the limits [Kuo and Mital 1993]. Also to be determined is the sample size and sample frequency.

The plan for quality control is done in a manner that minimizes the total cost overall for the product or service, cost of inspection, and cost of reworking a defective product or service [Bishop 1974].

Measure: The second stage of quality control systems is to perform an acceptance inspection on the product or service [Bishop 1974]. Inspection records the actual construction as it takes place, in terms of the metrics defined in the *define* stage of the control system, at the time of construction. As daily activities are completed, construction inspectors analyze work in place for acceptability.

Compare: Comparing actual to planned quality provides feedback on the accuracy of the work in place. The acceptability of a sample is weighed by its plot on the quality control chart, whether it lies between the two "acceptable" lines; a control point inside the lines is considered to be statistically in control, whereas an outlier is interpreted as out of control [Kuo and Mital 1993]. In construction, the control lines are a measurement tolerance of what is acceptable. This acceptability assessment contains two parts: validation and verification [Katasonov and Sakkinen 2006]. Validation is ensuring the right product is in place and verification is ensuring the product in place is right.

Predict: The main prediction tool in quality control systems are patterns in quality, as recognized on control charts. A change in a process is indicated by the following common signals: cycles; freaks; plotted points falling outside the control limits; gradual change in level; systematic variations; trends; mixtures; abnormal fluctuations [Kuo and Mital 1993]. This interpretation of the control chart provides grounds for the next stage of the control system.

Act: Upon investigating trends and patterns in quality and control charts, corrective action may be taken to eliminate assignable causes responsible for the behavior [Kuo and Mital

1993]. A *root cause analysis* determines what the source of defective products or services are. If defective products or services are found, it is at this stage they are eliminated and a plan for remedial action is taken. Unless there is a change in scope of the objective that affects the acceptability, the original standards and limits remain. "Quality control is generally composed of three successive actions: measuring, comparing, and correcting" [Yaseen and El-Marashly 1989]. There is no redefining, rather just assuring that the original quality standards are met.

Cyclic Control Systems

What distinguishes construction cost and schedule control systems from safety and quality control systems is that following defining, measuring, comparing, predicting, and acting, it is routine to reassess and possibly redefine the definition of the baseline cost or schedule. The closed loop system for cyclic control systems, as shown below, takes action that may include revising the original plan.

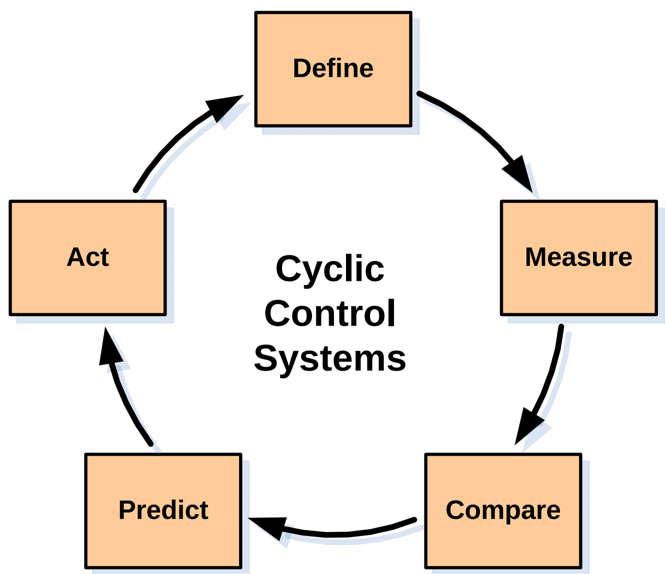

Figure 6: Cyclic Control Systems

Cost Control

Stevenson and Wilson's "Cost Control Program to Meet Your Needs" [1989] provide the following definitions: The Project Management Institute defines a cost control program as "to provide a mechanism that reacts to the current project status in order to ensure accomplishments of project budget/cost objectives." The American Association of Cost Engineers [Stevenson and Wilson 1989] elaborates further:

> The application of procedures to follow the progress of design and construction projects in order to minimize cost with the objective of increasing profitability and assuring efficient operations. There are three essential elements of control. The first is to establish the optimum condition, the second is to measure variation from the optimum and the third is to take

corrective action in order to minimize this variation. The application of these procedures attempts to limit costs to those authorized for capital projects or cost standards, focuses control efforts where they will be most effective, and achieves maximum control at minimum operating cost.

And finally, Stevenson and Wilson [1989] summarize the elements of control to coincide closely with the five stages of control:

1. *Define*: Baseline Budget
2. *Measure*: Monitor the Progress
3. *Compare*: Variance Analysis
4. *Predict*: Re-Forecasting
5. *Act*: Corrective Action

Through continuous recording, reporting, and forecasting of both obligations and expenditures, the project cost control system provides the information needed for decision making [Stevens 1986, Eldin 1989].

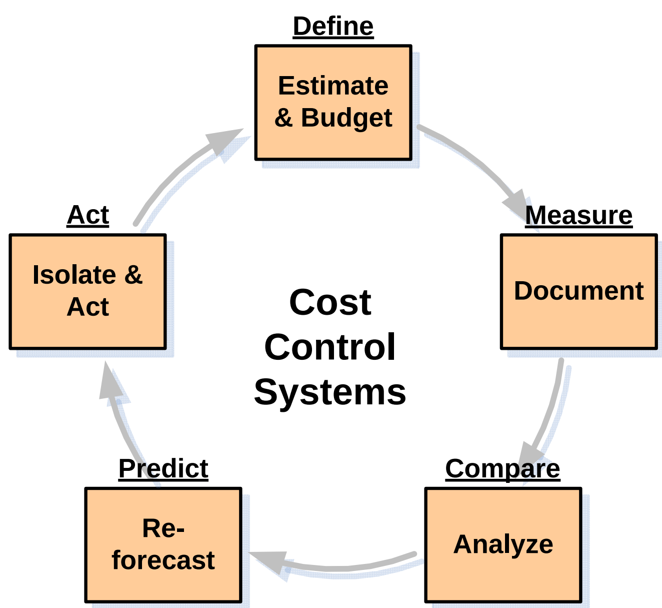

Figure 7: Cost Control Systems

Define: The first stage of cost control is to establish the optimum condition for cash flow on the project by inputting data such as planned earned values and budgeted cost for each month [Stevenson and Wilson 1989, Park et al. 2005]. These inputs create a level of expected accuracy and flexibility to uncertain factors such as time delay, cost overrun, and variation of cost [Park et al. 2005]. By the end of the *define* stage, there shall be clear guidelines for the cost control process, product, precision, and metrics to be used.

Measure: The second stage of cost control is to measure the actual costs though continuous recording, reporting, gathering, and accumulating project cost data [Stevens 1986, Stevenson and Wilson 1989]. The main variable in recording actual costs is the frequency with which it is performed; while data collection may be performed on routine, sufficient intervals, it is important to have the most pertinent, up-to-date information. Project accountants and those in charge of cost control shall have the same current knowledge to provide for the next stage of cost control.

Compare: Periodic comparisons between previous estimates and incremental costs form the basis for the *Compare* stage of cost control [Stevens 1986]. Budgeted costs and actual costs are weighed against each other to determine the current status of the project, quantifying any variation from the optimum (budgeted) values [Stevenson and Wilson 1989]. The frequency of measurements allows for realizing variations in cost information – transparency that is needed to make forecasts or predictions of the project's future [Peeples 1985]. How fast deviations are recognized are a product of how frequent measurements are made. In order to properly monitor and control sizable construction projects, a huge volume of information needs processing rapidly and accurately [Eldin 1989].

Predict: Data collected through cost progress monitoring systems, if current and accurate, provide a snapshot of the budgeted versus actual conditions. It is through the interpretation of this data that trends, patterns, and tendencies allow for predicting the path that the project is headed. Throughout the project, McMullan [1996] defines two objectives of forecasting: "1) to provide a forecast final cost for the project based on current status and trends, and 2) at the same, to highlight trends or potential budget deviations that require management control." Predicting the future and recognizing deviations that need attention prevent potential letdowns that cannot be fixed once money and time has been spent; "surprises" on projects can be avoided by forecasting with the same frequency that costs are measured and compared [McMullan 1996]. McMullan also provides a set of general rules for business cost forecasting:

1. A good forecast is more than a single number (a range).
2. Aggregate forecasts are more accurate.
3. The longer the forecast horizon, the less accurate.
4. Forecasts should not be used to the exclusion of known information.

Cost progress monitoring often results in actual values that vary from the budgeted values, resulting in amounts either above or below planned. Whichever the case, the value of this variation is a moving weight, which is distributed over the remaining duration of the item being controlled [Park et al. 2005]. An automatic redistribution of remaining cost for each item provides a rolling forecast of money to be earned over the time remaining to earn it [Park et al. 2005]. It is becoming more apparent that forecasts and cost control have a strong interrelationship with time control and schedule [Stevens 1986].

Act: Taking (or not taking) action is product of managing predictions and forecasts provided. Corrective action assures efficient operation and minimization of variation [Stevenson and Wilson 1989]. This stage of control is that which completes the cycle of the cyclic control system – acting to redefine the goals. Once the cost controller has sufficient information on current project status and projected project status, remedial actions are needed to control the cost system. Stevenson and Wilson [1989] offer the following process for the *Act* stage of cost control:

1. Isolate the deviation
2. Estimate the cost impact if not corrected
3. Identify and estimate alternative corrective action
4. Choose and implement corrective action
5. Monitor the correction

The process clearly shows the steps needed to close the cycle loop, redefining the cost control system and continue monitoring the costs of the corrected plan.

A Summary of Safety, Quality, and Cost Control Systems

Safety, quality and cost control systems have definitive stages for defining, measuring, comparing, predicting and acting. Table 2.1 summarizes the literature review for each of these control systems, broken down into the five stages. The literature review material presented in this chapter and the following figure provide valuable information on three of the four main construction control systems, which guide the development of the intellectual framework for the fourth construction control system, schedule control, in Chapter 4.

Table 1: Structure of Safety, Quality, and Cost Control Systems

STRUCTURE OF CONTROL SYSTEMS

	DEFINE	MEASURE	COMPARE	PREDICT	ACT
SAFETY CONTROL	• Spread out risk • Abide by regulations • Select metrics • Establish limits for cost (based on prevention and potential damages)	• Observation and recording • Immediate reporting of accidents • Inspection • Maintenance • Hazard analysis	• Communication between workers & supervisors • Assess the climate • Recognizing high-risk atmospheres • Seek feedback • Hazard logs and safety reports	• Preventative action, followed by reaction • Consider accident histories • Near misses • Heavy reliance on planning	• Manage situation to avoid injuries and accidents • Evaluate safety performance • Adjustments for desired goals • Root cause analysis
QUALITY CONTROL	• Determine metrics • Establish standards Determine acceptability • Establish limits • Sample size • Sample frequency	• Acceptance inspection • Data collection	• Pass judgment on acceptability • Validation (sound, logical) and Verification (correct) • Interpret control charts	• Project cycles • Gradual changes • Trends • Fluctuations	• Eliminate defective products • Diagnose assignable causes • Corrections
COST CONTROL	• Baseline estimate • Budget • Establish optimum conditions • Project details: process, product, precision, metrics	• Monitor actual earning and spending • Data collection • Frequency of measurement	• Variance analysis • Transparency of progress • Recognize costs' interrelationship with time • Isolate deviation	• Forecast planned monthly earned values with results of variance analysis • Highlight trends and potential deviations • Re-forecasting	• Corrective action • Budget revisions • Maximize profit while ensuring efficiency • Control risk • Minimize detrimental variation

Schedule Control Framework

The second type of cyclic control system, which comprises the first major objective of this research, is the schedule control system. The objective is to develop the intellectual framework for "schedule control", done by applying what has been learned in the three previous control systems. Both of the absolute control systems, safety and quality, as well as the cyclic control system, cost, have components in each stage that are standardized and applied to schedule control.

What is needed for schedule control is a clear understanding of all five stages that are *define, measure, compare, predict,* and *act.* Existing literature contains an abundance of pertinent literature on the first three stages, comprising progress monitoring systems, but the goal is to further develop what is needed to predict and act in a schedule environment. The following sections borrow concepts and ideas from safety, quality, and cost control systems to expand the intellectual knowledge base for "schedule control."

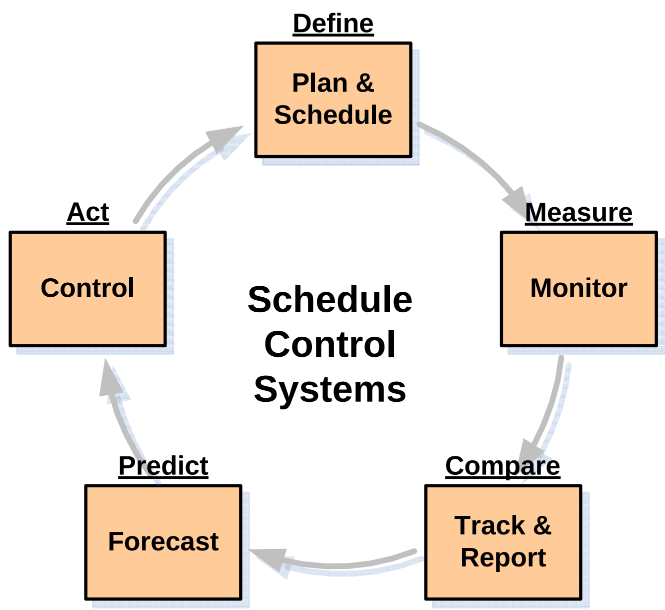

Figure 8: Schedule Control Systems

<u>Plan and Schedule Optimum Outcomes</u>

Absolute and cyclic control systems differ in that the latter involve regularly scheduled feedback to the *define* stage. While schedule control is categorized as a cyclic control system, this does not dismiss the strong presence of absolute control system characteristics within schedule control. The most prominent feature of absolute control systems incorporated in schedule control is the emphasis on the *define* stage.

Project planning involves setting the project scope and determining the means and methods. Upon developing a plan of attack for how construction will take place, quantities of work and rates of production add a time component to the plan, which are then used to build a project schedule. A reasonable and accurate schedule is approved and becomes the schedule of record. This scheduled work serves as a datum or baseline of the actual work as it takes place. Examples of standards for measurement include CPM schedules, control budgets, procurement schedules, quality control specifications, and construction working drawings [Paulson 1976]. As in absolute control systems, the initial schedule, the "baseline", establishes the planned conditions – a historic reference of where you want to be. It is at this time that the initial long-term, medium-term (look-ahead), and short-term plans are developed. Because schedule control is a closed-loop system, all three of these plans (and schedules) may be revised in the future.

Built into the schedule are proactive metrics, designed to provide feedback. Reliable data is needed for reliable feedback, to make reliable predictions. Metrics measure the most relevant project data to reveal quantities and production rates, used to measure the performance of the schedule. Performance metrics are defined with a level of acceptability – establishing a standard for what is deemed "acceptable". In CPM scheduling, a safe operating range for performance metrics represents this. The range denotes the expected accuracy of schedule performance. By the end of the *define* stage, there shall be clear guidelines for the schedule control process, product, precision, and metrics to be used.

Monitor Progress to Determine Current State

While the *define* stage outlines where you want to be, the *measure* stage determines where you are. Actual schedule progress is recorded through continuous observation, recording, reporting, gathering, and accumulating project schedule data. Data gathered coincides with the data outlined for measurement in the project *define* stage. These quantities, production rates, and other figures serve as historical project data, for later use in making forecasts based on actual project performance. Schedule performance is used to produce a current and up-to-date schedule, representative of the actual sequence of construction.

Construction is in a constant stage of change, and the updated project schedule represents this through careful and frequent observation of site activities. The frequency with which data is recorded directly correlates with the most precise rates and trends in performance. While data is recorded on a near instantaneous basis through construction inspection, ideally, the project schedule is updated the same. However often the updates, the most pertinent, up-to-date information is most useful when making comparisons between the planned and actual project performance.

Track and Report Current State and Variation

The *compare* stage completes the progress monitoring sequence through comparing the planned schedule with actual schedule performance, quantifying the deviation of where you are with respect to where you wanted to be. A "snapshot" of the actual schedule at a discreet point in time serves as the most defined approach for comparison.

While the frequency of measuring schedule performance is defined in the previous section, the frequency of comparison is considered separate. Measurements tell what is actually happening, yet comparisons tell if that *should* be happening. As with data collection, schedule comparisons are done at regular intervals, to make the construction performance as transparent as possible. The frequency with which comparisons are made determines how aware project parties are of any possible schedule deviations.

Comparing hard data is not the only means for determining project status; also beneficial is seeking feedback from individuals involved in the project (supervisors, project managers, foremen, workers) by arranging scheduled meetings and interviews. Communication throughout project parties aims to ensure that all pertinent schedule performance information is put to best use.

Updated project performance evaluations provide feedback on how accurate the “actual” is to the “planned”. The current status allows for quantifying variation from the optimum schedule set in the baseline. Any variation in schedule performance metrics is a call for attention. Whether or not there is variation, the “snapshot” comparisons are used in the following stage to make predictions of the future, based on the past and present.

Predict Possible Future States

A *prediction* is synonymous with a *forecast*, which serves as a necessary step in bridging the gap between monitoring progress, and taking action. According to Barrie and Paulson [1984], a *forecast* defined: “based on the best knowledge at hand, what is expected to happen to the project and its elements in the future.” Forecasts require reliable progress measurement in order to project the future, for you cannot initiate action without valid predictions. Improving the validity of projections provides strong grounds for improving actions.

There are two objectives of schedule forecasting: 1) to determine a project completion date based on current status and trends, and 2) at the same time, highlight trends or schedule deviations that require management control [McMullan 1996]. In other words, the goal is to ensure the project is going to finish on time, and to recognize any sign that it might not happen. The following rules of forecasting by McMullan [1996] are presented in the cost control system, yet are also highly applicable to schedule control:

1. Quality forecasts provide best and worst case scenarios.
2. Aggregate forecasts best represent project progress.
3. Forecasts lose accuracy with increased project duration.
4. Forecasts shall consider all known project information.

The *define* stage notes that reliable predictions are based on reliable data. Assuming project data is current and correct, forecasts are crucial for recognizing if the schedule may slip. The frequency of forecasts should be performed with the frequency of comparisons, as with the frequency of measurements – ideally, as often and current as possible. Doing so avoids surprises in status and trends that result from lagging behind on updates.

Forecasting data is often performed by extrapolation – taking the production rate to date, lining it up with where you are, and superimposing that rate on the future. This interpretation of data produces trends, patterns, and tendencies that identify where the project is heading. Variations between planned and actual result in the value of this variation being a moving weight, distributed over the remaining duration of that activity or the project.

Another important predicting tool is that which takes place during the planning stage. Often, there are signs of project distress before the project gets started. A poorly developed plan or incomprehensive understandings of the project may be early indications that the project will be in future distress. Such an early warning sign accelerates through the control system and requires action immediately.

Act to Achieve a Desired Future State

The final stage of schedule control systems is to act to achieve a desired future state. Acting is a product of predicting, which relies on reliable forecasts and warning signs to produce actionable information in a format that allows action to be taken, if needed, in order to end up where you want to be. The objective of predictions is to allow ample time for adjustments to be made in order to complete the project on time. Unfavorable trends in schedule performance metrics and other signs of project distress are the “smoke alarms” in schedule control that call for attention and require investigating if all is okay or something is wrong on the project.

To investigate the situation that may lead to project distress, call a “time-out” and perform a root cause analysis – a determination of what the root cause of the problem is, in an attempt to correct or eliminate it, as opposed to merely addressing the immediately obvious symptoms. The investigation determines if any metrics have crossed their predefined boundaries for acceptability, as well as identifies any other possible causes for the mishap. Failing to take action on a sign of distress may lead to the untimely completion of the project. Once sufficient information is known on the project status, remedial corrective action needs to be taken. As described by Stevenson and Wilson [1989], the process for acting in cost control is applied here for schedule control:

1. Isolate the conflict
2. Determine the schedule impact if not corrected
3. Develop corrective actions
4. Do nothing or implement corrective action
5. Evaluate action taken

The schedule conflict is isolated and quantified, remedial action identified and implemented, and the correction monitored. This process closes the cycle of the control system – reassessing, rescheduling, and redefining. The conflict is part of the new definition that is now monitored.

Table 2 is a summary of the intellectual framework for schedule control, as well as the three control systems used to develop the framework – safety control, quality control, and cost control. For each control system, the five control stages of *define*, *measure*, *compare*, *predict*, and *act* are defined.

Table 2: Structure of Control Systems

STRUCTURE OF CONTROL SYSTEMS

	DEFINE	MEASURE	COMPARE	PREDICT	ACT
SAFETY CONTROL	• Spread out risk • Abide by regulations • Select metrics • Establish limits for cost (based on prevention and potential damages)	• Observation and recording • Immediate reporting of accidents • Inspection • Maintenance • Hazard analysis	• Communication between workers & supervisors • Assess the climate • Recognizing high-risk atmospheres • Seek feedback • Hazard logs and safety reports	• Preventative action, followed by reaction • Consider accident histories • Near misses • Heavy reliance on planning	• Manage situation to avoid injuries and accidents • Evaluate safety performance • Adjustments for desired goals • Root cause analysis
QUALITY CONTROL	• Determine metrics • Establish standards Determine acceptability • Establish limits • Sample size • Sample frequency	• Acceptance inspection • Data collection	• Pass judgment on acceptability • Validation (sound, logical) and Verification (correct) • Interpret control charts	• Project cycles • Gradual changes • Trends • Fluctuations	• Eliminate defective products • Diagnose assignable causes • Corrections
COST CONTROL	• Baseline estimate • Budget • Establish optimum conditions • Project details: process, product, precision, metrics	• Monitor actual earning and spending • Data collection • Frequency of measurement	• Variance analysis • Transparency of progress • Recognize costs' interrelationship with time • Isolate deviation	• Forecast planned monthly earned values with results of variance analysis • Highlight trends and potential deviations • Re-forecasting	• Corrective action • Budget revisions • Maximize profit while ensuring efficiency • Control risk • Minimize detrimental variation
SCHEDULE CONTROL	Plan & Schedule • Project plan • Means and methods • Scope • Quantities • Rate of production • Progress metrics • Reasonable and accurate schedule (schedule of record) • Long, medium, short-term planning	Monitor • Observe construction • Record, gather, report, accumulate project data • Represent actual progress • Current and up-to-date schedule	Track & Report • Actual versus planned • Quantify deviation • Feedback and communication • Performance transparency • Snapshot at discreet point in time • Determines current status	Forecast • Valid predictions needed to initiate action • Find completion date • Highlight trends or deviations • Best and worst case scenarios • Aggregate forecasts best represent progress • Forecasts lose accuracy with increased project duration • Avoid surprises • Distribute variations • Reliance on planning	Control • Recognize "smoke alarms" • Allow time for adjustments • "Time-out", root cause analysis • Isolate the conflict • Determine impact • Develop corrective actions • Do nothing or implement corrective action • Evaluate action taken

Conclusion

Construction control systems should be developed around an intellectual framework of the desired system functions. The systems provide a means to monitor progress, predict future status, and act to influence the outcome. Functions fundamental can be used to describe control systems and are: *define, measure, compare, predict*, and *act*. It is the ability to predict a likely future project status that allows appropriate action to be taken to control the project outcome. Control systems can be categorized as either absolute or cyclic. Absolute systems are appropriate for use when the desired result does not vary as a result of performance. When it is necessary to redefine the desired result due to actual performance, it is appropriate to apply cyclic systems.

Schedule control systems are cyclic systems that serve to monitor and predict progress in terms of the construction schedule so that appropriate actions may be taken to promote on-time completion. The functions fundamental to schedule control are described as: *plan and schedule, monitor, track and report, forecast,* and *control.* The intellectual framework for schedule control developed bridges the gap between the well established progress monitoring techniques and the necessary forecasting function to provide a means for initiating appropriate action.

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