FACTORS AFFECTING WORK FLOW RELIABILITY --A CASE STUDY

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ABSTRACT

Low work flow reliability is a major contributor to the construction industry's dismal productivity record. The purposes of this paper are to identify the factors affecting work flow reliability, learn from failures of completing work plans, and recommend strategies to improve work flow reliability in order to improve productivity for construction projects. We collected production data of 592 working days in 12 working areas from a pipe installation project which implemented the Last Planner System. The data included the number of daily planned tasks, daily planned tasks completed, daily tasks completed non-planned, daily tasks uncompleted, daily planned man-days and completed man-days. Root causes of uncompleted tasks were also documented. Based on the data collected, correlation analysis was conducted to study the factors affecting work flow reliability. We found that commitment plan, prerequisite work, material and weather are the top four factors affecting work flow reliability. Strategies on how to effectively improve work flow reliability are also recommended. The findings can help project managers focus on the important factors causing work flow variation in their work plan and improve labor productivity. The results can also help consulting companies pinpoint root causes and responsibility for productivity losses in claims.

KEY WORDS

Work flow, work flow reliability, last planner system, lean construction, productivity.

INTRODUCTION

Construction projects are typically composed of complex networks of interrelated activities. Work flow is the movement of information and materials through the networks of production units (Ballard 1999; Ballard and Howell 1994). Improving work flow reliability is important for the productivity of linked production units, and consequently for project cost and duration. Work flow may be impacted by a number of factors, which may reduce work flow reliability and negatively affect productivity performance. Therefore, it becomes imperative on the part of the project management

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to understand the impact such factors may have on the workflow and take measures to mitigate the impact in order to achieve a smooth workflow.

A recent research (Liu and Ballard, 2008) has proved the significant correlation between work flow reliability and labor productivity for construction projects. An in-depth on what are the root causes of low work flow reliability is needed. This research studied failures of work plans and analyze them to actionable causes based on a comprehensive set of production data of a pipe installation project to fill this gap.

LITERATURE REVIEW

Construction projects are composted of numerous interrelated tasks. A continuously updated reliable work plan is essential to co-ordinate the various aspects of the tasks and maintain high productivity. Last Planner System (LPS) has been used effectively to improve work flow reliability for construction projects. LPS uses PPC (Percent Plan Completed) to measure work flow reliability (Ballard 2000). PPC is the number of planned tasks completed divided by the total number of planned tasks.

A number of factors can impact work flow reliability. Material is one of the key factors. If the material delivery is delayed then the schedule task time or the dimension of material is wrong, workers have to be idle and tasks could not be completed on time. This hampers the work to be performed as well as impacts the flow of work downstream (Arbulu et al., 2005). It has also been recognized that reducing the variability in material deliveries reduces the backlog of the crew, who in turn can work without disruption due to waiting for material and hence, achieve a smooth workflow. With a more certain in-flow of work, more optimum sequences can be selected and better matching of labor resources can be done (Ballard and Howell, 1994).

The lack of prerequisites is another important factor affecting the workflow. Koskela et al (2002) identified the issue of the lack of prerequisites in terms of predecessor tasks (or other inputs) which may not necessarily exist. It leads to the situation in which a major share of tasks has not been commenced, chronically lacking one or more of their inputs.

Adverse weather conditions may also negatively impact work flow reliability. These conditions may result in temporary disruption of the work or may be severe enough to damage the work already performed. Both the cases leads to a non-uniform work flow and the latter case may result in a complex situation of claims, re-work, etc (Ballard, 1999). It has been shown that rains on projects have resulted in the craftsmen being sent home, leading to complete disruption of the workflow. Re-work due adverse weather conditions has also been reported on a number of construction projects (Thomas et al, 2003).

Other factors such as resource, safety, and equipment can also impact work flow reliability. This paper studies how those factors and their relationship with PPC and productivity in a case study.

PROJECT DESCRIPTION

A case study was conducted to understand how factors affect work flow reliability. The case study project involved the construction of pipe for an oil refinery plant in mid west in U.S. The construction began in March 2005 and finished in May 2006. This study covers 592 workdays in 12 working areas. The activity being monitored was pipe installation, which includes four standard tasks: shake-out (identify pieces of pipe to be installed), erect, weld, and trim. The range of number of tasks on working days is from 2 to 165. The online production database keeps a daily record on the number of planned tasks, completed tasks as planned, completed tasks not planned, PPC, manhours planned, and manhours completed. The root causes why a task is not completed as planned are also recorded. The causes are divided into seven categories: commitment plan, weather, prerequisite work, resource, materials, equipment, and safety.

The crews were all composed of union journeymen. Crew size varied between 8 to 12 workers each week depending on the amount of available work in each area. Basically, each foreman and a largely stable crew worked on the same working area until that work was completed. According to the project manager, crowding was not an issue for any of the 12 working areas, all of which were outdoors. On the other hand, weather was a significant factor affecting work progress since the project was conducted in winter in Midwest. At the end of the project, welders were tested before being placed in production. The contractor had a reject rate below 3%.

DATA ANAYLSIS

Four statistical analyses were conducted to find out 1) the frequency of root cause occurrences, 2) how root causes are related with each other, 3) how each root cause relates with work flow reliability which is measured by PPC, and 4) how each root cause relates with productivity.

1. ROOT CAUSE FREQUENCY ANALYSIS:

The root causes of tasks not completed as planned were divided into seven categories: commitment plan, material, prerequisite work, weather, resource, safety, and Equipment. The meaning of each category is explained as below:

1. Commitment plan -- a task could not be completed as planned because 1) over commitment: Last Planner over estimated the amount of task could be completed in a daily work plan, 2) a bad plan: some prerequisites or crew/equipment/space interfere was forgotten to consider when the plan was made, or 3) the commitment plan was not followed in execution. An erect task (task ID: 18079) in working area A was planned to be done on January 9, 2006. This task needs 0.33 manhour. While all the material, equipment, prerequisite work, and resource were ready, the task could not be completed on January 9, 2006 because the crew did not have enough time to get it done. Three trim tasks, 0.25 manhour each, could not be

completed that day for the same reasons. Those 4 tasks were replanned and completed on January 10, 2006.

Another type of commitment plan problems is that some prerequisites or interference were not considered in the plan making process. Five tasks on January 18, 2009 in working area B were not completed because scaffold was not identified as a prerequisite when the plan was made. Five working hours were wasted due to this commitment plan problem.

Two trim tasks on December 2, 2005 in working area B could not be completed because workers were redirected to support compressor area equipment setting. Five tasks on October 4, 2005 in working area K were not completed because workers were redirected to accommodate civil needs for fireproofing pour.

2. Material -- a task could not be completed because material was not available or the material size or type was wrong. While late delivery was relatively easier to be pointed out, having wrong size or type of materials was harder to identify until the last minute when the material needed to be installed. Having materials not meeting the requirement is more common and usually takes longer to double check the size or type and make corrections. For example, an erect task (task ID: 76929) on Feburary 6, 2006 in area B could not be completed on time because the drawing dimensions of the pump lube oil connections do not match actual dimensions. The connection had to be refabricated. The task was rescheduled and completed on February 17th. Four tasks on December 1, 2005 in working area B could not be completed because the spool was not fitting up properly and they had to investigate why before any corrections can be made. The tasks were completed on December 7 and 20.

3. Prerequisite work – a task could not be completed because prerequisite work was not ready. For example, a weld task (task ID 37365) in working area B on February 8, 2009 was not completed because scaffold builders did not complete installing scaffold on time. The task was replanned and completed on February 9, 2009. An erect task (task ID 38018) in working area B on February 6, 2009 was not completed because a check valve was not heat treated. Three other tasks on the same day by the same crew could not be completed due to the same reason. Totally 4 manhours were wasted because valves were not heat treated ahead of time. Those tasks were replanned and completed on February 8.

4. Weather – a task could not be completed due to weather condition (heavy rain, strong wind, or very low temperature). For example, a weld task (ID 36251) in working area B takes 2 workers working together for 0.75 hours. It was planned to be completed on February 3, 2006. It could not be completed on February 3 because the crew had to leave early when it rained. Two other tasks (trim, 0.25 manhour each) could not be completed on that day either. The 3 tasks were replanned and completed on February 6, 2006. No task on January 17, 2006 in working area B was completed due to heavy rain. The eleven tasks were completed on January 18, 19, and 23.

5. Resource – tasks could not be completed because workers were not available (absence or leaving early). For example, 6 tasks on February 14, 2006 were not completed because welder did not show up on that day.

6. Safety – tasks could not be completed because 1) workers need to attend safety training or meetings, and 2) dangerous working situation may be caused by very low temperature or strong wind.

7. Equipment – tasks could not be completed because crane was not available to lift pipes.

Figure 1 summarizes root causes of not completing tasks for 592 working days in 12 working areas. The occurrence of commitment plan problem is the highest, 1085. The occurrences of root causes which caused tasks not completed as planned are 329, 322, 304, 118, 47, and 28 respectively for material, prerequisite work not ready, weather, resource, safety training, and equipment.

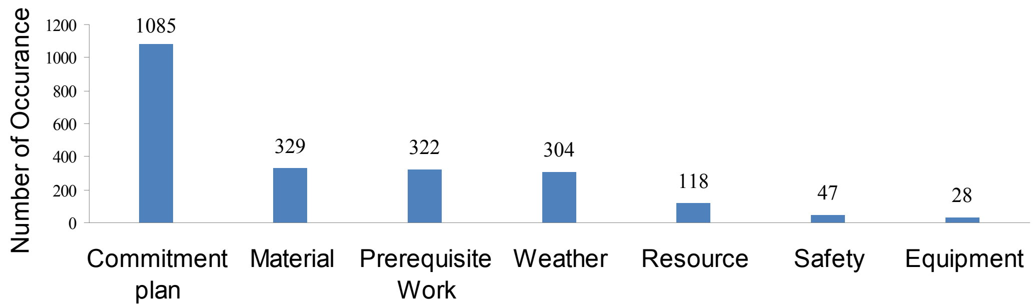

Figure 1: Summary of the Root Causes for 12 Working Areas

Under commitment plan category, 10 out of 12 working areas have had 3 types of problems: 1) over commitment, 2) a bad plan, and 3) not following the plan. The breakdown is shown in Figure 2. Figure 2 shows that bad plan counts the largest portion in almost all working areas. The reasons could be 1) this it the first time the crew using Last Planner System, 2) missing considering some interference in crews, space, and equipment usage in making the plan. Emphasize communication in the Phase Schedule and First Run study can reduce this type of problem. Over commitment is the second largest problem in most working areas.

A statistic correlation analysis was conducted between the ratio of over commitment over total commitment plan and the ratio of bad plan over total commitment plan on the 12 working areas. It was found that they are significantly negatively correlated (correlation coefficient is -0.844 at 0.01 level). The reason may be when there was a bad plan for a task was made, a crew could not do the task as planned and had time to work on other tasks. Therefore, the chances of over commitment got lower. It was also found that the more total tasks planned for a working area, the more tasks could not be completed due to commitment plan problems (correlation coefficient is 0.588 at 0.01 level). With more tasks needed to be done, the interference between crews about space and equipment can get more complicated. Therefore, it is more likely to have commitment plan problems.

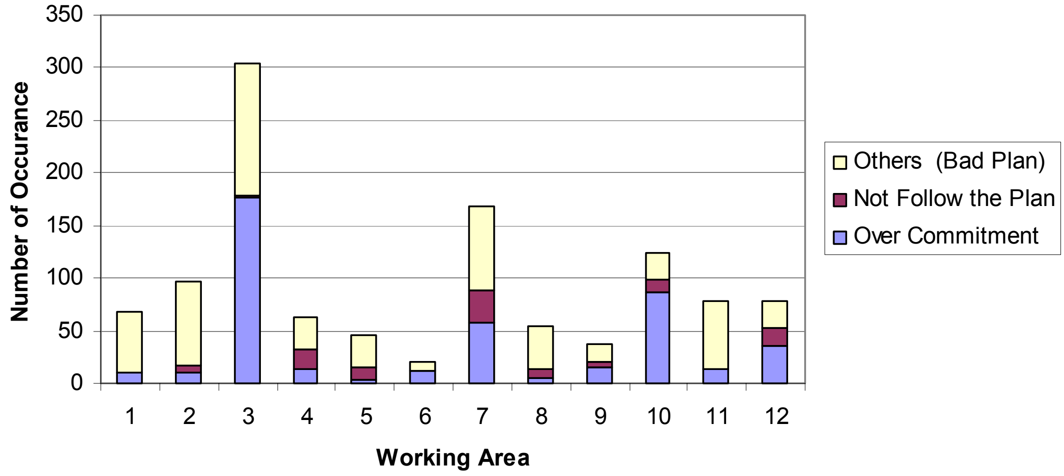

Figure 2: Breakdown of Three Types of Problems in Commitment Plan Root Cause

Breakdown of root causes in material are shown in Figure 3. It shows that while late delivery or missing material problem exists in 9 out of 12 working areas, the most common problem is that material type or size was wrong. 276 of 329 material root causes are related to material size or type problem, which counts 84%. Crews found that the material could not fit in when they need to install it. Sometimes drawing dimension of a pipe spool did not match actual dimension. Sometimes a spring can was at the full adjustment, but was still 1 inch short. Some on-site modifications were adequate. Some material needed to be returned to fabricator for adjustment, which took more than two weeks.

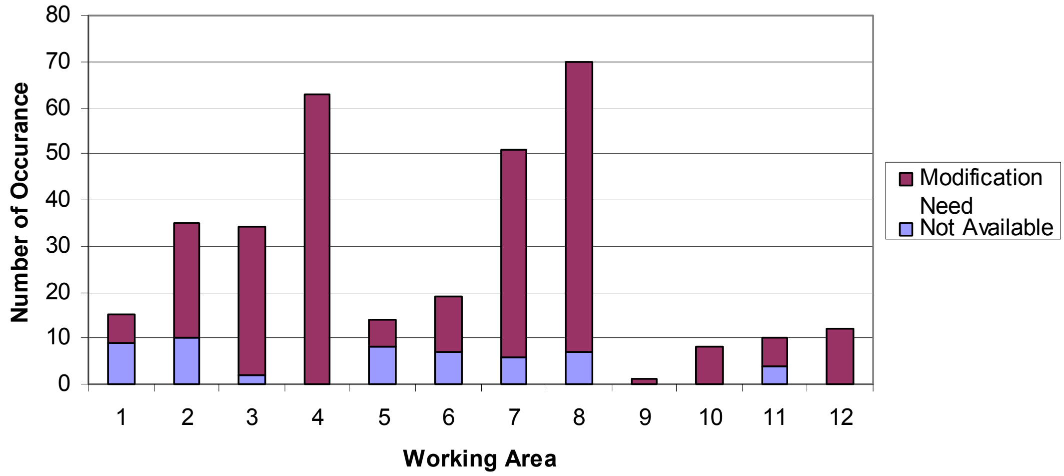

Figure 3: Breakdown of Two Types of Problems in Material Root Cause

2. CORRELATION ANALYSIS AMONG THE ROOT CAUSES

A correlation coefficient test was conducted among the daily occurrence of the root causes in the 592 working days. Correlation coefficient is a measure of the degree of linear association between two variables. The higher the correlation coefficient value, the stronger correlation exists between two variables. Statistical significance level is also tested. Two variables significantly correlated at 0.05 level means there is less than 5% chance of declaring a correlation significant when the population correlation is actually zero.

Two significant correlations were found: 1) equipment and prerequisite work are significantly correlated. The correlation coefficient is 0.150 at 0.05 significant level, and 2) equipment and material are significantly correlated. The correlation coefficient is 0.167 at 0.05 significant level. The results show that two pairs of root causes (equipment and prerequisite work, equipment and material) are significantly correlated. The more root causes associated with equipment occur, the more prerequisite work and material problems happen. But the correlations are not very strong. No other significant correlation among other root causes is observed.

3. THE RELATIONSHIP BETWEEN PPC AND ROOT CAUSE

The correlation coefficient between PPC and each root cause is tested. The results are shown in Table 1. Every root cause is significantly negatively correlated with PPC. Commitment plan and PPC have the largest correlation and coefficient value, which means the more commitment plan problems, the lower the PPC. In order to improve PPC, it is important to reduce the occurrences of the root causes.

4. THE RELATIONSHIP BETWEEN PRODUCTIVITY AND ROOT CAUSE

Productivity is measured by:

$$\text{Productivity} = \frac{\text{Completed Man-days}}{\text{Total Planned Man-days}} \qquad \text{Eq. 1.}$$

Table 1: Analysis on How Root Causes Affect PPC and Productivity

	CP	W	PW	R	M	E	S
PPC	-0.423**	-0.365**	-0.216**	-0.083*	-0.228**	-0.118**	-0.117**
Productivity	-0.387**	-0.344**	-0.201**	-0.072*	-0.217**	-0.110**	-0.123**

CP= Commitment Plan, W= Weather, PW=Prerequisite Work, R= Resource, M=Materials, E=Equipment, S=Safety
**significant level at 0.01, * significant level at 0.05

The correlation coefficient analysis between productivity and root causes is listed in Table 1. The results show that each root cause has significantly negative impact on productivity. In order to improve productivity, it is important to reduce the root causes.

CONCLUSION

This study found that commitment plan, material, prerequisite work, and weather are the top four root causes of tasks not completed as plan in the pipe installation project. Under commitment plan category, there are three types of problems: 1) over commitment, 2) not following plan in execution, and 3) a bad plan. It was found that over commitment and bad plans are the main reasons for reduced work flow reliability in most working areas. Under material category, while late delivery of material was easy to identify, wrong size or type of material was not discovered until the scheduled installation. That is actually the major reason of low work flow reliability. Making adjustment of material usually takes a long period of time, which can significantly disrupt work plan and reduce productivity.

It is found that all seven root causes are significantly negative correlated with PPC and productivity. The seven root causes are commitment plan, material, prerequisite work, weather, equipment, resources, and safety.

The correlation among root causes is not strong. Only two pairs of factors, equipment and prerequisite work, equipment and material are significantly correlated at the 0.05 level.

In order to improve work flow reliability and productivity, it is recommended that project managers and foremen focus on those root causes, especially commitment plan, material, and prerequisite work. Making plans based on realistic estimation of productivity, following plans in execution, and consistently conducting First Run Study can help reduce commitment plan type problems. Those strategies are hard to follow when management is under the pressure of tight schedule, which is very often the case in reality. Support from the organization leadership and empowerment of field management are important to make it happen.

It is also critical to enhance effective communication and coordination at the field management level as well as at the external level among owners, designers, and fabricators to reduce material problem and lead time to resolve the problem. It is usually easier to identify the problem of missing or delayed delivery of material than to find out the type or size of material is wrong. The later one is significantly more common and it takes much longer to have the problem resolved. Showing all related parties how pervasive the problem is and how much wastes are caused can help people to realize it is crucial to take action now.

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