Creating a Model to Evaluate Whether the Cost of Improved Temporary Lighting is Off-set by Increased Productivity

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The goal of construction companies is to maximize the utilization of all resources dedicated to the construction process. Labor is the largest single resource on most jobsites and the utilization of labor is measured by productivity. The decision about allocating more resources to labor is based on whether the increased resource, such as improved tools and equipment, improves productivity more that the increased cost of the resource. Temporary lighting on job sites requires resources. Recent studies have shown that many projects have large areas with inadequate lighting. The question posed in this paper is how a project manager would evaluate whether the cost of improved temporary lighting is offset by increased productivity. Forecasting productivity on specific projects is difficult due to the number of variables. The problem is addressed by creating a model which uses certain assumptions and limiting variables in order to calculate a minimum percent of increased productivity that must be met or exceeded to justify additional expenses. The result uses different building types and different location factors to give an accurate base line and process for the project manager to evaluate an individual project. The study does not attempt to forecast the change in productivity, but to give the project manager a tool to make an informed decision.

Keywords: productivity, temporary lighting, resource allocation, labor, forecasting

Introduction

Construction workers rely on temporary job site lighting to complete tasks on the site. With no temporary lighting, construction tasks would be difficult or impossible to complete. As lighting levels increase from zero foot candles, it stands to reason that productivity of workers would increase. In the finished building, proper lighting levels are designed and specified by electrical engineers. During construction, temporary lighting inside the building is often all a construction worker will have to complete an assigned task. If this lighting is inappropriate for the task assigned, output of that employee may suffer. Previous studies by Farrow and Smith (2007) have attempted to measure productivity in a lab environment using student workers. The authors have considered other studies that would measure productivity on jobsites under a variety of lighting conditions. However, such measures are difficult. Tasks are always changing and progressing, and levels of temporary lighting vary throughout the building. The key variables that would impact productivity measures are constantly changing. This study proposes the use of a quantitative model to quantify the amount of increased productivity necessary to offset the cost of higher levels of temporary lighting.

Background

Labor is the most costly input in many work environments, whether the work is in an office, factory, or construction site. Employers are constantly looking at ways to make workers more productive. There are many factors that influence productivity on a construction site. Four of the most obvious are weather, change orders, overtime, and working conditions.

The impact of weather was studied by Society of American Military Engineers. The study goes into a number of variables, including temperature, wind, snow, and the activity performed to determine the impact on productivity.

The result of the study was that winter weather conditions can decrease productivity by more than 50% (Abele 1986).

Change orders are often overlooked as impacting productivity, but there are a number of factors that relate to change orders (McDonald and Zack, 2004). These factors can decrease productivity by 15-25% on post installation change orders (Means 2008).

Another influence on productivity is overtime, which is also addressed in RS Means. Working ten hours per day six days per week will drop productivity to 80% by the fourth week. The average productivity over four weeks is 87% (Means 2008).

The impact of working conditions is a broad area, dealing with issues from project layout to availability of power. Small construction sites, adjacent properties, and high rise construction all have different working conditions that impact the construction process on a job.

Each of the four factors can have a significant impact on productivity (McDonald and Zack, 2004). These examples are brought out to show some of the many factors that impact productivity and that the scope of those factors is not insignificant. Understanding the scope of factors affecting productivity provides a basis for examining the impact of Temporary Lighting in productivity.

Temporary Lighting is one of the many factors included in "working conditions." Adequate lighting is required for workers to complete their activities. Adequate lighting is a vague description, and for the purposes of this paper, the standard used will be the minimum OSHA standard. Because temporary lighting is also a safety issue, OSHA has addressed the minimum level of lighting for construction areas. OSHA standard 29 CFR 1929.56 is entitled "Illumination", and 29 CFR 1926.56(a).Table A-1 requires a minimum of 5 foot candles (FC) in "general construction areas" (OSHA, 2009). As a reference point, a department store will have an average of 52 FC of illumination. Little research exists on whether or not OSHA standards for temporary lighting are "too much" or "too little". For the lack of other more established guidelines, the OSHA minimum requirement was used in this study.

The impact of temporary lighting on productivity is the focus of this paper because previous studies have shown that there are a significant number of construction sites that have less than 5 FC of illumination on the project. One study of 30 buildings under construction showed that 50% of the interior building areas did not meet the minimum OSHA standard on a summer day with full sunlight (Smith and Azhar 2006). A project manager may be able to conclude that an area with less than 5 FC of illumination may result in lower productivity related to visual performance and fatigue (Juslén and Tenner, 2005; Lechner 2001).

The link between the amount and quality of lighting and the productivity of workers has long been suspected. There have been several attempts to quantify the relationship. The Hawthorne Experiments are the most noted studies, but there have been several studies in recent years on the impact of lighting as well as other work aspects.

The Hawthorne Experiments from 1924-1927 sought to relate the task lighting to workers' productivity at the Western Electric Company. Although the experiments did not show that there was a conclusive relationship, the experiments did show the existence of what became known as the Hawthorne Effect. The Hawthorn Effect relates to a research situation where the subject of the research, in this case the workers at the Western Electric Company, change their behavior because they know they are being watched (Ballantyne, 2000).

Another set of studies at the Western Electric Company from 1928 to 1933 by Elton Mayo investigated some other factors influencing productivity. The core of the results was that productivity was linked to psychological influences (Mayo, 1949).

More recently, the Light Right Consortium released the results of a field simulation that indicated a causal relationship between lighting quality and worker satisfaction and motivation (Dilouie 2003). Although the simulation was conducted in an office environment, the relationship between lighting environment and worker motivation could possibly be applied to the construction process.

The Juslen Study, published in 2006, looked at lighting control in a manufacturing environment. The result showed that there was a 4.5% increase in productivity when workers could control their lighting, Though the Juslen researches acknowledge lighting impacted visual performance, they also noted, "Not so obvious, but maybe just as important, are the psychological effects of light and lighting. The fact itself of being provided with a new lighting installation might give the employee the message that he and his job are important" (Juslén and Tenner; 2005).

The studies noted above were conducted in a manufacturing environment. The variables can be closely controlled, with the same tasks repeated in the same environment numerous times to provide accurate data. Construction activities are more difficult to quantify to productivity from one project to another because of the multitude of variables. McDonald and Zack, in "Estimating Lost Labor Productivity in Construction Claims" list twenty five factors that impact construction productivity (McDonald and Zack, 2004).

Since the measurement of productivity on a specific project difficult to measure in the field and virtually impossible to forecast, a relationship between manufacturing and construction would help give a basis for a study. A recent study of productivity for on-site and off-site construction process showed that there has been a 100% increase in off-site productivity, while on-site activities have seen no improvement (Eastman and Sacks, 2008).

While it is impossible to recreate the manufacturing environment on the construction site, some aspects of the manufacturing process that impact productivity like temporary lighting can be implemented. The previously mentioned studies have also shown that there is a productivity benefit with appropriate lighting levels. The installation and maintenance of temporary lighting on a job site have a cost related to it. This cost can be calculated given a defined scope of work for the temporary lighting. The value of the temporary lighting is based on the increase in productivity as well as other factors, such as safety and quality control. Safety and quality control are difficult to quantify. Decisions are often more subjective than objective, but a baseline gives the project manager a starting point for the decision process. This paper will address a proposed baseline calculation to allow an initial evaluation of the cost of the temporary lighting and the anticipated increase in productivity, safety and quality management.

Methodology

The goal of the study is to quantify the amount of increased productivity that is necessary to offset the cost of the minimum standard of temporary lighting. The construction process does not allow the measuring of changes in productivity on one particular project due to the number of variables. Since it is not practical to isolate one variable in the construction process, a model was designed that allows a contractor to use two factors in a model-the type of building and the location of the project. Then, the increased productivity is derived that is required to offset the cost of the temporary lighting. The model uses certain assumptions to objectively derive the minimum increase in productivity required. The contractor will subjectively decide if the percentage increase is realistic and if other factors impact the decision. The results are expressed as a percentage increase in productivity.

The activities that would be most impacted by the quality of the temporary lighting are the mechanical, electrical, and plumbing (MEP). These trades often represent a substantial construction cost and occur after the building is enclosed and at least some interior walls are installed. Such conditions essentially provide the "darkest" conditions present inside the building from start of construction to occupancy. Thus, the MEP costs are the only costs that will be used in the calculations, although other trades will benefit at some level. No attempt to quantify these numbers was made.

The cost numbers were derived from RS Means Building Construction Cost Data, 66th Annual Edition, 2008. The square foot costs section uses information derived from approximately 11,200 projects. The projects are from throughout the Unites States and have a broad range of individual costs due to location and individual owner requirements. One column is marked ¼ and means that 25% of the projects were below the Median cost. The center column is the median cost, and the third column is ¾, which indicates that 75% of the projects were under the median (Means 2008). For this study, the median cost was used. Project managers using the model will need to evaluate if the project needs to use a higher or lower cost per square foot depending on the scope of the individual project.

RS Means gives some individual square foot costs, but it also has one number and a percentage of total cost for the "Total: Mechanical and Electrical". (Means 2008) The current study used "Total: Mechanical and Electrical" values in order to limit the number of variables. The location factors are included in the results in order to accurately measure the impact on labor cost as productivity is a function of labor cost. Individual cities are not referenced, but the impacts of different location factors are discussed.

The first assumption was that the cost of temporary lighting was fixed with the exact amount based on a previous study. The number used was $0.47 per square foot. The cost is based on OSHA requirements for temporary lighting and the National Electrical Code, using 12/3 SJTW cords with 23 watt florescent bulbs, with one bulb for every 100 square feet. The cost includes the energy usage at $0.08 per kilowatt hour. A project manager wishing to not include energy cost should deduct $0.17 from the cost for a cost per square foot cost of $0.30 (Smith, 2007; Smith, 2009).

The second assumption regards the construction activities ongoing during use of temporary lighting. There are several construction activities that take place on the interior of a project. These activities include:

- Interior framing
- Plumbing
- HVAC
- Electrical
- Fire protection
- Specialized systems
- Gypsum board hanging and finishing
- Interior painting
- Interior doors and trim
- Millwork
- Painting
- Ceiling grids

In order to simplify the study and make the results more conservative, only the Mechanical, Electrical, Plumbing (MEP) activities were included in the cost/benefit evaluation. These activities also have their cost based on building types listed in Means. The authors understand that other trades will benefit from the improved lighting, and the project manager will need to evaluate the impact on other trades in order to make the subjective evaluation.

The third assumption was that the cost of labor for the installation of the MEP systems was 40% of the total cost for scope of MEP work. The cost of labor in the construction process is generally considered to be between 30% and 50% of the entire contract costs (Hanna, et al 2008). This study used 40% as the MEP systems are relatively labor intensive.

The fourth and final assumption was that the cost per square foot of the temporary lighting will remain the same regardless of the location factor as labor is a small part of the cost of temporary lighting.

The process was as follows:

- Choose six of the fifty-nine building categories to evaluate. The six were chosen as frequently used building types.
    - Small bank
    - Classroom building at a university
    - Office building
    - Church
    - Hospital
    - Retail
- The median cost per square foot was recorded.
- The building cost per square foot adjusted for the location of the project was calculated.
- The cost of the MEP systems as a percentage of the total cost was recorded.

- The dollar cost of the MEP systems was calculated using the total cost adjusted for the location of the project.
- The cost of labor for the MEP systems was calculated using the cost of the MEP and the percent of labor for the MEP systems, as discussed in the third assumption.
- The minimum increase in productivity necessary to offset the cost of the lighting was calculated by dividing the cost of the lighting by the cost of the MEP labor.
- The result was expressed as a percentage which is the required increase in the productivity of the MEP trades to offset the temporary lighting cost.
- The temporary lighting decision can be based on whether or not the anticipated increased productivity, with the related savings in labor cost, meets or exceeds the calculated percentage.

Results

The results are shown in tables that list the type of building and the increase in productivity that is required to offset the cost of the temporary lighting. A detailed description of the table headings as shown below:

- The first column is the "Type of Building." RS Means lists fifty-nine building types, but due to space constraints, six building types were chosen for the study.
- The second column is the median building cost per square foot.
- The third column is the adjusted cost revised for the median building cost for the location factor noted in the heading. The numbers come out of RS Means and indicate the different building costs for different cities across the US. The location factors used in the calculations are 80, for areas where the cost of construction is lower than the mean; 100, for locations at or near the mean; 130, for areas that are above the mean.
- The forth column is the percent cost of the median building cost for MEP.
- The fifth column is the $ cost of the adjusted building cost for MEP.
- The sixth column is the $ cost of MEP labor based on the % of MEP cost noted in the heading.
- The seventh column is the minimum % increase in productivity necessary to offset the cost of temporary lighting.

Table 1 uses a Location Factor of 100, MEP labor as 40%, and temporary lighting cost of $0.47. The hospital has the lowest percentage increase because it has the highest percentage of mechanical trades. In other words, the hospital has the greatest potential for productivity gains. In an eight hour work day, the average worker would only need to have 7.4 more productive minutes to offset the costs. The project manager could use this information to decide if he or she felt the project would see that increase in productivity. The project manager could also weigh the value of safety, quality control, and other subjective factors based on this information.

A small office building needs to raise productivity 4.6%. Putting the percentage into the time of an eight hour day work day, a worker would need to save 22 minutes or have 22 more productive minutes. The decision of the project manager may lean harder on the subjective factors than the ability to increase productivity 4.6%.

Table 1- Required Increase in Productivity with Location Factor 100, Labor at 40% of MEP, and Lighting Cost at $0.47/sf

Type of Building	RS Means Building Cost per sq ft	Adjusted Cost per sq ft	MEP cost as % of total	MEP Cost per sq ft	Labor 40%	Min + Product.
Small Bank	176	176	24%	42	17	2.78%
University Classroom Building	149	149	32%	48	19	2.46%
Office Building (1-4 Story)	111	111	23%	26	10	4.60%
Church	121	121	26%	31	13	3.73%
Hospital	212	212	36%	76	31	1.54%
Retail	78	78	23%	18	7	6.55%

Table 2 maintains the same factors except for the location factor which has changed to 80. Since the building costs are lower, the labor costs are lower, and the cost of the temporary lighting remain constant. The minimum increase in productivity rises for all categories.

Table 2- Required Increase in Productivity with Location Factor 80, Labor at 40% of MEP, and Lighting Cost at $0.47/sf

Type of Building	RS Means Building Cost per sq ft	Adjusted Cost per sq ft	MEP cost as % of total	MEP Cost per sq ft	Labor 40%	Min + Product.
Small Bank	176	141	24%	34	14	3.48%
University Classroom Building	149	119	32%	38	15	3.08%
Office Building (1-4 Story)	111	89	23%	20	8	5.75%
Church	121	97	26%	25	10	4.67%
Hospital	212	170	36%	61	24	1.92%
Retail	78	62	23%	14	6	8.19%

Table 3 maintains the same factors except for the location factor which has changed to 130. Since the building costs are higher, the labor costs are higher, and the temporary lighting remains the same, the minimum increase in productivity is lower.

Table 3- Required Increase in Productivity with Location Factor 130, Labor at 40% of MEP, and Lighting Cost at $0.47/sf

Type of Building	RS Means Building Cost per sq ft	Adjusted Cost per sq ft	MEP cost as % of total	MEP Cost per sq ft	Labor 40%	Min + Product.
Small Bank	176	229	24%	55	22	2.14%
University Classroom Building	149	194	32%	62	25	1.90%
Office Building (1-4 Story)	111	144	23%	33	13	3.54%
Church	121	157	26%	41	16	2.87%
Hospital	212	276	36%	99	40	1.18%
Retail	78	101	23%	23	9	5.04%

Table 4 is an example where a project manager could use the model to fit a particular project. Suppose the project manager was going to build an office building in a city with a location code of 130. Further, he or she realized that there was a high percentage of labor for the MEP so MEP labor was increased to 50% of total system costs. Temporary lighting was already in the budget; however, the project manager calculated than an extra $0.20 per sf was required to have the desired higher quality of lighting. Table 4 details the required minimum productivity increases required for the various structures considered under these parameters.

Table 4- Required Increase in Productivity with Location Factor 130, Labor at 50% of MEP, and Lighting Cost at $0.20/sf

Type of Building	RS Means Building Cost per sq ft	Adjusted Cost per sq ft	MEP cost as % of total	MEP Cost per sq ft	Labor 50%	Min + Product.
Small Bank	176	229	24%	55	27	0.73%
University Classroom Building	149	194	32%	62	31	0.65%
Office Building (1-4 Story)	111	144	23%	33	17	1.21%
Church	121	157	26%	41	20	0.98%
Hospital	212	276	36%	99	50	0.40%
Retail	78	101	23%	23	12	1.72%

The results of the model are all related to RS Means data, and as such need to be recognized as the median value for a number of projects. The Project Manager must adjust the data given to reflect the particular project. Only then will the data be of value for decision making.

Conclusion

Previous studies have indicated that higher lighting levels appropriate to the required task have led to productivity improvements for workers. In construction, where labor costs sometimes exceed 50% of the total costs of an item, productivity is a key driver of profitability. Field studies of various lighting levels are difficult to complete reliably as conditions are continuously changing on the job site. This paper proposes a model that could be used by a project manager to evaluate whether the increased costs of higher temporary lighting would be offset by potential productivity gains.

Instead of directly measuring productivity gains under various temporary lighting conditions, this paper attempts to establish a minimum amount of productivity that would need to be achieved to offset the additional costs. Such a "reverse logic" approach was considered in an effort to limit the number of variables that must be addressed in any field measure of productivity. The authors established "how much more lighting needs to be provided" by using the OSHA requirement to determine a cost. The minimum amount of increase in productivity was quantified, and the contractor may use the information to make more quantifiable decisions on whether to increase the lighting based on their preditiction as to whether the actual increase in productivity will meet or exceed the minimum. The minimum was compared to other factors influencing productivity to give the contractor a baseline for the decision.

The model indicates that relatively little productivity gains are required when the cost of MEP systems is a high percentage of the cost of the job (hospitals). For example, Table 4 indicates that only a 0.40% productivity increase is required for a hospital. On the simplest basis, if a worker worked 60 minutes to complete a task and then repeated the task with a 0.40% increase in productivity, the task would be completed in 59 minutes, 45 seconds. The authors believe that such an improvement is appropriately classified as "minimal".

Conversely, small office buildings and retail which have limited MEP systems may not necessitate improved temporary lighting. As anticipated the model further indicates that as labor costs increase, less productivity gains are required to realize a savings on the job. For example, Table 2 indicates that an 8.19% productivity increase would be required for a retail building. On the simplest basis, if a worker worked 60 minutes to complete a task and then repeated the task with an 8.19% productivity increase , the task would be completed in 55 minutes, 5 seconds. This productivity gain is considered substantial and would be challenging to confirm without specific field testing.

The model only attempts to address productivity issues. Issues of safety and quality control may be impacted but are not quantified in this model. In addition, percentages are based on cost projected by RS Means. Changes to cost variables would significantly affect the results.

Efforts need to be made to confirm these anticipated results on an actual job. Field research to directly measure productivity under various lighting conditions is being designed by the authors. Howeever, such field tests require a set-up where precise condtions can be duplicated with only the lighting as a variable. Jobs that have repetitious floors where the levels of temporary lighting could be varied should be pursued. Field testing of this model could lead to a mathematical approach to evaluating the value of temporary lighting in relation to job site productivity. In the absence of field tests, it is hoped that this study will provide some objective measurement on which to base the field study.

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