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Abstract

For many construction estimating and scheduling activities, it is generally accepted that two workers can perform a given task twice as fast as one worker. Similarly, four workers can perform the same task in a quarter of the time. While using ratios to modify labor productivity is generally accepted, it is also recognized that for certain tasks it will take longer than one-half as long for two workers to perform the task than it would take one worker. Likewise, it will take four workers longer than one-quarter of the time required for one worker. This loss of productivity can be illustrated using a simple card game that can be useful to explain the concepts. This paper discusses the card game, its similarities with construction and the results of its use in a classroom situation.

Introduction

Predicting construction productivity is important but difficult. Sutermeister¹ enumerated many factors that would affect worker productivity. He indicates that work is a social experience and most workers' social needs can be fulfilled in a small work group. In small groups, workers can be influenced by several organization issues, such as the size of the group, the cohesiveness of the group and the goals of the group. In regards to the size factor, there is an ancient sociological generalization that, other factors being equal, the size of immediate work group is negatively correlated with productivity, job satisfaction, regular attendance, or industrial peace. Sutermeister states "This is due in part to the greater likelihood that primary relations (relations that are intimate, personal, inclusive, and experienced as spontaneous) are more likely to develop in small groups than in large groups. It is due in part also to the fact that the worker in the smaller group is likely to have more knowledge of the relations between effort and earnings, and this seems to increase his incentive to work."¹

Sanders and Thomas² in their research on masonry crews developed curves of crew size and productivity. This research showed that for some construction activities, the productivity would not linearly increase when crew size increased even in a labor-intensive activity. These studies may not be easy for students to understand, especially those with limited work experience. An illustrative technique is needed to demonstrate the impact on productivity when crew size increases and to explain this change.

This paper uses the, Construction Productivity Card Game (CPCG) to illustrate the concept that productivity does not increase in a linear manner with increased number of workers. The

game's results show the effect of increasing group size on productivity and many similarities of construction work.

Motivation

Many construction students struggle with the concepts and ideas of construction. This is complicated by the fact that it is very difficult to expose them to actual construction operations because of the lack of an appropriate project, distance to projects, class size and time needed for the visit. Many students gain valuable experience during internships and coops. However this experience may not always be applicable to the current topic in the classroom. The internet and simulation environments have helped to alleviate these problems but there are times when the dynamic environment that one can create in a hands-on classroom activity is not only stimulating for the students but the instructor as well.

Definition of Productivity

For manufacturing, productivity can be the cost per unit of output manufactured by a machine. For construction, it can be the cost of finished unit work per unit of time of labor or equipment. Drewin³ defined productivity as "... the amount of goods and services produced by a productive factor in a unit time". Adrian⁴ used the following equation:

$$\text{Productivity} = \frac{\text{Dollars of output}}{\text{Person - hour of input}} \quad (1)$$

In the definition of productivity, there are two concepts that are generally used. First, the output is compared with the simple sum of all the hours of labor spent in production. The second concept is the comparison between the output and the total input, where the total input includes all of the resources used in production. Generally, the first concept, output per labor-hour, is used more than the second concept, output per unit of labor and capital.⁵ Sonmez and Rowing⁶ stated that the ratio of output to work hours (production rate) or the ratio of work hours to output (inverse of the production rate) are generally used. The work hour often appears as labor-hour in construction, since the labor cost is such a large part of the cost of construction, which has more influence on the construction management than the quantities of either equipment or materials. For construction managers, the output can be construction tasks such as cubic yards of concrete, square feet of some surface, tons of steel, or linear feet of weld. It also can be a combination of some tasks that are developed to a higher level measure of the work, such as a mile of highway.⁷ In this paper, results of the CPCG game, are presented using productivity which will be in cards per person-second. Additionally, the time to complete the task will be reported. This is consistent with reporting the completion time of a certain quantity of work.

People and Productivity

Sutermeister¹ explains that in a work group, people will be affected by some organizational issues. This implies that groups are just like a small society. With a small sized group, it is

easier to set up a close relationship where the members may be affected by other group members. Although the small work group may have greater potential for improved employee performance and increased productivity, the potential opportunity for this to be realized depends in large measure on the cohesiveness and the goals of the group. “The cohesive group is one whose members will stick closely to group norms, whatever they are.”¹ This means a cohesive group has potential to be motivated to better performance or poorer performance depending on what the group is doing.

A very cohesive group is also called a jelled team.² There are characteristics that indicate that a jelled team has occurred. The most important of these is low turnover. The team members are not removed from the team. There is a sense of elitism on a good team. Team members feel they are part of something unique. The final sign of a jelled team is the obvious enjoyment that people take in their work. Jelled teams just feel healthy.²

Goal setting is a factor that will also affect the workers’ productivity.⁹ When an organization or group’s goal has been set, it also can fulfill their employees’ psychological, social and personal needs. It can give an expected improvement to the workers’ productivity. In the construction industry, managers set attainable targets based on the best historical performance for both quality and productivity. Individual goals can be directed toward the organization goals through incentives, such as money, promotion, work environment, and praise or recognition. It should be noted, however, that using financial incentives to urge workers to mesh their individual goals into the group or organization goals has limited use in the construction industry.⁹ In the manufacturing industry, workers generally do not feel much concern about the identity of the resulting product. Construction workers can get job satisfaction from seeing their efforts produce permanent structures and are therefore more easily motivated if the work is accomplished. “A construction worker will often be highly motivated if they get proper instruction, equipment, tools and materials to do his job properly.”² However, if the work progress is interrupted by lack of essential tools or materials, the worker may cease to be motivated.

There also are some factors that influence productivity which can be distinguished as positive forces or negative forces. Maloney¹⁰ provides some suggestions. To increase productivity, there is a need to eliminate or reduce the strength of the negative forces and increase the strength of the positive ones. Negative forces can be reduced or eliminated by providing security guarantees and negotiating changes in work rules through productivity bargaining. Productivity bargaining here means an agreement that stipulate certain changes in work rules to achieve greater productivity and ensure that workers receive their share of the resulting savings. Positive forces can be strengthened by using one or more influence processes: compliance, identification, and internalization. These three processes basically include the main demands of workers. Compliance means they can gain specific rewards for their performance. Identification means they want to establish or maintain a satisfying relationship with another person or group; and the internalization here means the worker’s behavior is intrinsically rewarding and congruent with their value system. The best way to improve productivity was not identified. This must depend on the specifics of the situation.¹⁰

In addition to the factors cited above, which will influence the productivity of workers, the participation of workers is also an important issue. Making workers involved in managerial decisions gives workers strong feelings of loyalty to a firm. It is also easier for workers to accept some working condition changes if they have been consulted in advance.⁹ The participation of decision making can often be seen in the construction process. Borcharding¹¹ noted that construction may be the only industry where the challenge of the participative decision making should occur naturally because of the challenge of the work environment. Foremen have to make many day-to-day decisions; they must participate with project management in establishing such jobsite policies as coffee breaks and crew sizes, while journeymen have an opportunity to participate in method selecting decisions and help to choose different trades.¹¹

When productivity is estimated, there are more factors which will affect productivity that must be considered. These factors are: nature of the work, labor and equipment productivity, management skill, material and equipment availability, seasonal conditions, work restrictions, quality of work, and concurrent activities.¹²

The law of diminishing returns states that as a factor of production is increased while the others remain constant, the overall returns will decrease after a certain point.¹³ The law of diminishing returns was first applied to agriculture, and was later accepted as an economic law underlying all productive enterprise.¹⁴ This concept is what is demonstrated by the game presented in this paper.

Labor Productivity Model Based on Different Construction Tasks

A few studies have concentrated on the impact of multiple factors on productivity based on different construction tasks. One is a model based on six factors forecasting the productivity of a mason crew. The six factors are work type, building element, design requirements, construction methods, weather, and crew size.² Here the crew size includes all crew members, both masons and support personnel, because so many variations of crew composition were observed. Consistent results of the model could not be achieved if only the masons' hours were included. No distinction was made between working and nonworking foremen, but it was suggested that future work should investigate this factor if sufficient data are available. The model includes three crew-size variables: the crew size, the crew size squared, and the crew size cubed. Also included in the equation for expected productivity are coefficients for work type, building element, design requirements, construction methods, and weather. Productivity decreased as crew size approached eight, stayed fairly constant until a crew size of 15 and then dropped as crew size increased further.²

Another model, based on a concrete crew, is described by Sonmez and Rowing.⁶ A methodology based on the regression and neural network modeling techniques is presented for quantitative evaluation of the impact of multiple factors on productivity. The methodology is applied to develop productivity models for concrete pouring, formwork, and concrete

finishing tasks, using data compiled from eight building projects. The sensitivity analysis result for concrete formwork task indicated the impact of crew size on productivity. The increase in crew size results in a decrease in production rate. The decrease in productivity due to large crew size may be caused by overcrowding.² It was also found that as the quantity of concrete placed in a week increased, the production rate also increased. The increase in productivity may be due to the repetition of the task. It was noted that the crew may become familiar with the task as the amount of concrete placed increased.⁶

Thomas et. al.¹⁵ introduced a concept: symbiotic crew relationships. Here symbiotic relationships mean the tight relationships which occurs when the work pace of one crew depends on the pace of a preceding crew. The consequences of labor flow delays are probably more significant in symbiotic relationships because they affect not only the immediate crew but also those around them. The paper reports that the baseline productivity is not strongly related to the size of the project but the productivity declines when crew size changes from three people to four people. Then the productivity increases when crew size changes to six people.¹⁵

Since the crew size will affect the productivity of construction work, a study was done regarding the application of a crew size factor. It is obvious that if 1,000 labor-hours are left in a job, 1,000 workers cannot be hired and have everything done in an hour. There will be a limit for adding workers to a task. This was found to be no more than 1.9 times the average manning of a job, and the lower the better. For example, if the average is 20 workers, the peak should be no more than 38 with a ratio of 1.9 as the ideal.¹⁶

Construction Productivity Card Game

The Construction Productivity Card Game (CPCG) game can be used to explain the effect of crew size on productivity similar to the research discussed earlier. This may be useful for students in a classroom situation where it would be difficult or impossible to demonstrate these effects using actual working conditions. CPCG could also be used as a tool for construction professionals to generate awareness of the importance of proper crew size and the influence on productivity and ultimately costs. While CPCG does not substitute for actual construction field experience it can provide some excellent interaction and realistic situations.

CPCG uses a standard deck of 52 playing cards. Each participant receives a deck of cards to begin. CPCG is a card sorting game that requires players to sort the cards in suits (Diamonds, Hearts, Spades, Clubs) and then to sort them from Ace to King. This double sort can be accomplished in any way that the player(s) decide. The time is recorded each time the sort (task) is completed. Players initially sort the cards individually then they find a partner and repeat the game. In the version discussed in this paper only one deck of cards is used as team members are added. The sort is repeated when a third player is added. This increase in group size by one player at one time continues until it is felt that the desired lesson has been learned, time runs out in the particular session that the game is being played in, or it becomes impractical to continue adding team members.

CPCG Rules

The rules of CPCG are simple and can be explained in a matter of minutes. This provides maximum opportunity to play the game as questions from participants are few. The basic rules of CPCG are summarized as follows:

1. Each player receives a deck of standard playing cards.
2. Remove Jokers and any other extra cards.
3. Shuffle the cards and place the deck on a surface. Keep the cards in one pile. Do not divide the cards into multiple piles until indication is given to start the game.
4. When told to begin:
 - a. Sort by suit (Diamonds, Hearts, Spades, Clubs)
 - b. Sort Ace to King.
5. When complete indicate to game leader. In teams with more than one player make sure that one person is designated to indicate when the sort is complete.
6. The above process is repeated for teams of two, three, four, five, and so on.

CPCG Data Collection

The data collection for the CPCG is intended to be inexpensive and available for use by anyone that has access to a computer. While the data collection may introduce errors it does not diminish the effectiveness of the game in demonstrating the effect of crew size on productivity.

The timing device used to collect the data presented in this paper was XNote Stopwatch, Version 1.4 which is available for free download at <http://www.xnotestopwatch.com/?ver=1403FB5>.¹⁷ XNote Stopwatch is a stopwatch/countdown timer that can measure time intervals in decimal seconds, seconds, minutes, and hours. It provides the ability to snap times. Each time the Snap button is used during the game a split time is recorded in the results window. Recorded are N, Time, percent of total time, gap from previous time, and percent of time to next data point. The purchased version of XNote Stopwatch permits the user to save the data as a text file or copy it to the clipboard. The data for this paper was saved to a text file and further manipulated in a spreadsheet. Only N and split time were used in the data analysis for this paper. The results window can also be displayed for the participants to view.

As mentioned earlier there were possibilities that the data collected may be inaccurate. This could have been introduced by more than one team member calling out that their team had completed the sorting task. While these possible errors could skew the data the intent of the game is to demonstrate the effect on productivity of crew size. The data was collected to compare the CPCG game to studies performed on actual construction tasks. In that regard the data is acceptable.

CPCG easily relates to two construction topics: scheduling and estimating. The activities in the schedule need a duration so that a completion time can be calculated. To determine the duration a production rate is needed. This production rate is affected by crew size, equipment, and the difficulty of the task. CPCG could also be used when studying estimating. Just like scheduling, estimating requires production rates to determine the time tasks take. Once the time is known, the cost can be determined by using the cost of the crew per hour. In both estimating and scheduling it may be necessary to increase crew size to meet specific contract requirements. CPCG is used to illustrate the effect of increasing crew size on productivity which impacts both the budget and schedule.

The data discussed in the next section was collected in CE3332, Fundamentals of Construction Engineering at Michigan Technological University. A total of 53 students participated in the game. As the game progressed not every student had the opportunity to play every time as there were not even multiples every time. Students would participate again as the opportunity presented itself. The game was played in a classroom with individual desks. There were crowded conditions and sloping desk tops which caused problems in the sorting task. Some players tried to improve working conditions by moving to the floor. As crew sizes continued to increase, space to play became limited. The similarities between CPCG and actual construction operations will be discussed in more detail later.

During data collection the immediate results of the fastest time for each crew size was available to discuss with the class. Additionally, students were given an assignment to comment on the game and to discuss any similarities to construction that CPCG has.

The time to play the CPCG in class was the majority of the 50 minute class time. The game went to eight players per group. This was done to collect data. It may not be necessary to go to eight players per group as many of the effects of increased group size are experienced at groups of five or six players.

Results

Figure 1 is a plot of the time to sort the 52 cards on the vertical scale and the crew size on the horizontal. As the crew size increased the time to sort the cards decreased. That is, it took less time to complete the task. As the number of people increases, each person in the group sorts fewer cards than the preceding game and the overall time decreases. The curve of the fastest time changes little, which may be due to a participant who is very good at this sorting card game. Some observations on the average curve can be made. As the group size changes from one person/group to four people/group, the completion time improves significantly each instance the game was played. That is, the productivity improves quickly. As the group size increases from four people/group to eight people/group, the productivity also improves, but not as fast as from one to four.

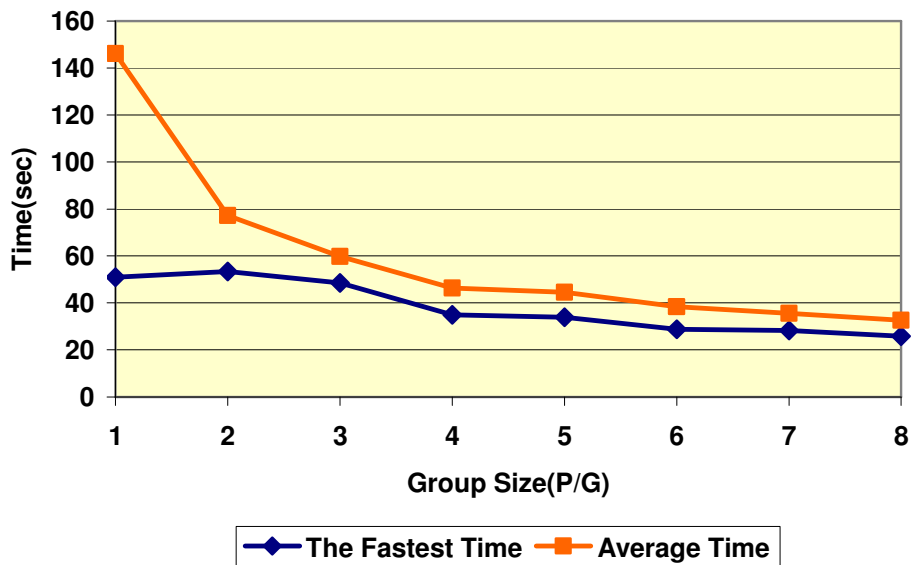


Figure 1. Sorting Time

Figure 2 is a plot of the productivity of the same data shown in Figure 1. The results presented by Sonmez and Rowing⁶ are a plot similar in shape with the average time curve shown in Figure 2. In Figure 2, the productivity is the output (52 cards) divided by the input (person-second). The person-second is similar to the work-hour discussed earlier. Figure 2 shows that the productivity decreases as group size increases.

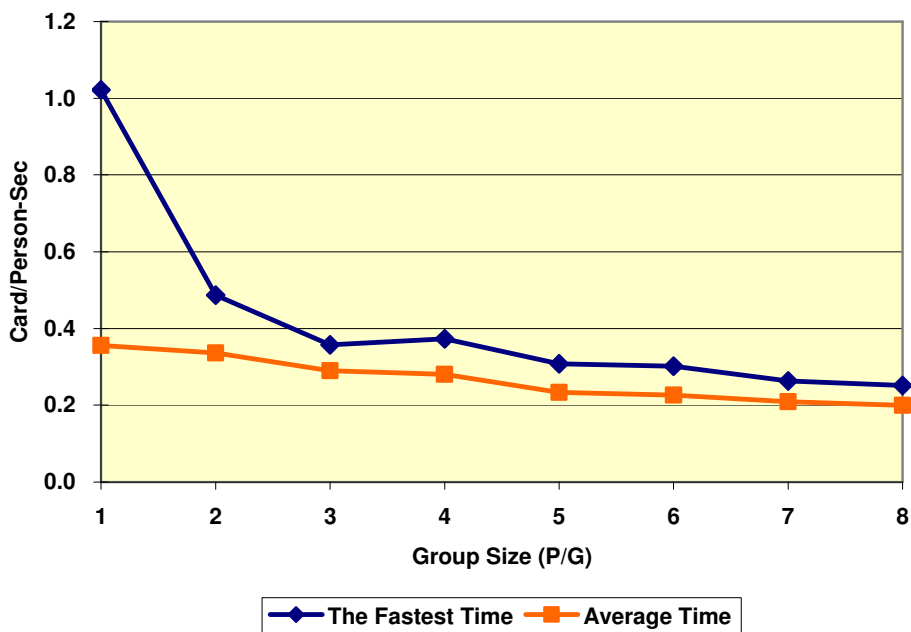


Figure 2. Productivity vs. Group Size

Since this study only increased the crew size to 8 people/group, it does not show the effect of a larger crew size and further decrease in productivity which was observed by Sanders and Thomas.² It might be predicted that when the crew size increases to a certain number, the productivity will not improve anymore. At that point there is no benefit to increasing crew size. However, this was not observed as the group size was not increased to sizes that would have exhibited that.

Similarities with Construction

The CPCG game can assist in understanding the factors which will affect crew and individual productivity. This occurs because of the many similarities with construction and what happens in the CPCG game.

The quality of the work (card sort) was not examined. Some of the cards may not have been sorted properly and would have required rework. A variation of CPCG would be to examine quality.

Comparing the results to typical construction tasks, the CPCG game has its own characteristics. First, the card sorting task is a highly repetitive task which means the productivity can be improved as the crew becomes more familiar with the task. Second, there are 52 cards, and always the 52 cards need to be sorted by players. This means that there is always a fixed quantity of work as the game progresses. If the number of cards that needs to be sorted would decrease, or as the game proceeds, the number of cards would increase to two decks or more, the results may have been different. Third, in the CPCG game, the process starts from 1 person/group. This obvious change can be seen on the first part of the curve.

This CPCG game not only can show the relationship between crew size and productivity, but also permits the players to experience it in a game situation. In the process of the game, some skillful players who always stay in a group act like a foreman in a construction crew. They will organize other players and explain their roles. Their sorting skill and organizing capability define their group productivity. Some students are more likely to be a helper in the game. They prefer to let others tell them what to do. This is decided by their personality. The performance of a work crew with different people also is important in the construction site.

From comments collected after the game, some students said they experienced how important communication is when there were several people in a group. This is also an important factor when construction tasks proceed. Before a project starts, the work crew always needs to make it clear what method they will use to do the job, and how to distribute the assignment between each member.

Some students commented that there was not enough room for every student to play when the group size increased. That is also one reason why the productivity decreases when crew size increases in a construction site. Some students noted that the device used to record the finish time wasn't accurate enough. Other students observed that the desk surface used to lay cards

on were not flat. They needed to prevent cards from sliding down as the game proceeded which increased the sorting time. These problems are the same as inaccurate measurements, inefficient tools, and difficult working conditions in a construction site. The imperfection of the game just shows the similar adverse factors that affect the process of construction.

Conclusions

For labor-intensive activities, people normally think that an increased crew size can get more work done. While this may be true, the studies discussed earlier showed that there is a downside to this. When crew size increases, the productivity will decrease. From Figure 1, the result shows that when group size increases, the finish time of the group decreases. This means when a construction task is late, you can add more people into the work group to make this task done earlier. However, when the group size increases gradually, the finish time of the task will not show a linear relationship with the group size. Two people may not complete the task in a half time, three people will not complete it in a third time, and four people will not complete it in a fourth time. The reason is that the individual labor productivity will decrease as shown in Figure 2, even if the group work time decreases.

The CPCG game is easy to play in class. The results of the CPCG game illustrate many situations when the group size of a cooperative task increases. The similarities with construction give students a great experience of what will happen on a construction project.

Note

The idea for the CPCG came from an Open House demonstration in 2003 by Steve Seidel of Michigan Tech's Computer Science Department. The demonstration was to illustrate the effects of parallel processing used for super computers. The first author participated in the demonstration with his son and recognized the similarities that the game had with construction productivity.

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