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THE IMPACT OF INCREASING TEAM SIZE ON PROJECT PRODUCTIVITY

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ABSTRACT

Purpose- Enterprises must increase operational efficiency to gain competitive advantage in this stiff global competition, and operational efficiency is resulted from fast problem resolution and opportunity creation. Project management has been regarded as an effective and efficient approach to quickly solve current problems and create future opportunities. Speed is the most vital factor when facing with problems and opportunities; slowness will breed a small problem to a huge one, even unmanageable, whereas a not quick enough pace will lead to opportunity untouchable and fade away.

Methodology- The challenge facing a project manager in this era is how to complete a project quickly, and one of the most commonly used methods is crashing, which implies shortening the project duration by increasing the number of workers and equipment, and by working overtime. Traditionally, it is a common believe that increasing the number of workers can certainly reduce the project length; even the law of diminishing return is widely recognized. Thus, this study intends to explore the interaction of number increase and diminishing return, and develop a quantitative model to concurrently consider the number of workers, worker experience, worker training and level of team work to obtain the most suitable number of worker increase, to avoid waste of human resources and optimize personnel utilization.

Findings- To demonstrate the applicability of the proposed model, this study uses two examples to illustrate the solution procedures. The results indicate that although the project productivity can increase along with the increase of workers, when the number of workers reaches a certain level, even the worker is further increased, the project cannot be positively benefited; therefore, the increased workers are not only wasted, but also decrease the entire project productivity.

Conclusion- Project managers can use the model to identify the optimal number of additional team members, thus improving human resource management. This study is the first theoretical verification of the law of diminishing returns and provides a more in-depth understanding of crashing, which has both academic and practical value to project management.

Keywords: Project, project management, crashing, law of diminishing return, productivity.
JEL Codes: C61, L84, M12

1.INTRODUCTION

In the competitive global environment of today, companies often manage cross-departmental activities as projects in order to adapt to varying business demands. To achieve their strategic goals, businesses must utilize project management to integrate their resources and respond with maximum speed and minimal cost to rapidly changing operational environments.

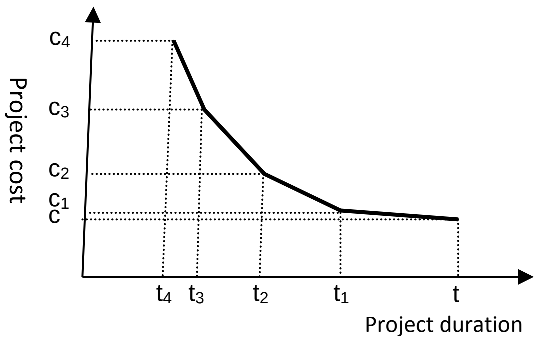
A project is a one-time plan or scheme to complete a set of non-customary activities. Each project is therefore unique to some extent and involves issues or elements that staffs have not previously experienced. This means that projects by their very nature have an inherent level of uncertainty and can easily exceed time and cost limitations unless they are properly managed. The key to the success of projects lies in the ability of project managers to effectively integrate resources and lead their team to achieve project objectives within the constraints of budget, cost, and quality.

As market changes and competition intensify, many work activities and initiatives are being organized as projects. According to Kerzner (1984), projects have specific start and end dates, and utilize specific resources to achieve a definite objective. Pinto & Slevin (1988) defined projects as having specific start and end dates, fixed budgets, and a series of interrelated activities, the purpose of which is to achieve specific objectives and pre-defined performance. Turner (2003) proposed the concept of a project as a temporary organization which must effectively allocate limited resources and control uncertainty in order to achieve pre-defined objectives. Project management is considered to be the most flexible type of management, because projects require the completion of interrelated tasks within a set timeframe and limited resources. According to Nicholas (1990), the three key elements of a project are the project manager, project team, and project management system. Kerzner (2001) described project management as the process of planning, employing, organizing, scheduling, and controlling, during which project managers must make full use of resources. As global competition intensifies, projects have also grown more complex, accelerated, and uncertain.

Lewis (1993) defined a team as a group of people working together to achieve a common objective. Drucker (1998) believed that teams are able to bring greater competitiveness and innovation to organizations because of mutual collaboration, communication, and coordination among team members. As stated by McGrath (1984), team performance is affected by the attitudes, skills, and personality traits of team members. Christina & Danny (2008) simulated the three factors of influence on team performance: size of team, skills of team members, and the structure of tasks and responsibilities. Cooperation, communication, size of team, and personality traits are all factors commonly perceived to affect team performance. Kennedy et al. (2011) found that email, telephone conversations, and face to face communication all have difference effects. Luthans (1988) found that managers spend an average of half their workday on communication, highlighting its importance. In the knowledge economy of today, says management guru Peter Drucker, organizations must enhance their performance by building the capabilities of their staff. Research has shown that effective training can increase staff output by up to 60%. Therefore, team training is an important factor of influence on productivity. El-Sabaa (2001) found that project managers can enhance performance through training. This study identified training as a consideration in improving productivity. Hsu et al. (2012) explored the impact of transactive memory system on teams' coordination, communication, and performance.

As indicated by Raz et al. (2002), project risks are often unexpected and can cause projects to exceed time and cost limitations. Project managers often employ crashing, which means allocating resources to significantly reduce the completion time for project activities, as a means of avoiding delays. Crashing requires additional resources and cost, usually in the form of increased manpower. Figure 1 illustrates the conventional concept of project duration crashed in relation to the project cost increased, and it can be seen that when project duration is compressed from t to t_1, the project cost is increased from c to c_1, and when the duration is consecutively compressed to t_4, project cost is also increased to c_4. The conventional concept implies that as long as more manpower is allocated, the project duration can always be shortened.

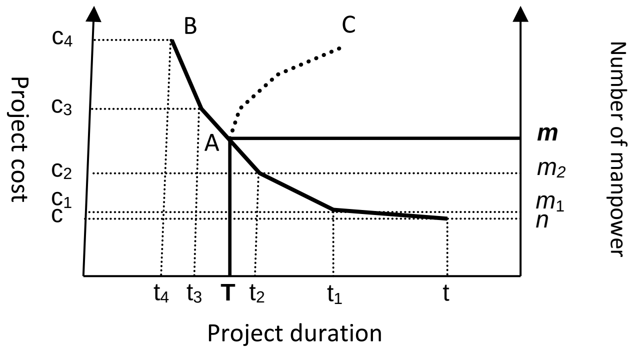
Figure 1: Project Cost and Duration Crashed



Wei & Wang (2003) used linear mathematical modeling to identify methods of reducing completion time. Other researchers have used non-linear modeling to find the optimal approach to managing project time and cost (Deckro et al., 1995; Elmaghraby & Salem,1982; Falk & Horowitz, 1972). Project management is a time-specific task that must be completed within time and cost constraints as well as meet quality standards. Therefore, how to efficiently solve problems and create opportunities with limited resources is the core objective of a project and an essential issue for businesses.

It must be emphasized that adding workers also increases the complexity of team communication, work assignment, coordination, and integration. This leads to a law of diminishing return scenario; Figure 2 depicts the law of diminishing return when crashing a project. In other words, more manpower may actually weaken productivity and waste resources. As a result, when the manpower added is more than a threshold value of *m*, the project duration will be lengthened instead of being shortened, i.e., the curve in Figure 2 will go from point A to point C rather than point B. The objective of this study is to develop a quantitative model to identify the most suitable number of additional manpower *m* to produce the shortest project duration as indicated in Figure 2 when crashing a project.

Figure 2: Law of Diminishing Return When Crashing a Project



2.MODEL FORMULATION

This study developed a model to quantify how overall productivity is affected by increasing manpower. This section comprises two sections: 2.1 explores factors that affect the productivity of project teams, and 2.2 explains the process of building the model.

2.1 Factors Influencing Productivity

Conventionally, the most obvious method of crashing is assigning more team members to urgent project activities. In many cases, however, adding manpower means increasing the complexity of team communication, work allocation, coordination, and integration. This leads to a law of diminishing return scenario. Although more manpower undeniably increases productivity, too large a team can actually weaken productivity. The collective experience of team members is another factor of influence on productivity. Those with more experience in similar projects will naturally find their work easier and be more productive. Another essential element to realizing the full potential of a team is whether its members have been adequately trained. Staff must be equipped with the skills to carry out project work in order to fulfill their responsibilities. Lastly, even if team members are well-trained and highly experienced, productivity will be limited if they are unable to build consensus and work together as a team. This article built a model that calculates productivity based on number of team members (including the detrimental effect of too large a team), their levels of experience and training, and teamwork. Each element is explained in further detail below.

(1) Number of team members

Generally speaking, the productivity of a project team increases as its headcount increases, because the team can simultaneously complete more tasks. The original number of project team members is indicated by *n*, and the additional members allocated as a result of crashing is represented by *m*. The total headcount is therefore calculated as $N=n+m$.

(2) Team experience

An important factor of influence on productivity is whether team members are equipped with relevant experience. Each individual has a different level of experience. If every team member was equipped with extensive and relevant experience, then obviously the team would achieve twofold results with half the effort. Experience is represented as *e*.

(3) Team training

Even if team members are all highly experienced, they will inevitably have different methods of thinking and operating, having come together from different areas of the business. Adequate training, therefore, can improve productivity. If team members have not had relevant project experience, then training is even more essential. We can use the analogy of a sports team: Even though each player is a world class athlete, they must still train intensively in order to play together as a world class team. Training, both formal and informal, can improve team competency and equip them with the skills and knowledge to complete required tasks. Training is indicated by *t* in this study.

(4) Teamwork

The ability of a project manager to build a team from a group of individuals in the shortest timeframe possible is crucial to achieving project objectives. Teamwork includes mutual understanding, solidarity, and commitment to fulfilling the mission of the team. Teamwork is represented by *g* in this study.

(5) Diminishing productivity

Expanding the size of the team has limited benefits in relation to improving productivity because at a certain point, any such benefits are offset by the additional communication and coordination required. The complexity of communication channels is proportional to the squared number of team members. Increasing head count can weaken productivity, particularly in relation to work requiring frequent communication. This reduction in productivity is designated as *r* in this study.

2.2. Model Development

This study developed a quantitative model to calculate productivity based on number of team members, their level of experience, training, teamwork, and the decline in productivity caused by increasing manpower. The computation procedures are explained below:

Step 1: Determine the value of each coefficient. Assuming that *N* = final number of team members, *n* = original number of team members, and *m* = number of additional members, then *N*=*n*+*m*, and *e*= experience. The higher the value of *e*, which can be specified as 0.1, 0.3, 0.5, 0.7, and 0.9, the more experienced the team members. The training coefficient *t* can also be set as 0.1, 0.3, 0.5, 0.7, and 0.9, with a higher value implying better training. Similarly, the teamwork coefficient *g* is set as 0.1, 0.3, 0.5, 0.7, and 0.9, the higher the stronger the teamwork function.

Step 2: Determine the reduction in productivity (*r*) caused by increase in team members. Table 1 shows the decline in productivity when $n \leq 5$. Table 2 shows the decline in productivity when $5 < n < 10$. Table 3 shows the decline in productivity when $n \geq 10$.

Table 1: Decline in Productivity ($n \leq 5$)

$n \leq 5$							
Ratio	$\frac{m}{n} \leq 0.5$	$\frac{m}{n} > 0.5$	$\frac{m}{n} > 0.6$	$\frac{m}{n} > 0.7$	$\frac{m}{n} > 0.8$	$\frac{m}{n} > 0.9$	$\frac{m}{n} \geq 1$
R	1	0.95	0.90	0.85	0.80	0.75	0.70

Table 2: Decline in Productivity ($5 < n < 10$)

$5 < n < 10$							
Ratio	$\frac{m}{n} \leq 0.5$	$\frac{m}{n} > 0.5$	$\frac{m}{n} > 0.6$	$\frac{m}{n} > 0.7$	$\frac{m}{n} > 0.8$	$\frac{m}{n} > 0.9$	$\frac{m}{n} \geq 1$
R	1	0.90	0.85	0.80	0.75	0.70	0.65

Table 3: Decline in Productivity ($n \geq 10$)

n≧10							
Ratio	$\frac{m}{n} \leq 0.5$	$\frac{m}{n} > 0.5$	$\frac{m}{n} > 0.6$	$\frac{m}{n} > 0.7$	$\frac{m}{n} > 0.8$	$\frac{m}{n} > 0.9$	$\frac{m}{n} \geq 1$
R	1	0.85	0.80	0.75	0.70	0.65	0.60

Step 3: Compute the team productivity. Generally, increasing manpower is seen to increase productivity, meaning that the two variables are proportional. By the same token, the more relevant experience team members have, the more they will contribute to productivity. Better training also implies improved productivity. Teamwork and productivity are positively correlated as well. The team productivity P can then be obtained as follows:

$$P = \frac{Net}{(1-g)} r \qquad (1)$$

Where *N* is final number of team members,

e is experience coefficient,

t is training coefficient,

g is teamwork coefficient,

r is diminishing productivity coefficient.

3. CASE IMLEMENTATION

This section experiments two cases to demonstrate the applicability of the developed model. Case I assumes that *n*=5 and Case II assumes that *n*=10, and both cases aim to identify the optimal number of team members when crashing is to be conducted.

Case I: Current number of project team members *n*=5.

Step 1: Assume that *e*=0.5, *t*=0.7, and *g*=0.7.

Step 2: Determine the diminishing productivity coefficient, and based on Table 1, the values of *r* are shown as Table 4.

Table 4: Changes in *r* Value (Case I)

n=5				
M	*N*	*e*	*t*	*r*
1	6	0.5	0.7	1
2	7	0.5	0.7	1
3	8	0.5	0.7	0.9
4	9	0.5	0.7	0.8
5	10	0.5	0.7	0.7

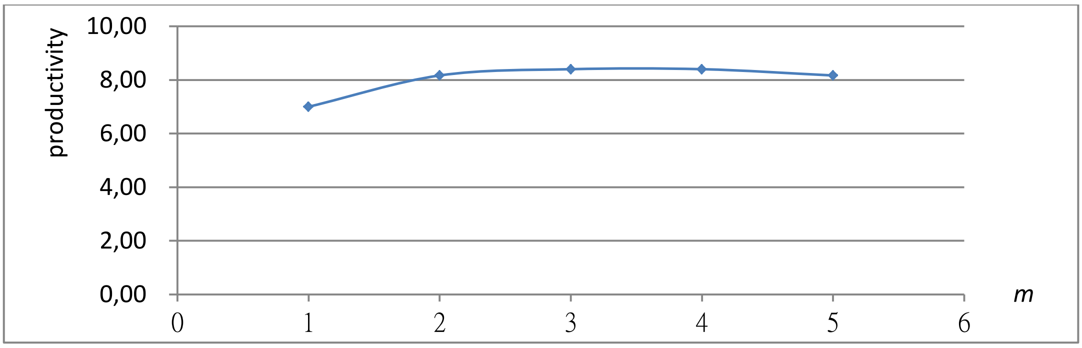
Step 3: Compute the productivity using Equation (1) and the values in Table 4. Results are shown in Table 5. Figure 1 illustrates variation in productivity based on increase in team size.

Table 5: Changes in Productivity of Project Team (Case I)

n=5							
M	*N*	*e*	*t*	*r*	*g*	1-*g*	P_I
1	6	0.5	0.7	1	0.7	0.3	7.00
2	7	0.5	0.7	1	0.7	0.3	8.17
3	8	0.5	0.7	0.9	0.7	0.3	8.40
4	9	0.5	0.7	0.8	0.7	0.3	8.40
5	10	0.5	0.7	0.7	0.7	0.3	8.17

The far right column of the table shows that productivity P was measured at 7.0 when one person was added to the team; 8.17 when two people were added to the team; and 8.4 when the team increased by three people. Productivity remained steady at 8.4 when four new members joined the team, but decreased to 8.17 when the head count increased by five. Figure 3 also shows that maximum productivity of 8.4 is achieved when three people are added to the team. The addition of a fourth person does not have any positive effects, while the addition of a fifth person negatively affects productivity and is therefore poor use of human resources.

Figure 3: Changes in Productivity (Case I)



Case II: Current number of project team members *n*=10.

Step 1: Assume that *e*=0.7, *t*=0.7, and *g*=0.7.

Step 2: Determine the diminishing productivity coefficient, and based on Table 3, the values of *r* are shown as Table 6.

Table 6: Changes in *r* Value (Case II)

n=10				
m	*N*	*e*	*t*	*r*
1	11	0.7	0.7	1.00
2	12	0.7	0.7	1.00
3	13	0.7	0.7	1.00
4	14	0.7	0.7	1.00
5	15	0.7	0.7	1.00
6	16	0.7	0.7	0.85
7	17	0.7	0.7	0.80
8	18	0.7	0.7	0.75
9	19	0.7	0.7	0.67
10	20	0.7	0.7	0.65

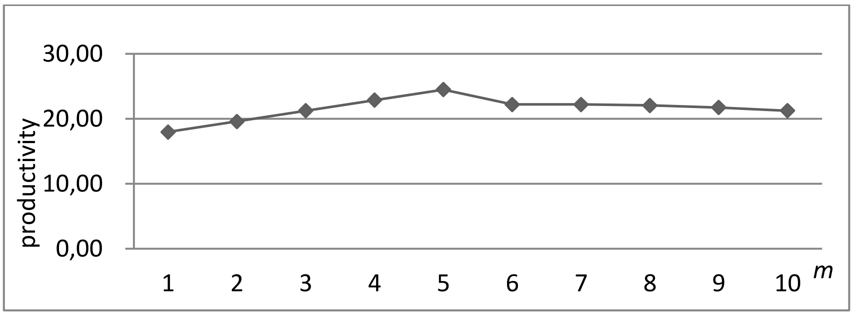
Step 3: Compute the productivity using Equation (1) and values in Table 6. Results are shown in Table 7. Figure 2 illustrates variation in productivity based on increase in team size.

Table 7: Changes in Productivity of Project Team (Case II)

n=10							
m	*N*	*e*	*t*	*r*	*g*	1-*g*	P_{II}
1	11	0.7	0.7	1.00	0.7	0.3	17.97
2	12	0.7	0.7	1.00	0.7	0.3	19.60
3	13	0.7	0.7	1.00	0.7	0.3	21.23
4	14	0.7	0.7	1.00	0.7	0.3	22.87
5	15	0.7	0.7	1.00	0.7	0.3	24.50
6	16	0.7	0.7	0.80	0.7	0.3	22.21
7	17	0.7	0.7	0.75	0.7	0.3	22.21
8	18	0.7	0.7	0.70	0.7	0.3	22.05
9	19	0.7	0.7	0.65	0.7	0.3	20.72
10	20	0.7	0.7	0.60	0.7	0.3	21.23

As shown in the far right column of Table 7, productivity was measured at 17.97 with one additional team member; 19.60 with two additional team members; 21.23 with three additional members; 22.87 with four additional members, and 24.50 with five additional workers. However, productivity was reduced to 22.21 when head count was increased by six. From this point onwards, more team members meant further decline in productivity. Figure 4 also illustrates this trend, showing that productivity reached a maximum of 24.50 when five additional members were added to the team. Expanding the team any further did not have a positive effect on the project, and in fact diminished productivity.

Figure 4: Changes in Productivity (Case II)



4. SENSITIVITY ANALYSIS

In this section, three scenarios were compared to further explore how coefficient variation affects team productivity. Scenario 1 = no diminishing effect on productivity; Scenario 2 = diminishing productivity, and Scenario 3 = diminishing productivity and changes in teamwork. The team comprises 10 members and the duration of the project is 20 days.

Scenario 1: This scenario assumes no diminishing effect on productivity (PO), *r* = 1; *e*=0.7; *t*=0.7, and *g*=0.7. Productivity values as calculated using Equation (1) are shown in the PO column of Table 8. Productivity increases with additional team members from 17.97 to 32.67.

Scenario 2: This scenario assumes diminishing productivity (P1), *e*=0.7, *t*=0.7, and *g*=0.7. The P1 column of Table 8 shows variation in the value of *r*, as well as productivity values as calculated using Equation (1). Productivity peaks once the head count of the team has increased by five.

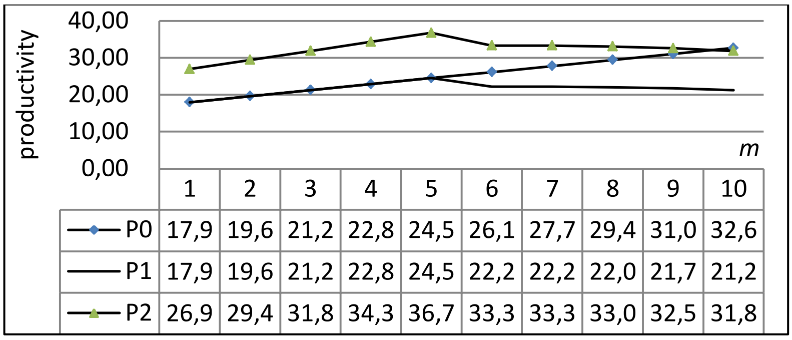
Scenario 3: This scenario (P2) intends to improve diminished productivity through enhancing teamwork. The coefficients are unchanged at *t*=0.7 and *e*=0.7, while *g* (teamwork) is increased from 0.7 to 0.8. Productivity measures as calculated using Equation (1) are shown in the P2 column of Table 8. Productivity increases from 26.95 to 31.85.

The value of *r* remains consistent at 1 in P0, as productivity was not diminished in this scenario. In the P1 column, however, increased manpower and the complexity of communications weakens productivity, which is at its maximum of 24.5 when the team is increased by five members. From this point onwards, productivity declines as the team size increases. In the P3 scenario, measures are taken to strengthen weakening productivity, such as promoting teamwork by providing incentives. The differences among the three scenarios are shown in Figure 5.

Table 8: Changes in Productivity of Project Team

N	e	t	P0			P1			P2		
			g	r	$\frac{Net}{(1-g)}$ r	g	r	$\frac{Net}{(1-g)}$ r	g	r	$\frac{Net}{(1-g)}$ r
11	0.7	0.7	0.7	1.00	17.97	0.70	1.00	17.97	0.8	1.00	26.95
12	0.7	0.7	0.7	1.00	19.60	0.70	1.00	19.60	0.8	1.00	29.40
13	0.7	0.7	0.7	1.00	21.23	0.70	1.00	21.23	0.8	1.00	31.85
14	0.7	0.7	0.7	1.00	22.87	0.70	1.00	22.87	0.8	1.00	34.30
15	0.7	0.7	0.7	1.00	24.50	0.70	1.00	24.50	0.8	1.00	36.75
16	0.7	0.7	0.7	1.00	26.13	0.70	0.85	22.21	0.8	0.85	33.32
17	0.7	0.7	0.7	1.00	27.77	0.70	0.80	22.21	0.8	0.80	33.32
18	0.7	0.7	0.7	1.00	29.40	0.70	0.75	22.05	0.8	0.75	33.08
19	0.7	0.7	0.7	1.00	31.03	0.70	0.70	21.72	0.8	0.70	32.59
20	0.7	0.7	0.7	1.00	32.67	0.70	0.65	21.23	0.8	0.65	31.85

Figure 5: Changes in Productivity vs Changes in Members

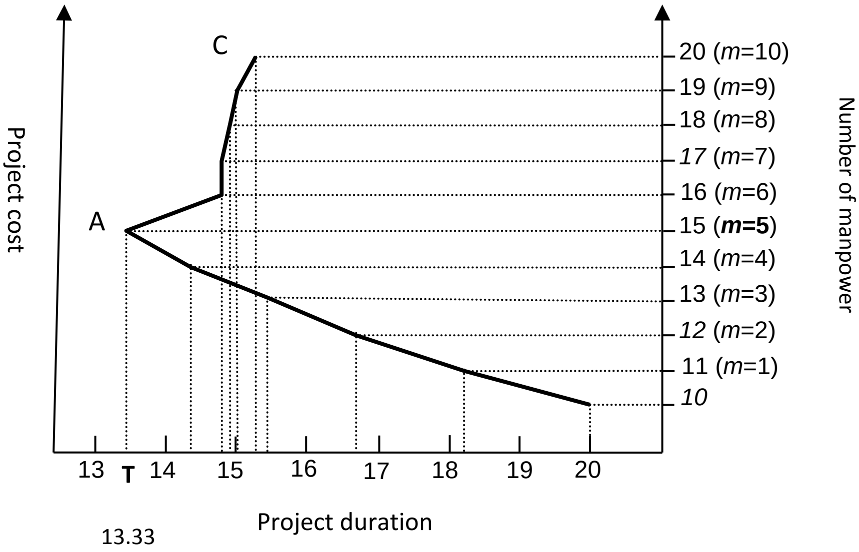


This section explores the effects of crashing on project duration. The original number of team members *N* = 10 and the turnover time T = 20 days. Productivity (**P_{II}**) values, as shown in Table 7, were converted into completion times as shown in Table 9. One additional team member reduced project duration from 20 to 18.18 days. Two additional team members further reduced duration to 16.67 days. Completion time was reduced to a minimum (13.33 days) when five additional members joined the team. However, once the team had increased by six members, duration increased to 14.71 days. This shows that increasing manpower heightens the complexity of communication, which weakens productivity. Figure 6 shows similar pattern to Figure 2 when crashing the example project, and the most suitable additional number of manpower *m* is found to be 5, and the corresponding shortest project duration T is obtained as 13.33 days. The project cost related to the number of manpower can also be easily computed, and because cost is not the focus of this study, therefore, it is not shown in Figure 6.

Table 9: Changes in Project Duration

Size of team	10	11	12	13	14	15	16	17	18	19	20
r		1	1	1	1	1	0.85	0.8	0.75	0.7	0.65
Project duration	20	18.18	16.67	15.38	14.29	13.33	14.71	14.71	14.81	15.03	15.38

Figure 6: Law of Diminishing Return of Example Project



5. CONCLUSIONS

In order to maintain their competitive edge in the volatile economy of today, companies must be adept at solving problems and creating opportunities in the shortest amount of time possible. Project management has become a popular way of business management as it allows companies to flexibly allocate human resources. In other words, solving a problem or creating an opportunity is identified as a project. A team is formed by managers to achieve the objective of the project, such as developing the next generation products within a specified timeframe. Projects have tight timeframes due to market competition, and increasing manpower is the most common method of reducing completion time. This is due to the common conception that more workers mean more work can be completed. However, increasing head count also increases requirements for communication, negotiation, and integration, which prevents team members from investing 100% of their time and efforts into the project at hand, diminishing productivity. This is known as the law of diminishing return. Although familiar with this principle, project managers do not have an in-depth understanding of how it can affect the productivity of their teams. This study therefore developed a quantitative model to verify the law of diminishing return by exploring how increasing team size weakens overall productivity. Considering number of team members, their experience, training, and teamwork, the model determines the number of team members that leads to optimal productivity and minimal turnover time. Project managers can use this model to determine how many additional members should be assigned to the team, in order to avoid waste of labor and decline in productivity. Two case studies were conducted, one involving a team of five and the other a team of ten, to demonstrate the applicability of the model, as well as carried out sensitivity analysis using three different scenarios. Results showed that project managers confronted with crashing can use the model to identify the optimal number of additional team members, thus improving human resource management. Authors believe that this study is the first theoretical verification of the law of diminishing returns and provides a more in-depth understanding of crashing, which has both academic and practical value to project management. It is recommended that future studies conduct further research on what factors affect project productivity and provide practical verification of same.

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