A NEW FRAMEWORK FOR DETERMINING PRODUCTIVITY FACTORS ON CONSTRUCTION SITES

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The productivity level within the construction industry is of direct interest to site managers and project management teams. Different researchers have tried to determine the factors that influence productivity but no general agreement could be made. The aim of this paper is to develop a conceptual framework on site productivity. Five major groups of independent variables, namely, project characteristics, labour characteristics, management system, resource management and the external environment are identified as crucial to site productivity. Based on these groupings, a conceptual model is to be developed to represent causal relationships. Once identified, this relationship is believed to be a useful piece of information to implement a project more productively.

KEYWORDS: resource management, productivity, project performance.

INTRODUCTION

It is axiomatic that the construction industry has a significant role to play in the economic growth of a nation. The industry employs a large number of skilled, semi-skilled and un-skilled workers and its activities provide work for the economic sector. The success or failure of the construction sector can therefore seriously influence the living standards of the population.

Site productivity is one of the most difficult factors to measure because its determinants can vary significantly depending on size of site and place of measurement. The definition of productivity ranges from industry-wide economic parameters to the measurement of crews and individuals. For instance, Single-Factor productivity measures such as Average Labour Productivity (ALP) looks at the impact of one factor input (labour), whereas total (Multi-Factor) productivity measures take into account the impact of all inputs and output. Crawford et al. (2006) provided an overview of methods used to measure productivity in the construction industry. It was concluded that most existing work provides a partial modelling of the production process, potentially resulting in biased productivity estimates. Furthermore, the simple-to-calculate output/labour input ratios used in most studies do not enable the establishment of robust cause and effect relationships, leaving the reader largely in the dark about drivers of performance and their relative importance.

In a more technical approach to measuring labour productivity, Radosavljević et al. (2002) have examined the complex variability of 12 construction labour productivity data sets by analysing the central moments of tendency, and applying the Kolmogorov-Smirnov and Anderson-Darling tests of normality. The results consistently show that the productivity is not normally distributed. In addition, undefined variance causes a failure of the central limit theorem, thus indicating that some basic statistical diagnostics like correlation coefficients and t statistics may give misleading results and are not applicable. A brief comparison with volatility studies in econometrics has revealed surprising similarity with Pareto distributions, which can model undefined or infinite variance. Such distributions are typical of chaotic systems like the logistic equation, whose properties also are described briefly. Therefore, it is suggested that future research should be focused on studying the applicability of chaos theory to construction labour.

Within the context of such theories, Winch et al. (2001) made an attempt to benchmark the on-site productivity in France and the UK. They conducted an interesting detailed analysis of structural concrete operations to compare the productivity performance of these two countries using the activity sampling approach CALIBRE. The results showed that the UK productivity performance is poorer than that in France, which can be explained by the elaborate divisions of labour, lack of investment in plant, and less effective work organization. However, it was further argued that these differences cannot be understood without reference to the overall contracting system and the constraints upon action that it imposes.

According to an earlier report by the European Construction Industry Federation (ECIF, 1996) the construction industry in Europe is facing a difficult time and the signs are that this crisis is not coming to an end in the near future. In the UK alone, between 1990-1996, 480,000-construction worker have lost their jobs. A subsequent survey by Arditi et al. (2000) of the top 400 US contractors were conducted in 1979, 1983 and 1993 indicated that cost control, scheduling, design practices, labour training, and quality control are the functions that consistently over the years are perceived as having considerable room for productivity improvement, whereas materials packaging and foreign developments in construction technologies are perceived consistently as functions that do not have much effect on improving construction productivity. The functions that were identified as needing more *improvement in 1993 compared with the previous surveys were: prefabrication, new materials, value engineering, specifications, labour availability, labour training, and quality control, whereas those that were identified as needing less improvement than in the previous surveys were field inspection and labour contract agreements. Also, respondents indicated consistently over the years that they were willing to participate in activities related to improving construction productivity but were not interested in funding any such activities.

A more recent study by Clarke et al. (2004) into productivity in social housing construction in England, Scotland, Denmark and Germany was apposite in demonstrating structural differences in the organization of the construction process, their implications for efficiency and productivity, and their impact on employment and contract relations as well as innovation and skills. The effects of the overriding cost rationale of the British system are illustrated in terms of labour deployment and the efficiency and productivity of the site construction process. This paper showed the high labour intensity in the British case, with 39% more labour needed to produce one m^2 compared with Germany and 50% compared with Denmark.

At the same time, the nature of labour deployment is qualitatively different being front-loaded in England, whilst in the other countries it is end-loaded in the sense that there is a gradual build-up of labour on site. It was also noted that the Danish building industry is facilitated by extensive prefabrication processes.

FACTORS AFFECTING SITE PRODUCTIVTY

In this paper, productivity factors are grouped under five main headings in an attempt to design a conceptual framework that links them together. These group headings are: project characteristics, labour characteristics, management system, resource management, internal and external environment. The purpose is to develop a conceptual framework that shows the interrelationship among these group factors.

Project characteristics

Type and size - Site productivity is determined by a number of factors, one of which is the type and size of the project including layout and complexity. Naturally, a large construction site requiring a large number of workers and will be relatively harder to manage than a smaller size. The difficulties in managing manpower on a large scale may result in productivity loss. A large proportion of high costs in construction works are as a result of excessive labour costs. These costs can be reduced if productivity on site is increased by improving labour efficiency. Thomas (1991) notes that work on a complex project such as the construction of a nuclear project becomes more difficult as the project advances. The construction method such as use of off-site pre-fabrication units will reduce the number of labour hours required. Other factors such as the level of skill amongst the workers and work practices and length of workday can affect productivity on construction site.

A further research by Proverbs et al. (1999) into construction resource and productivity level for high rise concrete construction was conducted among contractors across France, Germany and UK. For concrete placing productivity rates, none of the resource factors (material, plant or labour) when considered independently was found to be of significance. It was then concluded that international variations in concrete placing productivity rates were not connected directly to these individual factors. However, framework productivity rates were impacted by the type of framework utilized on column and beam work. The most unproductive rates were related to traditional timber solutions, while proprietary (for column work) and prefabricated (for beam work) solutions were associated with the most efficient (and hence most economic) productivity rates. Moreover, when working more than 5 days each week, the productivity of framework operations was found to decline.

Overcrowding – There is evidence to suggest that overcrowding leads to productivity loss. It has been suggested by Smith (1987) that a labour density greater than one man per 30 m^2 will lead to a decrease in productivity. According to Rad (1980) cited in Kaming et al. (1998), an average weekly loss of 5 hour per man resulting from congestion on nuclear power station sites. As working space deceases from 30 m^2 (standard working space) to 10 m^2 per operative, it incurs about a 40% productivity loss (Smith, 1987).

Thomas et al. (1985) conducted a comparative study in Europe to find out whether countries differ in their employment of sub-contractors. The result of their model based survey of contractors (planning engineers) in France, Germany and UK, indicated that the working schedule of UK and German contractors may be excessive, and can have an impact on construction productivity level. The survey also identified that the UK's labour force employed on site are 26% employed directly and 74% sub-contractors, but in France 93% of labour force on site are directly employed and only 7% are sub-contractors.

Factors related to Labour

Lack of measurement and benchmarking - Labour related factors affect the physical progress of any construction project. In order to improve labour productivity, site production should be measured on a regular basis, and then compared to an acceptable standard benchmarks. The management of each contracting company should maintain its own record which describing the baseline productivity in different previous projects with similar conditions. Enshassi et al. (2007) argues that such records can be used to help estimate labour productivity in future projects. For example, changes made to original scope of work are costly and have an effect on labour productivity and should be recorded. Although some changes are inevitable, the impact on site productivity is nonetheless significant. The impact of changes to original scope of work has been investigated by Thomas and Napolitan (1995). They studied the impact of changes in quantitative terms and discussed why change impacts on the labour forces efficiency. They also explored the relationship between changes and various types of disruption.

Labour efficiency - Efficiency is the relative loss of productivity compared with a benchmark setup in the original plan of work. The effect of changes on labour productivity was investigated by Leonard (1987). His study was based on a detailed review of 90 claim cases and the percentage loss of productivity was shown as a function of the total work hours spent on changes. The increase in the percentage of work hours spent on changes led to a 10-20% loss of productivity. Another study by Zink (1990) that dealt with labour efficiency and changes, suggested a measured mile method to quantify work hour overrun. Changes are considered as an indirect factor by many researches within the construction industry. However, it is also realised that changes themselves do not decrease productivity or efficiency, it is the manpower involved in the process. If a change occurs in the final stage of a construction project the crew must stop working until the changes are carried out first. Also the work method may require changes as well as more co-ordination being required. Once changes occur routine works will change, processes will slow and the total work hour will be several times greater. On average, there is a 30% loss of efficiency when changes are being performed, although it is possible to perform many changes without a loss of efficiency.

Skills and ability - Olomolaiye et al. (1998) explains that the personal attribution of workers contribute to the factors that directly affect productivity. He specifies these attributes as:

1. Worker's skills, experience, training and qualifications.
2. Innate physical and mental ability.
3. Intensity of the application of both skills and innate ability to the production process.

Management system

Decision support systems - Christian and Hachey (1995) found that delays and disruption within the construction site are created by idle and waiting times. An analysis and breakdown of delay would enable the management team to focus on this important and un-productive factor. The delays associated with waiting for supervisory instruction only occur when there are severe time constraints and problems with shortages of on-site managerial staff. In this context, the Construction Decision Support System for delay analysis [Delay Analysis System (DAS)] was developed by Yates (1993) to assist managers in decision-making process. The DAS brings together traditional project control techniques with interactive methods to produce a programme that can both monitor progress towards achieving project milestones and simultaneously it highlights the causes for deviations from established baselines. It also provides recommendations on how the management team can eliminate or minimize delay during construction periods.

Management influence - Thomas (1992) investigated the level of labour productivity for masonry activities from seven countries by selecting case study projects. Statistical analyses showed little difference in productivity amongst the seven countries, despite major differences in labour practice. The aim of this investigation was to show that productivity in Australia, Canada, England, Finland, Scotland, Sweden and the United States is similar but the principle difference was management influence. The site with the highest level of disruption had the worse productivity level on site. Other objectives of the investigation were to test the validation of factor model, the management influence on labour productivity and the level of control contractor has over labour productivity. Other investigations have shown that the labour disruption accounts for more than 50% of the variability in daily crew productivity (Sanders et al. 1989).

Variation orders - The variables affecting efficiency is believed to be the time of the change. Rework, disruption and presence of change work can lower labour performance (Thomas et al., 1995). Hanna et al. (1999) have identified the impact of changes on construction site and described that disputes are common between the client and contractors when these changes occur. Their study used data from 43 projects and a linear regression model was developed that predicted the impact of changes on labour efficiency. The model allows labour efficiency loss to be calculated in a particular project enabling both the client and the contractor to understand the impact such changes will have on labour productivity. However, this study is limited to mechanical trade with some specific plumbing, fire protection, and process piping. From a study carried out by Thomas and Napolitan (1995) over a period of 4 years, based on 3 projects, an equation was derived to calculate the efficiency loses from the impact of change order. Efficiency was defined as actual productivity ratio to baseline productivity. Baseline productivity was also measured for this survey. Efficiency was determined by dividing the performance ratio equation value on a normal day by the performance ratio equation when change order had occurred. The survey result showed an average loss efficiency of 30%. Change order impact on a project lowers labour efficiency and productivity. The result of a survey by Hanna et al. (1999) indicated that labour efficiency on a job that is not impacted by change has a higher level of efficiency. Disruption which was also found to cause changes in the original plan of work increased the project cost through re-work and decreased labour efficiency for the main contractors and sub-contractors.

Factors related to resource management

Material - Ferguson et al. (1995) suggest that 50% of the waste deposited in disposal sites in the UK is construction waste. In order to reduce waste and increase productivity Just-In-Time (JIT) has been introduced on construction sites. Pheng and Tan (1998) investigated whether the introduction of JIT can reduce the level of wastage on site. Their investigation showed that wastage of materials could be kept to a minimum and consequently productivity improved. From the result of the survey, both project and site managers did not regard wastage on site as an important factor in improving construction productivity. Faniran and Caban (1998) suggested that wastage on site could be reduced if design changes were kept to a minimum during the construction work. The respondents also identified leftover material scraps, waste from packaging and unreclaimable non-consumables, design/detailing errors, and poor weather as being important sources of construction waste.

Material management is a worldwide problem and ongoing researches have been conducted to highlight its effect on site productivity. Abdul Kadir et al. (2005) in their research into factors affecting construction labour productivity for Malaysian residential projects, found that material shortage at site as well as non-payment to suppliers causing the shortage of material delivery to site as highly important. Other factors that can cause time and cost overrun and subsequently affect productivity are change order by consultants; late issuance of construction drawing by consultants; and incapability of contractors' site management to organize site activities.

Waiting time - Christian and Hachey (1995) found that delays and disruption are created by idle and waiting time. Hester et al (1987) in his study into interruption time, found that the level of productivity for pipe work installation can be reduced by 70% when installation work was interrupted by more than one interruption per section of pipe work. Interruption lasting longer than a half hour was found to cause productivity loss of about 35% during a working day. Thomas et al. (1992) also found that disruption has a major effect on labour productivity. The average daily productivity for non-disrupted days was 0.44 work hours / m^2. Disrupted days had an average productivity of 2.16 work hours / m^2, an average increase of 388%. The respondents identified that ‘delays and disruption caused by design team mistakes’, can have a negative impact on productivity levels. Project managers identified ‘delay and disruption caused by late arrival of materials’, as a determinant that can reduce the level of productivity ranking this factor as the fourth most important determinant of productivity. Site managers ranked this factor as the seventh most important determinants of productivity.

Leadership - The construction process is a collective effort involving a team of specialists from different organizations. The leader of the team may affect the productivity of the design and construction. The person who leads the team varies dependent upon the contractual arrangement adopted for the project. A number of studies have been conducted to investigate the relationship between leadership styles and productivity rate. For example, Cheung et al. (2001) carried out an empirical survey that aimed to establish the relationship between leadership behaviours of design team leaders and the satisfaction of the design team members. The results indicate that charismatic and participative leadership behaviours primarily determine the satisfaction of the team members.

Motivating factors - Motivation is a prime determinant of worker performance. As far as known, researchers have failed to develop a commonly agreed theory that addresses worker motivation that is valid and relevant to the construction industry. A key motivator for one worker compared with another worker in a certain situation may differ. Individuals tend to seek a job, which will satisfy personal needs. Key motivators may be one or a combination of the following: high achievement, recognition, the nature of the work itself, responsibility and personal advancement and growth. In the view of some researchers, it appears that there are differences in opinion whether workers motivation contributes positively or at all to the level of productivity on construction sites.

A number of behavioural and psychological researchers have argued that the expenditure of effort by a worker is the physical manifestation of motivation. The greater worker motivation is, the greater the worker motivation becomes. For example, Kazaz et al. (2007) showed that monetary factors in Turkey remain pre-eminent in influencing productivity, but that the socio-psychological factors such as giving responsibility and taking account of cultural differences appear to be increasingly importance in a developing economy.

On the other hand, ranking on questions related to motivation showed that there is little support for the suggested motivating factors on construction site. For instance, Olomolaiye (1990) used a model to define how a bricklayer spent a working day on site. With the help of a computer aided activity-sampling package, his investigation showed that motivational issues did not influence the rate of work.

Others researchers argued that other independent factors such as lack of tools, shortage of materials, delays in decision-making by management, change order, late forwarding of information etc, can all have an indirect impact on worker satisfaction and therefore affect productivity on site.

Ranking of questions related to the hygiene factors on productivity showed that, in the view of the project or site managers, there was no strong correlation between: company policy, relationship with equals, relationship with sub-ordinates, status, and personal factors on the level of productivity on construction site. The only factors that seem to be of importance to the respondents are salary and supervision.

Other factors such as high salary and job security are other factors for high productivity among firms. Training is also considered to be an influential factor in high productivity on construction sites. In recent years the growth in labour only sub-contracting on sub-employment bases in UK construction sector and the level and quality of training within the industry is a source of concern. Productivity within the UK construction industry compared with West Germany and France is partly the result of low levels of training labour force receive in UK (Prais and Steedman 1986). In this context, UK government policy has emphasized the role of skills development and training as a means of improving productivity performance across all sectors of the economy. According to Abdel-Wahab et al. (2008), there is inconsistency in the industry's productivity performance, despite the overall increase in qualification attainment levels and participation rates in training over the same period. However, the year-by-year change in the participation rate of training was not consistently associated with an improvement in productivity performance. Therefore, there is an urgent need to consider skills development and training within the context of construction businesses in relation to other factors in order to unpack how skills can bring about improvement in productivity performance.

Resource planning – Many researchers have cited ineffective resource management as the primary cause of poor productivity rather than an unmotivated and unskilled workforce. For example, Allmon et al. (2000) revealed four primary ways of increasing productivity through management, namely planning, resource supply and control, supply of information and feedback, and selection of the right people to control certain factors.

The result of a model based survey by Proverbs et al. (1996) of contractors planning engineer in France and UK suggested that planned construction time for an identical high rise in-situ concrete framed structure in France is 9 weeks faster than UK. It takes French contractors 13 weeks where the average of 22 weeks is recorded for UK firms. French firms work less hours per week but are more productive when compared with UK firms. Since planned construction periods reflect past experience, French contractors appear to achieve superior levels of productivity on site, because they utilize directly employed workers and have less supervisors on site. The causes of high productivity amongst French contractors are:

- Scheduled overtime is avoided.
- Labour force is directly employed.
- They are main skilled work force.
- The maximum of 40 hour per week is the norm rather than the exception.

Naoum (1996) conducted a survey into productivity factors in construction to find out, first, whether there are significant differences in opinions between head office personnel and site managers on factors that influence construction productivity and, second, to determine groups of factors that mostly influence site productivity. A critical discussion was structured under three general headings: (1) management factors; (2) employee motivation; and (3) experience and training. Twenty-nine factors were extracted from the above headings and were assessed by 19 head office personnel and 17 site managers. The survey indicated that both samples regard 'ineffective project planning' and 'constraints on a worker's performance' as the most crucial factors influencing productivity. Other highly ranked factors by both samples are 'difficulties with material procurement', 'lack of integration of project information', 'disruption of site programme', 'lack of experience and training' and 'exclusion of site management from contract meetings'. Ultimately, when the factor analysis technique was applied on the 29 factors, the result shows that Resource Management Effectiveness appeared to be the most dominant group of factors influencing construction productivity.

This was later confirmed by Doloi (2008) in a research into the application of Analytical Hierarchy Process (AHP) in improving construction productivity from a management perspective. Anecdotal evidence suggests that workers' attitude towards high productivity may not be limited to purely financial rewards, but inherently linked to many other latent factors. This research shows that the biggest influences on productivity are planning and programming.

Impact of external environment

Technology - Technology has had a great effect on productivity output within the construction industry. Technological advancement has resulted in considerable changes to most tasks on construction sites. Machinery has become more powerful and complex. This new technological advancement requires new manpower skills to ensure proper and full use is made. It is becoming increasingly problematic to separate the contribution made by management, labour and machinery, to productivity. Innovation within the construction industry faces many barriers such as diversity of standards, fragmentation, business cycles, risk aversion and other factors, which all produce a complex and unfavourable climate, in which to work. High labour costs within the construction industry is a strong reason for this industry to move towards new technology. One of the reasons that many construction firms are reluctant to move towards new technology is the risk it carries if the new technology proves to be ineffective. The cost of changes may prove to be too high for the firms and may put their future in jeopardy. Heap (1987) argued that productivity could be improved if manpower is replaced by modern high capacity plant and equipment. In most developing countries with limited capital, mechanization may increase the unemployment. Other problems associated with introducing modern machines and equipments include costly and complicated maintenance, with machine downtime contributes towards a fall in productivity. Baldwin (1990) believed information technology would revolutionise management information systems and help management obtain accurate information that leads to faster and more accurate decisions on site. So far many productivity studies tend to concentrate on improving the technology related to the construction site. Rapid mechanisation within the industry has resulted in increasing productivity by the introduction of structural steel, system form work, pre-casting techniques, pre-fabrication and component manufacture, but the construction industry requires more innovation to remain competitive among other sectors.

Weather - The factor model by Thomas (1987) evaluated the effect of temperature and relative humidity on productivity. Multiple regression techniques were used to explain approximately 40% of the variability in the daily productivity data. Other statistical parameters are also described. The results of the weather model are compared to similar relationships reported by other researchers. The relationship developed by the writers is consistent with those reported in the literature. The factor model and the methods used to develop the weather model appear to be valid because the discounted productivity curve has less variability than the original productivity data. Lastly, an example is presented that illustrates the way in which impact of weather on productivity can be evaluated.

THE CONCEPTUAL FRAMEWORK

The model in Figure 1 shows the interrelationship between the factors that can affect productivity on a construction site (Naoum 2001). The purpose of the model is to represent or explain the phenomenon of the productivity issue. In this way, managers can assess and predict what needs changing to improve the productivity level on a construction site as well as for developing a strategy for achieving the change.

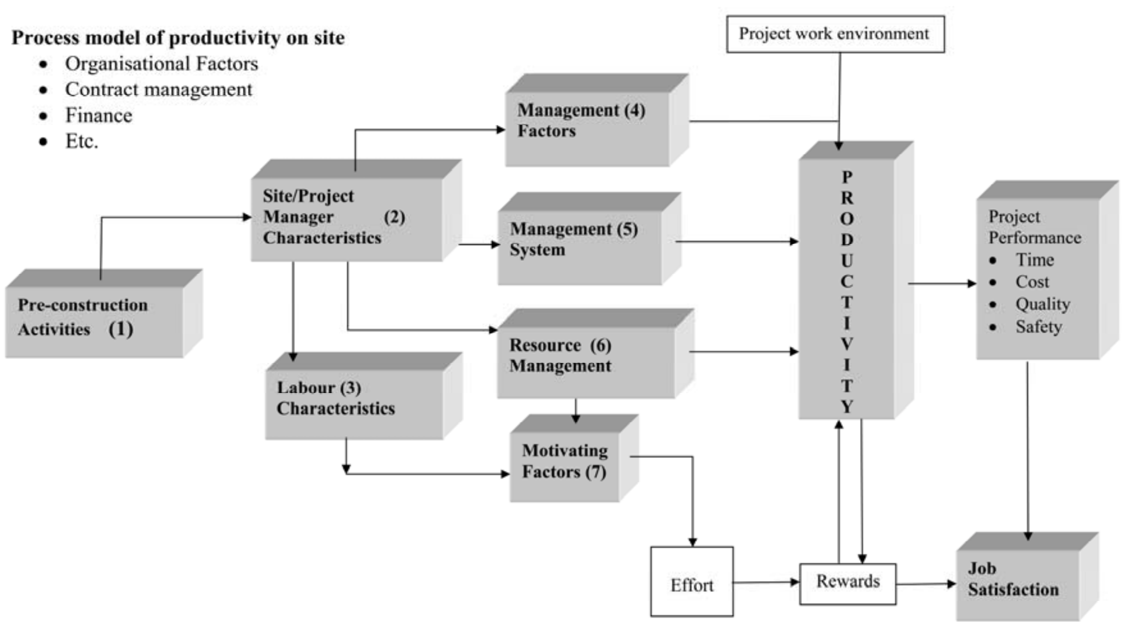

Figure 1: Factors affecting productivity on construction sites

Executive manager's responses can either reinforce and identify the productivity problem, or create pressures to change it. Much depends upon how sophisticated a diagnostic model the manager's use. For instance, one of the factors that can influence productivity is motivation of the workforce. Achieving high motivation depends on the working environment where financial or physical rewards can be regarded as an incentive for the efforts needed in achieving high productivity. In order to assure a good working environment, the management of resources needs to be highly effective, as recommended by previous research.

CONCLUSION

This paper reports on past and recent literature available into productivity in the construction industry. It has presented a conceptual framework that includes and groups the identified variables affecting site productivity. This framework is currently being used by the authors as a base model to test these proposed causal relationships. The term productivity has been defined by Naoum (2001) as the number of units (output) to be produced in a spell of time, utilizing an optimum number of human and non-human resources (inputs) in a safe and efficient manner. A high rate of productivity level can be achieved by eliminating the unnecessary wasteful resources from the construction operation by means of the following:

- using the Socio-Techno-Managerial approach,
- technically by an efficient planning and scheduling of the resources,
- socially, by creating the work environment that can motivate and lead the people effectively,
- managerially, by designing an efficient management system to communicate, co-ordinate and control the work activities.

The main hypothesis of the model shown in Figure 1 is that "site productivity is a function of pre-construction activities, the characteristics of the project manager/site manager, labour characteristics, management activities, the management system adopted, efficient management of the resource and the motivation of employees". These variables are both interrelated and intra-related. Once identified, this relationship is believed to be a useful piece of information to implement a project more productively.

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