59 Productivity Improvement in the Construction Industry: A Case Study of Mechanization in Singapore

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Abstract

Globally, the construction industry is a key contributor to national economies including Singapore's. However, the industry is a serial productivity underperformer. The literature argues that mechanization, automation and use of advanced technologies help improve construction productivity, but real-world case studies are limited in number. This paper presents a case study of the introduction of mechanization to improve the level of construction productivity in Singapore. The case study under investigation was the production/fabrication of steel gratings, the conventional process of which depends heavily on labor with few workers present on site. The majority of these workers are migrant workers, which contributes to a significant social concern in Singapore. The case study organization introduced a more advanced laser cutting machine to the process. The project team observed the process of using the laser cutting machine, and quantitative and qualitative data were obtained. The researchers observed the processes, both conventional and updated, and recorded the data on both methods. The quantitative data were comparatively analyzed to investigate the relative quality, efficiency and productivity of the two methods. The data revealed that the mechanization process achieved a productivity improvement (or savings) in man-days of at least 78%. Material wastage was reduced, and moreover, less reliance was placed on migrant workers, which helped to mitigate the social concerns created by the influx of foreign workers to Singapore. The findings also shed some light on the positive influence of government incentives to improve the industry's productivity.

Keywords

Construction industry • Productivity • Automation • Mechanization

59.1 Introduction

The construction industry provides a massive contribution to civilization and urbanization, and it is one of the most important industries in the world. The construction industry contributes significantly to the gross domestic product (GDP) of Singapore (5%) [8]. As stated in HOME [7], the construction industry in Singapore depends heavily on manpower, and more than 85% of the total construction workforce is made up of foreign workers. These workers are mostly unskilled and come from developing countries. The number of projects in Singapore is increasing at the same time as wages are rising and a shortage of local workers is making the country more dependent on foreign labor.

As the demand for housing and infrastructure increases, the productivity and efficiency of the construction industry must improve to meet it. The well-being and standard of living of a nation can be affected by the level of productivity in three ways: national competitiveness, real income, and quality of life [11, 12, p. 4]. Domestically produced goods will be less

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competitive if the level of productivity in the country does not increase as fast as in other countries. A nation's real income does not grow if the production of goods and services using the relevant resources is low [11, 12, pp. 3–4].

Productivity is the economic measure of the amount of output produced per unit of input [10]. Construction output is usually measured in length, weight or volume, and the input in man hours or labor. The government of Singapore has set an ambitious target of raising construction productivity by two to three per cent per year to 2020; raising productivity is the only viable route for the construction industry. The use of mechanization and the upgrading of workers' skills will help companies to lower their costs in the long term [3]. Productivity increases also help to improve a country's quality of life. The influx of foreign workers can create social problems, including overcrowding. There are currently 1.32 million foreign workers in Singapore, and this has increased social tensions; the government has received many complaints about overcrowding on trains and buses, for example [16]. Therefore, it is important to address ways to reduce the construction industry's reliance on labor.

59.2 Background

59.2.1 Mechanization to Improve Productivity

The construction industry depends heavily on manpower, especially in Singapore. Until now, Singapore's construction industry has depended a great deal on cheap foreign labor for certain types of work, such as tiling, fabricating steel gratings, plastering etc., and less on advanced technologies. The foreign workers come from nearby developing countries, and anecdotal evidence suggests that most have little or no experience working in the construction industry. Many of these workers have little education and do not have any knowledge or proper skills to work in the industry. With the increase of migrant workers in the industry comes a concern about safety management. Because workers face literacy, comprehension and other language barriers, safety education and training on site are not effective [4]. This not only increases the number of injuries and fatalities, but also decreases the level of construction productivity on sites.

Designs of buildings/structures are becoming more and more complex, and space on construction sites is becoming more and more limited. As a result of this, many countries are trying to adopt different type of advanced technology and mechanization to increase productivity [9, 15, 17]. For example, the Malaysian construction industry, facing problems such as low productivity, labor shortages, decreasing quality, safety issues etc., is trying to adopt innovative technology such as the industrialized building system (IBS) as an alternative to conventional construction methods [17]. Hong Kong's Housing Authority has adopted prefabrication technology for its projects, and this has proven to be beneficial in terms of environmental degradation, material wastage, and productivity [15]. It is recommended that wider adoption be achieved through government regulation and controls, and the provision of incentives. Some construction companies in Nigeria also relied heavily on labor, which caused delays and low quality outcomes. These problems were solved by mechanization [9].

59.2.2 Singapore Initiatives

The Productivity Innovation Project (PIP) Scheme is part of the S$250 million Construction Productivity and Capability Fund (CPCF) introduced by Singapore's government to help the construction industry improve its productivity and capability. The aim of the PIP Scheme is to encourage prefabricators and contractors in Singapore to begin development projects that will improve their site processes and to build up capability to achieve higher on-site productivity. This scheme also helps contractors to adopt labor-efficient technologies, or to re-engineer site processes to improve productivity or reduce the dependency on on-site workers. The types of cost supportable under this scheme include equipment, manpower, professional services/subcontracting, materials and acquisition of intellectual property rights. This financial support is provided on a reimbursement and co-funding basis. Under the standard PIP Scheme, the company can be co-funded up to 50%, capped at S$100 K per application, if the technology could improve productivity or generate savings in man-days of at least 20%. Under the enhanced PIP Scheme, the company can be co-funded up to 70%, capped at S$300 K per application [1].

59.3 Methodology

The case study organization (CSO) is a building and civil engineering company in Singapore registered as grade B2 for general building work and grade C1 for civil engineering work by the Building and Construction Authority (BCA). It employs 175 workers and has an annual turnover of S$20–25 million. The company is involved in public and private building, landscaping and infrastructure projects in Singapore.

The CSO has applied for support under the BCA's PIP Scheme for the use of laser cutting machines for their projects. The present study involved engagement with the experiments related to the introduction of this new machine. This study was carried out to comparatively analyze the productivity of the laser cutting machine in the manufacture of steel drain gratings compared to the conventional manual method. Recently, a laser cutting machine was purchased to take over the work. The machine is able to fabricate various metals, such as steel, aluminium etc. As an experiment, the CSO carried out production of steel gratings using both labor-based (conventional) and the laser cutting machine (new) simultaneously in the fabrication yard.

Data Collection and Test Protocol: The project team observed both the conventional and new processes during the real-time experiments. The project team observed and recorded the fabrication activities. Quantitative and qualitative data relevant to the processes were recorded, for example, the number of steel gratings produced and labor requirements. Figure 59.1 illustrates the experimental setup with conventional, manual (a) and the Bystronic BySprint Pro laser cutting machine-based (b) methods. The activities involved in each method were recorded, and are shown in Table 59.1.

(a) conventional method (b) Bystronic BySprint Pro

Fig. 59.1 Experimental set up

Table 59.1 Activities of conventional, method and the new method using a laser cutting machine

Conventional method (CM)	New method (NM)
Activity 1. Procurement of flat bars to size as per drawings	Activity 1. Procurement of plate to size as per drawings
Activity 2. Cutting of flat bars to the defined size (shearing machine, 1 operator required to feed)	Activity 2. Pre-program (one-off process) sizes/quantities in Computer Numerical Control (CNC) software
Activity 3. Collection of material from shearing machine, moving material to next station to notch and punch holes (multi-function iron worker m/c, 1 operator required)	Activity 3. Cutting of metal plate: place the metal plate on the laser cutting platform and initiate the machine to start the cutting process (1 operator required)
Activity 4. Straightening flat bar-tend to bend in iron worker machine (semi-skilled manpower required)	Activity 4. Laser machine starts to cut plates as required
Activity 5. Grinding grating after assembly in the assembly station. All the processed materials from activity stations 2 to 4 are collected to be ground flat to minimize fabrication tolerance, and this is followed by fitting the flat bars to form a grating as per drawings (1 fitter required)	Activity 5. Assembly work (1 fitter required)
Activity 6. Fabrication process at next station, all assembled/fitted gratings are fully welded and will be sent out for next process, galvanization (1 welder required)	Activity 6. After assembly, cut pieces fully welded to send for galvanization (1 fitter required)
	Activity 7. The completed product is sent to the site for use

59.4 Data Analysis and Results

Observations of the activities discussed in Table 59.1 revealed the following advantages of the new method:

- Wastage of material was minimized (NM: Activity 1 and NM: Activity 2) when procuring the plate of the size compared to the conventional method (CM: Activity 1 and CM: Activity 1). This was because the CNC software can generate cutting patterns which maximize material usage.
- Once the laser cutting is started, the operator was no longer needed (NM: Activity 3), in contrast to the conventional method where the operators presence was needed to feed material to the shearing machine (CM: Activity 2).
- The laser cutter started to cut the plates as required in Activity 4, which removed a number of activities in the conventional method (CM: Activities 1 to 5).
- Assembly work in the new method (NM: Activity 5) could be done without grinding due to the use of more precise high tech cutting technology. This enabled immediate assembly.

The laser cutting machine was able to cut metal sheets and other materials up to 4 × 2 m, and the process is fast and economical. Alignment and nozzle exchange are automated, and this increased autonomy reduces the need for an operator to intervene. The machine possesses the latest piercing and cutting technology, minimizing cutting time and producing good quality with high efficiency across various thicknesses of material. The observations also revealed that the machine was able to reduce noise and smoke emissions compared to the conventional method. Further, the laser cutting machine can also precisely produce different patterns on the steel (Fig. 59.2).

Table 59.2 shows a quantitative and qualitative comparison of the two methods. The total cost savings for labor using the laser cutting machine in comparison to the conventional manual method is S$11.02 per square meter. In terms of area,

Fig. 59.2 Wide variety of patterns cut using laser cutting machine

Table 59.2 Comparison of the two methods

Activity	Conventional fabrication method	Laser cutting fabrication method
Material	It must be in flat bars to start fabrication. Possibility of wastage	Any size of plate can be used; wastage is minimized
Cutting to size with shearing machine using manpower	Required	Not required
Punching and notching with iron working machine using manpower	Required	Not required
Straightening and grinding before assembly of grating using manpower	Required	Not required
Fabrication tolerances	More tolerance required	Less tolerance required
Production per day	18 m^2	60 m^2
Labor hours required	32 man hours	24 man hours
Labor cost per square meter	S$14.22/$m^2$	S$3.20/$m^2$
Output productivity	0.56 m^2/man-hour	2.5 m^2/man-hour
Over-all man-day saving—78%		

productivity is improved from 18 square meters per day to 60 square meters per day which is equal to 78% saving in man day.

The results show that it is more efficient, cost effective and productive to use the laser cutting machine to manufacture steel drain gratings. Only one operator is required during the whole process, and their task is simply to place the materials into the machine. The use of mechanization not only reduces reliance on labor, it also reduces material wastage, simplifies the processes, and more than triples productivity.

Among the findings are also the perceived challenges to implement the new technology. The senior management of the organization perceived some barriers to implementing the new method. The data also revealed that the new method required a significant amount of investment as capital cost. The relatively large amount of space required was also recorded as a challenge for small-medium enterprises (SMEs) in a country like Singapore, where land is scarce. There were also concerns raised about the potentially high electricity demands and the resulting economic challenges due to utility bills. The requirement of a qualified CNC programmer during pre-programming (NM: Activity 2) is also a challenge.

59.5 Discussion and Recommendations

Return on investment over time

The experiments revealed a significant productivity improvement through mechanisation, reduced reliance of labour, wastage minimisation (through the process' greater versatility), and higher quality products. However, due to ongoing barriers to implenentation and operation, mechanization might be more economical for high volume fabrication. Robust research conducted over time with rigorous return-on-investment analysis is needed to verify these observations and to identify suitable applications.

Support Structure for the investment cost

Successful adoption of new technologies depends on the capability and capacity of the construction company in question and on economic factors [13]. The high cost of the machinery and equipment is a major barrier to adoption for contractors. Research suggests that construction project clients should provide financial support to contractors for the purpose of purchasing the required equipment [9]. Government policies and incentives have been argued to be a major motivator for construction innovation [5, 6, 14]. The Singapore government's incentives on [1, 2] were perceived to be a motivator for innovation adoption. Further support though, for example, policies to reduce equipment costs or to provide exemption from duty will encourage mechanized construction.

Raising Awareness

Raising awareness of the benefits of mechanization can influence wider adoption of advanced technologies in the construction industry. Such awareness of mechanized construction allows stakeholders to realize its potential productivity and quality improvements [9]. Local campaigns to inform companies of success stories through BCA's portal and other websites are recommended. Sharing of real-world case studies by academics and the industry also raises international awareness.

Education and Encouragement

Studying previous successes in educating and changing the mind-set of people in the industry are another important way to ensure that the government's initiative will be successful [15]. Although many big and established contractors in Singapore are using advanced technologies for their projects, it is still important to encourage SME contractors to adopt these technologies so that the overall level of productivity in the country is raised.

Potential Technological Advancements

In future, laser cutting machines could be enhanced to cut larger architectural features, such as window frames, gates, doors etc., and the rate of production using the laser cutting machine can be further improved. 3D printing is also becoming increasingly popular and more advanced for the building and construction industry, and it could become the next most important technology for construction companies to adopt. Productivity levels could be improved tremendously if 3D printing can be integrated into laser cutting machines.

Government Role

The literature suggests that successful implementation of advanced technologies depends on existing government policies and incentives, and on the cost of adopting the system in question [13]. The government of Singapore could introduce new policies and provide incentives to encourage stakeholders in the construction industry to mechanize. In addition, the government could take the initiative to encourage and motivate wider adoption of new technology in the industry. Further, government could introduce a merit point system (similar to the current Buildable Design Score, and Constructability Score in Singapore) to contractors who adopt mechanization and advanced technologies for their projects, and these points would provide an advantage in applications to secure future public projects.

Because productivity is critical to the economy, a restructuring exercise was launched in 2014 to bring Singapore to a higher level of growth. The government provided generous monetary grants and tax reduction incentives, such as the Construction Productivity and Capability Fund (CPCF), Capability Development Grant (CDG), and Productivity and Innovation Credit Scheme (PIC) to offset the expenses. All of these call for growth integration. Studies show that the number of locals entering the workforce each year will shrink by 80% (to about 20,000 people), a significant decline [18]. This will lead to a costly labor squeeze. The Ministry of Manpower (MOM) has warned about the daunting difficulties for businesses, and has signaled that practices in work, communication and business are shifting to a totally technology-oriented model.

Industry should also take advantage of the support that the government is providing to up-skill their workforce when re-training for new technologies will enhance productivity. The trend in the direction of a labor crunch should be recognized, and organizations should venture into sophisticated processing machines requiring highly skilled workers. Singapore has the following schemes: Workforce Training and Upgrading (WTU), BCA-Industry Built Environment Undergraduate Scholarship/Sponsorship, Building Information Model (BIM), and the Mechanization Credit (MechC) etc. under the Construction Productivity and Capability Fund (CPCF). These incentive schemes allow the local construction industry to further develop its workforce, engineering capability, and technology adoption. The Investment Allowance Scheme (IAS), administered by the BCA, and the Productivity and Innovation Credit (PIC), administered by the Inland Revenue Authority of Singapore (IRAS), are tax deduction schemes that encourage businesses to improve their productivity [2].

59.6 Conclusions

Construction is an important industry for many countries and it contributes significantly to GDP. Globally in recent years, the focus and attention on construction productivity has been high. Many contractors in Singapore still rely heavily on labor to do the work, as this is a cheaper and more direct option, but this method also hinders the growth of construction productivity. The dependency on labor can also lead to material wastage, as human error is unavoidable. This research investigated the level of productivity and cost saving that adoption of mechanization could provide compared to conventional process in a specific case study organization.

Manual labor can only produce 18 square meters of steel grating per day, while laser cutting machines can produce 60 square meters per day. The number of people required to use a laser cutting machine is only one at any given stage, resulting 78% saving in man-day. This result shows that the level of productivity increased significantly, and that higher cost–savings were achieved when steel gratings were manufactured using a laser cutting machine instead of manual labor. It was also observed that the new method emitted less noise and smoke but improved the quality of production.

The project's relatively short duration prevented the researchers from conducting a comprehensive test and data comparison between the use of conventional cutting methods and mechanization, and this was a limitation of the current project. This could be investigated, together with a return-on-investment analysis of new equipment, in a robust future study.

This research is able to convey and raise awareness of the importance and benefits that productivity can bring to national economies and to the construction industry. It allows construction companies which are still dependent on labor to learn most of what they need to about the technological innovations they can adopt to improve their productivity. This study will also raise awareness of the usefulness of incentives similar to those provided by the government of Singapore and their impact on SMEs through the case study project. Such incentives will relieve the financial burden when adopting mechanization and are expected to motivate firms to adopt similar technologies.

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