MEASUREMENT AND ESTIMATION OF LABOR PRODUCTIVITY IN HONG KONG PUBLIC RENTAL HOUSING PROJECTS

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CERTIFICATE OF ORIGINALITY

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ABSTRACT

Labor productivity is of parametric importance to the construction industry. In Hong Kong, the construction industry failed to provide effective methods to measure and estimate labor productivity. Although previous research had developed a variety of labor productivity models with considering the impact of numerous factors, the direct application of these models in Hong Kong construction industry could be criticized due to the unreliability in data sources and the uncertainty of the quantitative results of the influences of factors. This study aimed at exploring the appropriate measurement and estimation method of labor productivity for public housing projects in Hong Kong. Based on a public rental housing project, a macro-level analysis was launched by utilizing work sampling techniques to acquire the overall labor performance in rebar fixing, formwork operation, and concrete placement of structural framing of the project. Concerning the effect of the influential factors, a micro-level analysis in which the data of rebar fixing activities were collected by utilizing real-time observation was also undertaken to analyze the labor productivity variation trends and to quantify the effects of weather-related factors and buildable factors on labor productivity. Taking the result of the two-level study into consideration, the labor productivity checklist was developed to provide a baseline for labor productivity in both optimistic estimation and pessimistic estimation for each type of component involved in this study. Finally,

comparisons had been made to conclude the consensus and the distinction between this study and literatures. It is expected that the research will shed some light on the productivity measurement and estimation in Hong Kong construction industry, and will contribute the body of knowledge in how the influential factors affecting labor productivity at component level.

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CHAPTER 1

INTRODUCTION

1.1 Background

Labor productivity is of parametric important for the economy of Hong Kong. Limiting with sluggish population growth and other resources, a growth in labor productivity is a positive way to improve the supply factor of the economy, as a unit of input can generate more outputs, thereby enlarge the capacity of the city (Government Logistic Department, 2012).

As with other countries, construction industry plays a critical role in Hong Kong's economy. The report from the Census and Statistics showed that the total receipts of Hong Kong construction sector of 2012 had amounted to $250.0 billion, while the figure of the real estate sector was $187.3 billion (Census and Statistics Department, 2012b). The total employees in construction industry had reached 290,700 which accounted for 8% of the total 3.66 million employees in Hong Kong. As several researchers have concluded that the cost regarding to labor can account for about 25% of the overall cost in construction projects, labor productivity has become a major concern for negotiators, estimators, and the people who are in charge of training labors as well as settling cost indices (Burton, 1991; Motwani et al., 1995; McTague and Jergeas, 2002; Jarkas and Bitar, 2011).

Nevertheless, the construction industry measures labor productivity inadequately, as the statistics of labor productivity has yet to be officially provided by the government for Hong Kong construction industry. The Census and Statistics Department (2012a) published a special edition of Monthly Digest of Statistics summarizing the Labor productivity Index (LPI) changes from 2000 to 2011, which showed that the LPIs increased for 3.1% annually in 2011. It should be noted that only six major economic activities constituted the data. The construction sector, however, one of the pillar industries in Hong Kong, was not included due to limitations in chain volume measure of government and business services estimated by input cost and labor input methods. It was believed that labor productivity of construction industry exhibited a decline trend over decades (Briscoe, 1988; Christian and Hachey, 1995). A decline of productivity was also reported in the Hong Kong construction industry (Walker and Chau, 1999; Wang, 2007). With the view to the size of the construction industry, the Labor productivity Index may lead to distortion and misunderstanding of labor productivity, which is aside from the reality.

The industry failed to provide a baseline of labor productivity, which is of parametric importance in the management of construction project, since labor productivity estimation value could enable contractors to achieve better performance in estimating, planning, and scheduling (Sanders and Thomas, 1991; Sonmez and Rowings, 1998). From a contractor's prospective, labor productivity is one of the most prominent factors affecting costs and time in construction projects (Al-Saleh, 1995; Mahamid, 2011). In the tendering stage of a construction project, the project manager is interested in understanding the estimation value of labor productivity to evaluate how much time and cost should be allocated (Moselhi and Khan, 2010). The measurement and estimation of labor productivity is also crucial in project execution because it provides a baseline to ensure well-prepared plans and schedules, and minimize the losses in capital, time, and other resources (Chang, 1991). These saves can directly translate into profitability, which determines the competitiveness of any profit-oriented organization (Mojahed, 2005).

To measure and predict labor productivity cannot be achieved without considering factors affecting productivity. Various factors, for example, the weather conditions, the buildable factors, etc., have been identified from previous researches, which have long-term or short-term impact on labor productivity (El-Rayes and Moselhi, 2001; Jarkars, 2010a).

Weather-related factors change daily and also significantly affect labor productivity in every project in one way or another (Thomas and Yiakoumis, 1987). The impact of weather-related factors on labor productivity can be enormous. Quantitative studies have demonstrated that weather can account for as much as a 30% decline in productivity (Thomas et al., 1999). Unlike the works in manufacturing industry that are usually operating in an indoor environment, construction works usually take place in an open area that the physical environment is unstable (Mohamed and Srinavin, 2005). Moreover, the construction works were carried out with four seasons in many projects. Factors such as adverse weather, temperature, and humidity cannot be easily controlled (Balci, 2004). Accordingly, construction tasks are adversely influenced by weather-related factors such as unexpected bad weather that can even cause suspension of construction (Halligan et al., 1994; Lee, 2003). Typical weather-related factors affecting labor productivity include cold, heat, inclement weather (rain, wind, snow, ice), and availability of weather protection (Klanac and Nelson, 2004). Regard of the geographical characteristics, a variety of weather factors, for example, the high temperature and the high rate of relative humidity, etc., may seriously affect productivity in Hong Kong construction cases.

Project-related factors and buildable factors vary from a component to another, and have been validated to have considerable influences on labor productivity (Thomas and Sakarcan, 1994; Jarkars 2011a). For instance, activities of one work type can achieve 30% better labor productivity than another (Sanders and Thomas, 1993). As defined by Sanders and Thomas (1991), project-related factors included work type, work method, building element, and design requirement. These factors were identified from the specific construction requirements which vary almost daily and lead to various methods and procedures. Buildable factors are highly connected to project-related factors. However, compared to project-related factors, the buildable factors are more specific in terms of characteristics of works. This family of factors was originated from the bulidablility principles which mainly consist of rationalization, standardization, and repetition of elements (Dong, 1996). The bulidablility principles can be expressed in different factors in construction operations. For example, buildable factors can be expressed by the variability of column sizes, the rebar diameter size specified, the reinforcement quantity installed, and the column geometry in rebar fixing of column (Jarkas, 2012a). In rebar fixing of wall, buildable factors mainly concern the diameter and quantity of rebar, the thickness of wall, the plan geometry, and the intensity of curvature (Jarkas, 2012b). As one of the most important influences affecting labor productivity, the implementation of buildable principles undoubtedly enhances the design effect on labor productivity not only in design stage, but also in construction process (Horner et al., 1989). The overall influences of these factors can lead to distinctive dimension of labor productivity value. For example, labor productivity of rebar fixing of beamless slab could reach 170kg/m-h, which was almost 3 times higher than that of curved wall within the same project (Jarkas 2010a, 2012b).

Construction labor productivity is influenced by these factors whose impact can be quantified in productivity models (Yi and Chan, 2013). Numerous studies have been undertaken to develop a variety of productivity estimation models. A number of models have been developed using conventional methods such as the Multiple Linear Regression techniques at the early stage of productivity-related studies (Koehn and Brown, 1985; Thomas and Yiakoumis, 1987; Smith, 1999). With the ongoing development of machine learning, a plenty of advanced techniques, for example, the artificial neural network (ANNS), have been adopted to shape models with higher accuracy in predicting performance (AbouRizk and Wales, 1997; Moselhi and Khan, 2010).

Although extensive research has been performed to analyze the influence of factors on labor productivity, most studies focused on the long-term or mid-term impacts of determinants, and considerably few studies have targeted on factors that cause short-term or daily variations in labor productivity (Moselhi and Khan, 2010). To be more specific, most studies only considered the impact of factors on the overall productivity of projects rather than the actual site productivity (Sanders and Thomas, 1991). On this occasion, the impact of factors on productivity was assumed at constant level throughout the whole project, while the short-term impacts of factors were often neglected (Thomas, 2012). Identification of the factors which significantly affect labor productivity and quantification of the short-term and daily influences of these factors are utmost important for supporting decision making as well as reducing their anticipated and unanticipated influences.

Unreliable data source is another serious problem (Allmon et al., 2000; Eddy and Peerapong, 2003; Moselhi and Khan, 2012), and is probably caused by the difficulty in measuring actual output (Goodrum et al., 2002). Most studies used data recycled from literatures or gathered by questionnaires, and those types of data are inconsistent or subjective, and only a few studies collected data directly from the field (Moselhi and Khan, 2010). Any conclusion based on such data sources is suspected and may lead to varying and sometimes conflicting findings. Moreover, previous research also found that the effect of factors on labor productivity varies from one region to another (Olomolaiye et al., 1998). Regarding the fact that there were few case studies concentrated on measuring and estimating labor productivity in Hong Kong, applying previous models directly to Hong Kong construction projects may be criticized due to the unreliable data sources that were originated from distinctive site conditions among construction projects of different regions, and more studies using field data in Hong Kong should be undertaken for the analysis and measurement of labor productivity of Hong Kong construction projects.

With high housing prices, the public housing is an important part of Hong Kong construction industry. Statistics shows that the overall internal floor area of public housing amounts to 26,090,366 square meters, accommodating over 2 million residences that account for almost 1/3 of the whole population of Hong Kong (Hong Kong Housing Authority, 2012). From year 2012 to 2013, nearly 210,000 square meters in this sector had been constructed (Hong Kong Housing Authority, 2013). By extensively analyzing labor productivity with reliable field data that was collected from a public housing project together with considering the impacts of multiple factors, it could be expected that this study has the potential to identify the trend of change of labor productivity corresponding to the variation of the influential factors, and meanwhile present a reliable productivity measurement and estimation method for Hong Kong construction industry.

1.2 Aims and Objectives

The purpose of the study is to establish an approach to measure and estimate construction labor productivity for Hong Kong public housing sector. Normally, the planning and scheduling are mostly based on previous experience and information. The main reason is that the project estimator cannot acquire the information of adequate and accurate labor productivity values of the project (Muqeem et al., 2011). From the management perspective, it is desirable to predict labor productivity at component level and reduce their anticipated and unanticipated influences. If actual labor productivity can be estimated, the contractor can reduce its impact by taking measures, for example, the optimization of construction plan.

To isolate the framing aspect of the construction process and analyze activities for structure framing activities especially for the rebar fixing, this study utilized field data to guarantee the availability of data sources. With the application of several measurement and modeling techniques, this research aimed at achieving the following four objectives:

1. Estimate the overall labor performance in the '6 day circle' of the structural framing process of Hong Kong public residential buildings
2. Analyze the trend of changes of weather-related factors and buildable factors with labor productivity in rebar fixing activities
3. Compare the outcomes (quantified results and productivity variation trends) between different work types within this study, and also make a comparison between the outcomes of this study and those of previous studies
4. Evaluate labor productivity of rebar fixing activities in view of pessimistic estimation as well as optimistic estimation

1.3 Scope of the Research

Construction projects can be divided into numerous types in regard of project characteristics. Although most of the public rental houses in Hong Kong were constructed by private companies, the site management of these projects differs from that of private projects in many aspects, for example, time control, cost control, etc. Embedded in the structural framing phase of a public housing project, this study focuses on analyzing labor productivity as well as the utilization of labor sources in major framing activities, namely, the fixing of rebar, the installation of formwork, and the placement of concrete. These types of activities are all labor-intensive activities and seldom depend on equipment.

The main objective of this study is to provide an approach for the measurement and estimation of labor productivity in Hong Kong construction industry. Labor productivity is affected by a wide range of factors. In this study, the factors that have significant effects on rebar fixing are chosen to be analyzed at component level. To conduct the research in the framing process of typical repetitive floors, the effects of factors in terms of materials aspect and management aspect might be comparatively stable. The factors that cannot be controlled but are strongly related to labor productivity, for example, the weather conditions, the average diameter of rebar, etc. are focused. Industry level factors (Economic Situation, Labor Wage Level, Overall Productivity Index, etc.) and project level factors (General Project Characteristic, Location of Construction Site, Transportation Condition of the Project, The Client, Type of Contacts and Natural Source, etc.) are excluded.

Within this research, the construction productivity is analyzed at component level. Labor Productivity is adopted as the definition of productivity as well as productivity measurement methods. The general definition of labor productivity is the ration between output and input. The more detailed definition of the formula within the study is that the outputs express as specific physical units, for example, kilograms of reinforcement, and inputs express as labor hours, while labor is the only parameter included in input. Other definitions such as TFP (total factor productivity) or TP (total productivity) is not considered in this research.

1.4 Methodology

This study mainly concerns the analysis of framing activities at both macro and micro level with the utilization of field data and the commitment of statistical techniques, which are illustrated in Figure 1.1 with the use of a flow char diagram.

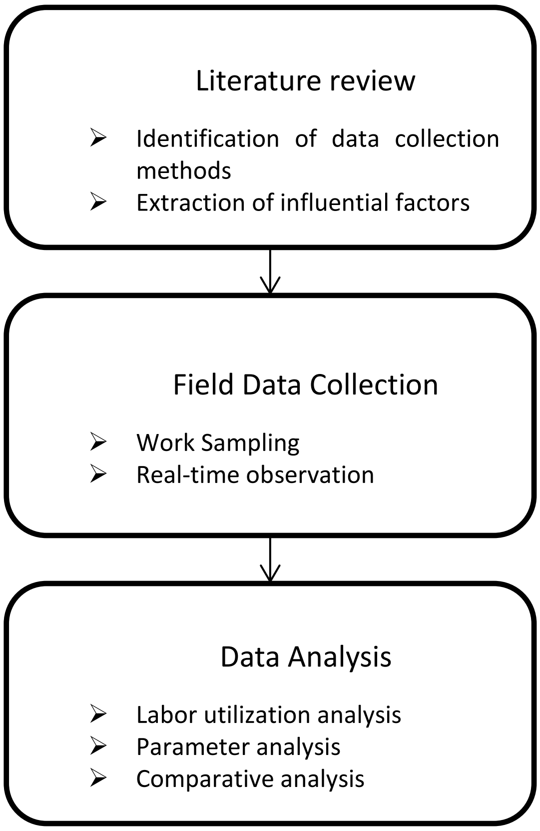


Figure 1.1 Methodology of this research

As showed in Fig 1.1, this research consists of 3 main steps. An extensive literature review was performed to identify reliable data collection methods and extract factors which significantly affect labor productivity at component level. In the next step, an on-site study was conducted in the construction process of a public residential building project in Hong Kong. With sufficient and dependable sources, data was collected by work sampling and real-time observation techniques respectively, and it was analyzed by quantitative analysis methods accordingly. At this step, several curves were generated to explore the relation between labor productivity and the selected parameters, and a labor productivity checklist was established. At the last stage, a comparative study on the labor productivity variation trends and the quantification of effects of factors was conducted not only among different work types within this study, but also between this study and previous research.

1.5 General Description of the TTACE

The field study was conducted in the TTACE (Tung Tau Cottage Area East) project in Hong Kong. The project was constructed by a middle size contractor. The subject site is located at Wong Tai Sin in Lok Fu district in the east of Kowloon. It is adjacent to Mei Tung Estate and bounded by Pui Man Street to the North and East, Mei Tung Estate to the South, and The Hong Kong Chinese Christian Churches Union Cemetery to the West. The Public Rental Housing Development at Tung Tau Cottage Area East comprises one 34-storey domestic block providing 990 flats, with typical floors from 7th to 33rd. The project was started in Sep, 2011 and had been finished in the fourth quarter of 2013, with a 26-month time limit.

Similar to other public residential building projects, it took 6 days to complete a floor in the structure framing of typical floors within this project. This is so called a '6 day cycle'. This term is commonly used in Hong Kong construction projects. Comparing with the general completion period for finishing a floor (3 to 4 days) in private sector, it is relatively loose in terms of scheduling.

Figure 1.2 Site photos of TTACE (A)

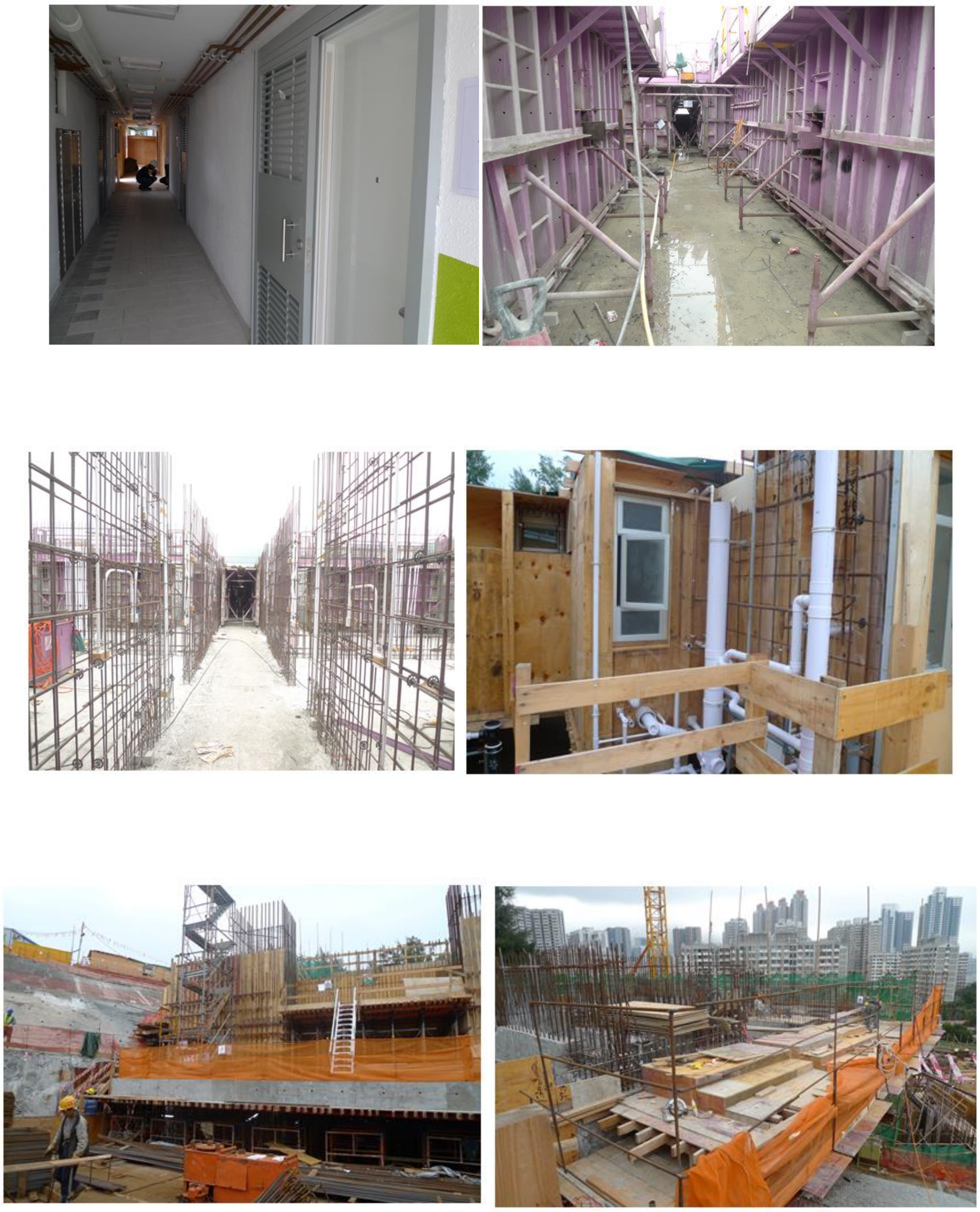


Figure 1.3 Site photos of TTACE (B)

1.6 Thesis Organization

This thesis is divided into five chapters to verify the idea of this study. Chapter 1 introduces the initial background of this study, including the current labor productivity measurement method in Hong Kong, the significance of measuring labor productivity for the region's economy and for construction projects, the importance of analyzing labor productivity in public housing projects, and the restriction and limitation of previous research in Hong Kong. It also outlines the scope of this research, sets up the research goal and objectives, and describes the research methodology. Chapter 2 provides a critical review of the literature on labor productivity definition, productivity measurement methods, factors affecting labor productivity, and productivity modeling techniques. Chapter 3 presents the research methodology applied in this research which contains content of research design, data collection methods, and the application of modeling techniques. An in-depth statistics analysis of labor productivity is performed, and the quantitative results are showed in Chapter 4. Chapter 5 consists of a conclusion of the thesis, contribution and limitation of the study, and recommendation for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter was organized to present the summary of the relevant literatures which covers the definitions of labor productivity, the measurement techniques of labor productivity, the identification of factors affecting labor productivity, and the modeling techniques of labor productivity.

2.2 Labor Productivity Definitions

Thomas and Mathews (1986) stated that no standardized productivity definition had been established in the construction industry. In general, productivity can be simply illustrated by an association between an output and an input (Sink, 1985). The most widely used formulations found in literature were shown as following (Greenberg, 1973; Chang, 1991):

$$\boldsymbol{Productivity = Output \div Input \quad (Output\ per\ unit\ of\ input)}$$

Eq (1)

In construction industry, three productivity measurements methods had been universally used in the academic circle, namely, the economic model or the multifactor productivity model that defines productivity as total factor productivity (TFP), the project-specific model that defines productivity as total productivity (TP), and an activity-oriented model that defines productivity as labor productivity (LP) (Oglesby et al., 1989; Arditi, 2000). Among these definitions, labor productivity has been recognized as the most appropriate definition for the construction industry in monitoring the performance of field activities as well as evaluating the total cost (Liu and Song, 2005).

As defined by Arditi (2000) and Goodrum and Haas (2002), labor productivity describes the relationship between specific physical units and man-hours, which is shown in Eq (2).

$$\boldsymbol{Productivity} = \frac{\boldsymbol{Installed, completed\ or\ produced\ units}}{\textbf{Corresponding time of workers}} \qquad \text{Eq (2)}$$

In a more detailed manner, researchers have transformed this equation to analyze different construction activities, as the output can be alternatively expressed by kilograms of steel, square meters of formwork, and cubic meters of concrete (Anson et al., 1996; Mojahed, 2005; Moselhi and Khan, 2010; Jarkas, 2010a). In the calculation of labor input, some researchers used total paid time that was mostly derived from project records and project final settlement reports (Moselhi and Khan, 2010). Simultaneously, some studies adopted the productive time as the only input (Jarkas, 2010b). Under this definition, the input only contains the actual work time of a specific task, while delays, breaks, and other non-productive time are excluded (Horner and Talhouni, 1993; Shehata and El-Gohary, 2011).

2.3 Measurement Techniques

Productivity, especially in the construction industry, is usually very difficult to be measured (Motwani et al, 1995). Despite the fact that continuous effort have been made, there is no standard way in productivity measurement (Business Roundtable, 1982; Alarcon, 1993). Table 2-3 listed the techniques that had been universally utilized in the construction industry for productivity measurement and labor performance judgment (Mojahed, 2005; Khan, 2005; Moselhi and Khan, 2010; Jarkas, 2010a).

Table 2.1 Productivity measurement methods in previous studies

Field Ratings
Work Sampling
Five-Minute Rating
Craftsmen Questionnaire
Field Surveys
Foremen Delay Survey
Time-Lapse Photography
Group Timing Technique
Real-time observation

2.4 Factors Affecting Labor Productivity

Construction labor Productivity variations are dependent on the interaction of numerous factors (Lema, 1995). Extensive efforts related to factors affecting construction labor productivity have been put forth, and various factors have been identified by the researchers. A detailed review of these factors can be found in Oglesby et al. (1989), Borcherding and Alarcon (1991), Sanders and Thomas (1991), Halligan et al. (1994), Lema (1995), Lim et al. (1995), Heizer and Render (1996), Kaming et al. (1996), Sonmez (1996), Kaming et al. (1998), Olomolaiye et al. (1998), Thomas et al. (1999), Teicholz (2001), Rojas and Aramvareekul (2003), Hanna et al. (2005), Khoramshahi et al. (2006), Alinaitwe et al. (2007), and Kazaz et al. (2008). Examples of factors identified from previous works include weather, equipment and tools, overtime, manpower, over manning, learning curves, delays, disrupts, drawings, general project characteristic, materials, management and control, site, change order, general activity conditions, congestion of trades, crew size, etc. In accordance with the research objective, this research only concerned factors that have short-term effect on actual labor productivity.

2.4.1 Weather-Related Factors

Weather-related factors are probably the most commonly cited causes for construction labor productivity losses in the literature (Teicholz, 2001).

Adverse weather and environmental conditions were identified as overriding factors which negatively impaired productivity (Klanac and Nelson, 2004). The construction industry is highly labor-dependent and requires workers to do physical tasks in various climates (Thomas et al., 1999). Adverse weather extensively affects construction labor's work owing to the open work environment (Mohamed and Srinavin, 2005). Numerous weather-related factors affecting labor productivity had been identified. These factors can be: hot weather, cold weather, adverse weather, thermal comfort, Inclement weather events, high winds, snow, ice, hot and cold temperatures, and rain showers, etc. (Halligan et al., 1994; Hancher and abd-Elkhalek, 1998; Thomas et al. 1999; Klanac and Nelson, 2004).

The impact of weather-related factors on labor productivity had been extensively discussed by a number of studies. Among these factors, temperature and humidity were extensively studied and turned out to have negative impact on labor productivity. A study conducted by the National Electrical Contractors Association involved two labors fabricating electrical facilities in an enclosing environment that the humidity and the temperature could be controlled, and the result made clear that both humidity and temperature can cause losses in labor productivity (NECA, 1974). It also indicated that the extent of irritability, belligerence, and fatigue of the involved labors increases progressively as any rising of temperature above 90℉ (32℃).

Dozzi and AbouRizk (1993) validated this finding and stated that irritability, belligerence, and fatigue occur between the temperatures over 120℉ (49℃) at relative humidity 10% and the temperatures around 88℉ (31℃) at relative humidity 100%.

It was found that humidity affects labor productivity in hot environment as well as in cold circumstance. Koehn and Brown (1985) studied the climatic effect on construction and developed two models respectively for hot and cold weather. In their study, the variation of labor productivity was depicted as the pattern of curve. At relative humidity of 60%, labor productivity corresponding to temperature that varies from -20℉ to 120℉ was shown in Figure 2.1. A tabular relationship to estimate the construction productivity percentages as a function of temperature and relative humidity was also created (showed in figure 2.2), which suggested that it is difficult to achieve efficient construction operations below -10° F (-23.3°C) and above 110°F (43.3°C).

Another study also indicated that labor productivity loses due to temperature and humidity. Thomas and Yiakoumis (1987) stated that the increase of temperature from 13℃ and humidity from 80% can cause reductions in productivity. They gathered data for activities in terms of masonry, formwork installation and rebar fixing from three multistory building projects to investigate the influences of humidity and temperature on labor productivity. A factor model was then developed by utilizing multiple regression technique, which was shown as following:

$$\boldsymbol{PR'} = \mathbf{9.448} + \mathbf{0.0518}\boldsymbol{T} - \mathbf{2.819}\,\boldsymbol{ln\,T} + \mathbf{3.89} \times \mathbf{10}^{-\mathbf{37}}\boldsymbol{e}^{\boldsymbol{H}}$$

Other than temperature and humidity, all heat stress factors which include temperature, relative humidity, wind speed and solar radiation level were also analyzed by some researchers. Hancher and abd-Elkhalek (1998) developed a model to evaluate the overall effect of the aforementioned heat stress factors by utilizing the US Army Corps model. They converted the Wet Bulb Globe Temperature index (WBGT) which consists of air temperature, wet bulb temperature and globe temperature to a single factor that was called the Temperature Factor, and adopted the Temperature Factor as the only input in their equation. The model was then used to develop four curves to portray the variation trend of labor productivity in different construction activities such as excavation and concrete placement, which made clear that labor productivity continuously decreases above 60℉. Mohamed and Srinavin (2005) argued that the models developed by Koehn and Brown (1985), Thomas and Yiakoumis (1987) and Hancher and abd-Elkhalek (1998) failed to comprehensively reflect the relation between labor productivity and weather environment. They criticized that the Koehn and Brown's model (1985) and the Thomas and Yiakoumis's model (1987) only considered the effect of temperature and humidity, and the model developed by Hancher and abd-Elkhalek (1998) could only output good results in hot weather. Thereafter, they adopted the Predicted Mean Vote (PMV) index that includes the parameters of WBGT as well as work type to develop three labor productivity forecasting models for light, medium and heavy construction activities respectively. These three models were also used to depict a curve representing labor productivity variation trend, which showed that labor productivity yields its peak value at a temperature of 15℃ and its nadir value at a temperature beyond 40℃.

Moselhi and Khan (2010) emphasized the existing unreliability in terms of raw data in previous productivity-related studies. To avoid this uncertainty, they gathered daily data directly from the construction site and inputted these sets of data to train a NN model that considered nine parameters in terms of weather factor, labor factor, and job factor (Khan, 2005). The temperature-productivity curve was developed by setting the rest 8 factors at their average value, which showed that the highest value of daily labor productivity was achieved at a temperature of 22℃. They stated in another article that temperature has the most significantly impact on daily labor productivity (Moselhi and Khan, 2012).

2.4.2 Project-Related Factors

Sanders and Thomas (1991) defined project-related factors as specific construction requirements that are derived from the project design and the work methods to complete the work. They classified a number of project-related factors into four categories: work type, work method, building element, and design requirement. In their study, data was collected from 11 projects to quantify the impact of these factors by utilizing variance analysis techniques, which indicated that different work types and different elements could have deviation in labor productivity at 30% and 39% respectively. To consider the effect of weather factors, site conditions, and project-related factors, a model was developed to forecasting labor productivity by utilizing additive regression techniques (Sanders and Thomas, 1993). They stated that this model is the first labor productivity forecasting model concerning with the effects of project-related factors. Thomas and Sakarcan (1994) conducted a comparative study to validate the forecasting capability of this factor model by collecting data from 22 projects. They compared the forecasting performance of the factor model and that of the traditional percent-complete method. The result indicated that the factor model is a more accurate method than the percent-complete method, as the error range of the factor model can be controlled at merely ±5%. The result highlighted the importance of considering these project-related factors in productivity measurement and estimation. In a more recent study, Moselhi and Khan (2010) studied the daily impact of 9 parameters on labor productivity. Two project-related factors, namely the Work Type and the Work Method were included in the concerned parameters. They tested the significance of the influence of the selected parameters by applying Fuzzy Subtractive Clustering, Stepwise Variable Selection and Neural Network Modeling, and the result showed that Work Type ranked at second just after Temperature (Moselhi and Khan, 2012).

2.4.3 Buildability

The word "buildability" appears to enter the language in the late 1970s (Cheetham and Lewis, 2001). The research effort on buildability can be traced back to 1980s. The Construction Industry Research and Information Association (CIRIA, 1983) defined buildability as "the extent to which the design of a building facilitates ease of construction, subject to the overall requirements for the completed building". Buildability, as defined by Ferguson (1989), is "the ability to construct a building efficiently, economically and to agreed levels from its constituent materials, components and sub-assemblies". In 1993 the periodical Southeast Asia Building gave another definition of buildability, which was "the end-result when designs and plans are translated on-site into a building with minimum difficulty to give the best possible results" (SAB, 1993).

The effect of buildability on construction has become the subject of many studies. The effect of element size had been studied by O'Connor et al. (1987) as well as Alshawi and Underwood (1996). Fischer and Tatum (1997) found that not only element sizes, but also some other aspects of elements such as width, depth, length, and type could impact the work performance. Other than the attributes of element, they also identified the location of reinforcement as another concern of buildability. A buildable design appraisal system (BDAS) emerged in the 1990s, which provided an approach to systematically measure the design effect of buildability (CIDB, 1995). However, the researchers still failed to reach any consensus in measuring the benefits of buildability (Poh and Chen, 1998). Jarkas (2010b) argued that the buildable score adapted in the system for appraisal use could be criticized. He stated that only considering the overall performance is too general to reflect the complexity of the whole construction process.

Buildability is found to have a close relationship with labor productivity. Poh and Chen (1998) collected the data of buildable score for 37 building projects in Singapore and found that high buildable score usually leads to better labor productivity on-site. The positive effect of buildable design had also been substantiated by Williamson (1999) and Carter (1999).

More specific research identified numerous buildable factors affecting labor productivity, especially in rebar installation activities. Aldana (1991) and Hidayatalla (1992) found that the diameter size of rebar positively affects labor productivity. In Hidayatalla's study (1992), the steel content was identified as another buildable factor and was determined to have negative impact on labor productivity in rebar fixing of slabs.

Recently, numerous articles that focused on quantifying the influence of buildable factors on labor productivity were published. In these studies, the basic concept of buildability had been applied to extract several groups of buildable factors for different framing activities, namely, rebar fixing, formwork installation and concrete pouring (Jarkars 2010a, 2010b, 2010c, 2011a, 2011b, 2012a, 2012b). Focusing on the rebar fixing activities, three studies were performed to quantify the effect of buildable factors respectively for beams, walls and columns (Jarkars 2010a, 2012a, 2012b). To incorporate the characteristics of each type of component into the buildability principle, these studies adopted different buildable factors, which were listed in the following table:

Table 2.2 Buildable factors concerned for beam, wall, and column in rebar fixing

Beam	Wall	Column
rebar diameter	rebar diameter	rebar diameter
reinforcement quantity	reinforcement quantity	reinforcement quantity
geometry	wall thickness	column geometry
reinforcement layer's location	geometry	Element size

2.5 Modeling Techniques

Productivity modeling was commonly used to effectively measure and estimate labor productivity since the impact of multiple factors on productivity can be quantified by the expression of mathematical models (Thomas and Sakarcan, 1994; Thomas et al., 1997; Sonmez and Rowings, 1998). In the early stage of the research of labor productivity, numerous studies had utilized regression analysis to develop a variety of statistical models. Koehn and Brown (1985) used regression analysis to quantify the impact of temperature and humidity individually on labor productivity. Thomas and Yiakoumis (1987) applied multiple regression techniques to develop a factor model that reflecting the relationship between productivity and temperature as well as productivity and humidity. Sanders and Thomas (1993) constructed a productivity forecasting model for masonry activities by utilizing additive regression technique. Smith (1999) utilized the stepwise multiple regression techniques to analyze the relationship between the operations of earth moving and nine selected parameters. Thomas et al. (1999) conducted a multiple regression analysis to quantify the effect of material handling and delivery methods on labor productivity by using the data collected from two projects. Mohamed and Srinavin (2005) constructed a mathematical model to estimate labor productivity as a function of thermal-environment-factors by using polynomial regression technique.

As the innovation of computer science and the development of machine learning techniques, more studies analyzed the influence of factors on labor productivity through Artificial Intelligence Based Techniques to resolve the non-linear relationship between labor productivity and influential factors (Moselhi, 1991; Khan, 2005; Muqeem et al., 2012). AbouRizk and Wales (1997) adopted Neural Networks (NNs) to measure and estimate labor productivity as a function of the site environmental conditions. The site environmental conditions included daily precipitation, previous seven day’s precipitation, and daily temperature. Another study conducted by Lu et al. (2000) utilized probability inference neural network to model labor productivity in spool fabrication with concerning the impact of various factors. Ezeldin and Sharara (2006) suggested an approach which based on the feed-forward back propagation (BP) neural networks for estimating labor productivity in concrete pouring. In a more recent research, Moselhi and Khan (2010) utilized artificial neural network techniques to identify the relationship between daily productivity and the nine selected factors by using the quantities of daily-work performed.

In the academic cycle, a variety of artificial intelligence based techniques other than the NNs had been widely used to construct robust models for prediction. It is widely acknowledged that the stochastic gradient boosting technique is premium in predictive performance (Lawrence et al., 2004; Anderson et al. 2006; De'Ath, 2007; Elith et al., 2008). Stochastic gradient boosting is an advanced machine learning technique that was developed based on the theory of gradient boosting. Gradient boosting combines an ensemble of weak models, for example, decision trees, and then a more powerful model in terms of predicting performance is developed. The first simple boosting procedure was developed by Schapire (1990) in the framework of PAC-learning. Friedman did a research in 1999 and found that boosting technology fits well with additive regression models (Friedman, 2001). Consequently, an advanced technique, the Stochastic Gradient Boosting, was introduced by Friedman (2002) by incorporating randomization into normal gradient boosting. This technology improves the approximation accuracy of gradient boosting. In other words, the subsample data for training use is extracted by random selection from all training data in every iteration process (Friedman, 2002).

2.6 Summary of Literature Review

In this chapter, four major topics were discussed. The first topic reviewed the definitions of productivity at different level and discussed their scope of application. In the second topic, the data collection techniques which had been commonly used in measuring labor productivity were listed. The researcher highlighted the short-term impact of three categories of factors in the third topic, and in the fourth topic the application of the major productivity modeling techniques was discussed.

As stated by researchers, there is no standard way to measure productivity in the construction industry though continuous effort had been made in this field. Regarding of the unreliability in raw data, more research with the utilization of field data is needed. It is substantiated by the previous works that the weather-related factors, the project-related factors and the buildable factors significantly affect labor productivity. This emphasized the importance of considering the impact of these factors in the measurement and estimation of labor productivity at component level. In the selection of modeling techniques, regression analysis had been enormously adopted in various studies in the 1990s, while recently more studies used the artificial intelligence tools instead of the conventional methods in view of the non-linear relationship that cannot be well-addressed by conventional techniques.

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter outlined the general design of this research, the types and sources of data, the procedure of data collection, and the application of data analysis techniques. Corresponding to the research objectives, this study had employed real-time observations and work sampling techniques to gather data in the construction job site of a public residential project in Hong Kong, and applied modeling techniques as well as other statistics analysis methods to gain further understanding of labor productivity in structure framing activities. This chapter also contained a detailed description of the general principles and operation procedures of the work sampling technique, the real-time observation, and the Stochastic Gradient Boosting technique that was selected to develop the proposed model.

For the purpose of this study, productivity of each work item is defined as the quantity of production divided by the corresponding time of workers (Moselhi and Khan, 2010). Translating Eq (3) that was mentioned in Chapter 2 into a more detailed pattern, the formula for the measurement of labor productivity of rebar fixing was presented as following:

$$\boldsymbol{Productivity} = \frac{\textbf{Fixed or Installed kilograms of Rebar}}{\textbf{hours of labor works}}$$

Eq (4)

To analyze labor productivity at component level, the labor hour only contains the productive time in the calculation of labor productivity. On the other hand, to acquire the general labor performance of construction job site, the direct work rate (DWR) and the labor utilization factor (LUF) are calculated using Eq. (5) and Eq. (6).

$$\boldsymbol{Direct\ Work\ Rate\ =\ Direct\ work\ \div\ all\ work\ finished\ \times\ 100\%}$$

Eq (5)

$$\boldsymbol{LUF\ =\ \frac{Direct\ work\ +\ \frac{1}{4} \times\ Essential\ Contributory}{all\ work\ finished}\ \times\ 100\%}$$

Eq (6)

By integrating Eq (4) and Eq (5), the overall labor productivity using paid time as labor input can be calculated by the following formula:

$$\boldsymbol{Overall\ Labor\ Productivity\ =\ \frac{Actual\ Productivity}{Direct\ Work\ Rate}}$$

Eq (7)

3.2 Research Design

One of the main purposes of this study is to quantify the impact of factors affecting labor productivity and to find an appropriate labor productivity measurement method that could provide actual and more detailed labor productivity estimation values for Hong Kong public rental housing projects. At the same time, the researcher also intended to explore the overall labor utilization of different structure framing activities. To achieve these objectives, this research proposed a macro-level study as well as a micro-level study.

The macro-level study aimed at exploring the overall labor performance of the construction job site by utilizing work sampling techniques. Rebar fixing, formwork installation and concrete placement were chosen to be observed through the structure framing of typical floors. The collected data was then transferred into indicators that reflect the productive and non-productive rate of each types of activity.

Meanwhile, a micro-level research which aimed at measuring and estimating labor productivity at component level was also performed. The methodology of the micro-level study started at the initial stage by collecting sufficient data in terms of fixing quantity, consumed time, temperature, diameter of rebar, etc., for rebar fixing of walls and beams. Using Eq. (4), labor productivity of each observed activity was calculated. Based on the literature review, a hypothesis was proposed as “Weather-related factors, project-related factors and buildable factors significantly affect labor productivity of rebar fixing in the structure framing work of typical floors within a public rental housing project, and other factors have limited impact at this stage.” Under this hypothesis, a model was constructed by stochastic gradient boosting to reflect the relationship between labor productivity and the factors concerned. Thereafter, the impact of individual factor was quantified by applying sensitive analysis, and several curves were generated to portray the labor productivity variation trends by multiple times of configurations of the model. The model was also used to provide the pessimistic and optimistic baseline of labor productivity for 10 types of beam as well as 2 types of wall. These outcomes were discussed, and comparisons were made between different work types within this study, or among this study and historical studies.

3.3 Data Collection

In this study, rebar fixing, formwork installation and concrete placement were chosen to be analyzed in the macro-level study, while the micro-level study focused on rebar fixing only. To conduct such a research, several types of data were required to be collected and analyzed. Fig 3.1 illustrated the framework of data collection.

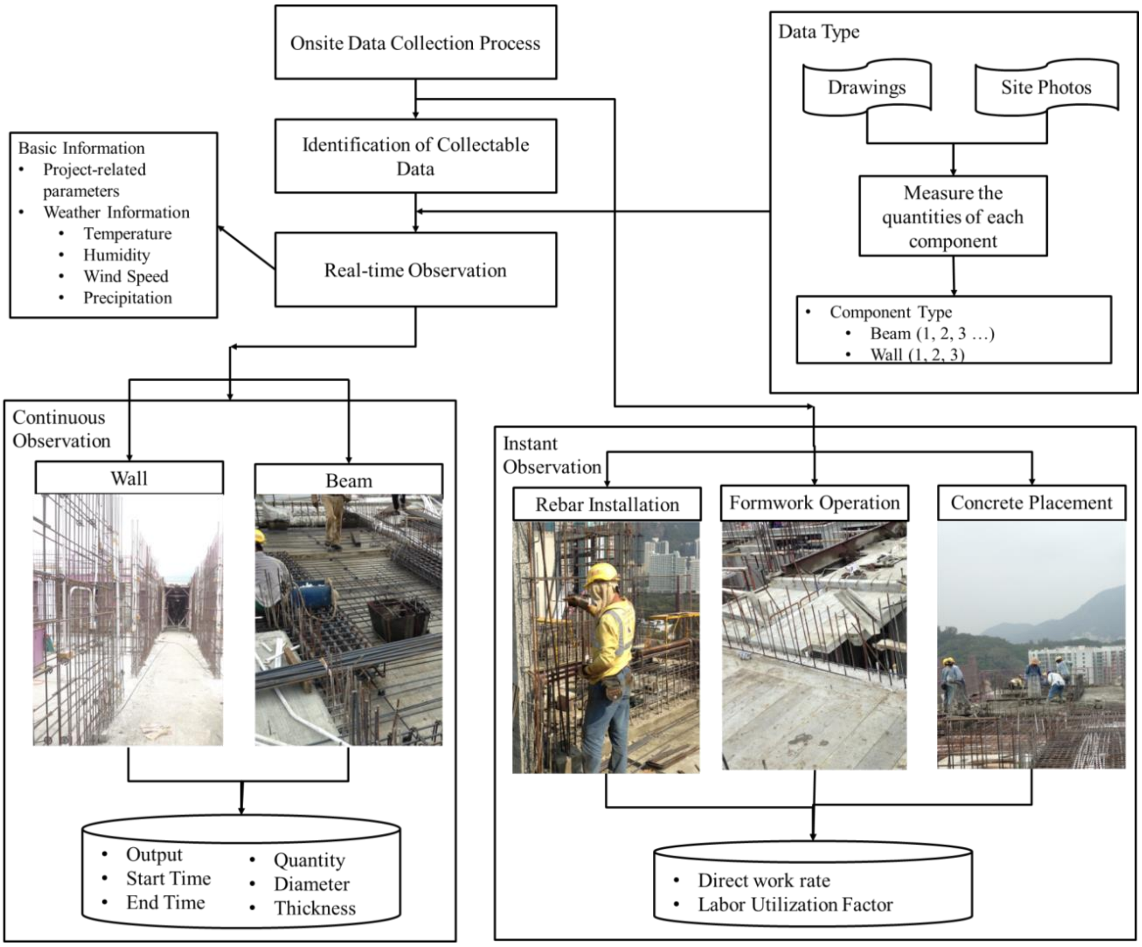


Figure 3.1 Workflow of Data Collection Process

As shown in Figure 3.1, the field study and data collection process consisted of four mean parts: Part one was related to the data types of output for the preparation of the on-site observation; Part two was concerned with the basic weather conditions; Part three was about the on-site observations of working process of labors; And part four was the work status of each observe. Data of part one, part two, and part three was derived by studying the CAD drawings and inspecting the components at the construction site, recording the value of weather parameters, and observing the activities on-site respectively. The work status was obtained by work sampling method. To reduce the probability of operational errors, each working process was watched and recorded by two observers.

The data collection was undertaken from Jan 1st, 2013 to Jun 31st, 2013 to ensure that the data was collected in most climate situations of Hong Kong. All the data were gathered from the structure framing process of typical repetitive floors of the embedded project. As mentioned before, the typical floor started at 7th floor. To let the observers be more familiar with the characteristics of the project, the data collection process started at 14th floor to reduce the probability of error and facilitate the on-site observations. Another reason of the late beginning was to avoid the interference of the learning effect, although it only has negligible influence on labor productivity in typical floor's structure framing (Jarkas and Horner, 2011). These guaranteed that the collected data can universally represent the actual situation of the structure framing process of the Hong Kong public residential buildings.

3.4 Site Study & CAD Drawing Study

In this study, the output values of components were identified from CAD drawings that provided by the contractor and from the field visit. The outputs of rebar can be divided into several types of beam and wall. With the help of construction drawings and site photos, the quantity of each component was calculated. Table 3.1 illustrated the calculation process of each component, which was determined by the rebar diameter, the rebar quantity, and the length of rebar. The output value of each type of beam was calculated by adding the weight of all enrolled reinforcement. The distribution of components was showed in table 3.2.

Table 3.1 Types of beams

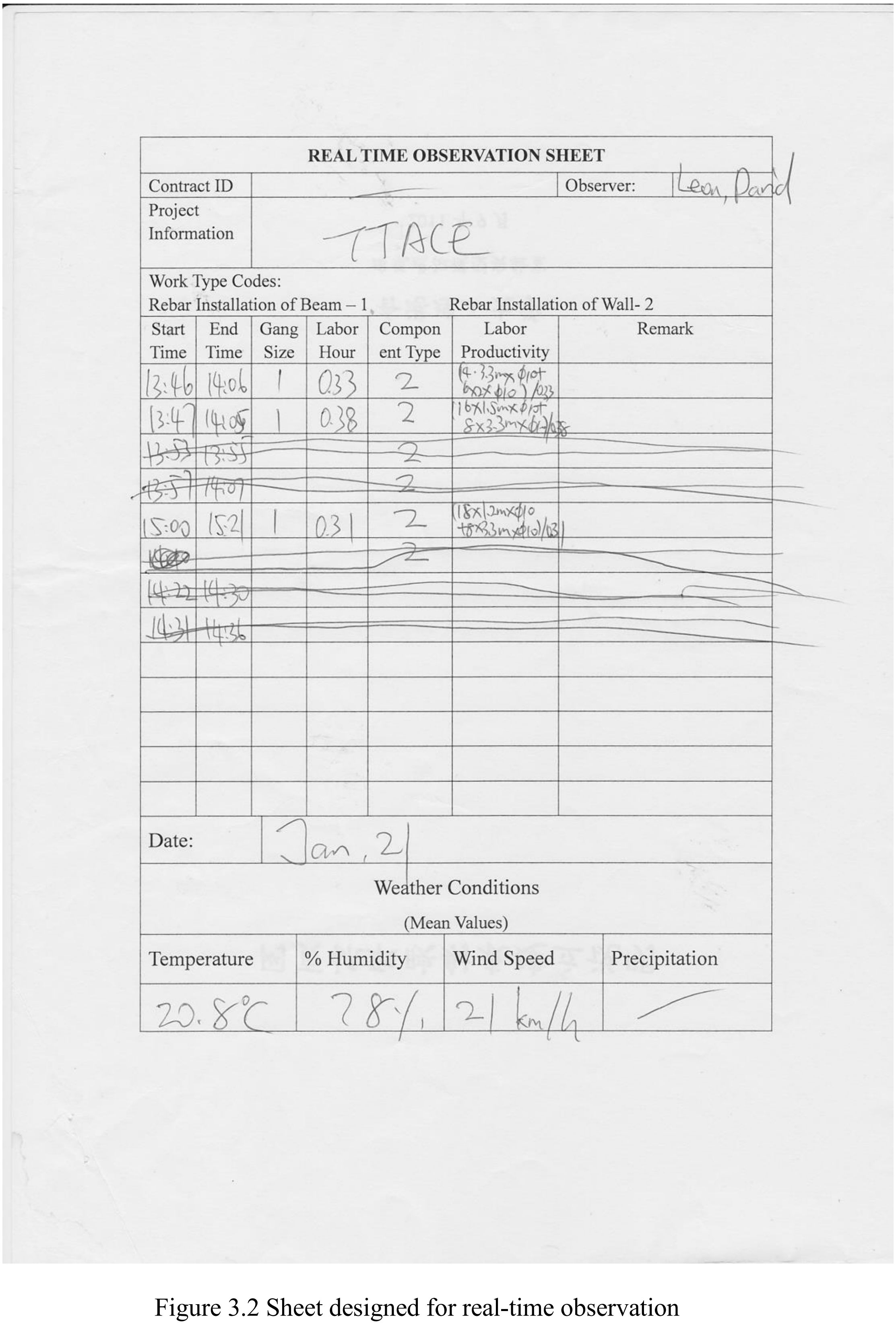
Component: Beam (Slab Beam)	number of mean rebar						length of main rebar	number of hoop rebar			total weight
Type	#16	#20	#25	#32	#40	Distribution	(m2)	0.8m	1.2m	1.5m	
1	8	4	0	0	0	6-—33	4	40	20	0	124.48
2	10	0	6	0	0	22-—33	3	45	0	15	152.778
3	10	0	0	6	0	6-—21	3	45	0	15	197.04
4	0	8	4	0	0	6-—7, 22-—33	4	40	20	0	175.072
5	0	8	0	4	0	28-—33	4	40	20	0	214.416
6	0	12	0	0	0	28-—33	4	40	20	0	152.864
7	0	0	6	0	6	8-—21	5.15	66	33	0	480.805
8	0	0	8	4	0	6-—33	4	40	20	0	258.832
9	0	0	8	0	4	6-—33	5.15	66	33	0	418.902
10	0	0	12	0	0	6-—33	4	40	20	0	219.488

Table 3.2 Distribution of beams at each floor

floor level \ Type	1	2	3	4	5	6	7	8	9	10
6	✓		✓	✓				✓	✓	✓
7	✓		✓	✓				✓	✓	✓
8	✓		✓				✓	✓	✓	✓
9	✓		✓				✓	✓	✓	✓
10	✓		✓				✓	✓	✓	✓
11	✓		✓				✓	✓	✓	✓
12	✓		✓				✓	✓	✓	✓
13	✓		✓				✓	✓	✓	✓
14	✓		✓				✓	✓	✓	✓
15	✓		✓				✓	✓	✓	✓
16	✓		✓				✓	✓	✓	✓
17	✓		✓				✓	✓	✓	✓
18	✓		✓				✓	✓	✓	✓
19	✓		✓				✓	✓	✓	✓
20	✓		✓				✓	✓	✓	✓
21	✓		✓				✓	✓	✓	✓
22	✓	✓		✓				✓	✓	✓
23	✓	✓		✓				✓	✓	✓
24	✓	✓		✓				✓	✓	✓
25	✓	✓		✓				✓	✓	✓
26	✓	✓		✓				✓	✓	✓
27	✓	✓		✓				✓	✓	✓
28	✓	✓		✓	✓	✓		✓	✓	✓
29	✓	✓		✓	✓	✓		✓	✓	✓
30	✓	✓		✓	✓	✓		✓	✓	✓
31	✓	✓		✓	✓	✓		✓	✓	✓
32	✓	✓		✓	✓	✓		✓	✓	✓
33	✓	✓		✓	✓	✓		✓	✓	✓

3.5 Real-Time Observation

Each week, the researchers visited the work site three times commonly to acquire 10 to 20 sets of data each time by observing the working process of selected components. To conduct the real-time observation for rebar fixing, a table was designed and shown as below. The supportive and non-productive time were deducted in calculating labor input at this stage. Work type, work duration, labor number, and weather conditions of each certain work were recorded in the form. The weather conditions included four parameters, those are, temperature, relative humidity, wind speed, and precipitation.



REAL TIME OBSERVATION SHEET						
Contract ID	—			Observer:	Leon, David	
Project Information	TTACE					
Work Type Codes: Rebar Installation of Beam – 1, Rebar Installation of Wall- 2						
Start Time	End Time	Gang Size	Labor Hour	Component Type	Labor Productivity	Remark
13:46	14:06	1	0.33	2	(4·3.3m×ϕ10+ 6×2×ϕ10)/0.33	
13:47	14:05	1	0.38	2	(16×1.5m×ϕ10+ 8×3.3m×ϕ10)/0.38	
~~13:53~~	~~13:55~~			~~2~~		
~~13:57~~	~~14:07~~			~~2~~		
15:00	15:21	1	0.31	2	(18×1.2m×ϕ10 + 8×3.3m×ϕ10)/0.31	
[illegible]				~~2~~		
~~14:22~~	~~14:30~~					
~~14:31~~	~~14:36~~					
Date:	Jan, 21					
Weather Conditions (Mean Values)						
Temperature	% Humidity	Wind Speed	Precipitation			
20.8°C	78%	21 km/h	—			

Figure 3.2 Sheet designed for real-time observation

3.6 Work Sampling

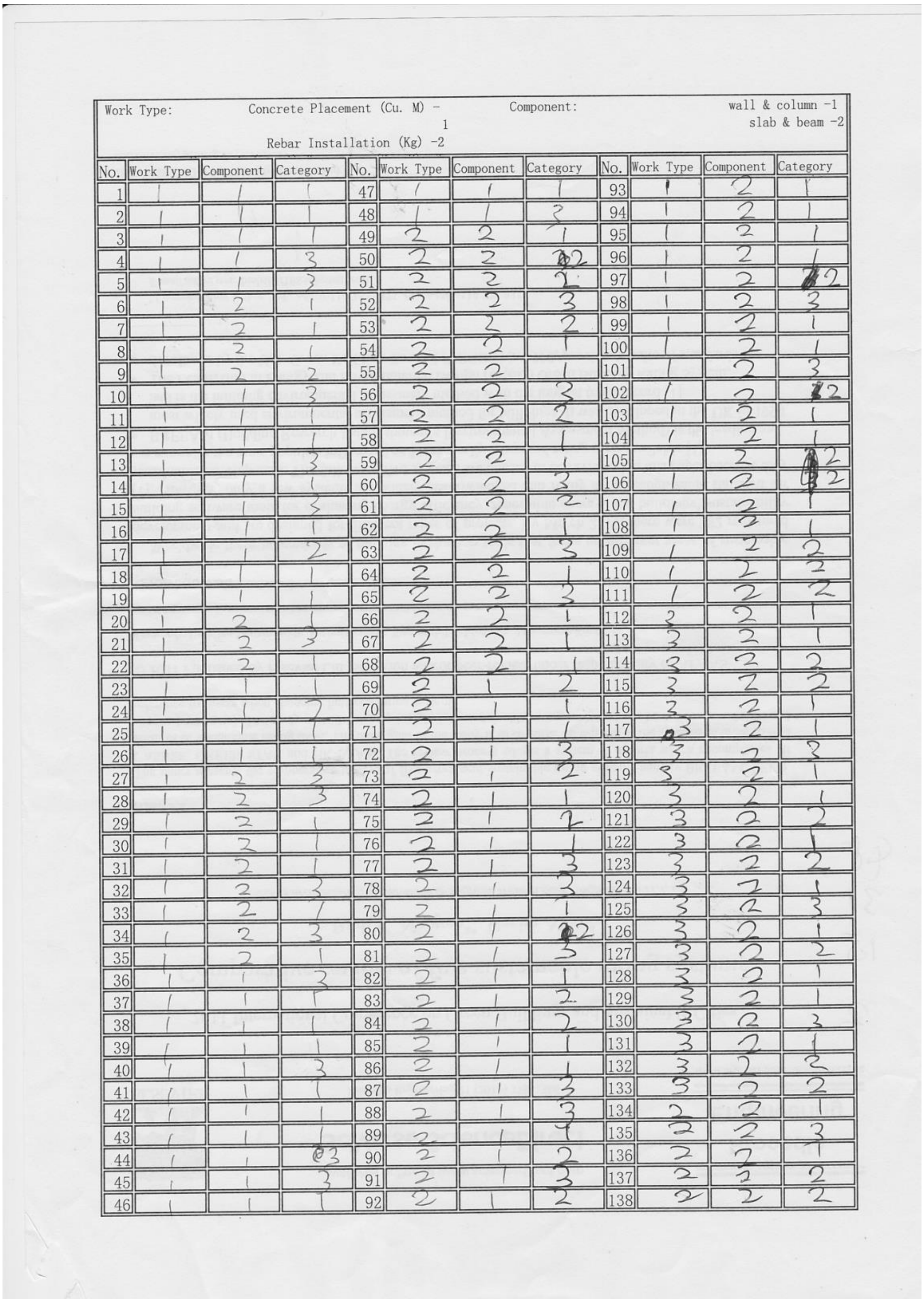
Work sampling is a system which has been widely adopted for measuring productivity on construction sites (Thomas, 1991). It is an effective way to establish a benchmark for managerial purposes and aid in discovering productivity constraints (Liou and Borcherding, 1986). The American Institute of Industrial Engineers (1972) defined work sampling as "the application of statistical sampling theory and technique to the study of work systems in order to estimate universe parameters from sample data". Work sampling is a work measurement technique that offers an effective means for analyzing the activity of workers in terms of time spent on productive and non-productive activities (Mojahed, 2005). For this purpose, the direct work rate is used as an indicator to determine the efficiency of construction workers. The direct work rate is a percentage of the time spent on direct work in all sample hours (Allmon et al., 2000).

In this study, the technique of work sampling was practiced. Numbers of on-site observations on rebar fixing, concrete placement, and formwork operation were made during the framing process of the public housing project. The objective of using working sampling was to determine how time was utilized by the labor force and estimate the direct work rate in these activities. Plenty of observations were made to record what each worker was doing at a particular instant. The work statuses of workers were divided into three main categories: direct work, essential contributory work, and ineffective work or delay (Thomas and Daily, 1983; Thomas et al., 1984; Allmon et al., 2000).

In the design of a work sampling study, one of the initial and most important steps is to set clear definitions of the categories for reliable data collection to take place (Business Roundtable, 1982). Extracting from the existing studies, the detailed definitions of these categories were chosen and listed in table 3.3 (Allmon et al., 2000; Chui and Shields, 2012; Chang and Yoo, 2013). The table design for work sampling was shown in Figure 3.3.

Table 3.3 Definitions of activity categories

Activity Categories	Task Content
direct work	1. productive actions
	2. picking up tools at the area where the work is taking place
	3. measurement on the area where the work is taking place
	4. holding materials in place
	5. inspecting for proper fit
	6. putting on safety equipment
	7. all cleanup
essential contributory work	8. supervision
	9. planning or instruction
	10. all travel
	11. carrying or handling materials or tools
	12. walking emptyhanded to get materials or tools
ineffective work or delay	13. waiting for another trade to finish work
	14. standing
	15. sitting or any nonaction
	16. personal time
	17. late starts or early quits



Work Type: Concrete Placement (Cu. M) - 1 Rebar Installation (Kg) -2

Component: wall & column -1 slab & beam -2

No.	Work Type	Component	Category	No.	Work Type	Component	Category	No.	Work Type	Component	Category
1	1	1	1	47	1	1	1	93	1	2	1
2	1	1	1	48	1	1	3	94	1	2	1
3	1	1	1	49	2	2	1	95	1	2	1
4	1	1	3	50	2	2	2	96	1	2	1
5	1	1	3	51	2	2	2	97	1	2	2
6	1	2	1	52	2	2	3	98	1	2	3
7	1	2	1	53	2	2	2	99	1	2	1
8	1	2	1	54	2	2	1	100	1	2	1
9	1	2	2	55	2	2	1	101	1	2	3
10	1	1	3	56	2	2	3	102	1	2	2
11	1	1	1	57	2	2	2	103	1	2	1
12	1	1	1	58	2	2	1	104	1	2	1
13	1	1	3	59	2	2	1	105	1	2	2
14	1	1	1	60	2	2	3	106	1	2	2
15	1	1	3	61	2	2	2	107	1	3	1
16	1	1	1	62	2	2	1	108	1	3	1
17	1	1	2	63	2	2	3	109	1	2	2
18	1	1	1	64	2	2	1	110	1	2	2
19	1	1	1	65	2	2	3	111	1	2	2
20	1	2	1	66	2	2	1	112	2	2	1
21	1	2	3	67	2	2	1	113	3	2	1
22	1	2	1	68	2	2	1	114	3	2	2
23	1	1	1	69	2	1	2	115	3	2	2
24	1	1	2	70	2	1	1	116	3	2	1
25	1	1	1	71	2	1	1	117	3	2	1
26	1	1	1	72	2	1	3	118	3	2	3
27	1	2	3	73	2	1	2	119	3	2	1
28	1	2	3	74	2	1	1	120	3	2	1
29	1	2	1	75	2	1	2	121	3	2	2
30	1	2	1	76	2	1	1	122	3	2	1
31	1	2	1	77	2	1	3	123	3	2	2
32	1	2	3	78	2	1	3	124	3	2	1
33	1	2	1	79	2	1	1	125	3	2	3
34	1	2	3	80	2	1	2	126	3	2	1
35	1	2	1	81	2	1	3	127	3	2	2
36	1	1	3	82	2	1	1	128	3	2	1
37	1	1	1	83	2	1	2	129	3	2	1
38	1	1	1	84	2	1	2	130	3	2	3
39	1	1	1	85	2	1	1	131	3	2	1
40	1	1	3	86	2	1	1	132	3	2	2
41	1	1	1	87	2	1	3	133	3	2	2
42	1	1	1	88	2	1	3	134	2	2	1
43	1	1	1	89	2	1	1	135	2	2	3
44	1	1	3	90	2	1	2	136	2	2	1
45	1	1	3	91	2	1	3	137	2	2	2
46	1	1	1	92	2	1	2	138	2	2	2

Figure 3.3 Sheet designed for work sampling

3.7 Labor Productivity Modeling

With the implementation of the Stochastic Gradient Boosting (SGB) techniques, several models were constructed to reflect the relation between labor productivity and 19 parameters. The algorithm of stochastic gradient boosting was shown as below (Friedman, 2002).

Sample: TreeBoost warped in additive regression

1. $F_0(x) = arg \quad min_\gamma \sum_{i-1}^{N} \Psi(y_i, \gamma)$

2. For m = 1 to M do:

3. $\{\pi(i)\}_1^N = rand\_perm \, \{i\}_1^N$

4. $\tilde{y}_{\pi(i)m} = -\left[\frac{\partial\Psi\left(y_{\pi(i)}, F\left(x_{\pi(i)}\right)\right)}{\partial F\left(x_{\pi(i)}\right)}\right], i = 1, \tilde{N}$

5. $\{R_{lm}\}_1^L = L - terminal\ node\ tree(\{\tilde{y}_{\pi(i)m}, x_{\pi(i)}\}_1^{\tilde{N}})$

6. $\gamma_{lm} = arg \quad min_\gamma \sum_{x_{\pi(i)} \in R_{lm}} \Psi\left(y_{\pi(i)m}, F_{m-1}\left(x_{\pi(i)}\right) + y\right)$

7. $F_m(x) = F_{m-1}(x) + v \cdot \gamma_{lm} 1(x \in R_{lm})$

8. endFor.

Based on the algorithm of SGB that was developed by Friedman (2002), randomness was incorporated into the procedure of gradient boosting. $\{y_i, \mathrm{x}_i\}_1^N$

stands for the entire training dataset, and $\{\pi(i)\}_1^N$ stands for the random permutation of the figures from 1 to N. To obtain the better-performed model, several times of optimization of the first model were made through the iteration process. At each iteration, a random subsample of the inputted training data was used in place of the full set, and modification of the system parameters was made in accordance with the decrease of the gradient. As the loss function $\Psi(y_i, \gamma)$ was minimized, the direction of the gradient in current iteration was decided. The model was then updated with the new coefficients. The learning rate (v, also known as the shrinkage) was an index which decided the decreasing speed of the gradient in each time of iteration. It turned out that the value of the learning rate below 0.1 can lead to better generalization error (Friedman, 1999).

It is worth noting that a universal best choice for all situations does not exist in the selection of base-method for stochastic gradient boosting (Friedman, 1999). In this study, two primary modeling techniques, the Decision Stump and the Extra Trees, were selected as the base-method to be embedded into the additive regression in the algorithm of the Stochastic Gradient Boosting technique. The modeling procedure was implemented in the software “Weka”. The main procedure of the modeling process was divided into two steps. The first step aimed at extracting the base-method with better performance as well as finding the learning rate that appropriately fit the training data. To this end, the iteration was set as 10, 33, 100, 333, and 1000 corresponding to the learning rate respectively be set as 1.0, 0.3, 0.1, 0.03, and 0.01 to perform the additive regression, while the Decision Stump and the Extra Trees were separately wrapped in. The model with premium degree of fitting was then selected, and the base-method as well as the appropriate learning rate was decided. In the second step, for the purpose of determining the optimum number of iterations, a series of models with the number of iterations at 10, 30, 100, 300, 1000 and 3000, etc., were shaped. The value of shrinkage was set as the same of the model that had been selected in step 1. Comparisons had been made between these models. The modeling process ended when distinctive convergence was observed, and the proposed model was determined.

The values of the Mean Absolute Error (MAE) and the Coefficient of Determinations (R square) were selected as the mean criteria to evaluate the performance of these generated models. In statistics, the coefficient of determinations was used to reflect the fitness of the model (Willmott and Matsuura, 2005; Hair et al., 2010). The mean absolute error is a quantity used to measure how close the forecasts or the predictions are in accordance with the eventual outcomes. The mean absolute error (MAE) can be calculated by the following equation.

$$
\mathrm{M} = \frac{1}{n}\sum_{i=1}^{n} |A_t - F_t|
$$

Eq. (8)

In this equation, “n” stands for the number of datasets for testing the proposed model. “At” and “Ft” stand for actual value and predicted value respectively. When developing a model with multiple variables, validation of the prediction performance of the model is of parametric important. To acquire a more objective outcome, a ten folder cross-validation was employed to assure the accuracy and reliability of the MAE values (Hastie et al. 2001).

3.8 Software

For training and testing models, Waikato Environment for Knowledge Analysis (Weka, version 3.710) was selected. The collected data was transformed into Attribute-Relation File Format (Arff), and then the aforementioned modeling techniques could be implemented in this software.

Weka is an open-source software, which was developed by University of Waikato. The reason for selecting this software was simply its free availability and its user friendly graphical user interface (GUI). These allow the easy usage without the need of programming. Regarding the fact that small-scales contractors often limited in information technologies (IT) capabilities, the easy accessibility of the software enables the users to start the operation immediately.

3.9 Summary of Chapter 3

In this chapter, the framework of this study was presented, and the data collection methods were described. The researcher explained the details of the data that was needed to be collected at micro level as well as macro level. These types of data can be divided into four categories: field data, details of selected components, weather-related information, and work status of each instant observation. Thereafter, the mechanism of the selected data analysis techniques, namely, the stochastic gradient boosting, was specified. A brief introduction of the data analysis software was also included.

CHAPTER 4

RESULTS AND FINDINGS

4.1 Overview of the Collected Data

In this study, work sampling and real-time observation were performed to collect field data for the two-level analysis. The observations were carried out during a period of 6 months that covers most of the climate variations in Hong Kong. Structure framing activities of typical floors from 14th to 33rd were studies during this period.

4.2 Evaluation of the Overall Labor Performance

The researcher collected data for studying the overall labor performance of the construction process by using work sampling technique. The collected data covered activities of rebar fixing, formwork installation, and concrete placement from a total of 2082 observations, which was shown in Table 4.1.

Table 4.1 Work sampling categories and statistics

Category	concrete pouring		rebar fixing		formwork installation
	BS	CW	BS	CW	BS
Direct Work	0.64	0.48	0.46	0.47	0.45
Essential Contributory Work	0.04	0.13	0.32	0.32	0.36
Ineffective Work or Delay	0.32	0.39	0.21	0.22	0.19
Labor Utilization Factor	0.65	0.5125	0.54	0.55	0.54

Since the formworks used for wall erection were precast and hoisted directly to the working face, data was not available for formwork installation of walls. Comparisons of the direct work rate of these works had been made and showed that concrete pouring of slab and beam had the highest direct work rate (64%). Unlike rebar fixing and formwork installation, in concrete pouring activities, the concrete was hoisted to the work site by equipments and the tools were commonly prepared before the work started. Labors had no need to get materials or tools away from the area where the works had been taken place. The supportive work rate was distinctively low in concrete related activities, which were at 4% for beam and slab and 13% for column and wall, in comparison with 30% to 35% in rebar fixing activities and formwork installation activities respectively. Evidence had shown that the labor utilization of rebar fixing of beam and wall were similar, as the rate of direct work, essential contributory work, ineffective work and labor utilization factor of rebar fixing of beam followed closely to it counterparts of wall in the 879 observes.

The result also indicated that concrete pouring activities suffered more from the occurrences of ineffective work or delays, as the rate of ineffective work or delay reached over 30 percent, compared to around 20 percent in rebar fixing activities and formwork installation activities. If a pour had been finished and the concrete for the following pour had not yet been hoisted to the work site, the non-productive labor would appear (standing, sitting, personal time). It was totally different in the activities in terms of rebar and formwork, as labors would depart to get the lacked materials or tools instead of waiting for the supply.

4.3 Statistics of the Micro-Level Study

Rebar fixing activities of beam and wall from floor 14th to 33th were observed, and 326 sets of data were recorded for 49414.1kg of rebar, which was shown in Table 4.2. More detailed information of the collected data can be found in Appendix A.

Table 4.2 Details of collected data

Component	Data Set Amount	Size(kg)	Duration(Mins)			Labour Hours(h)			Average Productivity (kg/h)
			UQ	M	LQ	UQ	M	LQ	
Slab Beam	199	49414.1	16	34.71	61	0.53	1.16	2.03	191.9
Wall	127		4	25.32	63	0.06	0.43	1.23	128.6
All	326		16	31.05	63	0.06	0.876	2.03	167.240184

Information was collected for each activity on how the time had been spent on site. The means of duration time for each component in different activities were presented in Table 4.2. The collected data revealed that the labors normally spent more time to finish a continuous task in rebar fixing of beam than that of wall. The value of means in rebar fixing of beam (35mins) is higher than that of wall (25mins). Figure 4.1, Figure 4.2, and Figure 4.3 described the distribution of rebar installation durations of beams and walls. In rebar fixing of beam, the durations of most sample were distributed from 20 to 50 minutes, compared to 10 to 30 minutes for those of walls. For the purpose of calculating the input of labor resources, the duration time of each construction task was transferred into labor hours. Figure 4.4 showed that a continuous rebar fixing task usually consumed 0.2 to 1.4 labor hour in this project. The descriptive figures provided in Table 4.2 revealed that the rebar fixing of beam consumed almost triple labor resources than that of wall in a continuous work process of finishing a component, averaging 1.16m-h for beam comparing to 0.43m-h for wall. Figure 4.5 and Figure 4.6 illustrated the consumption of labor hour for different types of component, which indicated that 162 of 199 rebar fixing tasks of beam consumed labor hour at a range from 0.8m-h to 1.4m-h, and 91 of 127 rebar fixing tasks of beam consumed labor hour at a range from 0.2m-h to 0.6m-h.

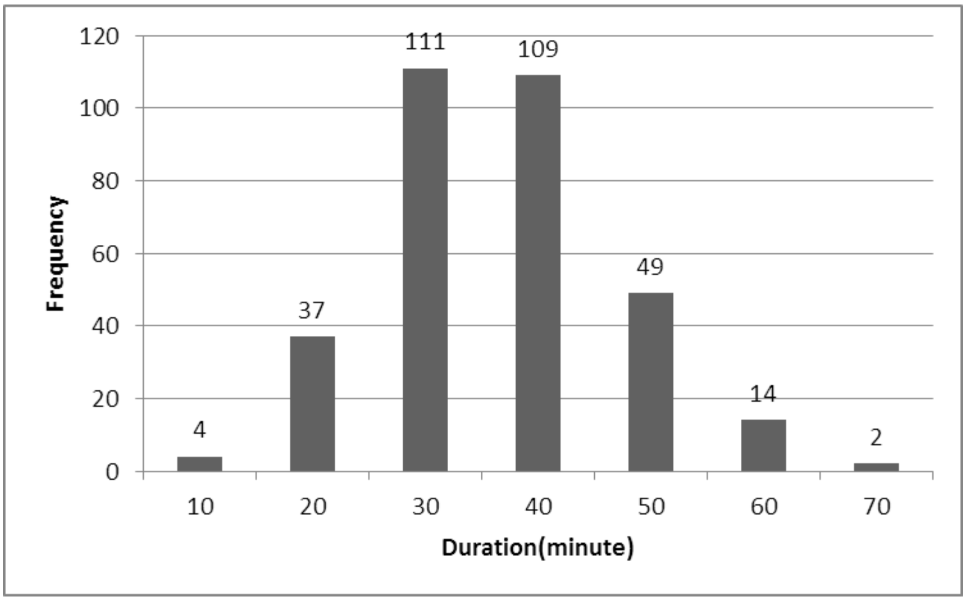


Figure 4.1 Distribution of rebar fixing durations

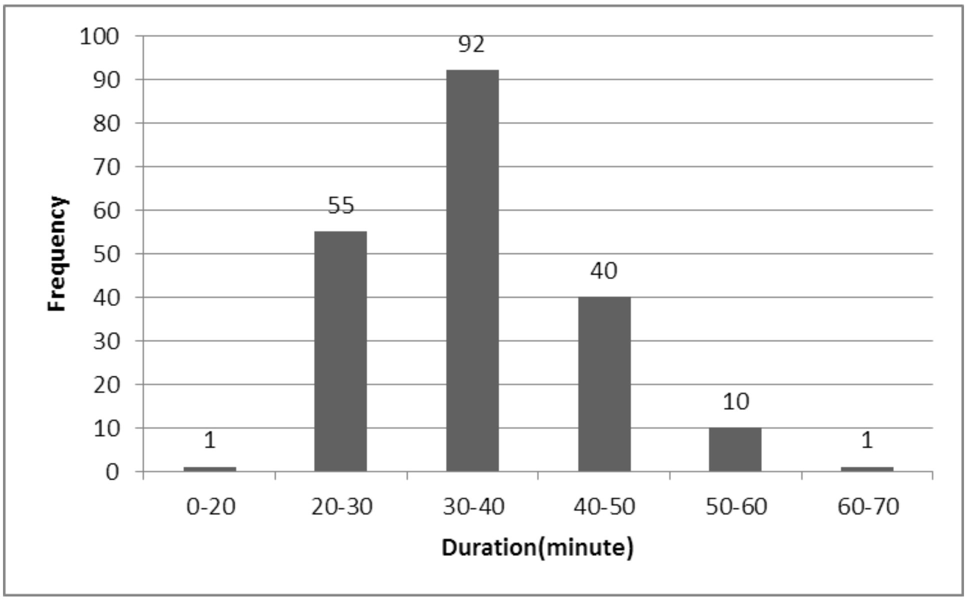


Figure 4.2 Distribution of durations of beam

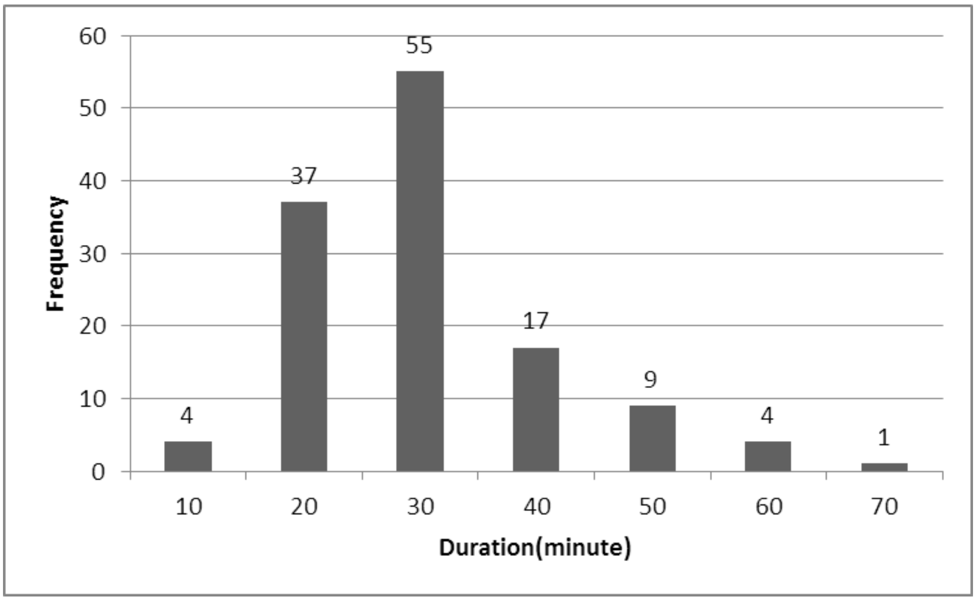


Figure 4.3 Distribution of durations of wall

Figure 4.4 Labor hour consumed for each task

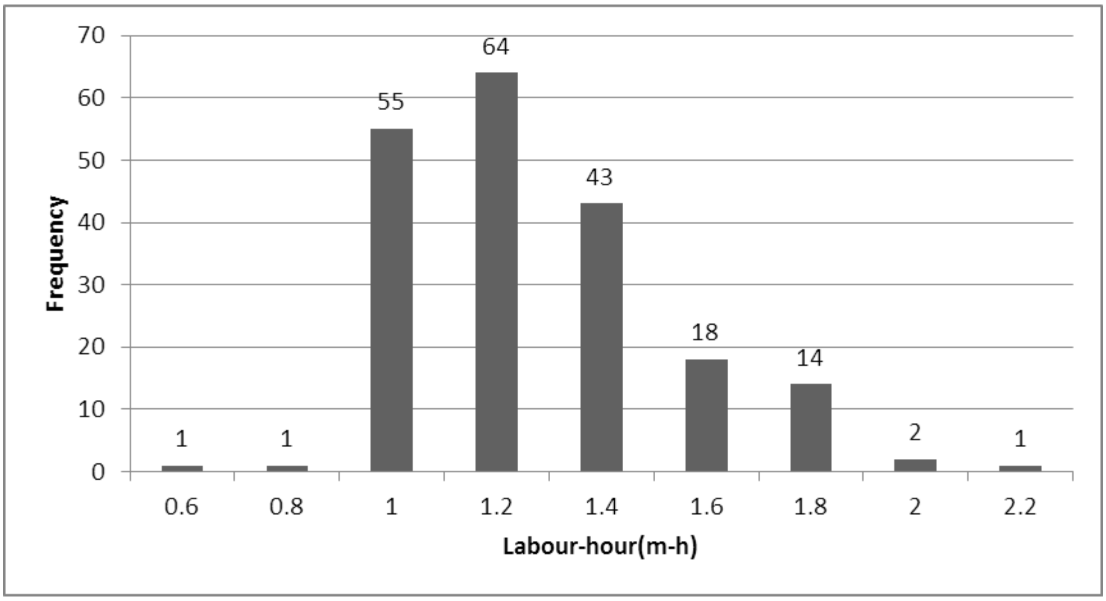


Figure 4.5 Labor hour consumed for each beam task

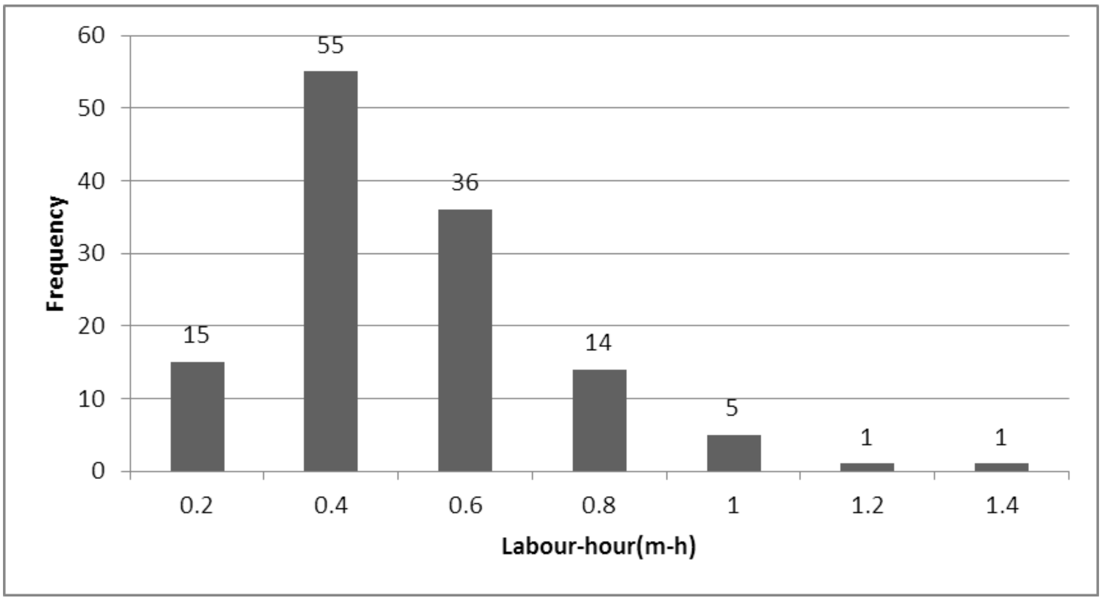


Figure 4.6 Labor hour consumed for each wall task

Labor productivity of each component was also calculated and listed in Table 4.2, and the distribution of productivity is provided in Figure 4.7, Figure 4.8, and Figure 4.9. Figure 4.7 suggested that most samples achieved labor productivity rate at 50kg/m-h to 250 kg/m-h in rebar fixing activities. As shown in Figure 4.8, the rebar fixing of beam yielded labor productivity mostly at a range of 150 to 200 kilograms per man-hour. Reported at a lower interval, the values of labor productivity for rebar fixing of wall scattered between 75 kg/m-h and 125 kg/m-h, which was shown in Figure 4.9. It is clear that labor productivity had a distinctive dimension for different types of components. The rebar fixing of beam achieved higher labor productivity than its counterpart (wall), averaging 191.9 kg/m-h and 128.6kg/m-h respectively. As shown in table 4.2, the average labor productivity for binding & assembling of reinforcement counted to 167.2 kg/m-h.

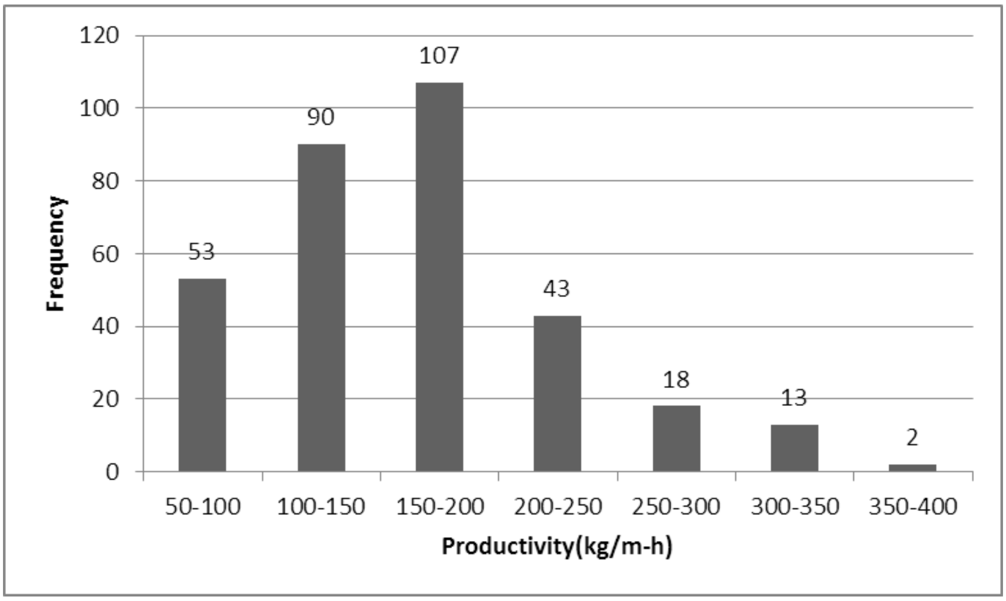


Figure 4.7 Distribution of labor productivity of each task

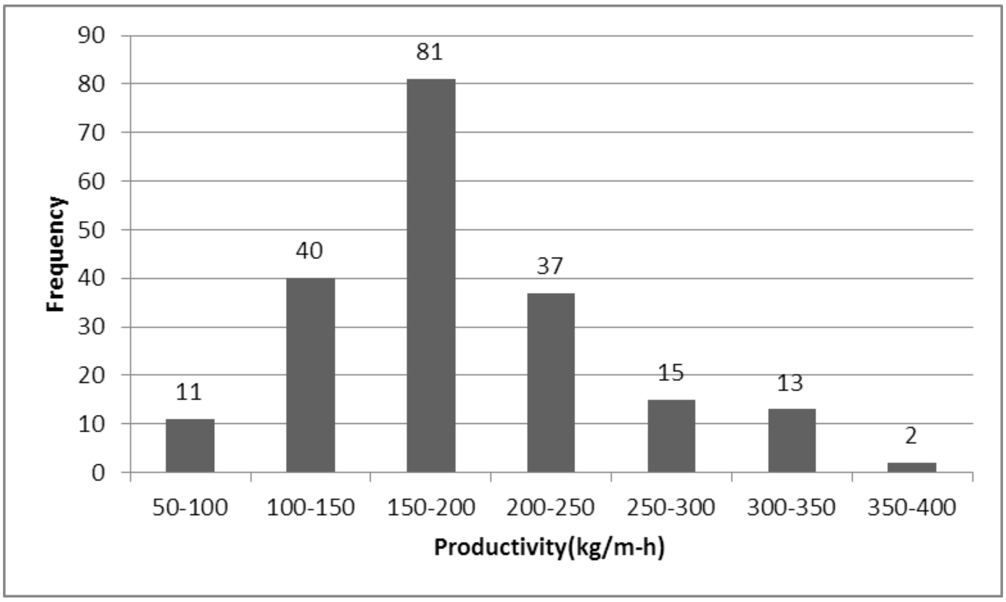


Figure 4.8 Distribution of labor productivity of each beam task

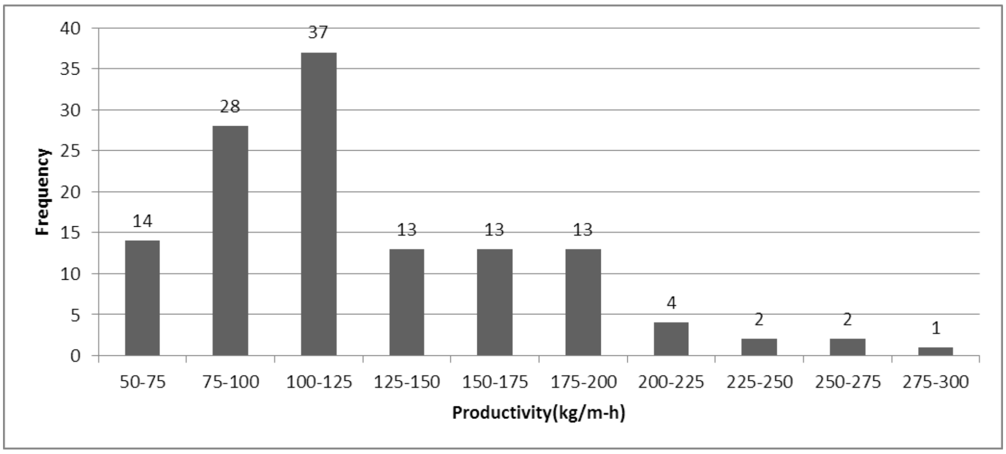


Figure 4.9 Distribution of labor productivity of each wall task

Numerous factors in terms of weather condition, buildability and project-related aspect were considered, and the relevant parameters of these factors had been gathered in each set of data. The variance range, the minimum/maximum/mean value, the sum value, and the standard deviation of the recorded data were summarized in Table 4.3. Several plots had been made to illustrate the pairwise relation of parameters, which were demonstrated in Figure 4.10.

Table 4.3 Descriptive statistics

	N	Minimum	Maximum	Sum	Mean	Std. Deviation
TP	326	12.9	29.8	7463.4	22.8939	4.28285
HM	326	61	94	26439	81.1012	8.50623
WS	326	4.3	23.9	3698.22	11.3442	4.26372
PT	326	0	31.3	971.2	2.9791	7.33194
M_16	326	0	10	736	2.2577	3.96382
M_20	326	0	8	420	1.2883	2.61763
M_25	326	0	12	1004	3.0798	4.0413
M_32	326	0	6	278	0.8528	1.82203
M_40	326	0	6	126	0.3865	1.25918
H_0.8	326	0	66	8934	27.4049	23.01762
H_1.2	326	0	33	3477	10.6656	11.75344
H_1.5	326	0	15	660	2.0245	5.13324
ML	326	0	5.15	785.35	2.409	1.99168
HT	326	0	22	1409	4.3221	5.80005
VT	326	0	16	1419	4.3528	5.80886
QT	326	16	111	18463	56.635	29.61328
WT	326	0	250	28450	87.2699	110.51864
GZ	326	1	3	527.5	1.6181	0.49831
LP	326	56.66	360.6	53628.89	164.5058	63.76371

TP=temperature, HM=humidity, WS=wind speed, PT=precipitation, M_16=quantity of 16mm diameter rebar, M_20=quantity of 20mm diameter rebar, M_25=quantity of 25mm diameter rebar, M_32=quantity of 32mm diameter rebar, M_40=quantity of 40mm diameter rebar, H_0.8=quantity of hoop rebar (length=0.8), ML=length of mean rebar, HT= quantity of horizontal rebar, VT=quantity of vertical rebar, QT=total quantity of rebar, WT=thickness of wall, LP=labor productivity, WT=work type (1=beam, 2=wall, not showed in the table)

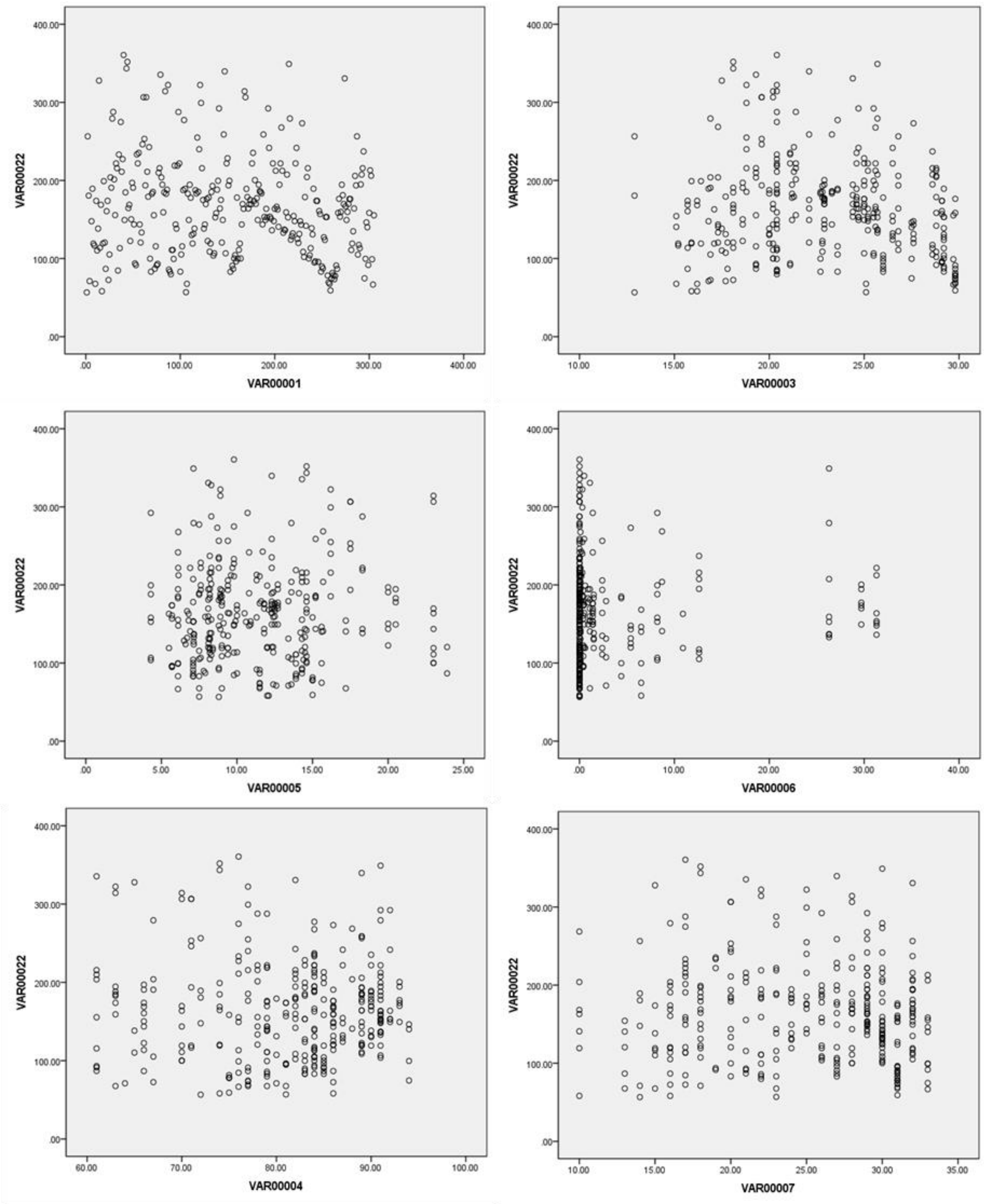


Figure 4.10 Standardized scatter plot for rebar fabrication

4.4 Labor Productivity Modeling

The collected data was used to develop the productivity–factor model. This study adopted the Stochastic Gradient Boosting techniques to identify the relationship between labor productivity and the selected factors.

As proved by many researchers, the stochastic gradient boosting technique has superior predictive performance as well as premium overall accuracy (Elith et al., 2008; MOHAMED, 2010; Li et al., 2014). In this research, a comparison had been also made to test the forecasting capability of the stochastic gradient boosting and several other modeling techniques. The collected data was used as training data to develop a group of models by these techniques, and the value of mean absolute error of each method was calculated by the 10-fold cross validation. It turned out that the stochastic gradient boosting surpassed other methods in terms of predictive performance as it reported the lowest value of MAE, which was shown in Table 4.4.

Table 4.4: Plain performance comparisons of 10-fold tests

ML Model	**Mean Abs Err**
Linear Regression	29.93
Neural Network	39.64
RBF Network	42.48
1-Nearest Neighbor (Euclidean)	26.97
1- Nearest Neighbor (Manhattan)	26.56
Decision Stump	39.32
Naive Bayes	28.88
SVM	43.89
NN (optimized, Feature Sel)	31.45

SGB (DecisionStump)	**23.10**
SGB (ExtraTree)	**21.21**

Based on the algorithm of the Stochastic Gradient Boosting, the Decision Stump and the Extra Trees were chosen to be warped in the Additive Regression to develop several models. The collected 326 sets of data were used to train the models, as the labor productivity was set as the dependent and other 19 parameters in the respect of weather, work type, etc., were set as the independents. These parameters were extracted from the literature review, which were believed to have extensive influence on labor's on-site working. As stated in chapter 3, the performances of these models were evaluated by comparing the values of Mean Absolute Error (MAE) and the Coefficient of Determinations (R^2) of these models. The value of MAE and R^2 were derived from the employed ten-fold cross validation. Table 4.4 and Table 4.5 described the modeling process and the detail of these models.

Table 4.5 Parameters for based method, iteration & learning rate

Base		**10x1.0 (no learning)**	**33x0.3 (fast learning)**	**100x0.1**	**333x0.03**	**1000x0.01 (slow)**
DecisionStump	MAE	23.6188	22.5718	22.8366	23.0565	23.1
	R2	0.8634	0.8763	0.8766	0.876	0.8759
extraTree	MAE	26.5015	22.1606	21.9154	21.5079	**21.2134**
	R2	0.7967	0.8451	0.8546	0.8562	**0.8642**

Table 4.6 Convergence (trees = 10 to 3000) (base= extraTree, learing rate=0.01)

10	**30**	**100**	**300**	**1000**	**3000**
46.097	39.8005	26.7244	**20.6787**	21.2134	21.2408

Table 4.7 Details of the proposed model

(The proposed model can be obtained by using the following configuration in Weka 3.710)

Additive Regression ZeroR model predicts class value: 164.50579456441713 Scheme: weka.classifiers.meta.AdditiveRegression -S 0.01 -I 300 –W weka.classifiers.trees.ExtraTree -- -K -1 -N -1 -S 1 300 models generated. Model number 0 Extra-Tree with K = -1 and Nmin = -1 (259 nodes in tree) Model number 1 Extra-Tree with K = -1 and Nmin = -1 (253 nodes in tree) Model number 2 Extra-Tree with K = -1 and Nmin = -1 (271 nodes in tree) ... Model number 297 Extra-Tree with K = -1 and Nmin = -1 (269 nodes in tree) Model number 298 Extra-Tree with K = -1 and Nmin = -1 (243 nodes in tree) Model number 299 Extra-Tree with K = -1 and Nmin = -1 (271 nodes in tree) Time taken to build model: 0.38 seconds

As shown in Table 4.4, the Extra Trees was proved to have better capability than the Decision Stump. The Learning Rate and the Iteration were decided by the subsequent step of the modeling process. As shown in Table 4.5, the model with the Learning Rate of 0.01 and the Iteration of 300 was selected as the final model that was found to outperform than other models. The detailed information of the proposed model was shown in Table 4.6. The coefficient of determinations reached 0.86, which indicated that the model fits over 85 percent of the training data. In other word, weather-related factors, project-related factors, and buildable factors were determined as the factors that significantly affecting labor productivity, as these factors could explain 85% variance of labor productivity. This outcome validated the research hypothesis that was made in chapter 3. The result also revealed that the model possessed a stable prediction capability, as the MAE calculated by the ten-fold cross validation reported at only 20.6. Such deviation is reasonable since labor productivity of the construction activities is highly variable by itself.

4.5 Parameter Analysis

The parameter analysis was performed for temperature, humidity, wind speed, and the buildable factors which had been extensively analyzed in previous study. As the implementation of the Stochastic Gradient Boosting technique, the productivity variation trends were expressed as a function of the variation of 19 parameters involved in this study. To perform the parameter analysis which aimed at exploring the variation trend between productivity and factors as well as quantifying the impact of factors, several groups of test datasets were prepared and inputted in the developed model. For example, in the analysis of temperature and productivity, the parameter of temperature varied from the minimum to the maximum value and the rest of the parameters were kept constantly at their respective average values to form several sets of testing data.

The prediction model that was shaped by the Stochastic Gradient Boosting technique was applied to each set of the testing data to output the estimation value of labor productivity. Each estimation value of labor productivity was normalized from 0 to 1 to enable comparisons among different data dimensions. By doing the same procedure in analyzing other parameters, series of curves were shaped and showed in Figure 4.11 to Figure 4.16. The feature scaling was used to normalize each estimation data. The equation was given as following:

$$x' = \frac{\mathrm{x} - \mathrm{x}_{min}}{\mathrm{x}_{max} - \mathrm{x}_{min}}$$

Eq(9)

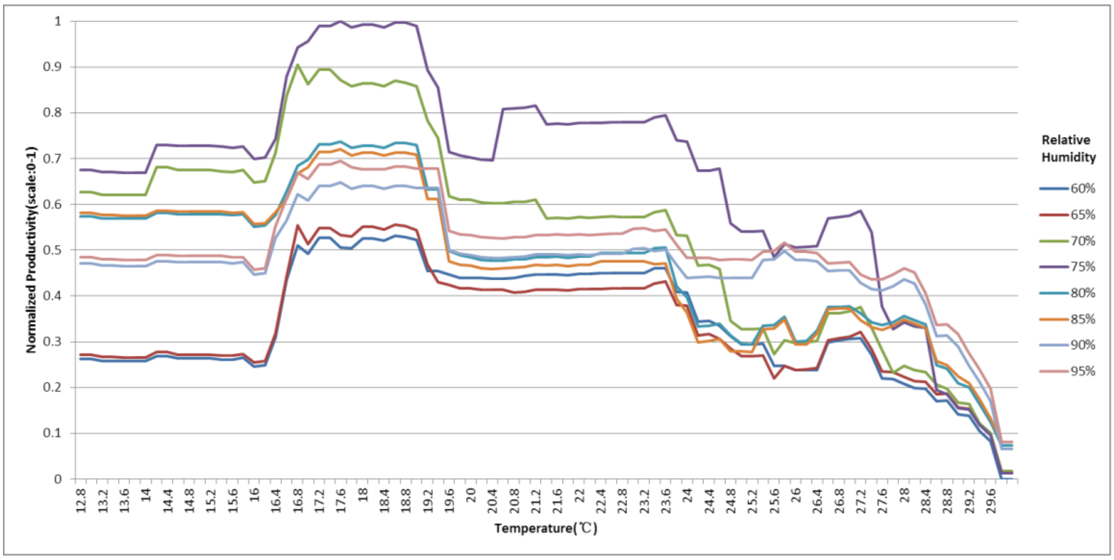


Figure 4.11 Labor productivity variation trends in different humidity level (from 60% to 95%)

Labor productivity at a temperature ranging from 12.8℃ to 30℃ in different humidity conditions was studied. The result made clear that the labor productivity variation trends of same components in different humidity level were similar. Figure 4.11 illustrated the variation trends of labor productivity with temperature in rebar fixing activities of wall when the relative humidity rate varied from a range of 60% to 95%. It also suggested that a working environment of relative humidity at 70% to 75% could yield higher labor productivity value of 30%.

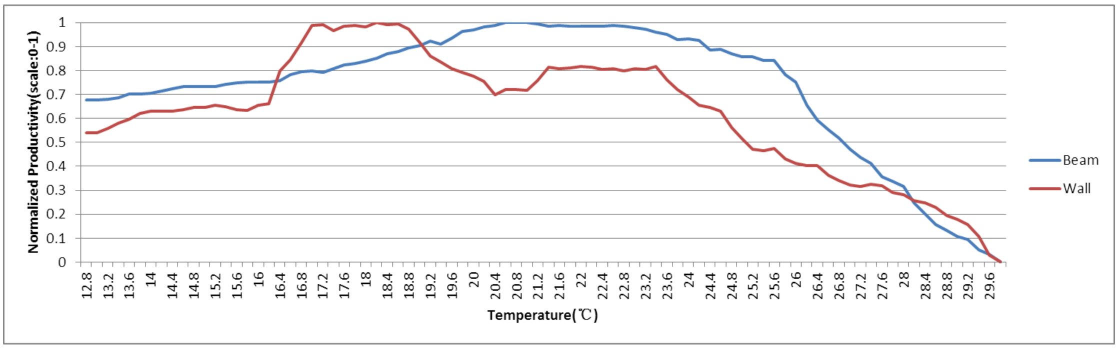


Figure 4.12 Labor productivity variations corresponding to temperature from 12.8℃ to 30℃ for beam and wall

It turned out that the variation trends of productivity with temperature were different between beams and walls in rebar fixing activities. As shown in Figure 4.12, in rebar installation of beams, the productivity increased smoothly to the peak corresponding to the temperature ranged from 12.8℃ to 21℃. It showed a declining trend when the temperature exceeded 21℃, and the decrease tended to be more sharply after the temperature reached 26℃. In rebar fixing activities of walls, although the productivity also rose up at the beginning and followed by a decrease which depicted a similar trend with that of beams, it showed that the productivity peaked at the temperature of 17℃ and did not go down before the temperature reached 18.5℃. Any further ascent in temperature up to 30℃ has negative impact on productivity.

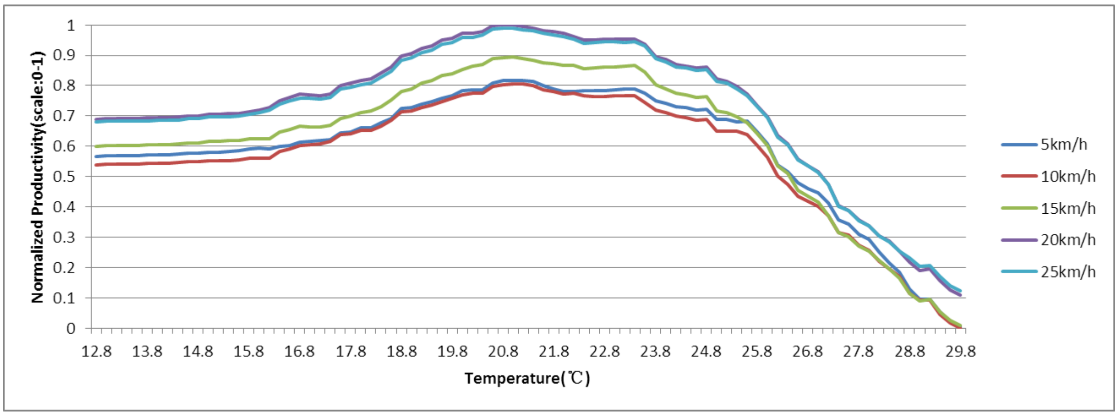


Figure 4.13 Labor productivity variations corresponding to wind speed from 5℃ to 25℃

Evidence had shown that rising in wind velocity also increased labor productivity. In this study, a positive relationship between labor productivity and wind velocity was detected, which was shown in Figure 4.13. It revealed that the work environment with the wind speed at 20 km/h to 25 km/h can achieve better labor productivity of 10% to 15% comparing with that of 5 km/h to 15 km/h. It also showed that the curves of 25 km/h and that of 20 km/h almost coincide with each other, which indicated that there was no increase in labor productivity corresponding to the rising in wind speed from 20 km/h to 25 km/h. This phenomenon could be explained by the rationale that, in an open-air work environment, wind could offset the negative impact of hot weather on human body in labor intensive works such as the rebar fixing, and this consequently leads to increasing in labor productivity. Wind speed at 20 km/h to 25 km/h could be the comfortable zone for on-site working of construction task.

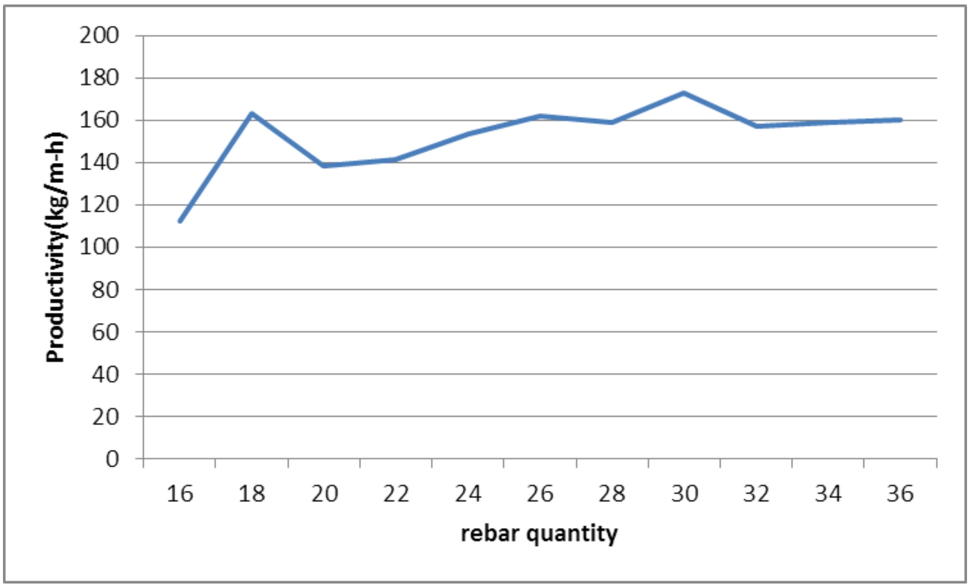


Figure 4.14 Relation between quantity and labor productivity in rebar fixing of wall

Regarding the buildability concerns, the effect of rebar quantity had been analyzed. The outcome depicted a positive relation between labor productivity and rebar quantity in rebar fixing of wall, which was shown in Figure 4.14. It was found that labor productivity increases by 1.346 kg/m-h as the quantity increases by one.

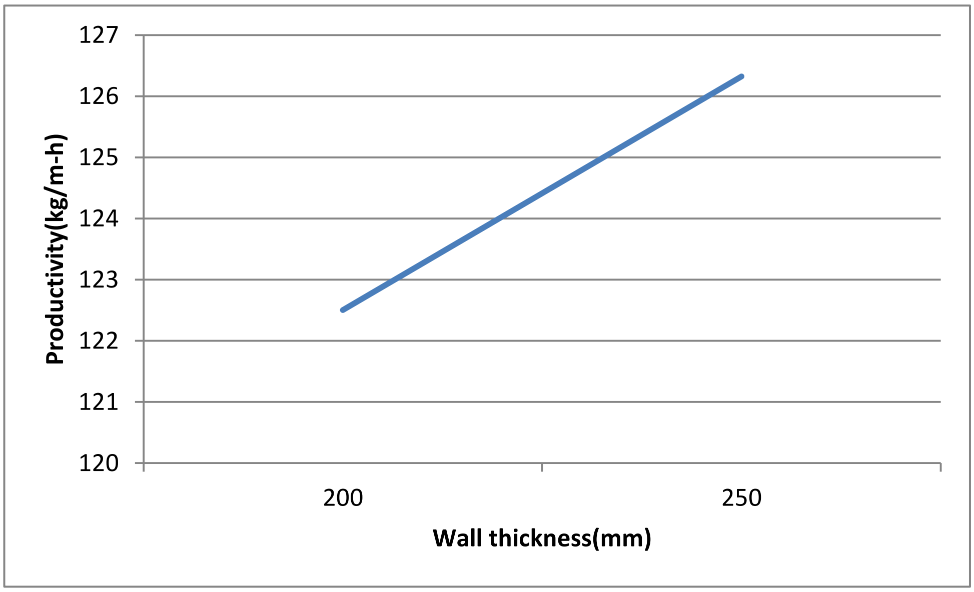


Figure 4.15 Relation between wall thickness and labor productivity

The effect of wall thickness was analyzed. As stated in previous research, the thickness of wall was also an important factor which had been proved to have positive effect on labor productivity (CIRIA, 1983; Jarkas, 2012). The outcome of this study further validated this trend, which showed an increasing labor productivity of 0.07634 kg/m-h as per millimeter's increase in the thickness of wall.

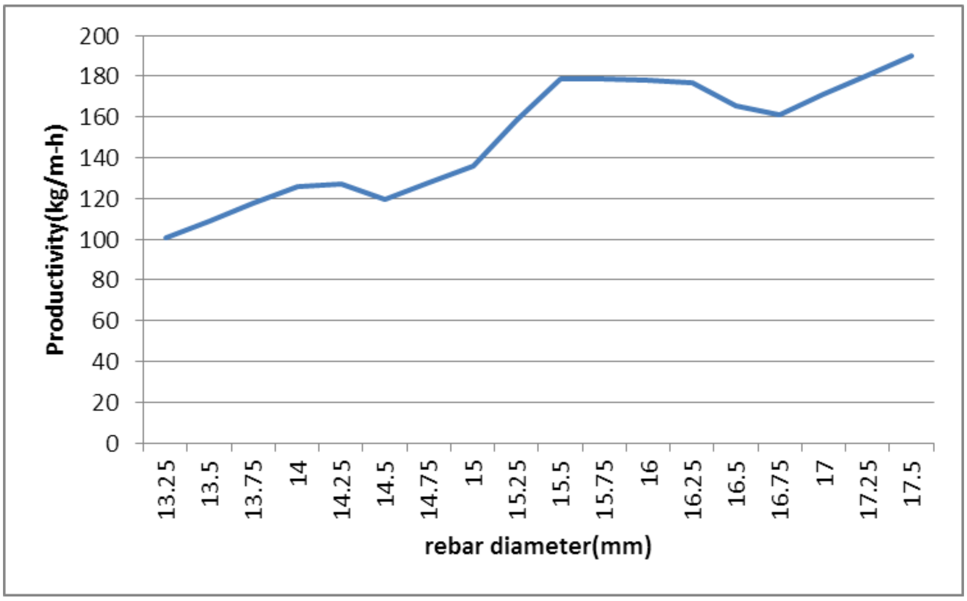


Figure 4.16 Relation between rebar diameter and labor productivity in rebar fixing of beam

The influence of rebar diameter was also focused. Figure 4.16 showed that labor productivity rose from 100 km/m-h to around 190 km/m-h as the rebar diameter increased from 13.25 mm to 17.5 mm in rebar fixing of beam. A positive relationship between labor productivity and rebar diameter were concluded, as labor productivity rises 21.05kg/m-h corresponding to a millimeters' rise in the average diameter of rebar. Data of beam type 7 and beam type 9 was excluded because of the distinctive design geometry that differed from other types of beams.

4.6 Labor Productivity Checklist

The parameter impact analysis helped to gain better understanding of the factors affecting labor productivity by analyzing the variation trend of productivity with factors as well as quantitatively identifying the impact of weather-related factors and buildable factors. To meet the management concern in terms of project scheduling and planning, this study had proposed to initiate a labor productivity checklist to provide estimation values of labor productivity at both macro and micro level.

Comparing to other industries, the construction industry is commonly subject to more risks, therefore the risk management played an important role in any aspect of project management (Shen, 1997). Some previous studies have identified Time Delay and Cost Overrun as the major concerns of risk management in construction. These risks are highly related to labor productivity. For instance, perceiving higher labor productivity beyond the reality in planning might lead to failure of punctual completion of construction tasks, and result in overtime working which can generate unexpected cost.

In general, the identification and estimation of risks are believed to be the necessary prerequisite to risk control (Hubbard, 2009). To this end, this study aimed at providing the baseline for labor productivity in view of both optimistic and pessimistic situation, which was showed in Table 4.6.

Table 4.8 Labor productivity checklist

Component	Actual productivity		Overall productivity	
	pessimistic	optimistic	pessimistic	optimistic
Beam 1	100.862	150.99	46.39652	69.4554
Beam 2	133.899	173.078	61.59354	79.61588
Beam 3	179.258	199.468	82.45868	91.75528
Beam 4	142.268	180.007	65.44328	82.80322
Beam 5	177.796	190.853	81.78616	87.79238
Beam 6	117.546	160.462	54.07116	73.81252
Beam 7	303.684	344.102	139.69464	158.28692
Beam 8	198.174	245.389	91.16004	112.87894
Beam 9	264.071	310.536	121.47266	142.84656
Beam 10	157.96	186.704	72.6616	85.88384
Wall 1(200mm)	101.905	143.105	47.89535	67.25935
Wall 2(250mm)	103.109	149.535	48.46123	70.28145

In this study, since the influence of buildable factors and project-related factors were ascribed to the design of components or the work type, the checklist was designed to provide the reference values of labor productivity for each type of beam and wall. Regarding of the remarkable effect of weather-related factors, optimistic and pessimistic estimations of labor productivity were made for each type of component by configuring the weather-related factors to stay at the values corresponding to their maximum and minimum impact on labor productivity. On the other hand, two groups of values with different calculation method of labor input were presented, as the first group applied the actual consumed labor hour as the labor input while the second group adopted the paid time as the labor input.

It is clear from the checklist that the data dimension of labor productivity for different types of beams can be distinctive. This can be explained by the effect of the buildable factors and the project-related factors. Tying rebar is the main activity in rebar fixing tasks which is time consuming, and commonly the consumption of time in tying thick rebar has no difference with thin rebar. Hence, it is no surprise that beams with thicker main reinforcement bar achieves higher level of productivity.

4.7 Comparative Analysis

4.7.1 Dimension of Data

Comparisons had been made between this study and related articles in the subsequent step. The dimension of data was studied. Labor productivity of rebar fixing was also analyzed by Nguyen (2013). In his study, the data used for calculating labor productivity was collected from the construction process of structural work of a 20 floor apartment building, which was similar to the selected project of this study. Nonetheless, his research reported labor productivity at 5.71 to 22.81 kilograms per man-hour, which was far from the result of this study.

The significant discrepancy in data dimension was likely to ascribe to the application of different data collection method. Normally, the man-hour provided by contractors was often used to calculate labor productivity in previous labor productivity studies. In Nguyen's research (2013), the value of labor productivity was determined by the project records. Rebar fixing of columns, shear walls, and slabs were chosen to be focused on. Labor productivity of each floor was calculated and shown in table 4.7. However, it had been demonstrated that a considerable part of labor hours is non-productive in any construction projects (Thomas, 1991). If the construction planning is too loose or the management capability of site supervisor is overestimated, the non-productive time will increase and labor productivity will be undervalued due to the misperception of the prolonged labor hours.

Table 4.9 Data for labor productivity in Nguyen's study (source: Nguyen et al., 2013)

Floor	Floor area (m^2)	Rebar	Formwork	Rebar (10^3 kg)	Formwork (m^2)	Rebar (kg/WH)	Formwork (m^2/WH)
Fl. 2	579	4,119	3,881	23.51	1,172	**5.71**	0.3
Fl. 3	949	4,216	4,121	32.69	1,472	**7.75**	0.36
Fl. 4	943	4,462	2,949	32.5	1,469	**7.28**	0.5
Fl. 5	943	4,262	2,312	32.5	1,469	**7.62**	0.64
Fl. 6	949	4,004	2,153	33.38	1,520	**8.34**	0.71
Fl. 7	966	3,457	2,173	33.37	1,493	**9.65**	0.69

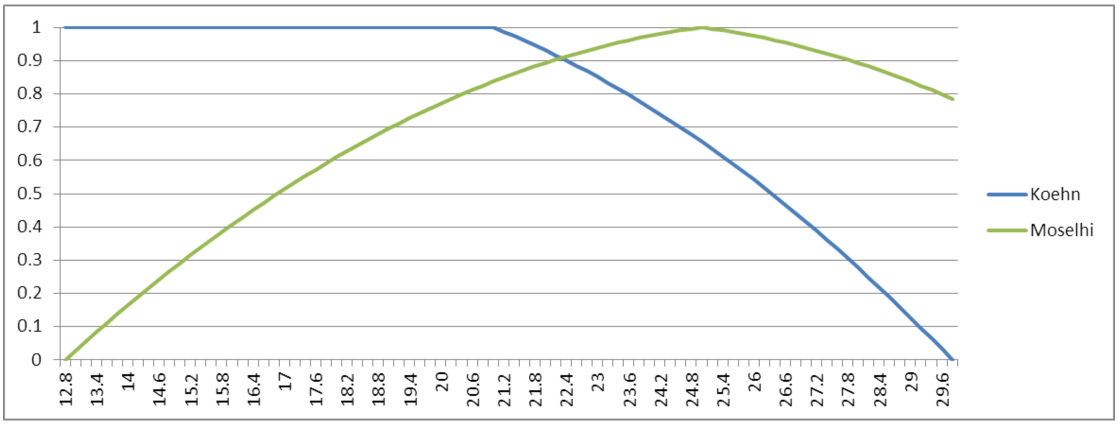
Fl. 8	966	2,591	2,024	33.37	1,493	**12.88**	0.74
Fl. 9	966	2,356	2,351	33.37	1,493	**14.17**	0.64
Fl. 10	966	2,324	3,004	33.37	1,493	**14.36**	0.5
Fl. 11	966	2,560	3,382	33.37	1,493	**13.04**	0.44
Fl. 12	966	2,231	2,281	33.37	1,493	**14.96**	0.65
Fl. 13	966	2,166	2,520	46.63	1,498	**21.53**	0.59
Fl. 14	966	2,845	2,767	46.63	1,498	**16.39**	0.54
Fl. 15	966	2,046	2,496	45.5	1,498	**22.24**	0.6
Fl. 16	966	1,983	2,700	45.23	1,497	**22.81**	0.55
Fl. 17	919	3,260	2,393	45.47	1,404	**13.95**	0.59
Fl. 18	919	3,317	1,904	45.35	1,411	**13.67**	0.74
Fl. 19	919	3,540	2,774	45.35	1,411	**12.81**	0.51

In another study, Jarkas (2010a) used real-time observation to analyze rebar fixing of beamless slabs, which registered labor productivity at 148.2 kg/m-h and 174.3 kg/m-h for non-rectangular slabs and rectangular slabs respectively. The real-time observation had been also used in another research that focused on rebar fixing (Jarkas, 2012b), which presented labor productivity values for different types of walls (112.9 kg/m-h for straight walls and 69.1 kg/m-h for curved walls). Using the same method as the proposed study, in Jarkas's studies (2010a, 2012b), only productive working time was taken into account in the calculation of labor input. These two studies reported labor productivity values to be at the same level of data dimension as the proposed study. The characteristics of region, project and component between this study and Jarkas's studies might contribute to the remaining differences.

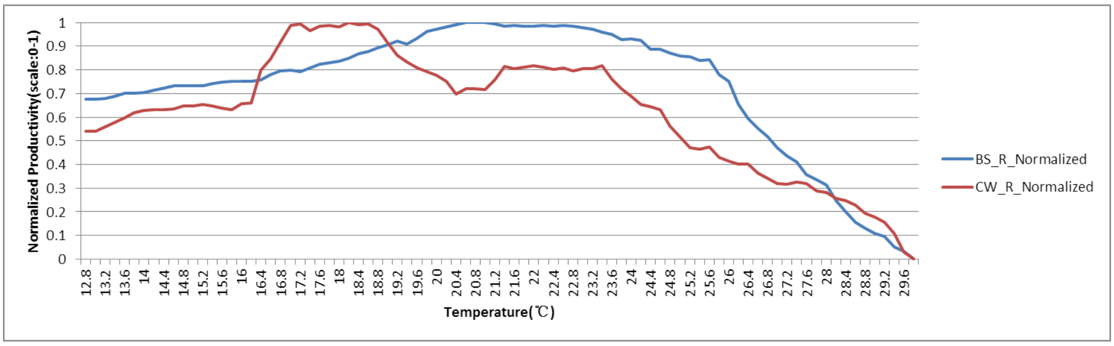
Obviously, the real-time observation is time consuming, but it provides an available approach to track the entire process of a construction task. The influence of non-productive time and supportive time on calculating man-hour can be minimized by using real-time observation to gather data, and the actual work time can be recorded.

4.7.2 Effect of Parameters

Two articles focusing on quantifying the impact of weather-related factors were chosen to be studied. With different data sources, Koehn and Brown (1985) recycled historical data to study the overall effect of these factors on the overall productivity of construction projects, while Moselhi and Khan (2010) analyzed the impact of these factors on labor productivity by using daily records of a project, and identified the labor productivity variation trends.



(a)



(b)

Figure 4.17 Productivity variations corresponding to temperature range from 12.8℃ to 30℃

From a macro prospective, it was stated that the overall variation trend of labor productivity detected by Moselhi and Khan (2010) followed closely to that of Koehn and Brown (1985) at a temperature range from -30℃ to 50℃. However, Figure 4.17a showed that from a narrow scope, the variations of labor productivity depicted different trends. In temperature between 12.8℃ and 21 ℃, labor productivity had reached its optimum and stayed constant in Koehn and Brown's study (1985), while the outcome of Moselhi and Khan's study (2010) demonstrated a continuous rise of labor productivity. The distinctive difference of these two curves was observed in temperature between 21℃ and 25℃, as one depicted an upward trend and another went against. Figure 4.18a and Figure 4.17b illustrated the variation trends of labor productivity with temperature of this study, Koehn and Brown's study (1985), and Moselhi and

Khan’s study (2010), which indicated that no consensus had been reached among these curves at a temperature range from 12.8℃ to 30℃. The differences might be attributed to the fact that the data sources of Koehn and Brown’s study (1985) and Moselhi and Khan’s study (2010) were the historical studies and the records of project daily quantities that derived from the project superintendent, while the data used in this research was gathered through on-site observations. These outcomes suggested that the quantified influences of factors and the identified variation trends of labor productivity in previous studies might be criticized if they are applied to the micro-level analysis of labor productivity.

The effects of buildable factors on labor productivity that had been identified from this study were compared with the related articles. Jarkas (2012b) conducted a research to quantify the impact of buildable factors on rebar fixing operations. He concluded a positive relationship between rebar quantity and labor productivity, as labor productivity rises 0.00386 kg/m-h corresponding to one kilogram’s increase of the rebar quantity. The outcome of the proposed study further validated this trend. Transferring the outcome into kilograms, this study demonstrated a 0.647 kg/m-h of increasing in labor productivity corresponding to 1 kg of increase in the quantity of reinforcement, which is more significant than the outcome of Jarkas’s study (2012b). In another aspect of buidability, the finding of this research also revealed good agreement with

Jarkas's study (2012b), as both of the studies determined a positive relation between wall thickness and fixing labor productivity. A more significant upward trend was identified in Jarkas's study, as 1.00 mm of adding in the thickness of wall could lead to 0.29 kg/m-h of rising in labor productivity.

Another study of Jarkas (2010a) focusing on the operation of rebar fixing of beamless slabs exhibited a positive relationship between labor productivity and rebar diameter, which claimed the same point of view of this study. In his study, the effect of rebar diameter on labor productivity was quantified and the result was that, labor productivity rises by 8.71 kg/m-h as per millimeter's increase in the average diameter of rebar. The quantified result of the proposed study also reported a positive relationship between labor productivity and rebar diameter, but the rise in labor productivity in this study was more significant as the rebar diameter increased. Regarding the fact that the average bar diameter of all samples of this study (15.4 mm) was higher than that of Jarkars (14.2 mm), a more rational comparison had been made between this study and Jarkars's study (2010a) by analyzing the outcomes in same external conditions. To restrict the rebar diameter from 13.25 mm to 15.00 mm, the mean value of rebar diameter of the selected sample datasets was controlled at the same level of that of Jarkas. The quantified result of this study showed that labor productivity increased by 8.53 kg/m-h on average as the rebar diameter increased by 1.00 mm, which was found to be in good agreement with Jarkas's finding. The result also indicated that the effect of rebar diameter on labor productivity could be more significant as the rebar became thicker.

The result of the parameter analysis suggested that this study reached a good agreement with the studies that had analyzed the impact of factors affecting labor productivity at component level. However, the result also highlighted the discrepancy between this study and the studies that focused on the weather impact, as different data sources were utilized. The outcomes of the parameter analysis suggested that the impact of factors at component level might be overlooked if the estimations of labor productivity based on aggregate data were used to support decision-making or scheduling in the operation of construction project management.

4.8 Conclusion of Chapter 4

This chapter described the implementation of the macro-level analysis as well as the micro-level analysis. In the macro-level study, the overall labor performance was studied by utilizing work sampling technique. The characteristics of labor utilization in rebar fixing, formwork installation, and concrete pouring of the selected project were presented and discussed. In the micro level analysis, the statistics of the data that was collected by real-time observation was elaborated, and the value of labor productivity of each observation was calculated. With the purpose of quantifying the influences of factors, the Stochastic Gradient Boosting technique was applied, and the developed model demonstrated a good fit of the training data as well as a stable forecasting capability. By numerous times of configurations of the model, the effects of some factors were quantified, and several curves that reflected the variation trends of labor productivity with the influential factors were portrayed. The outcomes of the micro-level analysis and the macro-level analysis helped to develop the proposed labor productivity checklist that provided baseline for the estimation of labor productivity. Thereafter, the outcomes of this study were compared with literatures, and the result suggested that this study reached a comparatively good agreement with the studies which also applied the actual work time as the labor input. The data dimensions of this research and the previous research were studied by the comparative analysis, and the result indicated that the real-time observation could provide available data sources for estimating labor productivity because the interferences of non-direct work time can be minimized in calculating labor inputs. The impacts of parameters were also compared, and the result highlighted the uncertainty of the labor productivity variation trend that had been identified in previous studies. The outcomes of this research further criticized the direct application of previous labor productivity estimation models for planning and scheduling use in Hong Kong construction projects.

CHAPTER 5

CONCLUSION

5.1 Overview

This chapter summarized the results and the findings of this research. It reviewed the achievements of the stated research objectives at the first stage, followed by summarizing the main contributions of this study. The limitation of this study was highlighted, and the recommendation for future work was put forward.

5.2 Review of Research Purpose

Referring back to the first chapter, the need of an effective labor productivity measurement and estimation method in Hong Kong construction industry was stated, and the major challenges for the application of the existing methods which had been described in previous research were spotlighted. From a scope of the public housing sector that has provided accommodations for over 2 million local people, this research was proposed to tackle the research gap in four ways: (1) analyze the characteristics of labor utilization in rebar fixing, formwork installation, and concrete placement; (2) generate the variation trends of labor productivity with numerous influential factors, and quantify the actual impacts of some factors on labor productivity; (3) conduct a comparative study to discuss the findings; (4) develop a labor productivity checklist to provide a baseline for the estimation of labor productivity with considering the effects of factors as well as the ratio of direct work time. A systematic review of the literatures was undertaken to determine the appropriate definition of labor productivity as well as the applicable data collection and analysis techniques for this study. Based on the theory of previous research, the literature review also helped to identified several categories of factors that vary frequently and significantly affect labor productivity. The quantification results of these factors were critically discussed.

To accomplish the research objectives, this thesis proposed a two-level study that gathered data at both macro level and micro level. The macro-level study focused on rebar fixing, formwork installation (not available for walls), and concrete placement, while the micro level study focused on rebar fixing only. In the macro-level study, the work sampling technique was adopted to capture a total of 2082 instant observations to calculate the direct work rate as well as the non-productive rate. The result of the macro-level study demonstrated distinctive situations of labor utilization between different types of framing activities. The micro level analysis concentrated on generating labor productivity variation trends as well as quantifying the impact of weather-related factors and buildable factors on labor productivity through the statistical analysis of 326 sets of data that were gathered by real-time observation. The result of the micro-level study suggested that over 80%

variance of labor productivity can be explained by these factors. In the parameter analysis, the effects of temperature, humidity, wind speed, rebar diameter, thickness of wall, and rebar quantity on labor productivity were studied, and the variation trends as well as the quantitative result were analyzed and discussed. Considering the effect of the influential factors, a labor productivity checklist was presented to provide optimistic estimations as well as pessimistic estimations for 10 types of beam and 2 types of wall. The labor utilization rate was also concerned, as the developed checklist provided estimation values for both actual labor productivity and overall labor productivity.

To obtain further understanding of the results of this study, comparisons had been made not only between different types of component within this study but also among this study and the literatures. It was interesting to find that the effect of buildable factors quantified in this study reached good agreements with the finding of Jarkars's study (2010a, 2012b) in which the direct observation was also used to gather the data. On the other hand, the result of the comparative analysis also indicated that the quantified impact of factors and the dimension of data of this study failed to reach consensus with the studies that gathered the data from project records or literatures.

5.3 Contributions to Existing Knowledge

Regarding the existing defection of labor productivity measurement in Hong Kong construction industry, this study has provided an applicable approach to estimate labor productivity at component level that holistically considers the impact of the most significant factors. The proposed study has also minimized the unreliability in raw data of labor productivity.

The outcomes of this research further validate that the buildable factors significantly affect labor productivity at component level, and demonstrate that the variation trends of some factors identified in this study failed to reach good agreements with previous studies. These results indicate that applying the previous developed models directly to Hong Kong construction projects can be criticized in regard of the uncertainty of data sources.

The presented labor productivity checklist is another major contribution of this study. It covers both optimistic and pessimistic situations and provides several groups of floating labor productivity values rather than simple absolute values, which is more rational because labor productivity itself is changeable.

It is worth mentioning that this research utilized real-time data from the field rather than retrieving data from afterwards project records or from previous studies by which it is apparently more objective and detailed. The finding of this research not only provides an estimation method of actual labor productivity to facilitate project managers' works in Hong Kong public rental housing projects, but also contributes to enhancing the body of knowledge in the labor productivity analysis, measurement, and estimation at component level.

5.4 Limitations and Recommendations for Future Research

In this study, labor productivity was evaluated at component level through the utilization of field data. Since the data utilized in this study was collected from only one project, the finding of this research may limit its use in other projects that have different characteristics, and effort should be undertaken to analyze labor productivity by conducting more case studies in the housing sector. Being limited to the conditions of the selected case, the labor productivity checklist developed by the available data source of this project only covers 12 types of rebar fixing activities, and analysis for more types of construction activities are recommended. Furthermore, although the real-time observation has been substantiated to output more objective feedback rather than other aforementioned data collection method, it is a time-consuming technique that the observers have to track the whole work process of finishing a component on-site to collect every set of data. The future study may incorporate advanced real-time tracking techniques into the data collection method to improve its efficiency.

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APPENDIX

Data Collected by Real Time Observations

No.	WT	TP	HM	WS	PT	M_16	M_20	M_25	M_32	M_40	H_0.8	H_1.2	H_1.5	ML	HT	VT	QT	WT	GZ	LP
1	2	12.9	72	8.8	0	0	0	0	0	0	0	0	0	0	12	12	24	250	1.5	56.66
2	1	12.9	72	8.8	0	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	256.47
3	1	12.9	72	8.8	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	180.58
4	1	16.8	64	12.6	0	8	4	0	0	0	40	20	0	4	0	0	72	0	3	71.13
5	1	16.8	72	10.8	0	10	0	0	6	0	45	0	15	3	0	0	76	0	2	147.78
6	1	16.8	72	10.8	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	189.39
7	2	15.2	71	8.4	0	0	0	0	0	0	0	0	0	0	8	8	16	250	1	119.19
8	1	15.2	71	8.4	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	116.7
9	1	15.1	79	17.2	1.1	0	0	12	0	0	40	20	0	4	0	0	72	0	2	154.3
10	1	15.1	79	17.2	1.1	8	4	0	0	0	40	20	0	4	0	0	72	0	2	140.52
11	2	15.1	79	17.2	1.1	0	0	0	0	0	0	0	0	0	8	8	16	200	1	67.65
12	2	16.2	63	9	0	0	0	0	0	0	0	0	0	0	8	8	16	200	1	67.65
13	1	16.2	63	9	0	10	0	0	6	0	45	0	15	3	0	0	76	0	2	173.86
14	2	17.5	65	8.3	0	0	0	0	0	0	0	0	0	0	12	12	24	200	1	110.25
15	1	17.5	65	8.3	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	138.31
16	1	17.5	65	8.3	0	0	0	6	0	6	66	33	0	5.15	0	0	111	0	2	327.82
17	2	15.7	66	10	0	0	0	0	0	0	0	0	0	0	8	8	16	200	1	113.77
18	1	15.7	66	10	0	0	0	12	0	0	40	20	0	4	0	0	72	0	2	168.84
19	2	15.9	74	12	0	0	0	0	0	0	0	0	0	0	8	8	16	200	1	58.21
20	2	15.9	74	12	0	0	0	0	0	0	0	0	0	0	8	8	16	200	1	119.19
21	1	15.9	74	12	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	199.1
22	1	15.9	74	12	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	120.46
23	2	15.7	66	10	0	0	0	0	0	0	0	0	0	0	12	12	24	250	1	86.79
24	1	15.7	66	10	0	0	0	12	0	0	40	20	0	4	0	0	72	0	2	160.6
25	1	15.7	66	10	0	10	0	0	6	0	45	0	15	3	0	0	76	0	2	173.86

26	1	16.2	86	12.1	6.5	10	0	0	6	0	45	0	15	3	0	0	76	0	2	168.25
27	2	16.2	86	12.1	6.5	0	0	0	0	0	0	0	0	0	8	8	16	200	1	58.21
28	2	16.9	67	13.6	0	0	0	0	0	0	0	0	0	0	10	6	16	250	1	72.6
29	2	16.9	67	13.6	0	0	0	0	0	0	0	0	0	0	10	16	26	250	1	105.2
30	2	16.9	67	13.6	0	0	0	0	0	0	0	0	0	0	12	12	24	250	1	203.95
31	1	16.9	67	13.6	0	10	0	0	6	0	45	0	15	3	0	0	76	0	2	190.68
32	1	16.9	67	13.6	0	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	279.27
33	1	16.4	85	9.4	0.6	0	0	8	4	0	40	20	0	4	0	0	72	0	2	199.1
34	2	16.4	85	9.4	0.6	0	0	0	0	0	0	0	0	0	8	8	16	250	1	119.19
35	2	21.4	78	8.3	0	0	0	0	0	0	0	0	0	0	10	8	18	250	1	287.71
36	2	21.4	78	8.3	0	0	0	0	0	0	0	0	0	0	18	11	29	200	1	201.31
37	1	21.4	78	8.3	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	155.6
38	1	21.4	78	8.3	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	221.86
39	1	21.4	78	8.3	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	215.69
40	2	20.4	76	9.8	0	0	0	0	0	0	0	0	0	0	10	14	24	250	1	84.6
41	2	20.4	76	9.8	0	0	0	0	0	0	0	0	0	0	10	15	25	200	1	233.19
42	2	20.4	76	9.8	0	0	0	0	0	0	0	0	0	0	11	16	27	200	1	113.38
43	2	20.4	76	9.8	0	0	0	0	0	0	0	0	0	0	14	6	20	250	1	274.83
44	1	20.4	76	9.8	0	10	0	0	6	0	45	0	15	3	0	0	76	0	2	211.11
45	1	20.4	76	9.8	0	10	0	0	6	0	45	0	15	3	0	0	76	0	2	227.35
46	1	20.4	76	9.8	0	0	0	6	0	6	66	33	0	5.15	0	0	111	0	2	360.6
47	1	20.4	76	9.8	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	149.38
48	2	18.1	74	14.6	0	0	0	0	0	0	0	0	0	0	10	13	23	250	1	184.7
49	1	18.1	74	14.6	0	0	0	6	0	6	66	33	0	5.15	0	0	111	0	2	343.43
50	1	18.1	74	14.6	0	0	0	6	0	6	66	33	0	5.15	0	0	111	0	2	351.81
51	1	18.1	74	14.6	0	0	0	12	0	0	40	20	0	4	0	0	72	0	2	164.62

52	1	18.1	74	14.6	0	0	0	12	0	0	40	20	0	4	0	0	72	0	2	168.84
53	1	17.1	91	5.5	10.9	0	0	12	0	0	40	20	0	4	0	0	72	0	2	162.98
54	2	17.1	91	5.5	10.9	0	0	0	0	0	0	0	0	0	8	8	16	200	1	119.19
55	2	18.6	66	20	0	0	0	0	0	0	0	0	0	0	11	16	27	200	1	122.47
56	2	18.6	66	20	0	0	0	0	0	0	0	0	0	0	22	13	35	250	1	150.29
57	1	18.6	66	20	0	10	0	0	6	0	45	0	15	3	0	0	76	0	2	197.04
58	1	18.6	66	20	0	10	0	0	6	0	45	0	15	3	0	0	76	0	2	190.68
59	1	18.6	66	20	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	143.63
60	2	21.1	84	8.8	0	0	0	0	0	0	0	0	0	0	10	10	20	250	1	93.77
61	2	21.1	84	8.8	0	0	0	0	0	0	0	0	0	0	10	11	21	200	1	91.58
62	1	21.1	84	8.8	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	233.4
63	1	21.1	84	8.8	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	221.86
64	1	21.1	84	8.8	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	235.3
65	1	17.3	78	14.5	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	143.63
66	1	17.3	78	14.5	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	120.46
67	1	17.3	78	14.5	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	133.37
68	1	19.6	71	17.5	0	10	0	0	6	0	45	0	15	3	0	0	76	0	2	246.3
69	1	19.6	71	17.5	0	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	306.51
70	1	19.6	71	17.5	0	0	0	12	0	0	40	20	0	4	0	0	72	0	2	253.26
71	1	19.6	71	17.5	0	0	0	12	0	0	40	20	0	4	0	0	72	0	2	193.67
72	1	19.6	71	17.5	0	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	306.51
73	1	21.3	82	11.5	0.2	10	0	0	6	0	45	0	15	3	0	0	76	0	2	211.11
74	1	21.3	82	11.6	0.2	10	0	0	6	0	45	0	15	3	0	0	76	0	2	179.13
75	1	21.3	82	11.7	0.2	0	0	8	4	0	40	20	0	4	0	0	72	0	2	242.66
76	2	22.7	83	6.1	4.4	0	0	0	0	0	0	0	0	0	10	16	26	200	1	99.79
77	2	22.7	83	6.1	4.4	0	0	0	0	0	0	0	0	0	10	16	26	250	1	83.16

78	1	17.3	88	15.7	8.7	10	0	0	6	0	45	0	15	3	0	0	76	0	2	140.9
79	1	17.3	88	15.7	8.7	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	268.55
80	2	17.3	88	15.7	8.7	0	0	0	0	0	0	0	0	0	12	12	24	250	1	203.95
81	2	22.7	83	6.1	4.4	0	0	0	0	0	0	0	0	0	14	6	20	200	1	182.95
82	2	22.7	83	6.1	4.4	0	0	0	0	0	0	0	0	0	18	11	29	250	1	185.2
83	2	19.3	61	14.3	0	0	0	0	0	0	0	0	0	0	10	15	25	200	1	155.46
84	2	19.3	61	14.3	0	0	0	0	0	0	0	0	0	0	10	16	26	250	1	86.9
85	2	19.3	61	14.3	0	0	0	0	0	0	0	0	0	0	11	16	27	250	1	115.67
86	2	19.3	61	14.3	0	0	0	0	0	0	0	0	0	0	14	6	20	200	1	91.41
87	2	19.3	61	14.3	0	0	0	0	0	0	0	0	0	0	14	8	22	250	1	93.08
88	1	19.3	61	14.3	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	209.86
89	1	19.3	61	14.3	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	215.69
90	1	19.3	61	14.3	0	0	0	6	0	6	66	33	0	5.15	0	0	111	0	2	335.45
91	1	19.3	61	14.3	0	10	0	0	6	0	45	0	15	3	0	0	76	0	2	203.83
92	1	17.7	80	13.4	2.8	8	4	0	0	0	40	20	0	4	0	0	72	0	2	131.23
93	1	17.7	80	13.4	2.8	8	4	0	0	0	40	20	0	4	0	0	72	0	3	71.13
94	2	17.7	80	13.4	2.8	0	0	0	0	0	0	0	0	0	10	13	23	250	1	179.29
95	2	17.7	80	13.4	2.8	0	0	0	0	0	0	0	0	0	12	12	24	200	1	107.39
96	1	20.4	63	8.9	0	0	8	4	0	0	40	20	0	4	0	0	72	0	2	194.52
97	1	20.4	63	8.9	0	0	8	4	0	0	40	20	0	4	0	0	72	0	2	159.16
98	1	20.4	63	8.9	0	10	0	0	6	0	45	0	15	3	0	0	76	0	2	184.73
99	1	20.4	63	8.9	0	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	314.18
100	1	20.4	63	8.9	0	0	0	12	0	0	40	20	0	4	0	0	72	0	2	182.91
101	1	20.4	63	8.9	0	0	0	12	0	0	40	20	0	4	0	0	72	0	2	188.13
102	1	20.4	63	8.9	0	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	322.23
103	2	20.4	79	13.9	0	0	0	0	0	0	0	0	0	0	10	6	16	200	1	85.81

104	2	20.4	79	13.9	0	0	0	0	0	0	0	0	0	0	10	16	26	250	1	83.16
105	2	20.4	79	13.9	0	0	0	0	0	0	0	0	0	0	10	16	26	200	1	79.83
106	2	20.4	79	13.9	0	0	0	0	0	0	0	0	0	0	10	16	26	250	1	110.88
107	2	20.4	79	13.9	0	0	0	0	0	0	0	0	0	0	10	16	26	250	1	111.04
108	2	20.4	79	13.9	0	0	0	0	0	0	0	0	0	0	12	12	24	250	1	99.49
109	1	20.4	79	13.9	0	10	0	0	6	0	45	0	15	3	0	0	76	0	2	218.93
110	1	20.4	79	18.3	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	143.63
111	1	20.4	79	18.3	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	138.31
112	1	20.4	79	18.3	0	0	8	4	0	0	40	20	0	4	0	0	72	0	2	218.84
113	1	20.4	79	18.3	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	287.59
114	1	20.4	79	18.3	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	221.86
115	1	17.8	86	23.9	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	120.46
116	2	17.8	86	23.9	0	0	0	0	0	0	0	0	0	0	12	12	24	250	1	86.79
117	2	23.6	84	7.5	0	0	0	0	0	0	0	0	0	0	10	16	26	250	1	83.16
118	2	23.6	84	7.5	0	0	0	0	0	0	0	0	0	0	10	16	26	200	1	105.2
119	2	23.6	84	7.5	0	0	0	0	0	0	0	0	0	0	11	16	27	250	1	115.67
120	1	23.6	84	7.5	0	0	8	4	0	0	40	20	0	4	0	0	72	0	2	187.58
121	1	23.6	84	7.5	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	277.32
122	1	23.6	84	7.5	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	189.39
123	2	25.1	81	7.5	0	0	0	0	0	0	0	0	0	0	8	8	16	250	1	56.88
124	2	25.1	81	7.5	0	0	0	0	0	0	0	0	0	0	8	8	16	200	1	67.65
125	2	21.2	91	20.5	0.9	0	0	0	0	0	0	0	0	0	14	6	20	200	1	182.95
126	1	21.2	91	20.5	0.9	8	4	0	0	0	40	20	0	4	0	0	72	0	2	149.38
127	1	21.2	91	20.5	0.9	0	8	4	0	0	40	20	0	4	0	0	72	0	2	194.52
128	1	21.2	91	20.5	0.9	8	4	0	0	0	40	20	0	4	0	0	72	0	2	177.83
129	2	20	90	8.2	1.5	0	0	0	0	0	0	0	0	0	11	16	27	250	1	130.13

130	2	20	90	8.2	1.5	0	0	0	0	0	0	0	0	0	8	8	16	200	1	119.19
131	2	20	90	8.2	1.5	0	0	0	0	0	0	0	0	0	8	8	16	200	1	131.73
132	1	20	90	8.2	1.5	8	4	0	0	0	40	20	0	4	0	0	72	0	2	138.31
133	1	20	90	8.2	1.5	0	8	4	0	0	40	20	0	4	0	0	72	0	2	187.58
134	1	20	90	8.2	1.5	10	0	6	0	0	45	0	15	3	0	0	76	0	2	183.33
135	2	18.8	77	16.2	0.3	0	0	0	0	0	0	0	0	0	12	12	24	250	1	254.94
136	2	18.8	77	16.2	0.3	0	0	0	0	0	0	0	0	0	12	12	24	250	1	185.41
137	2	18.8	77	16.2	0.3	0	0	0	0	0	0	0	0	0	12	12	24	200	1	239.94
138	1	18.8	77	16.2	0.3	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	322.23
139	1	18.8	77	16.2	0.3	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	299.22
140	1	18.8	77	16.2	0.3	0	0	8	4	0	40	20	0	4	0	0	72	0	2	215.69
141	1	22.9	79	11.8	0	0	8	4	0	0	40	20	0	4	0	0	72	0	2	175.07
142	1	22.9	79	11.8	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	138.31
143	1	22.9	79	11.8	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	143.63
144	1	22.9	79	11.8	0	10	0	6	0	0	45	0	15	3	0	0	76	0	2	169.75
145	1	22.9	79	11.8	0	10	0	6	0	0	45	0	15	3	0	0	76	0	2	176.28
146	1	18.1	86	12.4	0	0	0	12	0	0	40	20	0	4	0	0	72	0	2	158.87
147	1	18.1	86	12.4	0	10	0	0	6	0	45	0	15	3	0	0	76	0	2	190.68
148	1	18.1	86	12.4	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	120.46
149	2	18.1	86	12.4	0	0	0	0	0	0	0	0	0	0	10	6	16	250	1	72.6
150	2	18.1	86	12.4	0	0	0	0	0	0	0	0	0	0	8	8	16	200	1	113.77
151	2	22.8	89	9	0.4	0	0	0	0	0	0	0	0	0	11	16	27	200	1	122.47
152	2	22.8	89	9	0.4	0	0	0	0	0	0	0	0	0	14	8	22	250	1	178.08
153	2	22.8	89	9	0.4	0	0	0	0	0	0	0	0	0	8	8	16	250	1	108.82
154	2	22.8	89	9	0.4	0	0	0	0	0	0	0	0	0	8	8	16	200	1	119.19
155	2	22.8	89	9	0.4	0	0	0	0	0	0	0	0	0	18	11	29	250	1	185.2

156	2	22.8	89	9	0.4	0	0	0	0	0	0	0	0	0	18	11	29	250	1	192.92
157	1	25.5	91	4.3	8.2	8	4	0	0	0	40	20	0	4	0	0	72	0	2	103.73
158	1	25.5	91	4.3	8.2	8	4	0	0	0	40	20	0	4	0	0	72	0	2	106.7
159	1	25.5	91	4.3	8.2	10	0	6	0	0	45	0	15	3	0	0	76	0	2	152.78
160	1	25.5	91	4.3	8.2	10	0	6	0	0	45	0	15	3	0	0	76	0	2	158.05
161	1	25.5	91	4.3	8.2	0	0	12	0	0	40	20	0	4	0	0	72	0	2	188.13
162	1	25.5	91	4.3	8.2	0	0	12	0	0	40	20	0	4	0	0	72	0	2	199.53
163	1	25.5	91	4.3	8.2	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	292.26
164	1	22.1	89	12.3	0.5	0	8	4	0	0	40	20	0	4	0	0	72	0	2	164.13
165	1	22.1	89	12.3	0.5	0	8	4	0	0	40	20	0	4	0	0	72	0	2	175.07
166	1	22.1	89	12.3	0.5	8	4	0	0	0	40	20	0	4	0	0	72	0	2	120.46
167	1	22.1	89	12.3	0.5	8	4	0	0	0	40	20	0	4	0	0	72	0	2	149.38
168	1	22.1	89	12.3	0.5	0	0	8	4	0	40	20	0	4	0	0	72	0	2	258.83
169	1	22.1	89	12.3	0.5	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	339.65
170	1	25	83	7.6	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	106.7
171	1	25	83	7.6	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	221.86
172	1	25	83	7.6	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	228.38
173	1	25	83	7.6	0	0	0	12	0	0	40	20	0	4	0	0	72	0	2	193.67
174	1	25	83	7.6	0	0	0	12	0	0	40	20	0	4	0	0	72	0	2	199.53
175	2	26	85	7.1	0	0	0	0	0	0	0	0	0	0	10	16	26	250	1	83.1
176	2	26	85	7.1	0	0	0	0	0	0	0	0	0	0	11	16	27	200	1	90.85
177	2	26	85	7.1	0	0	0	0	0	0	0	0	0	0	14	8	22	250	1	86.75
178	2	26	85	7.1	0	0	0	0	0	0	0	0	0	0	8	8	16	200	1	100.12
179	2	26	85	7.1	0	0	0	0	0	0	0	0	0	0	8	8	16	200	1	104.29
180	2	26	85	7.1	0	0	0	0	0	0	0	0	0	0	8	8	16	250	1	96.26
181	2	26	85	7.1	0	0	0	0	0	0	0	0	0	0	18	11	29	200	1	178.08

182	2	20.2	70	23	0	0	0	0	0	0	0	0	0	0	10	16	26	200	1	99.94
183	2	20.2	70	23	0	0	0	0	0	0	0	0	0	0	10	16	26	250	1	111.04
184	2	20.2	70	23	0	0	0	0	0	0	0	0	0	0	8	8	16	250	1	119.19
185	2	20.2	70	23	0	0	0	0	0	0	0	0	0	0	8	8	16	200	1	100.12
186	1	20.2	70	23	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	143.63
187	1	20.2	70	23	0	10	0	6	0	0	45	0	15	3	0	0	76	0	2	169.75
188	1	20.2	70	23	0	10	0	6	0	0	45	0	15	3	0	0	76	0	2	163.69
189	1	20.2	70	23	0	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	314.18
190	1	20.2	70	23	0	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	306.51
191	1	24.6	90	12.3	0	0	8	0	4	0	40	20	0	4	0	0	72	0	2	189.19
192	1	24.6	90	12.3	0	0	8	0	4	0	40	20	0	4	0	0	72	0	2	178.68
193	1	24.6	90	12.3	0	0	8	4	0	0	40	20	0	4	0	0	72	0	2	164.13
194	1	24.6	90	12.3	0	0	8	4	0	0	40	20	0	4	0	0	72	0	2	169.42
195	1	24.6	90	12.3	0	0	8	4	0	0	40	20	0	4	0	0	72	0	2	175.07
196	1	24.6	90	12.3	0	0	8	4	0	0	40	20	0	4	0	0	72	0	2	169.42
197	1	24.6	90	12.3	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	221.86
198	1	24.6	90	12.3	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	235.3
199	2	22.9	93	12.7	29.7	0	0	0	0	0	0	0	0	0	8	9	17	200	1	173.69
200	2	22.9	93	12.7	29.7	0	0	0	0	0	0	0	0	0	8	9	17	250	1	200.41
201	2	22.9	93	12.7	29.7	0	0	0	0	0	0	0	0	0	12	12	24	200	1	169.92
202	2	22.9	93	12.7	29.7	0	0	0	0	0	0	0	0	0	12	12	24	250	1	177.31
203	1	22.9	93	12.7	29.7	8	4	0	0	0	40	20	0	4	0	0	72	0	2	149.38
204	1	22.9	93	12.7	29.7	0	8	4	0	0	40	20	0	4	0	0	72	0	2	194.52
205	2	23.3	89	15.2	0	0	0	0	0	0	0	0	0	0	8	9	17	250	1	186.1
206	2	23.3	89	15.2	0	0	0	0	0	0	0	0	0	0	12	12	24	200	1	185.37
207	1	23.3	89	15.2	0	10	0	6	0	0	45	0	15	3	0	0	76	0	2	183.44

208	1	23.3	89	15.2	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	143.63
209	1	23.3	89	15.2	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	258.83
210	2	24.7	92	10.9	1.4	0	0	0	0	0	0	0	0	0	8	9	17	200	1	153.26
211	2	24.7	92	10.9	1.4	0	0	0	0	0	0	0	0	0	18	11	29	200	1	149.36
212	1	24.7	92	10.9	1.4	10	0	6	0	0	45	0	15	3	0	0	76	0	2	163.69
213	1	24.7	92	10.9	1.4	10	0	6	0	0	45	0	15	3	0	0	76	0	2	152.78
214	1	24.7	92	10.9	1.4	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	292.26
215	1	24.7	92	10.9	1.4	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	241.67
216	2	25.2	91	9.9	31.3	0	0	0	0	0	0	0	0	0	10	16	26	250	1	153.53
217	2	25.2	91	9.9	31.3	0	0	0	0	0	0	0	0	0	12	12	24	250	1	151.04
218	2	25.2	91	9.9	31.3	0	0	0	0	0	0	0	0	0	18	11	29	200	1	136.18
219	1	25.2	91	9.9	31.3	0	8	0	4	0	40	20	0	4	0	0	72	0	2	221.81
220	1	25.2	91	9.9	31.3	10	0	6	0	0	45	0	15	3	0	0	76	0	2	147.93
221	1	25.2	91	9.9	31.3	10	0	6	0	0	45	0	15	3	0	0	76	0	2	163.69
222	1	25.2	91	9.9	31.3	0	0	12	0	0	40	20	0	4	0	0	72	0	2	212.41
223	2	25.6	84	6.7	0.1	0	0	0	0	0	0	0	0	0	10	16	26	200	1	166.32
224	2	25.6	84	6.7	0.1	0	0	0	0	0	0	0	0	0	8	9	17	250	1	162.84
225	2	25.6	84	6.7	0.1	0	0	0	0	0	0	0	0	0	12	12	24	200	1	140.62
226	1	25.6	84	6.7	0.1	0	8	4	0	0	40	20	0	4	0	0	72	0	2	194.52
227	1	25.6	84	6.7	0.1	0	8	0	4	0	40	20	0	4	0	0	72	0	2	221.81
228	1	25.6	84	6.7	0.1	0	0	8	4	0	40	20	0	4	0	0	72	0	2	267.76
229	1	25.6	84	6.7	0.1	0	0	12	0	0	40	20	0	4	0	0	72	0	2	212.41
230	2	25.7	91	7.9	26.3	0	0	0	0	0	0	0	0	0	10	16	26	250	1	133.06
231	2	25.7	91	7.9	26.3	0	0	0	0	0	0	0	0	0	8	9	17	200	1	137.13
232	2	25.7	91	7.9	26.3	0	0	0	0	0	0	0	0	0	18	11	29	250	1	136.18
233	1	25.7	91	7.9	26.3	0	8	4	0	0	40	20	0	4	0	0	72	0	2	159.16

234	1	25.7	91	7.9	26.3	0	8	0	4	0	40	20	0	4	0	0	72	0	2	207.5
235	1	25.7	91	7.9	26.3	10	0	6	0	0	45	0	15	3	0	0	76	0	2	152.78
236	1	25.7	91	7.9	26.3	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	349.08
237	1	25.7	91	7.9	26.3	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	279.27
238	2	26.5	87	6.5	0	0	0	0	0	0	0	0	0	0	8	9	17	200	1	124.07
239	2	26.5	87	6.5	0	0	0	0	0	0	0	0	0	0	18	11	29	200	1	128.61
240	2	26.5	87	6.5	0	0	0	0	0	0	0	0	0	0	18	11	29	250	1	132.29
241	1	26.5	87	6.5	0	0	8	4	0	0	40	20	0	4	0	0	72	0	2	154.48
242	1	26.5	87	6.5	0	10	0	6	0	0	45	0	15	3	0	0	76	0	2	147.85
243	1	26.5	87	6.5	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	221.86
244	1	26.5	87	6.5	0	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	241.67
245	2	27.6	86	8.1	5.4	0	0	0	0	0	0	0	0	0	8	8	16	200	1	125.14
246	2	27.6	86	8.1	5.4	0	0	0	0	0	0	0	0	0	12	12	24	200	1	119.94
247	2	27.6	86	8.1	5.4	0	0	0	0	0	0	0	0	0	12	12	24	250	1	131.55
248	1	27.6	86	8.1	5.4	10	0	6	0	0	45	0	15	3	0	0	76	0	2	147.85
249	1	27.6	86	8.1	5.4	10	0	6	0	0	45	0	15	3	0	0	76	0	2	143.23
250	1	27.6	86	8.1	5.4	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	273.2
251	2	28.8	82	14.6	0.1	0	0	0	0	0	0	0	0	0	8	9	17	250	1	108.56
252	2	28.8	82	14.6	0.1	0	0	0	0	0	0	0	0	0	12	12	24	250	1	101.95
253	1	28.8	82	14.6	0.1	0	8	0	4	0	40	20	0	4	0	0	72	0	2	178.68
254	1	28.8	82	14.6	0.1	0	8	4	0	0	40	20	0	4	0	0	72	0	2	141.95
255	1	28.8	82	14.6	0.1	0	0	8	4	0	40	20	0	4	0	0	72	0	2	204.34
256	1	28.8	82	14.6	0.1	0	0	8	4	0	40	20	0	4	0	0	72	0	2	215.69
257	2	29.2	84	14.6	0.1	0	0	0	0	0	0	0	0	0	8	8	16	200	1	100.12
258	2	29.2	84	14.6	0.1	0	0	0	0	0	0	0	0	0	8	9	17	200	1	104.22
259	2	29.2	84	14.6	0.1	0	0	0	0	0	0	0	0	0	8	9	17	200	1	113.28

260	1	29.2	84	14.6	0.1	10	0	6	0	0	45	0	15	3	0	0	76	0	2	138.89
261	1	29.2	84	14.6	0.1	10	0	6	0	0	45	0	15	3	0	0	76	0	2	130.95
262	1	29.2	84	14.6	0.1	0	0	8	4	0	40	20	0	4	0	0	72	0	2	189.39
263	2	29.1	81	5.7	0.4	0	0	0	0	0	0	0	0	0	12	12	24	200	1	94.84
264	2	29.1	81	5.7	0.4	0	0	0	0	0	0	0	0	0	18	11	29	250	1	96.46
265	1	29.1	81	5.7	0.4	0	8	0	4	0	40	20	0	4	0	0	72	0	2	173.85
266	1	29.1	81	5.7	0.4	0	8	0	4	0	40	20	0	4	0	0	72	0	2	173.85
267	1	29.1	81	5.7	0.4	8	4	0	0	0	40	20	0	4	0	0	72	0	2	95.75
268	1	29.1	81	5.7	0.4	0	8	0	4	0	40	20	0	4	0	0	72	0	2	160.81
269	1	29.1	81	5.7	0.4	0	8	0	4	0	40	20	0	4	0	0	72	0	2	156.89
270	2	29.2	83	7.1	0	0	0	0	0	0	0	0	0	0	10	16	26	200	1	83.16
271	2	29.2	83	7.1	0	0	0	0	0	0	0	0	0	0	8	9	17	250	1	89.84
272	2	29.2	83	7.1	0	0	0	0	0	0	0	0	0	0	18	11	29	200	1	87.36
273	1	29.2	83	7.1	0	10	0	6	0	0	45	0	15	3	0	0	76	0	2	127.32
274	1	29.2	83	7.1	0	10	0	6	0	0	45	0	15	3	0	0	76	0	2	123.87
275	1	29.2	83	7.1	0	0	0	12	0	0	40	20	0	4	0	0	72	0	2	153.13
276	1	29.2	83	7.1	0	0	0	12	0	0	40	20	0	4	0	0	72	0	2	153.13
277	2	29.8	75	15	0	0	0	0	0	0	0	0	0	0	8	8	16	250	1	78.22
278	2	29.8	77	11.5	0	0	0	0	0	0	0	0	0	0	8	8	16	200	1	69.52
279	2	29.8	77	11.5	0	0	0	0	0	0	0	0	0	0	8	8	16	250	1	67.65
280	2	29.8	75	15	0	0	0	0	0	0	0	0	0	0	8	9	17	200	1	59.21
281	2	29.8	77	11.5	0	0	0	0	0	0	0	0	0	0	8	9	17	200	1	74.44
282	2	29.8	75	15	0	0	0	0	0	0	0	0	0	0	12	12	24	200	1	81.56
283	2	29.8	75	15	0	0	0	0	0	0	0	0	0	0	12	12	24	250	1	78.42
284	2	29.8	77	11.5	0	0	0	0	0	0	0	0	0	0	18	11	29	200	1	73.49
285	1	29.8	75	15	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	77.8

286	1	29.8	77	11.5	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	91.08
287	1	29.8	77	11.5	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	86.85
288	1	29.8	75	15	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	158.47
289	1	29.8	77	11.5	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	176.48
290	2	24.4	82	8.1	1.1	0	0	0	0	0	0	0	0	0	10	16	26	250	1	153.53
291	2	24.4	82	8.1	1.1	0	0	0	0	0	0	0	0	0	18	11	29	200	1	159.66
292	1	24.4	82	8.1	1.1	0	8	4	0	0	40	20	0	4	0	0	72	0	2	194.52
293	1	24.4	82	8.1	1.1	0	8	4	0	0	40	20	0	4	0	0	72	0	2	181.11
294	1	24.4	82	8.1	1.1	10	0	6	0	0	45	0	15	3	0	0	76	0	2	169.75
295	1	24.4	82	8.1	1.1	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	330.71
296	2	25	86	12.5	1.4	0	0	0	0	0	0	0	0	0	8	8	16	250	1	166.86
297	2	25	86	12.5	1.4	0	0	0	0	0	0	0	0	0	18	11	29	200	1	149.36
298	2	25	86	12.5	1.4	0	0	0	0	0	0	0	0	0	18	11	29	200	1	159.66
299	1	25	86	12.5	1.4	10	0	6	0	0	45	0	15	3	0	0	76	0	2	169.85
300	1	25	86	12.5	1.4	10	0	6	0	0	45	0	15	3	0	0	76	0	2	176.28
301	1	25	86	12.5	1.4	10	0	6	0	0	45	0	15	3	0	0	76	0	2	176.28
302	2	26.8	89	9.4	2.4	0	0	0	0	0	0	0	0	0	10	16	26	200	1	110.88
303	2	26.8	89	9.4	2.4	0	0	0	0	0	0	0	0	0	8	8	16	250	1	119.19
304	1	26.8	89	9.4	2.4	10	0	6	0	0	45	0	15	3	0	0	76	0	2	134.88
305	1	26.8	89	9.4	2.4	0	8	4	0	0	40	20	0	4	0	0	72	0	2	164.13
306	1	26.8	89	9.4	2.4	0	0	12	0	0	40	20	0	4	0	0	72	0	2	205.77
307	1	26.8	89	9.4	2.4	0	0	12	0	0	40	20	0	4	0	0	72	0	2	193.67
308	1	26.8	89	9.4	2.4	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	256.47
309	2	28.6	84	8.2	12.6	0	0	0	0	0	0	0	0	0	10	16	26	200	1	105.04
310	2	28.6	84	8.2	12.6	0	0	0	0	0	0	0	0	0	10	16	26	200	1	117.4
311	2	28.6	84	8.2	12.6	0	0	0	0	0	0	0	0	0	12	12	24	200	1	113.28

312	1	28.6	84	8.2	12.6	0	8	0	4	0	40	20	0	4	0	0	72	0	2	194.92
313	1	28.6	84	8.2	12.6	0	8	0	4	0	40	20	0	4	0	0	72	0	2	207.5
314	1	28.6	84	8.2	12.6	0	0	8	4	0	40	20	0	4	0	0	72	0	2	215.69
315	1	28.6	84	8.2	12.6	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	237.11
316	1	27.5	94	15.6	6.5	8	4	0	0	0	40	20	0	4	0	0	72	0	2	74.69
317	1	27.5	94	15.6	6.5	10	0	6	0	0	45	0	15	3	0	0	76	0	2	99.69
318	1	27.5	94	15.6	6.5	0	0	12	0	0	40	20	0	4	0	0	72	0	2	146.33
319	1	27.5	94	15.6	6.5	0	0	12	0	0	40	20	0	4	0	0	72	0	2	140.1
320	1	28.8	85	11.3	0	10	0	6	0	0	45	0	15	3	0	0	76	0	2	91.72
321	1	28.8	85	11.3	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	158.47
322	1	28.8	85	11.3	0	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	213
323	1	28.8	85	11.3	0	0	0	8	0	4	66	33	0	5.15	0	0	111	0	2	206.02
324	1	29.7	76	6.1	0	0	8	4	0	0	40	20	0	4	0	0	72	0	2	99.1
325	1	29.7	76	6.1	0	8	4	0	0	0	40	20	0	4	0	0	72	0	2	66.69
326	1	29.7	76	6.1	0	0	0	8	4	0	40	20	0	4	0	0	72	0	2	155.3