SIM-BOOST: AN ALTERNATIVE TECHNIQUE FOR MEASURING LABOUR PRODUCTIVITY AT CONSTRUCTION SITES

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Abstract

Previous studies showed that labour productivity level has continuously been low at construction sites. One of the appropriate approaches for improving the labour productivity is by implementing the industrialised building system. However, this approach is fewer implemented globally in the construction sites because the previous researchers concentrated more on the IBS hardware rather than IBS software. Earlier productivity measuring techniques based on statistical theory, expert system and neural networks models are said to be unsatisfactory because they are incapable of considering the combined effects of the various factors and cost in measuring labour productivity at work sites. Therefore, this research has focused on developing an alternative labour productivity measurement technique to be better able to overcome the shortcomings in the others called SIM-BOOST. A series of experiments via simulation model have been performed, which depicted detailed information on the labour productivity in the construction sites. Evidently, the comprehensive information namely labour productivity of monetary units, labour productivity ratio and loss of labour productivity in terms of percentage and monetary unit of the installation of Industrialised Building System (IBS) components in the construction sites have been fully generated via this approach.

Keywords: industrialised building system, labour productivity, measurement, simulation

Introduction

The construction industry plays an important role in the development process by establishing the outcomes fundamental to the fulfilment of development objectives. The construction industry seems to provide significant backward and forward linkages to other industries. Backward linkages can be interpreted as the dependence created by one economic sector for the products of the other sectors whereas forward linkages are persuaded by the production of intermediate goods. The construction industry has employed a large number of people in all phases in both developed as well as developing countries, being labour-intensive. The contribution is very crucial, thus construction industry as a whole can start a chain reaction of growth of labour section, opportunities and development of the country. However, the problem of poor performance in the construction industry has been widely recognised and documented. Department of Environment, Transport and Regions (1988) reported that studies in the UK, Scandinavian countries, and US suggest that up to 30 percent of construction is rework; labour is used at only 40-60 percent of potential efficiency; accidents can account for 3-6 percent of total costs; and at least 10 percent of materials are wasted. In fact, Business Round Table has been formulated due to the consciousness on increasing the construction labour productivity (Oglesby *et al.,* 1989).

Therefore, the word `productivity' is increasingly important in construction industry due to the background of rising world-class standards as a crucial pillar in the performance context. Clients need better value with respect to cost, time and quality from their projects, and construction companies need reasonable profits to assure their long-term future. Summanth (1984) depicted the whole process of productivity cycles consisting of measuring, evaluating, planning and improving. The measurement is the first stage in order to increase the productivity in operations. Moreover, It is vital and can be seen on the argument raised by Peterson (2000), who said `what gets measured gets improved', and Chrysostomou (2000) from the British Research Establishment, who stated that `to manage, you must measure, if you do not, you are only practicing'. Evidently, measurement is a vital component in the productivity improvement agenda and its accuracy of subsequent stages depends on the accuracy altitude of measurement stage.

In order to discover the more refined tool for measuring of construction operations, learning from the other industries is a crucial strategy. Adaptation of management tools from other industries to construction industry is a common approach particularly after World War II. The benefits of cross-industry learning are successfully adapted by Khalid (1993) who utilized the Hedonic Price Model to estimate adolescence of commercial office buildings originally from the agriculture industry; Abdul-Hamid (1996) and Sonmez & Rowing (1998) employed Neural Networks for predicting construction duration and modelling labour productivity from physical structure of the human brain; Pheng & Hui (1999) facilitated the demand for site storage space, sequential process in handling the materials, ensuring that all plant, equipment and materials necessary for any activity arrive just in time. Moreover, the management theory and approaches such as mass and lean manufacturing system for housing production (Gann, 1996); Six-Sigma (Pheng & Hui, 2004); Total Quality Management (Cottrell, 1995) and Concurrent Engineering (Love *et al*., 1998; Mohamad, 1999) have been well adapted from manufacturing into the construction industry. Evidently, the manufacturing industry comes to be a point of reference and a potential source of innovation in the construction industry since both industries have fundamental similarities i.e., they both produce engineered products that provide service to the users; process new materials and assemble many diverse pre-manufactured components in the final products; and the conceptual basis both of the industries is conversion oriented (Mace, 2001). In addition, manufacturing once used the conversion model like construction industry, but has since evolved to flow-oriented production theories (mass and lean production) and system wide optimisation or theory of constraints.

The manufacturing industry has shown the most significant advances in productivity and the application of technology that has brought about fundamental change (Flanagan, 2001). Therefore, the Operation-Based Costing Model for measuring productivity in production system of manufacturing industry is then employed for measuring productivity in the construction operations. Basically, this model consists of 3 main components namely total factor productivity, activity-based costing and simulation approach (Deo, 2001). Since, the construction operations always refer to the craft-based, they are more volatile and their contribution is significant in terms of cost, most researchers in the construction productivity context agree that it should be related to labour (see Oglesby, 1989; Chang & Borcherding, 1986; Christian & Hackey, 1995; Ng *et al.,* 2004). The definitions of productivity are numerous but the widely accepted definition in the construction industry is output/input or input/output, where output is the actual physically measured progress and input is the man-hours to achieve such progress. However, due to the increasing competition in the construction industry, similar to the former trend in manufacturing, the cost per unit of output (input/output) has been applied to measure the labour productivity in construction operations. Moreover, it is due to the evidence gained from the manufacturing industry where using time as a basis of measuring productivity can be distorted since it does not mimic the behaviour of cost per unit of output (Deo & Strong, 2000). Also, according to Clarke and Harrmann (2004a, 2004b), construction companies in Britain are more competitive compared to those in Germany. One of the reasons is that the construction companies in Britain focus more on the cost by making an appearance of measurement, estimating and ordering sections in their organisation.

Although both of the industries have similarities on the structural, they are still contained differences on the fringe context. Therefore, the newly construction labour productivity measurement technique called SIM-BOOST has comprised the specific features as Figure 1.

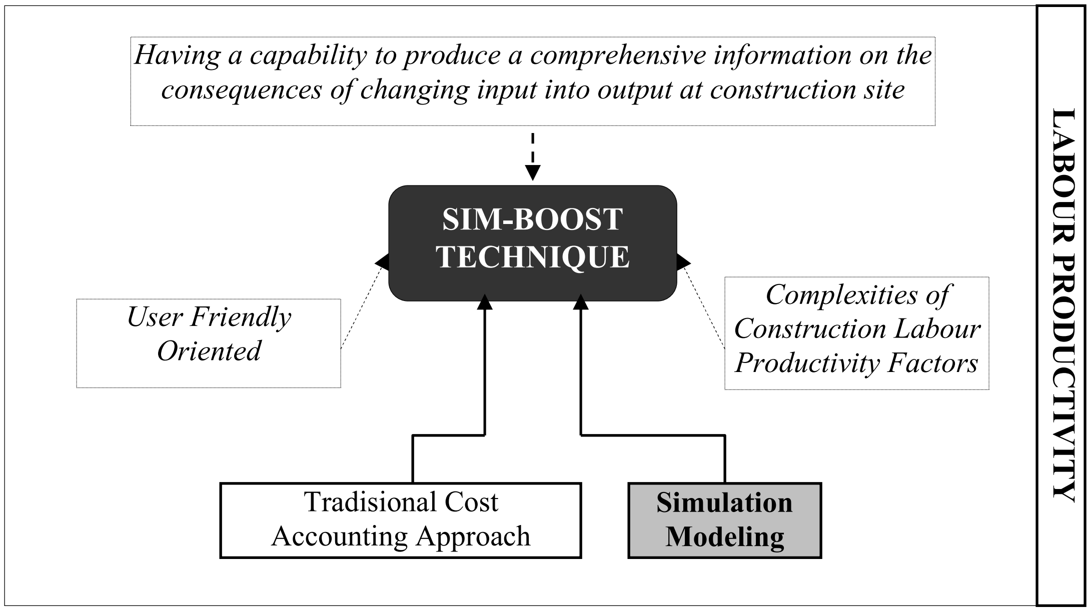


Figure 1: SIM-BOOST Technique Characteristics

Simulation and construction labour productivity

Simulation is an extremely general term since the idea applies to many fields, industries and applications. The use of simulation approach is more common due to the rapidly expanding computer technology. According to Deo (2001), simulation is widely used to understand and evaluate the production and time relationships under various sets of conditions. The analysis of data generated by computer simulation models is helpful in selecting a more efficient circumstance of production purposes. According to Abudayyeh *et al.* (2004), simulation is one of the approaches that is becoming important particularly in United States to solve the various complex circumstances in the construction industry. Shi (2002) mentioned that the simulation approach in the construction industry was initially reported by Teicholz in year 1963. However, after CYCLic Operation Network, commonly known as CYCLONE developed by Halpin in 1973, a variety of simulation systems have been introduced in the construction industry. CYCLONE has given some inspiration to construction researchers in developing a simulation package simpler, more attractive and capable of solving the complex circumstances in the construction industry. However, according to Maxwell *et al.* (1998), this traditional simulation is not compatible for applying Activity Based Costing techniques to stochastic systems. It is because the traditional simulation is incapable of duplicating the timing and queuing result. According to Halpin & Riggs (1992) and AbouRizk & Wales (1997), discrete-event simulation is a fundamental approach to mimic the circumstance of construction activities. WITNESS simulation package is evidently appropriate to generate the productivity information in the production systems; with high capability in discrete event simulation. In fact, WITNESS package is a graphically interactive simulation based on FORTRAN produced by AT&T ISTEL VISUAL INTERACTIVE SYSTEMS, accommodated in Windows environment (Armstrong & Summer, 1988; Hollocks, 1996). In addition, this package has strength in detailing graphical display, depicting the false 3-D graphic, making some interaction during the cycle time and the ability to display the statistic report in consistent manner. Therefore, it has been selected and used to generate the utilization of labour productivity throughout various circumstances of construction projects.

Research Aim and Objectives

Having described the need for higher accuracy in productivity measurement approach in construction operations, it is imperative to examine the use of simulation approach in generating the labour productivity figures in construction sites. In other words, this research is conducted to examine the applicability of the productivity measurement technique originally developed from manufacturing into the construction industry. This research is an initial effort in adapting the productivity measurement technique from the manufacturing industry. The scope is therefore on the projects that employ IBS particularly prefabricated (concrete) since the system is slightly similar to the production system in manufacturing industry, compared to the conventional system. Due to column, beam and hollow core slab are some of the most popular of IBS intertwined components preferred by architects and engineers in Malaysia (CIDB Malaysia, 2006), therefore, they have been chosen to be a scope of this research.

In order to develop SIM-BOOST technique, there are three procedures carefully integrated and employed as follows:

a) To identify the main labour productivity factors and to determine their levels
b) To develop simulation models for generating data towards the formation of regression models
c) To develop labour productivity regression models to represent the implementation setting.

Research Methodology

The identification procedure of the main labour productivity factors have been initiated by distributing 95 questionnaires to contractor and consultant firms represented a population size of fixing IBS components at construction sites in Malaysia. Five Likert Scale approach has been used namely: 1=Very Important; 2=Important; 3=Neutral; 4=Unimportant; 5=Very Unimportant. Priory, the pilot survey to four respondents has been conducted in order to verify its suitability. At least 43 questionnaires, which represented 45 percent have been returned and analysed via Alpha Cronbach, Frequencies, Important Indexes, Mean and Mann Whitney approaches.

Subsequently, 36 questionnaires have distributed to the contractor firms in determining the main factors that has refined via the stated approaches. Mostly, the procedures in determining the level of main labour productivity factors were similar with the previous stage unless the analysis approaches. At least 19 questionnaires, which represented 53 percent have been returned and analysed via Alpha Cronbach, Frequencies and Mean approaches. Both of the information i.e. the main labour productivity factors and their levels were vital in developing a simulation models afterwards.

Simulation modelling and experimentation. There are many diagrams and descriptions that outline the key processes in the simulation study as there are authors who have written about the subject. Among them are Hoover and Perry (1989), Law and Kelton (2000), Robinson (2004), Banks *et al.* (2001) and Lanner (2000). Each has his own preferred way of explanation on how to develop simulation modelling. A detailed inspection of their procedures showed that they are very similar, outlining a set of processes that must be performed. The main difference can be defined as the naming of the processes that must be performed. However, most of them do not discuss specifically how to develop the hypothetical/theoretically model, which needs to be used in this study.

A detail assessment has been made in developing the simulation model in this study, which can be divided into 6 steps as follows:

i. Establishing the objective of simulation modelling.
The statement of simulation modelling can be described as follows:
`The objective of developing the simulation model and experimentation is to visualize the labour productivity in various circumstances of construction sites, employing the IBS model'.

ii. Scope and level of simulation modelling detail.
The scopes of simulation modelling are: -
- The involvement of direct workforces and site supervisor employed by the main/sub contractor in the construction site only. Installing IBS components referred to as arriving, assembling, allocating, holding the components and grouting with cement agent.
- Through the questionnaire survey as stated in (b); the number of projects involved in the experimentation stage is 64 for each simulation model. Moreover, since crane operator/s and technician (for maintaining the machinery) on the construction sites are not normally employed by contractors, this study does not include them.
- Assumption has been made i.e. all direct workforce is always available in construction sites.

iii. Developing a theory-based conceptual model.
Detailed inspection on diagrams and descriptions that outline the processes for installing the IBS components have been described by Chudley & Greeno (1999), Barritt (1987) and Ramli (1991). Most of them showed close similarity. Therefore, a conceptual model for that particular operation can be summarized as Figure 2.

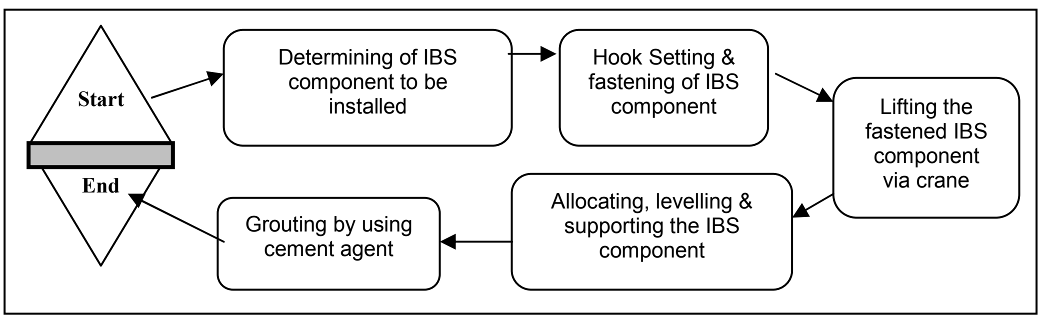


Figure 2: Conceptual Model of Installation of IBS components on the construction sites

iv. Developing and verification of simulation model.
According to Lanner (2000), building a simulation model via WITNESS should follow the procedure of Define – Display – Detail. Referring to the conceptual model, which has been developed from the previous stage, the entities, objects, and components have been defined and displayed on a WITNESS platform. A connection and detailing of each entity, object and component has been done in order to make the simulation model run as needed. Then, the verification process is conducted to ensure that the model design has been transformed into a computer model with sufficient accuracy. However, verification process has been performed along the life cycle of the simulation study. In this study, 3 methods of verification have been used i.e. checking the code, visual check and inspection output reports.

v. Validation of simulation model.
Validation is a vital stage to increase the level of confidence of simulation modelling and experimentation. In order to produce the valid simulation model, interviews was conducted on 11 participants involved directly in the installation of IBS components. The construction projects that they have been engaged with, can be categorized as office building, learning and education building, hospital and commercial building. The interview survey encompassed the validation of conceptual model, data, white box (micro) and black box (macro), experimentation (based on (a)) and solution. An example of data gained from the interview survey has been summarized in the Appendix A. By referring to this result, calibration of simulation modelling has been conducted from time to time until the models become stable.

vi. Experimentation via simulation model.
Before conducting a series of experimentation, the model is tested for their stability on the variety of Pseudo Random Numbers. Then, experimentations are conducted on the strategy identified from stage (b); i.e. point of view on the level of management practice and workforce experience in the installation of IBS components in Malaysia.

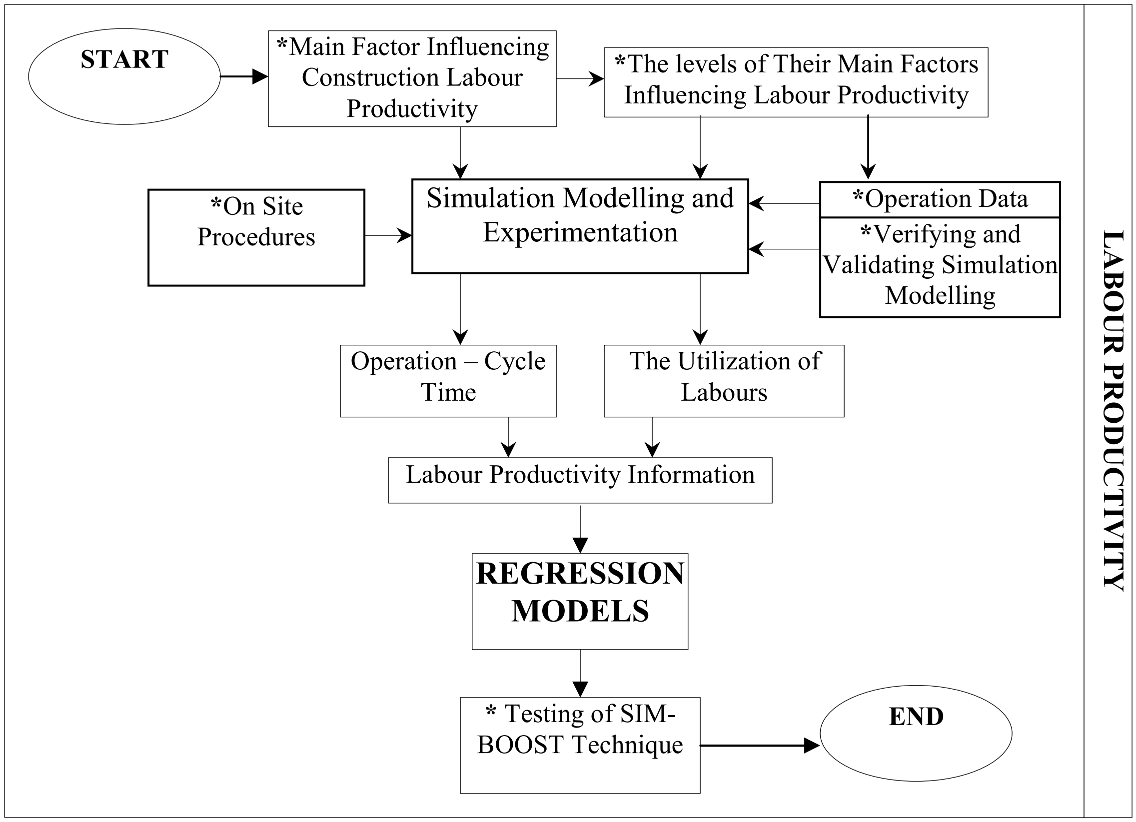
Measuring labour productivity and labour productivity loss.
The results gained from the above procedures [(a), (b) and (c) i, ii, iii, iv, v and vi] are then transferred into essential information consisting of measurement on labour productivity of monetary units, labour productivity ratio and loss of labour productivity in terms of percentage and monetary unit.

The development of SIM-BOOST technique has followed by formulating regression models to represent the implementation setting. In formulating the regression model for labour productivity of monetary units, labour productivity ratio and loss of labour productivity in terms of percentage and monetary unit, three steps have been employed as follows:

i. Selection of Best and Fit of Regression Model
ii. Overall Test of Regression Model
iii. Coefficient Individual Test of Regression Model

The overall methodology in developing the SIM-BOOST technique showed in Figure 3.

This paper only described the regression models that formulated via simulation modelling namely construction labour productivity of monetary units, labour productivity ratio and loss of labour productivity in terms of percentage and monetary unit models for three implementation systems at construction sites. System: 1, 2 and 3 have followed the standard procedure i.e. arriving, positioning, determining, fastening, supporting and grouting of each IBS component. The differences were on the number of labours and alternate fixing column, beam and HCS slab in gridline segment.



Note: * – The information of fixing IBS components operation were needed from parties involved

Figure 3: The Process of Developing SIM-BOOST Technique

Results and findings

The abbreviations of developing the regression models are as follows:

β_0 – Constant
$\beta_{1...6}$ – Coefficient of PS, DT, SS, AC, AM and SL
PS – The Accuracy of Work Planning and Scheduling
DT – The Competence of Design Team
SS – The Capable of Site Supervisor
AC – The Availability of IBS Components
AM – The Availability of Machinery
SL – The Skill of Labour

Selection of Best and Fit of Regression Model

In this research, stepwise procedure has been used in developing the regression labour productivity models. The values of R^2 and Adjusted R^2 have been observed in determining the best and fit model as it was a vital step in developing the regression labour productivity models. The highest R^2 and Adjusted R^2 values represented the best and fit model.

The best and fit regression model for labour productivity rates in terms of monetary units (System: 1, 2 and 3)

$$= \beta_0+\beta_1 (PS) + \beta_2 (SS) + \beta_3 (AC) + \beta_4 (AM) + \beta_5(SL)$$

The best and fit regression model for labour *productivity ratio* (System: 1, 2 and 3)

$$= \beta_0+ \beta_1 (PS) +\beta_2 (SS)+ \beta_3(AC)+\beta_4(AM) + \beta_5(SL)$$

The best and fit regression model for loss of labour productivity in terms of percentage-Directly (System: 1)

$$= \beta_0+\beta_1 (PS) + \beta_2(SS)+\beta_3 (AC)+\beta_4 (AM.)+\beta_5 (SL)$$

The best and fit regression model for loss of labour productivity in terms of percentage-Directly (System: 2, 3)

$$=\beta_0+\beta_1(DT)+ \beta_1(PS) +\beta_2(SS)+\beta_3(AC)+\beta_5(AM)+\beta_6(SL)$$

The best and fit regression model for loss of labour productivity in terms of percentage-Indirectly (System: 1, 2, 3)

$$= \beta_0 + \beta_1 (DT) + \beta_1 (PS)+\beta_2 (SS) + \beta_3 (AC) + \beta_5 (AM)$$

The best and fit regression model for loss of labour productivity in terms of monetary-Directly (System: 1)

$$= \beta_0 + \beta_1 (PS) + \beta_2 (SS)+ \beta_3 (AC)+ \beta_4 (AM) + \beta_5 (SL)$$

The best and fit regression model for loss of labour productivity in terms of monetary-Directly (System: 2, 3)

$$= \beta_0+ \beta_1 (DT) + \beta_1 (PS) + \beta_2 (SS) + \beta_3 (AC) + \beta_5 (AM) + \beta_6 (SL)$$

The best and fit regression model for loss of labour productivity in terms of monetary-Indirectly (System: 1, 2, 3)

$$= \beta_0 + \beta_1 (DT) + \beta_1 (PS) + \beta_2 (SS) + \beta_3 (AC) + \beta_5 (AM)$$

Overall Test of Regression Model

Hypothesis of the regression models have been tested by observing P Value (Sig.), which less than 0.05 (P-Value <α) where significant value was 95 percent.

H_0: $\beta_1 = \beta_2 = \beta_3 = \beta_4 = \beta_5 = \beta_6 = 0$; P value (Sig.) > α (0.05)
H_1: $\beta_1 \neq \beta_2 \neq \beta_3 \neq \beta_4 \neq \beta_5 \neq \beta_6 \neq 0$; P value (Sig.) < α (0.05)

All models namely labour productivity of monetary units, labour productivity ratio and loss of labour productivity in terms of percentage and monetary unit valued P = 0 or < α (0.05).

Therefore, The **H_0** rejected and **H_1** received

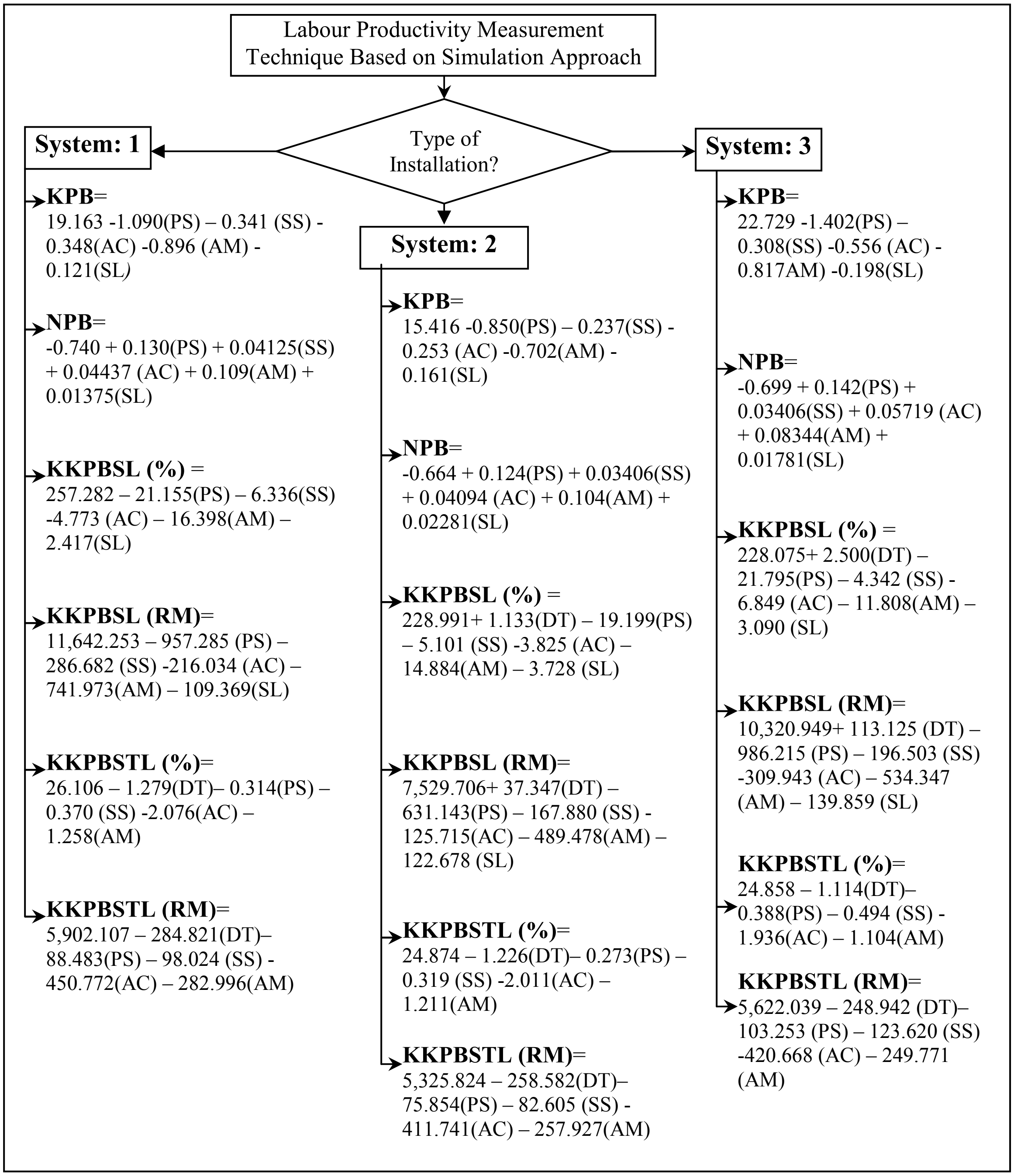
Coefficient Individual Test of Regression Model

Hypothesis of the regression models have been tested by observing P Value (Sig.), which less than 0.05 (P-Value <α) where significant value was 95 percent.

Null Hypothesis (**H_0**) was each of coefficient value β_1, β_2, β_3, β_4, β_5, $\beta_6 = 0$.
Alternate Hypothesis (**H_1**) was all of coefficient value β_1, β_2, β_3, β_4, β_5, $\beta_6 \neq 0$

The result showed that all labour productivity regression models for System: 1, 2 or 3 were less than 0.05. Therefore, **H_0** rejected and **H_1** received.

Figure 4 showed that the overall labour productivity regression models that have been developed by using the regression analysis as they are vital component of SIM-BOOST technique.



Note: **KPB=** labour productivity in terms of monetary units; NPB= labour productivity ratio; **KKPBSL=** loss of labour productivity in terms of percentage - Directly; **KKPBSTL=** loss of labour productivity in terms of percentage - Indirectly. **PS** – The Accuracy of Work Planning and Scheduling; **DT** – The Competence of Design Team; **SS** – The Capable of Site Supervisor; **AC** – The Availability of IBS Components; **AM** – The Availability of Machinery; **SL** – The Skill of Labour, These main factors influencing construction labour productivity should be scored **4** = High level or **5** = Highest Level

Figure 4: Labour Productivity Regression Models Based on Simulation Modelling

Conclusion

The role of construction industry in the process of development cannot be denied. However, the phenomenon of construction industry is still remaining at a low level in terms of performance. Since the background of construction is under continuous pressure to increase performance, the word `productivity' and `measurement' is becoming more important. As a result, the measurement technique based on the simulation approach initially produced in the manufacturing industry has been well tested and it is capable to produce the detailed information on labour productivity of the installation of IBS components.

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