Performance Measurement Indicators for Plastic Injection Manufacturing

Parames Chutima[1]* and Nonticha Nimsaard[2]

บทคัดย่อ

งานวิจัยนี้มีวัตถุประสงค์เพื่อจัดทำระบบควบคุมพื้นที่ผลิตและดัชนีวัดสมรรถนะของกระบวนการผลิตที่เหมาะสมกับอุตสาหกรรมฉีดพลาสติกของประเทศไทย การวิจัยจะสำรวจข้อมูลเบื้องต้นจากอุตสาหกรรมจริง โดยการใช้แบบสอบถาม สัมภาษณ์ และศึกษาข้อมูลจากแหล่งอ้างอิงต่างๆ แล้วพัฒนาระบบควบคุมพื้นที่ผลิตโดยนำเสนอด้วยเทคนิค IDEF0 และพัฒนาดัชนีวัดสมรรถนะของกระบวนการผลิตให้สอดคล้องกับระบบควบคุมพื้นที่ผลิตที่จัดทำขึ้นจากนั้นจึงทำการตรวจสอบความถูกต้องโดยการสำรวจข้อมูลเพื่อนำมาวิเคราะห์โดยใช้หลักการทางสถิติ ในรูปของแบบจำลองโครงสร้างทางคณิตศาสตร์ ผลจากการวิจัยสามารถใช้เป็นแนวทางให้ผู้ประกอบการสามารถผลิตได้อย่างต่อเนื่องและเต็มกำลังการผลิต และมีความสะดวกในการประเมินศักยภาพองค์กรของตนเอง นอกจากนั้นยังสามารถเทียบเคียงกับผู้ประกอบการรายอื่นเพื่อนำผลมาใช้ปรับปรุงประสิทธิภาพการทำงานให้ดีขึ้นได้อีกด้วย

คำสำคัญ: ระบบควบคุมพื้นที่ผลิต ดัชนีวัดสมรรถนะ อุตสาหกรรมฉีดพลาสติก

Abstract

The objective of this research is to develop a shop floor control system and performance measurement indicators suitable for plastic injection manufacturing in Thailand. This research collected primary data from several factories and used a systematically designed questionnaire to interview both experts and practitioners in the field. The shop floor control system represented by IDEF0 technique was then developed. Furthermore, the performance indicators (PIs) of the production operations that conformed to the real operations occurring on the shop floor were created. The surveyed data were analyzedby statistical techniques to construct the structural equation model. The results fromthe research could be used as a guideline for entrepreneurs in order to produce continuously and fully utilize the production capacity. In addition, they can use the selected performance indicators to assess the efficiency of their organizations and can benchmark against other entrepreneurs in order to find the ways for productivity improvement.

Keywords: Plastic Injection Manufacturing, Shop Floor Control, Performance Indicators

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1. Introduction

Plastic injection manufacturing is the largest group of plastic manufacturers in Thailand. It has significant impacts to Thai's economy and tends to expand continuously. However, it is now facing fierce local and international competitions, e.g. cheap plastic products from China are flooding the Thai market. In contrast, the regulations of plastic-product importer countries create trade barriers for manufacturers in Thailand. Thus, plastic injection manufacturers have to adjust themselves for future survival and strengthen their abilities for international competition.

The main problem of the plastic injection manufacturers is that they are mostly small to medium in size. They are often family businesses with self-administrative systems within the factory depending solely on the decisions of the owner. Moreover, its organization has no formal structure. As a result, responsibility and authority of personnel are rather blurred, resulting in conflicts and poor coordination among departments, work contention, and different work priorities. These affect the production system directly in terms of an unclear production plan, underutilized production capacity, idle machines and workers, material shortage, missed delivery dates, etc. These also cause high production cost and low completive ability for plastic injection manufacturers. Therefore, plastic injection manufacturers need to adopt the concept of shop floor control to adjust their operations management so that they can operate more efficiently [1], [2].

Shop floor control plays a critical role in the development of an effective production system since it maps various shop floor activities onto a formal architecture which recognizes each individual component and their interactions. Researchers have divided shop floor control problems into 4 issues as follows: (1) *Control Architecture* provides mechanisms to coordinate the activities within shop floor control systems [3], [4]; (2) *Function Architecture* shows what tasks are required and what formalizes the functional behaviors of the shop floor control system [5], [6]; (3) *Information Architecture* defines the data and provides the informational handling for information requirement; and (4) *Communication Architecture* provides mechanisms for transferring messages between different software and between different computer hardware systems [1], [4]. This research focused on Function Architecture based on hierarchical control which is the most popular control structure applied in industries.

Several shop floor control architectures have been developed. The National Bureau of Standards (NBS) established a hierarchical control model (Control Architecture) based on a classical hierarchical structure. Five hierarchical levels were recognized namely facility, shop, cell, workstation, and equipment. After that ISO developed more refined structure comprising six levels, i.e. enterprise, facility, section, cell, station, and equipment [7]. Our emphasis in this research is on the operational (shop) level of the hierarchy of NBS. When describing Function Architecture, the Bauer's model is referred to for reviewing the control activities in this paper [7]. According to this model, shop floor control consists of three main elements, i.e. scheduler, dispatcher, and monitor, which can be used to develop a plan based on timely knowledge and date, implement that plan taking into account the current status of the production system, monitor the status of the system, and take actions if the current status deviates from the target significantly.

Performance measurement is a system for assessing performance of development interventions against stated goals. It involves ongoing data collection to determine if a program is implementing activities and achieving the set objective by measuring inputs, outputs, and outcomes over time. Traditional performance measurements which include cost and accounting are criticized for encouraging short termism, local optimization, and not being externally focused. In an attempt to overcome these criticisms, new performance measurement frameworks have been developed to encourage a more balanced view. For example, Balanced Scorecard [8] measures four perspectives, i.e. financial, internal business, customer, and learning and growth. Business Process Reengineering considers time, cost, quality, flexibility, and environment. In addition, quality, cost, flexibility, time, delivery, and future growth are considered in [9]. Suitable performance measurement can be used to benchmark against those of industrial leaders to understand better how outstanding companies do business so that an appropriate direction for improvement can be identified without trial and error.

These new performance measurement frameworks may answer the question of “what types of measures should a company use?” but they did not provide specific advice in detail to any manufacturing industry [10]. To achieve this, understanding of its operation process is inevitable for designing suitable performance indicators for a manufacturing system. There are a number of methods available for describing processes. Many of them are fairly informal, such as block diagrams or flowcharts. However, using shop floor control architecture is a better way to understand an operation process. Data obtained from visiting several plastic injection manufacturers in Thailand indicated that most of them did not use any performance measurement system while several of them used it incorrectly. Moreover, most performance measures usually focus on past activities. One of the main barriers to the development of performance measurement systems in this manufacturing is the lack of a managerial system and formalized management of the processes. Thus, the objective of this research is to develop shop floor control systems and performance indicators that are suitable for plastic injection manufacturing. A two-phase study approach was employed in this research. In Phase I, the shop floor control model was created. After that, in Phase II, the performance indicators (PI) of each operation in the shop floor control model were recommended.

2. Phase I: Shop Floor Control Model Development

2.1 Methodology

In this phase, a shop floor control system was developed in the form of IDEF0. This technique has been widely used for presenting functional relationship of the shop floor control system [5]. In IDEF0, the top level activity can be further broken down into several sub-activities allowing users to present complex manufacturing functional relationships hierarchically [11]. The IDEF0 model consists of a hierarchy of related diagrams where each diagram base on a diagonal row of boxes connected by a network arrow. *Boxes* represent the activities described by an active verb phrase. *Arrows*

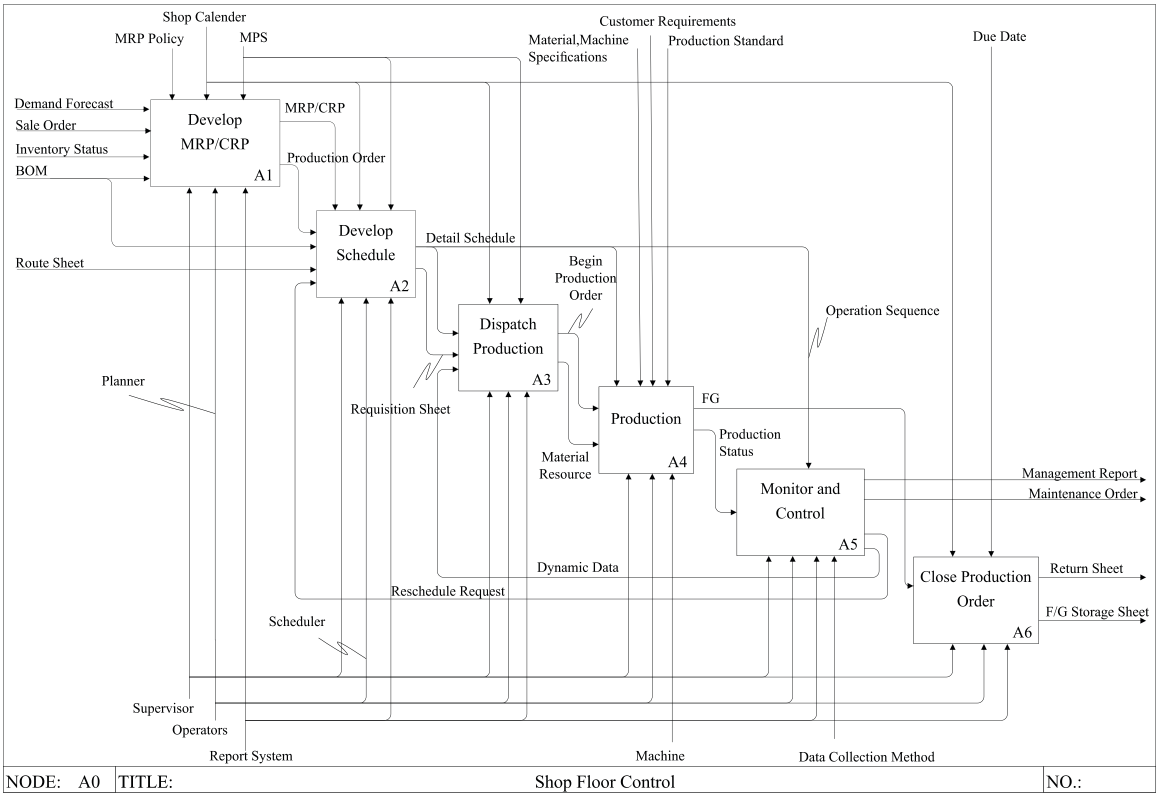

Figure 1 Top-level activity of shop floor control.

represent the relationship between activities. *Input data*, transformed by the activity to the output data, are on the left side of the box with arrows pointing to the box. *Control data*, which are used to regulate the internal process of the activity, are above the box with arrows pointing to the box. *Mechanism data,* which support and enable the activity, are below the box with arrows pointing to the box. *Output data* are on the right side of the box with arrows pointing to the output data from the box. In this study, the shop floor control system represented by the IDEF0 technique was developed from the data collected by using a systematically designed questionnaire to interview experts and practitioners in the field. The validity of the model was approved once again by the experts using another questionnaire. The Likert scale consisting of 5 response categories ranging from “strongly disagree (1)” to “strongly agree (5)” were employed. The statistics used for data analysis are median and inter-quartile range. The acceptance criteria was used for median is equal to or more than 3.5, and less than 1.5 for inter-quartile range.

2.2 Result

Based on the interviews, an activity model of plastic injection product realization represented in IDEF0 was developed (Figure 1). This is because the IDEF0 model can show the linkages between

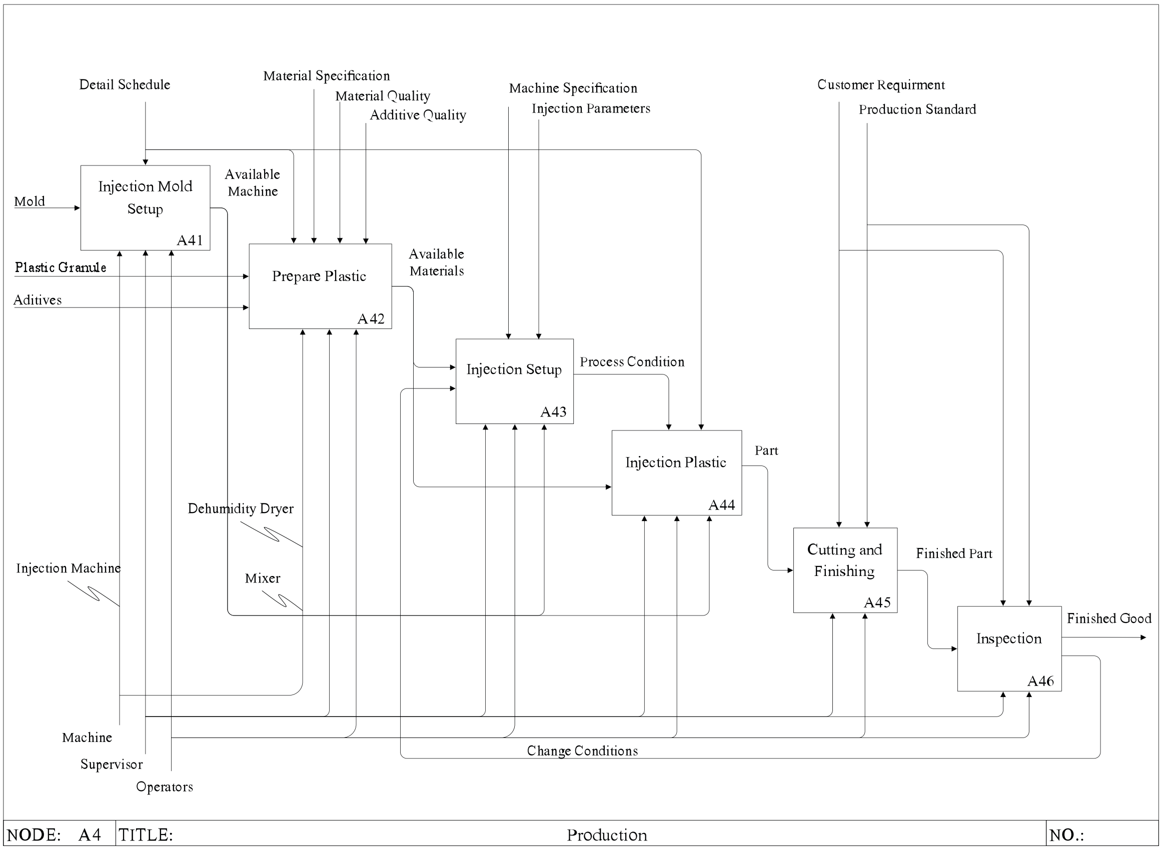

Figure 2 Activity A4 – production.

each activity, how they will interact, and provide a way of communication. The top-level activity of shop floor control consists of six main activities, i.e. (A1) Develop MRP/CRP, (A2) Develop Schedule, (A3) Dispatch Production, (A4) Production, (A5) Monitor and Control, and (A6) Close Production Order. Instead of giving detailed presentation of each top-level activity, we selected to present only the most significant one (A4) to show how it works in details which can be explained as follows.

A4 (Production) can be decomposed into six sub-activities (Figure 2). The detail is explained as follows:

A41 *Injection Mold Setup*: Setting up an injection molding machine is composed of removing the previous mold and then setting up the new one. An efficient mold changeover process will decrease scrap rates, tool damage, flawed parts, rework, an unsteady process, and cost of maintenance.

A42 *Prepare Plastic:* This activity provides materials ready to produce. Plastic preparation procedure is generally compose of mixing and drying. Mixing is the process of combining two or more materials into a single one. Plastic additive materials are added for improved properties of the plastic product. Drying method is used to remove water moisture or moisture from granulated plastic and preheating before injection processes.

A43 *Injection Setup:* This is setting up of parameters required to prepare an injection machine ready for the production run. The parameters are melt temperature, mold temperature, de-mold temperature, barrel temperature, metering stroke, screw speed, injection pressure, holding pressure, holding time, cushion, resident time, injection speed, back pressure, switch over, clamping force, and cooling time.

A44 *Injection Plastic:* This is a manufacturing technique for making parts from plastic materials in production. The basic injection cycle is as follows: mold close, injection carriage forward, inject plastic, metering, carriage retract, mold open, and eject part. Some machines are run by electric motors instead of hydraulics or a combination of both. The water-cooling channels that assist in cooling the mold and the heated plastic solidifies into the part. Improper cooling can result in distorted molding. The cycle is completed when the mold is opened and the part is ejected with the assistance of ejector pins within the mold. This part is composed of the spurs and runners and count as defect.

A45 *Cutting and Finishing:* The spurs and runner system can be cut or twisted off in line with customer requirements.

A46 *Inspection:* An inspection is measurements, tests, and gauges applied to certain characteristics in regard to an object or activity. The results are usually compared to specified requirements and standards for determining whether the item or activity is in line with the targets.

In total, 33 boxes of activities in the shop floor control system represented by IDEF0 were developed [12]. The details of other activities are shown by node index of shop floor control in Table 1.

Table 1 Node indexes of shop floor control system for plastic injection manufacturing

Node	Activity Name	Node	Activity Name
A0	Shop Floor Control		
A1	Develop MRP/CRP	A4	Production
A11	Prepare Data	A41	Injection Mold Setup
A12	Calculate MRP	A42	Prepare Plastic
A13	Calculate CRP	A43	Injection Setup
A14	Create Report	A44	Injection Plastic
A2	Develop Schedule	A45	Cutting and Finishing
A21	Check Material Status	A46	Inspection
A22	Check Capacity Status	A5	Monitor and Control
A23	Prepare Schedule	A51	Collect Production Data
A24	Release Schedule	A52	Analyze Data
A3	Dispatch Production	A53	Create Report
A31	Receive Information	A6	Close Production Order
A32	Analyze Alternative	A61	Material Return
A33	Release Materials	A62	Tool/Equipment Return
A34	Release Resource	A63	Finished Good Storage
A35	Assign Worker		
A36	Release Production		

3. Phase II: Performance Indicators

This phase of study consists of five steps to identify suitable PIs for activities of the shop floor control system.

First, PIs which affect assessing the efficiency of activities of plastic injection manufacturing from several sources were collected. These PIs were assigned to each activity from main activities (Figure 1) to sub-activities (Figure 2) of shop floor control system. Second, the tentative structural equation model (SEM) was proposed for specifying, estimating, and testing hypothesized models that described relationships among a set of meaningful variables [13]. Third, the questionnaire to prove the validity of SEM was designed and relevant data were collected from injection plastic experts. Fourth, a factor analysis of the observed variables was performed to deduce the independent variables (PIs) and dependent variables (shop floor's activities) of the SEM model. Finally, relationship between PIs and shop floor's activities were analyzed by regression analysis. The final SEM that can explain the causal relationship between PIs and shop floor's activity with the degrees of influence of PIs on each activity was established.

Step 1: PI Collection

General PIs were collected from several sources such as previous research, reports, books, etc. 913 general PIs were identified. It was noticeable that some PIs measured similar things but used different wordings. Hence, they were all reorganized and grouped together. PIs that were suitable for plastic injection manufacturing were selected or modified from such group. These PIs were assigned to each activity from major activities to sub activities of the shop floor control system represented by IDEF0 from previous phase. Finally, 294 PIs were established for all activities.

Step 2: SEM Development

SEM was constructed as shown in Figure 3. It consists of observed and structural components. The observed component is a characterized model that shows the relationship between dependent variables as defined in IDEF0, illustrated by "I, M, C, O, and A" and observed variables, illustrated by "X1–X14 and Y1-Y4" (Figure 3). The structural component is a characterized model of the causal relationship between the independent and dependent variables. In this study, A4 was selected as an example to demonstrate the relationship between the observed variables, independent variables, and dependent variables of the proposed SEM.

Step 3: Data Collection

The instrument of the data collection was the questionnaire developed based on literature reviews on performance indicators in the areas of shop floor control and from one-on-one in-depth interviewing plastic injection experts. The questionnaire was created through the procedure of systematic creating the questionnaire for general research [14]. The questionnaire was rated using a 5-point Likert scale, ranging from "Unimportant (1)" to "Very Important (5)" The drafted questionnaire was examined for the content accuracy which can be measured by the index of Item Objective Consistency (IOC) [15]. If the IOC value, which is examined and evaluated by 3 qualified experts who have experience and knowledge in this field, is equal to 0.5 or above, the questionnaire has the content accuracy. After that, the questionnaire was

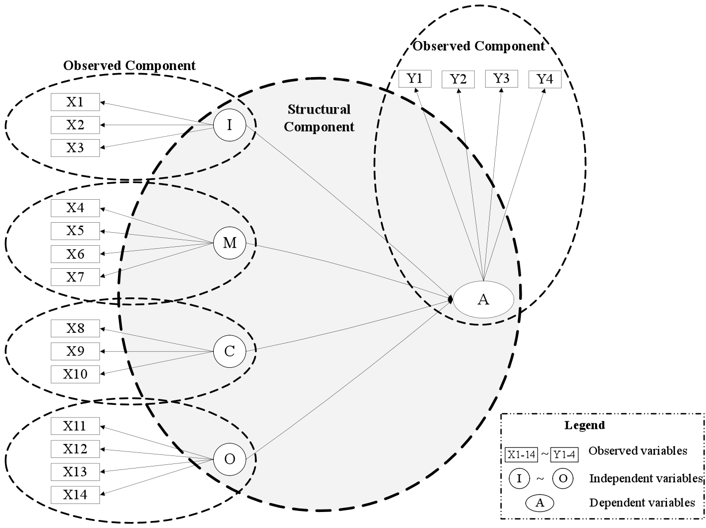

Figure 3 Proposed structural equation model.

pre-tested to the plastic injection manufacturers who were not included in the samples of the study. The result was analyzed to find the reliability of the questionnaire by Cronbach's alpha coefficient.

After the questionnaire was well-prepared, the field work was conducted. The respondents in this research were production managers in plastic injection manufacturing, or the people directly concerned who the researchers agreed to have sufficient experience, knowledge, and competency to give correct information to our objectives. In this research, 25 case studies (from 237 populations: www.diw.go.th) were interviewed and found that interviewees in each case had enough qualification to give correct and reliable data. They are all in high level positions and their responsibilities affect the shop floor control and performance measurement directly.

Step 4: Factor Analysis

Two methods can be used to obtain independent variables and dependent variables of SEM: (1) from the results (theories) of previous studies, or (2) use factor analysis to identify their latent variables. In this study, the latent independent and dependent variables were obtained via the latter method. The purpose of the factor analysis is to find simplified information (new smaller number of variables) from many initial variables. Four main elements of IDEF0 were used as independent variables, i.e. input (I), control (C), mechanism (M), and output (O). PIs that affected assessing the efficiency of activities were classified with respect to these 4 factors as follows: (1) PIs related to the input of the activity, e.g. raw material; (2) PIs related to the control of the activity, e.g. specifications, standards; (3) PIs related to the mechanism of the activity, e.g. people, tools, machine; and (4) PIs related to the output of the activity, e.g. finish goods.

After assigning each observed variable to each factor, validity and reliability were tested by using factor loading and Cronbach's Alpha. If the observed variable has a valid structure corresponding to the main factor, its factor loading value must be positive and high. The value of 0.300 or more is the criteria to accept internal validity [16].

Furthermore, for the reliability of structure, all main factors were tested. The reliability is the measurement of the internal consistency which is measured from reliability Cronbach's alpha. If the value is more than 0.700, the internal factors have strong relationships to each other and will affect the main factor and be reliable. However, if the value of the reliability Cronbach's alpha is between 0.400-0.700, the internal factor still being matched moderately and acceptable [17].

For example, the validity and reliability of the output PI (O) were tested. Output PI consists of 5 observed variables as shown in Figure 4. Factor loading of each observed variables was between 0.469 (O5: yield) and 0.939 (O3: average rejection case by QA). The lowest value was more than 0.300, hence it was inferred that all of the observed variables had the validity structure. Also, since the value of the reliability Cronbach's alpha was 0.828 (more than 0.400), it was acceptable that the observed variables had relationship to each other and make all main factor structures reliable. The results of other factors of A4 activity were shown in Table 2.

From factor analysis, dummy variables being considered as the representatives of independent and dependent variables used for further testing relationship between PIs and the associated activitieswere obtained by choosing the observed variables from each factor with maximum factor loading value. The results are shown in Table 3.

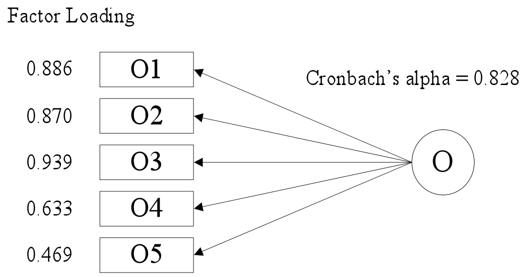

Figure 4 Validity and reliability of output PI.

Step 5: Regression Analysis

The regression analysis was used to test relationship between PIs and the activities. In this research, several independent variables were revealed. Therefore, multi-variable regression analysis was used to test which set of the variables influenced the behavior of the activity. Three statistics were measured as follows:

(1) Adjusted R^2: It is a modification of R^2 which is a measure of the correlation and indicates the proportion of the variance in the dependent variable which is accounted for the model. However, R^2 tends to somewhat over-estimate the success of the model when applied to real word, so an adjusted R^2 is used. It takes into account the number of variables in the model and the number of observations upon which the model is based. Its value is between 0 and 1 and large value indicates the well-fitting of the model to the data.

(2) The F-test (ANOVA test): is used to determine whether a significant relationship exists between the dependent variable and the set of all the independent variables.

(3) The T-test: If the F-test is significant, the T-test is further used to determine whether a significant relationship exists between the

Table 2 Variable name, factor loading and reliability Cronbach's alpha

Factor	Observed Variables	Factor Loading	Cronbach's Alpha
I: Input PI	I1: Raw Material Quality	0.715	*0.712*
	I2: % Material Shortage	0.862	
	I3: Raw Material Yield	0.809	
M: Mechanism PI	M1: Machine Utilization	0.675	*0.844*
	M2: OEE – Overall Equipment Effectiveness	0.769	
	M3: MTBF - Mean time between failures	0.871	
	M4: MTTR - Mean Time to Repair	0.459	
	M5: Training Hour	0.813	
	M6: % Accident Frequency Rate	0.722	
	M7: Autonomous Maintenance Ratio	0.851	
C: Control PI	C1: Number of CAR (Corrective Action Request) from Audit	0.919	*0.776*
	C2: % On time Delivery	0.815	
	C3: Production Planned Ratio	0.773	
O: Output PI	O1: Weight of Defect	0.886	*0.828*
	O2: Product Cost	0.870	
	O3: Average Rejection Case by QA	0.939	
	O4: Scrap Cost	0.633	
	O5: Yield	0.469	
A4:Activity Efficiency	P: Production Rate	0.323	*0.747*
	Q: Quality of Product	0.831	
	C: Product Cost	0.617	
	D: Delivery	0.850	
	S: Safety	0.479	
	M: Morale	0.816	

Table 3 Dummy variable and factor loading

Factor	Dummy Variable	Factor Loading
I: Input PI	I2	0.862
M: Mechanism PI	M7	0.851
C: Control PI	C1	0.919
O: Output PI	O3	0.939
A4:Activity Efficiency	Q	0.831

dependent variable and each of the individual independent variables. When the model has only one independent variable, then beta is equivalent to the correlation coefficient between independent variable and dependent variable. This equivalence makes sense, as this situation is a correlation between two variables. When the model has more than one independent variable, it cannot compare the contribution of each dependent variable by

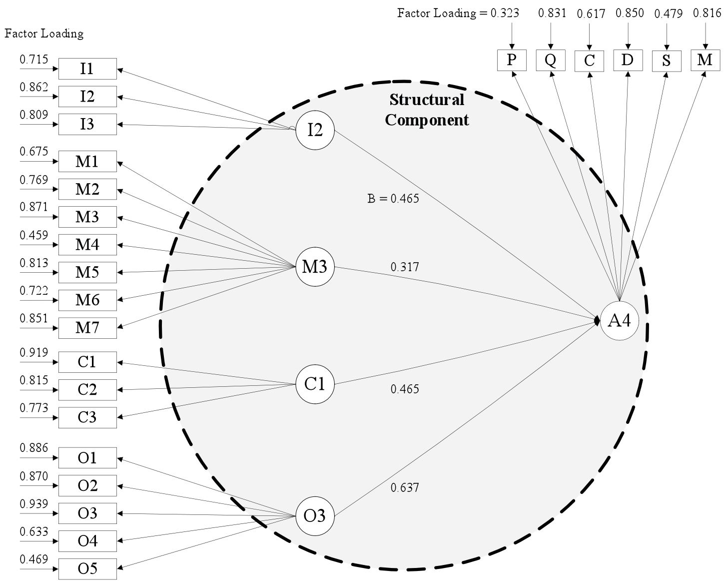

Figure 5 Final SEM Model.

simply comparing the correlation coefficients. The beta regression coefficient is computed to allow us to make such comparisons and to assess the strength of the relationship between each independent variable to the dependent variable.

In this study, for example, we used the dummy variables obtained from the factor analysis to test the relationship between independent variables "Input PI (I), Mechanism PI (M), Control PI (C) and Output PI (O)" and dependent variable "Production Activity Efficiency (A4)". The result from regression analysis showed that adjusted R^2 value was 0.738 meaning that our model had accounted for 73.8% of the variance in the dependent variable. From F-test, F-value was 17.869 which were significant at 0.01 levels. Therefore, there existed a relationship between the dependent variable and the set of all the independent variables. The standardized regression coefficients (Beta) in Table 4 can be used to estimate the change in the dependent variable that can be attributed to a change of one unit in the independent variable. As a result, the relationship between dependent variable and each of individual independent variables can be formulated as follows.

$$A_4 = 2.866 + 0.465I + 0.317M + 0.465C + 0.637O$$

Table 4 Coefficients obtained from regression analysis[a]

Model	Non-standardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
1 (Constant)	2.866	1.125		2.546	.019
I	.465	.167	.378	2.785	.011
M	.317	.102	3.55	3.115	.005
C	.465	.167	.465	2.785	.011
O	.637	220.	.432	2.894	.009

[a] = Dependent Variable: A

The final SEM was deduced from the statistical analysis as show in Figure 5. The final model of the Production Activity (A4) consists of 18 observed variables represented by PIs that affected the production efficiency activity A4. Four factors (Input PI, Mechanism PI, Control PI and Output PI) represented by 18 observed variables from the factor analysis. The final model explained the casual relationship between activity and their performance indicators. Moreover, described on each arrow (Figure 5) is a regression weight or regression coefficient that shows the level of influence in each casual relationship. Further analysis results can be seen in [12].

4. Conclusion

This research developed shop floor control systems for plastic injection manufacturing and developed performance indicators of the production that conform to the shop floor control system. We expected to provide a basis for guiding the implementation of a system by suggesting a functional architecture that is more systematic, unambiguous, and modular. Clearly, the shop floor control system represented by IDEF0 technique was considered more appropriate for the presentation of complex manufacturing functional relationships. The IDEF0 contains the necessary functional requirements and their input-output relationships of a complex system in a hierarchical manner and becomes the process description for designing performance indicators suitable for plastic injection manufacturing. The performance indicators were proposed to suit each activity in the shop floor control system from major activities to sub-activities measures that are both financial and non-financial. These performance indicators can support shop floor control systems to manage uncertainty, can be used on the selected performance indicators to assess the efficiency of their organizations and can benchmark against other entrepreneurs in order to improve their productivity. In addition, the proposed performance indicators might be applicable to other manufacturing.

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