Chapter

Automotive Industrial Supply Chain Performance Evaluation under Uncertain Constraints on Cloud Computing System

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Abstract

Performance evaluation is a critical and complex task as well as uncertain demands for automotive supply chain. Several methods are applied and adopted to deal with current situations and maintain competitiveness such as fuzzy logic, neuro fuzzy, agent (multi) based evaluation, etc. However, such systems are not rapid enough to respond customer requirements by real-time on mobile cloud computing system. There are many companies that operate under the first tier company as subcontractors on the same goal. Cloud computing system is capable to monitor real-time production processes for every subcontractor to assist the 1st tier to make decision and respond customer effectively. Daily monitoring data of all subcontractors in the supply chain are stored in the central database and finally the performance evaluation can be done. The implication is cost reduction of the whole supply chain and increase competitiveness as well as continuous process improvement for all.

Keywords: performance evaluation, automotive supply chain, uncertain constraints, neuro fuzzy system, CPOM system

1. Introduction

Supply chain management is emphasized on delivery parts on demands both regular, irregular, and uncertain circumstances. Inventory management is a critical aspect of management. There are four elements of inventory; raw materials, work in process (WIP), finished goods, and spare parts. The raw materials are components, subassemblies, or material that are purchased from outside the factory and used in the fabrication or assembly processes inside the factory. The WIP includes all finished parts or products that have been released to a production line. The finished good is final products or parts that are kept in the warehouse waiting to ship to customers by purchasing orders. Spare parts are standard components they bought from suppliers to maintain or repair production equipment. In automotive industry, a subcontractor is used as a major player in supply chain manufacturing cluster. The subcontractor is normally SME companies which makes contract for long period of time. Mostly, the subcontractor is sighed the contract according to the specific parts. However, the parts can be done by several contracts in order to

reduce and distribute risky. The subcontractor can be classified into several levels namely 2nd tier, 3rd tier, and so on which relied on the role and performance evaluation. To become a subcontractor, a company is applied and audited by a SCM committee of the 1st tier company. The applicants are evaluated by company profile, factory visit, auditing 3 divisions; planning, quality assurance, and supply chain, based on the subcontracting criteria. There are 4 main criteria such as safety, planning, production control, and quality. The safety aims to check that the subcontractor works safely in the well-prepared environment including machine protection, operator protection, and part protection. Planning involves with production supporting process. They are production planning, raw material requirement planning, order receiving plan, compound and components receiving plan, sending raw material back to the 1st tier, delivery plan, packing standard plan, and inventory control. In terms of supply chain, It can be classified into 3 main group based on manufacturing types: sheet metal parts, plastic parts, and rubber parts. However, production technology is not concern in this chapter but it focuses on performance management and evaluation of delivery, back order clearance, and quality of finished parts. One of the most important aspects is that customer satisfaction on the customer service process that suppliers must provide any automotive parts needed whenever they want. In this paper, it is concerned on the case study and information based on the rubber part manufacturing industry. Production process control consists of compound storage control, curing and de-flashing, machine and mold preventive maintenance, and production control. Quality involves with inspection, finished goods and defect management as well as problem solving, quality assurance based on ISO (record, traceability, and change management).

The evaluation for renew-contract consists of two parts; monthly audit and yearly audit. The monthly audit is evaluated by the performance. They are mainly on delivery on-time, quality of finished goods, back order delivery. The result is achieved by grade level; A, B, C, and D. Grade A is excellent. B is good. C and D are needed to be improved. If the improvement is not successful and unsatisfaction, then the contract is resigned. The more details are in the later section. The yearly audit includes working system, ISO, improvement, control, and safety environment.

Supply chain performance evaluation for automotive supply chain is quite seriously emphasized on product quality and delivery on-time which are impact on human's live. The general problem is that the market is fluctuate and heavy competitiveness on the cost leadership. Supply chain and subcontractors are the key success methodology which are widely used all over the world. However, the problems are; 1. how to select subcontractors to produce parts effectively; 2. how to maximize cost when the capacities are suitably shared and distributes; 3. how to maximize cost for transportation of the whole subcontractor locations; 4. how to manage machine availability and uncertainty; 5. how to deal with uncertain performance and allocate production planning.

Modern computer information technology is currently applied to supply chain management such as computer integrated manufacturing (CIM), enterprise resources planning (ERP), internet of things (IOT), could manufacturing and so on. However, the SME subcontractors are not need to implement the fully high information technology or fully automation but it should invest or develop the parts of technology that can link to accompany the 1st tier company. One of the most critical part of the computer information technology used in the supply chain is could computing and monitoring as well as production execution in order to distribute and share information rapidly, real-time and on-time needed. Delivery is the most important for the automotive subcontractors especially at the 1st tier company. This chapter proposes automotive industrial supply chain performance evaluation under

uncertain constraints on cloud computing system. Fuzzy logic based together with neural network or called neuro-fuzzy is developed to evaluate the performance of subcontractors and can be used for prediction the future events for rapid changes and provide a flexibility management on inventory and delivery to the end customer of OEM.

2. Concept and theory

This section presents the concept and theory of supply chain management, fuzzy logic, fuzzy AHP, Neural network and performance evaluation. Supply chain is major links to every parts of the business processes and communicate to their chains and the 1st tier in both vertical and horizontal organization. Fuzzy logic is a methodology used to deal with uncertainty including fuzzy AHP which helps to arrange the priority factors for multi-decision making to reduce complexity. Neural network is used to deal with qualitative data of performance evaluation.

2.1 Supply chain management

Supply chain plays significant role to OEMs in terms of increasing market share in a highly competition industrial cluster such as automotive industry by accessing to advanced manufacturing technology, reduced time to market, lower production costs, and more effectively used of assets. Modern supply chain management has seamless relationship in dealing with uncertain and fluctuate demands, risk management, stock management, allocate capacity, real-time tracking manufacturing progress with on-line and could system as well as using and selection outsource as engineering service providers. In addition, the customer relationship management is critical for the effective supply chain management. In the previous time, the average time required for company to process and delivery to market and customer from warehouse inventory taken many days or even unpredictable time because of uncertainty. It might be inventory out of stock, misplaced work order, misdirected shipment, total time to service customer escalated rapidly.

Presently, the world changing a lot influencing from digital age and disruption. Therefore, the information technology together with computerization are performed as a backbone of most of the business process according to 4G and 5G even the 6G is coming soon. Orders from customer are rapidly changed to e-commerce and on-line purchasing which is supported by modern logistics controlling by GPS and cloud monitoring. The reality of connectivity among collaborating business organization continues to drive a new order of relationship called supply chain management.

Supply chain is traditionally combined with logistic which consists of two major elements; inbound and out bound logistics. The process begins with second tier suppliers to deliver parts or products to the first-tier suppliers' through manufacturing processes. The inbound logistics are applied in this stage. Then, the finished goods are sent to distributors, agencies, and retails or even end users and customers. The structure of the supply chain is varied based on the companies. Therefore, the unique management is properly designed and created. However, the principle characteristics of supply chain are defined as ability of a firm to work with its suppliers to provide high quality material and components which are competitively priced. The closeness of relationship between vendor and customer in respects purchasing materials and inventory management reflects to the company's strategy and the role of supplier contributing to the long-term success of the firm.

Supply chain management is a well-known concept to applied in the modern business management all over the world particularly in the era of digital disruption and transformation. In the past, the supply chain management is applied to manage material flows among work stations inside the companies accompany with kanban, push-pull system, WIP and buffer inventory control in the JIT system including waste management of the lean manufacturing. Presently, the supply chain management is applied to a group of distributed manufacturing and outbound logistics in and out of the first company. It is recognized to be a critical tool to make survival and competitiveness even up to the competitive advantage of the whole chain. The key success factors are communication, delivery, quality, cost under uncertain circumstance. The digital transportation used is applied the progress of manufacturing processes by on-line and real- time tracking using cloud computing system. The evaluation can be measured by the key success factors in order to achieve the customer satisfaction. On the other hand, the supply chain cluster has to implement lean production in order to dealing with competitiveness problem. Company often had an antagonistic relationship with their suppliers inside the supply chain cluster. Every item that was purchased had several vendors who are played off against each other in order to obtain the lowest possible prices, which was the first criteria for being awarded a contract. Subcontractors recognizing that the relationship could very likely be terminated with the next contract, invested minimal time and money to address the specific needs of individual customers. The purchasing function within the manufacturing company often reported to the supply chain manager in order to make decision on purchasing raw material and components at the lowest possible cost.

2.2 Performance evaluation

Performance of production is the final goal of manufacturing which needs to measure for evaluation at the end of processes or periods of time. It can consider on quantity, quality, cost, value, productivity, resource used and so on. Effective performance evaluation for competitive advantage particularly in supply chain logistics includes monitoring, controlling, and directing operations. Monitoring is accomplished by the establishment of appropriate metrics to track system performance for reporting to management such as on-time delivery, production rate, production quality on planned, finished goods, defects, transportation tracking, warehousing and so on [1]. Controlling is accomplished by having appropriate standards of the whole life cycle of operation performance related to the customer requirements or international standard (ISO). Controlling is also used to ensure that planning time is managed effectively on the productive operations. Directing is related to shop floor control on the machine level and operators to run the production properly, correctly, and perfectly in order to achieve high level of productivity.

Performance metrics is typically involved with several criteria; cost, customer services, quality, productivity and asset. Costs are cost per unit, total cost, percentage cost of sales, administrative coat, direct labor cost, inventory carrying cost, cost of return goods, cost of defect, cost of damage, cost of service failures, cost of back order, cost of logistics, cost of materials and so on. Criteria of customer services are on-time delivery, back orders, cycle time, complete orders, delivery consistency, fill rate stockouts, response accuracy, customer complaints, reliability, overall satisfaction. Quality is the most criteria consisting of product quality, order entry accuracy, invoicing accuracy, information accuracy, number of customer complaints, number of customer returns, picking and shipping accuracy. Productivity criteria are decrease cost rate, number of increase production quantity rate, productivity index, order per sales representation, units per labor values, units shipped per employee,

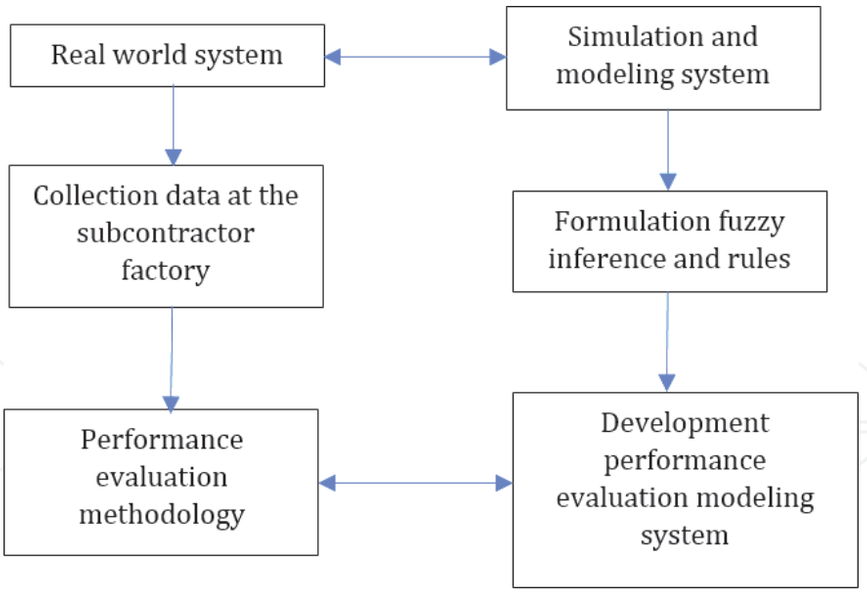

Figure 1.
Simulation and modeling framework for performance evaluation.

decrease of standard time, reduction of equipment downtime, warehouse and transportation labor productivity. Asset is measured by inventory turns, inventory levels, number of days of supply, obsolete inventory, return on net assets, return on investment, economical value added (EVA) and so on.

Performance evaluation for supply chain is different from a common firm particularly for subcontractors. There are multi-criteria evaluation in several hierarchy and different weights depending of the importance priorities. The main criteria are delivery on the purchasing orders and on-time and on quality. If any uncertainty is occurred on the delivery, back order must be released on the certain time. The quality involves with defects and errors occurring on the delivery. It is normally measured by six sigma (ppm). Presently, modeling and simulation are used as a manufacturing system tool for production flow and performance evaluation that most of the mathematical models are used in operations management and industrial engineering.

Figure 1 shows the simulation and modeling which applies fuzzy logic and Neuro fuzzy to evaluate the performance of subcontractors in automotive supply chain. It is started on the real-world system. The objectives, constraints, and alternatives are identified. Customer requirements are taken into account for designing and creating measurement parameters and controls for modeling using mathematic model or intelligent system such as fuzzy logic, neural networks and so on. Data at the current and activated factory of the subcontractors while doing real business is collected. Then the performance evaluation methodology is designed and implemented. On the other hand, the simulation and modeling system are developed. Fuzzy logic and neuro fuzzy system are formulated with membership functions, fuzzification and defuzzification. Finally, the performance evaluation modeling system are created and implemented.

3. Related works

This section explains the previous works on the methodology dealing with performance evaluation in the uncertainty circumstances because of changing world caused by modern communication and management of digital technology. Fuzzy

logic is firstly explained following with neuro-fuzzy system. Then previous works on performance evaluation particularly on supply chain management is reviewed and comments. Finally, the modern management on cloud monitoring is stated and discussed to be the way of applying to the monitor performance operation at shop floor level.

3.1 Fuzzy logic

Fuzzy logic is very useful tool to support decision making under uncertainty and complexity when information is not sufficient and imprecision. Traditionally, probability theory is used to deal with uncertainty. However, the uncertainty can be different forms. The probability can deal with the expectation of the future event based on something known before. By contrast, fuzzy logic handles with a prediction about the event which represents fuzziness expression in terms of linguistic [2]. Zadeh [3] first presented a Fuzzy Set theory. It is a tool that helps in decision making under the uncertainty of data. The fuzzy logic has flexibility and can make easy decision making by applied in the representation of human reasoning and linguistic terms with the following definitions:

3.1.1 Definition 1. Fuzzy set

A fuzzy set is a member function that attributes the elements of the domain in the interval [0,1] as the following Eq. (1). The interval is a degree of membership when the given value is close to 1, there will be a higher level of membership. If the membership is zero, it means that there is no membership.

$$U_a(X) : U \rightarrow [0, 1] \tag{1}$$

In which U_a (x): U → [0,1] is called pertinence function and U_a (x) is the degree of pertinence of x.

3.1.2 Definition 2. Linguistic variable

A Fuzzy set can be used to describe the value of a variable. A linguistic variable is a linguistic expression which is used to determine the value of what is described in terms of qualitative scales such as very low, low, medium, high and very high.

3.1.3 Definition 3. Fuzzification

The fuzzification is used to convert the input into fuzzy variables or fuzzy sets or language variables.

3.1.4 Definition 4. Membership function

The membership function is the process of determining the membership level of a variable, which is important for the process of thinking and solving problems. The membership functions are not symmetric or symmetrical in all respects. The membership function used in this paper is triangular. The triangular membership function has a triangle shape, which depends on the 3 variable values, a, b and c as shown in **Figure 2**. It is a commonly used in many researches.

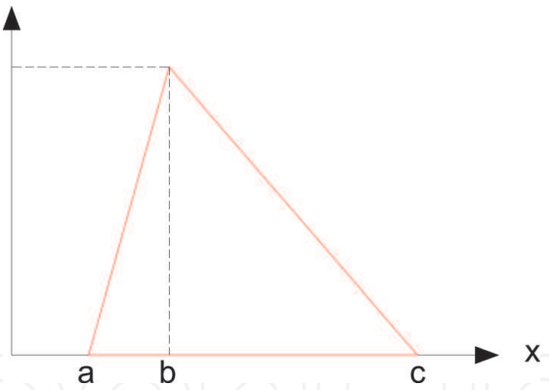

Figure 2.
Triangular membership function.

3.1.5 Definition 5. Defuzzification

A defuzzification operation is a process to transform fuzzy set into a crisp output. The center of gravity (COG) is the most commonly technique calculating the center of the area of combined membership function. In this paper, fuzzy logic sugeno type was used to approximate output as the following Eq. (2):

$$y = \frac{\sum |y = y'| \times y'}{\sum |y = y'|} \tag{2}$$

Previous works have been done using fuzzy logic for operation performance evaluation particularly in the area of supply chain management. Fuzzy logic for logistics management using SCOR model for evaluating performance in supply chain is widely studied [4–6]. The model developed can evaluate overall performance by real-time network. The model can predict the performance based on causal relationship of the SCOR metrics using fuzzy rules to build the prediction model. The fuzzy logic model can be combined with Linear Programming (LP) which aimed to evaluate the performance and capability in order to distribute purchasing orders in the cluster environment. The study presented the cluster body manufacturing in Thailand [7]. The cluster consists of 40 SME companies which located in the same areas. The have limitation of manufacturing resources. Therefore, they have to combine capacity in order to serve the big lots of purchasing orders. It is normally order with big lots of busses particularly the order from local government. For example, the 2016 purchasing orders were around 500 city busses with limited delivery time. The cluster of bus body manufacturing needs to join and share capacity, resources and even profit. The model develop was tested and help lots of benefits to them. The KPI indicators of the efficiency performance evaluation which is designed with 5 criteria; capacity, quality, reliability, flexibility and source. The fuzzy logic is extended to integrated with other methods such as Quality Function Deployment (QFD) to use for quality design of large complex products and structures. Although the fuzzy logic is effective but it has got a weakness in term of prediction by learning. In this case, the Artificial Neural Network (ANN) can be done and substitute the fuzzy logic.

3.2 Artificial neural network and neuro fuzzy system

ANN mimics human's brain working using algorithms and graph theory. It represents biological nervous systems such as brain processing information deriving

from imprecise and complicated data. Training ANN can be used to provide projections given new situations [8]. Kocamaz et al. [9] proposed ANN which was used to control chaotic supply chain based on a nonlinear dynamic system. It is sensitive dependence on initial conditions and involves with infinite number of different periodic responses. Zayegh and Bassam [10] presented neural network principals and applications. ANN can be used to implement different stages of processing systems based on leaning algorithms by controlling their weights and biases. The paper presented the ANN application for digital signal processing performed by the concept of a multilayer perceptron which feeding forward as networking system by a set of neurons together with weights. It consists of an input layer, multi hidden layers and output layer. Back propagation is an algorithm working together with the multilayer perceptron as shown in the **Figure 3**.

Feng et al. [11] proposed the application of ANN to solve the problem of job shop scheduling using MLP networks. Job shop scheduling involves with several tasks varying from customer orders. A job shop consists of many jobs which are assigned to perform on many machines. ANN is advantage on learning by training approach and mostly deal with qualitative information. However, there are various types of application in manufacturing need to deal with the combination of quantitative and qualitative information. Previous articles stated that neuro-fuzzy can deal with the combination information effectively. There are many applications of ANN to production manufacturing such as Lee and Shaw [12] applied a neural network to deal with a real-time floe shop sequencing. Che [13] proposed the ANN for estimation cost of plastic injection molding. Efendigil and Onut [14] proposed the neuro-fuzzy based methodology to make multi-decision on multi-stage supply chains which integrates from customers to suppliers through warehouses, retailers, and factory. The ANFIS is used for making decision as artificial neural fuzzy inference system on the customer demands. It consists of several procedures; fuzzification, rule antecedent, normalization, rule consequent, and rule interface. The output carries out with new demand data. Chupin et al. [15] proposed neuro-fuzzy model in supply chain management for object state assessing in the conditions of uncertainty-based supply chain strategy. Didehkhani et al. [16] presented assessing flexibility in supply chain using adaptive neuro fuzzy inference system in order to consider the factors of competitiveness of the world class manufacturing. The criteria include speed, variety, flexibility and integration in production main line. Sremac et al. [17] proposed neuro-fuzzy inference systems approach to decision support system for economic order quantity in supply chain management based on a dynamic situation of information flow, products and funds among different participants. SCM is a complex process and mostly involving uncertainty.

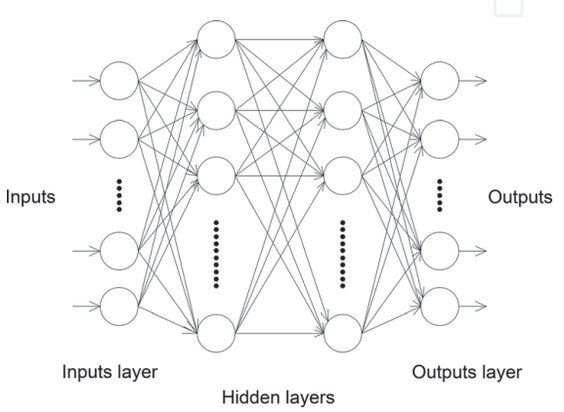

Figure 3.
A multilayer perceptron of neural network [11].

Thipparat [18] proposed application of adaptive neuro fuzzy inference system in supply chain management evaluation in the case study of construction project. The project consists of design, contract, liabilities, weather, soil conditions, environment, and so on which are uncertain. The construction project often deals with many parties of stakeholders in supply chain. The criteria are taken into account such as cost, asset, flexibility, reliability, responsiveness.

3.3 Sub-contractor evaluation

Evaluation is needed to all subcontractors every month and every year in order to check capability, performance and availability to continuous the business. The major criteria are delivery finished goods and all item according to the purchasing order. The 1st tier company plays responsibility to the OEM which is to delivery any part their needs on demands uncertainly. The facing troubles are that demands are fluctuated based on the world economic situations. Therefore, the real-time monitoring is needed in order to dealing with rapid change and effective control stock of inventory. Mahmood [19], Kaganski [20], Amrina & Yusof [21] proposed the concept of production evaluation in SME network using virtual enterprise. Key performance indicators (KPIs) is created which affect operation such as efficiency, utilization, and productivity. Hon [22] proposed the KPIs of production performance consisting of 5 criteria; quality, cost, delivery, and flexibility. Performance evaluation with KPIs is a good tool for controlling and enhancing the company to improve productivity and competitiveness but the methodology cannot use the same criteria particularly for evaluating a supply chain performance. Behrouzi et al. [23] presented the performance evaluation for supply chain management in the automotive industry. It consists of 20 KPIs which applied lean concepts in the context. The studied collected data from the 133 supply chain companies. The criteria contain attributes; waste elimination, continuous improvement, just in time, and flexibility. Roda & Macchi [24] proposed an evaluation model for production system based on the need of factory level performance metric tracking system which adopted OEE criteria to create KPIs. Joppena et al. [25] introduced a KPIs for production performance evaluation consisting of 5 criteria; quality rate, manufacturing defect rate, rework rate, rejection rate and OEE. Hyytia and Rgihter [26] proposed a performance evaluation using simulation modeling for dispatching systems of the routing jobs to the work stations using parallel computing systems. The system can deal with dynamic dispatching policy accompanied with monte Carlo methodology. In supply chain, the problem sometimes needs to deal with capacity sharing in order to increase potential a large order quantity which is benefited to SME industrial cluster. Butdee and Nitnara [8] proposed a fuzzy logic combined with linear programming (LP) modeling for the cluster capacity and performance evaluation to distribute purchased order suitably for each supply chain cluster of bus body manufacturing in Thailand. The modeling can deal with uncertainty situations when demands are fluctuated. The criteria include capacity, quality, reliability, sources, and flexibility. Jagan et al. [27] reviewed a supply chain performance of the whole production system using the concept of Balance Score Card combined with SCOR model as well as AHP model. Hudson et al. [28] proposed the theory and practice of performance measurement systems for SMEs using multi-criteria such as quality, flexibility, time, finance, customer satisfaction, and human resources. Svalina et al. [29] proposed a neuro fuzzy system for evaluation surface roughness with minimize machining time and maximize material removal rate, recommendation optimal cutting parameters under alternated possibility controlling of the machining processes. The system can deal with complexity, imprecision and uncertainty environment. The developed AHP and Fuzzy AHP

modeling to deal with constraints and dynamic situations as well as uncertainty risk management.

Performance evaluation is currently involved with energy consumption which is enable to save production cost. Energy evaluation is concerned with the energy used for machines, oven, welding machines and so on. The energy consumption management is taken into account together with manufacturing efficiency. Energy is one of the major costs of automotive supply chain particularly the rubber part manufacturing. Most of the compression machines, injection machines are used the heaters to heat rubber materials and continuously heated whole day and whole weeks. It is sometimes worked around 20 days or more per month. Therefore, the energy is critical for the company in supply chine because cost is the major criterion of the competition. Energy control is dynamic and uncertain in aspects of obtaining the OEE of s firm. Scientific methods are applied to deal with the energy control. AHP and Fuzzy AHP including Fuzzy FMEA or even the combination of them. The criteria concern with the cause of uncertainty and risk such as severity, occurrence, and detection. The major goals of production control are cost control, improving quality, and on-time delivery.

3.4 Cloud management system

Cloud manufacturing system is emerged which is developed from the advanced manufacturing systems using the information and computer technologies such as cloud computing, internet of things (IOT), virtualization and service-oriented technologies, virtualization, cyber physical system. It transforms manufacturing resources and manufacturing capabilities into manufacturing services, which can be managed and operated in an intelligent and unified way to enable sharing facilities. The cloud manufacturing system can provide efficient and reliable, high quality, cost saving control. The system can enhance in the decision-making process while the material flow is tracked following the production process particularly at the final operation of the supply chain which needs to control on-time delivery. Problem solving can be rapidly done even immediately to increase productivity. The collaborative manufacturing management can be done along the whole life cycle of production. Few papers studied and presented could computing, cloud-based infrastructure. Lin Zhang et al. [30] expressed the cloud manufacturing which is the combination of cloud computing, IOT, serviced-oriented technologies and high-performance computing in order to solve the bottlenecks in the informatization development and manufacturing applications. It consists of three core components such as resources, cloud service and manufacturing on cloud. The evolutionary of modern manufacturing started from computer integrated manufacturing system (CIM). Then, the agile manufacturing is established to deal with time to market and supply chain management. It can support the responsiveness quickly while cost and quality can be consistently controlled. Afterward, concurrent engineering and collaborative design are developed to save time to market which was the life cycle of product taken into account. Peng Wang [31] explained the benefits and limitations of could computing for cloud manufacturing. Cloud computing is recognized at the moment that is an aggregate computing resources and a service of things. Presently, services on demand is dramatically increased when the world is in the digital disruption and transformation. Cloud computing is enabled to transition of computation in various forms such as platform, hardware, and software. The benefits of the cloud computing are to obtain lower start-up and operating costs, to ease of access and scalability, to reduce risk on resource provision.

The characteristics of cloud management system are to envision for any feature of IOT such as self-service, visualization of system image, workload optimization,

interfaced tool management, service catalogs, network and storage configurations, and service governors, high performance management [32]. Self-service is the portal that interfaces to log and manage on infrastructure easily for configurations and execution deployments via a templates and customization. Visualization system image is enabled you to access different kind of system images that can be chosen and deployed via the self-service feature. Workload optimization can link to work anywhere seamlessly. It can work automatically or support decision making. It can manage resources better under policy and management rules. For example, the system server is used up to 60% or 75% with 2 GB of the ram. Interface to other management tools is to be a centralization of the data for monitoring overall information and work flow and deployment automation both existing technology and new equipment. This feature can assist the potential of execution system. Service catalogs is allowed users to choose service templates or configurations to apply any service in the catalogs via a list of promotion packages. In addition, users can create and developed their own template in different service categories. Network and storage resource configuration permit users to define several types of storage and networks even set up new storage configuration and sharing bloc level. Service governors are a smart tool which help users understand IT system inside company. The cloud has to support high performance management for gathering and collecting policies from the services based on infrastructure pattern use. It can configure automatically and deploy services using the right amount of resources and give high performance.

There are a lot of application using cloud system in different domains; automotive industry for process improvements and cost reduction, pharmaceutical production data for down time analysis, medical devices monitoring, education and training, production data for real time monitoring, food and beverage for OEE analysis to increase productivity.

4. Research system methodology

4.1 Subcontractor operation

Subcontractors are operated under the supply chain management which are closely linked to the 1st tier company. The most important aspect is that the subcontractors must understand the role of collaborative working. The main responsibility of the subcontractors is to receive purchasing order and delivery plan. The **Figure 4** shows the cycle of operations. It starts from receiving parts and delivery order. The raw material requirement planning is done by subcontractors. The production plan is created immediately after finished good stock is checked. Raw material is critical aspect when synthetic rubber is taken into account because its life is limited. It needs to be well-organized and can deal with uncertain environments. The raw material is ordered from the 1st tier company which all volume is combined from several subcontractors when the same material is used. This is the first advantage of the subcontractor supply chain which can share critical scale of resource by obtaining cost reduction. The production can start suddenly when the raw material is arrived. However, the material needs to test beforehand according to the standard specification and operation standard procedure given by the engineering department. The production consists of three operations before delivery to the customer of the 1st tier according to the delivery plan. The production also must be well-prepared for preventive maintenance both machines and molds. The molds are design accompanied with new part model before they are distributed to the subcontractors. This point is the 2nd advantage of the subcontractor supply chain

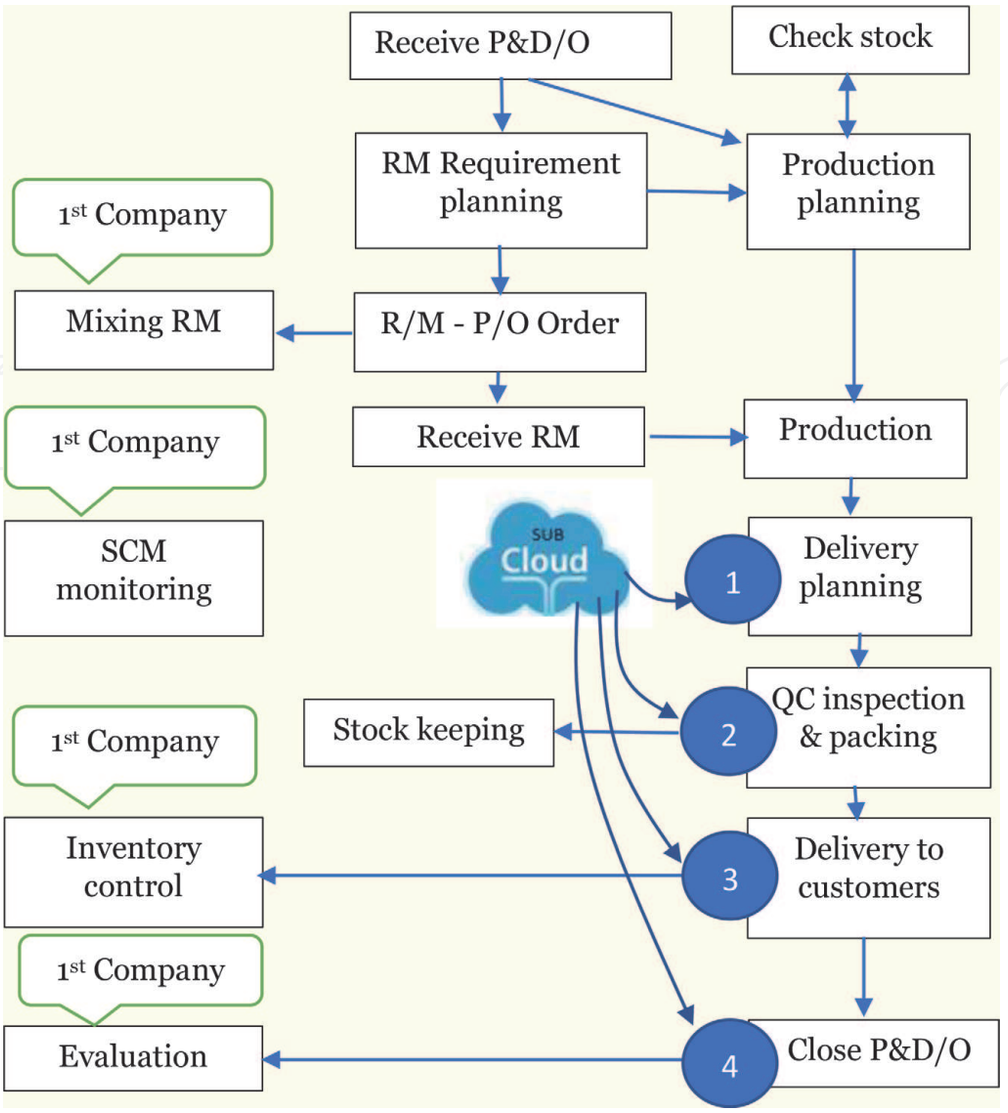

Figure 4.
The cycle of subcontractor in automotive supply chain management.

method. It is not only cost reduction but also the quality improvement. The delivery plan is monitored by the SCM department of the 1st tier following with the QC inspection and packing progress in order to predict the efficiency of the supply chain management. All of the parts required on the exact due date are delivered to the 1st tier inventory which is controlled by RFID and barcode inside the centralized data based and linked to the OEM. The final step is to close the P&D order and evaluated the performance. The concept of CPOM, detailed in 4.3, system is applied to the 4 last steps of the SCM. First is the delivery plan. Then, the QC& packing work station and stock control. The 3rd operation is delivery parts to customers which is linked to the 1st tier inventory control. The last operation is to close the P&D order which is linked to evaluation system.

Figure 5 shows production flow for supply chain collaborative of the 1st tier and the subcontractors. Based on the functional department. There are 5 departments which are defined in the same supply chain; engineering, planning supply chain, subcontractor and QC. The P&D order starts from the planning department and sends to the supply chain department and passes to the subcontractor. The engineering department prepares molds and operation standard procedure which is obtained from the new model testing at the real environment. The mold is sent to the subcontractor and tested for completion quality. Then, the subcontractor begins the preproduction and first lot experiment. The result is recorded and sent to the

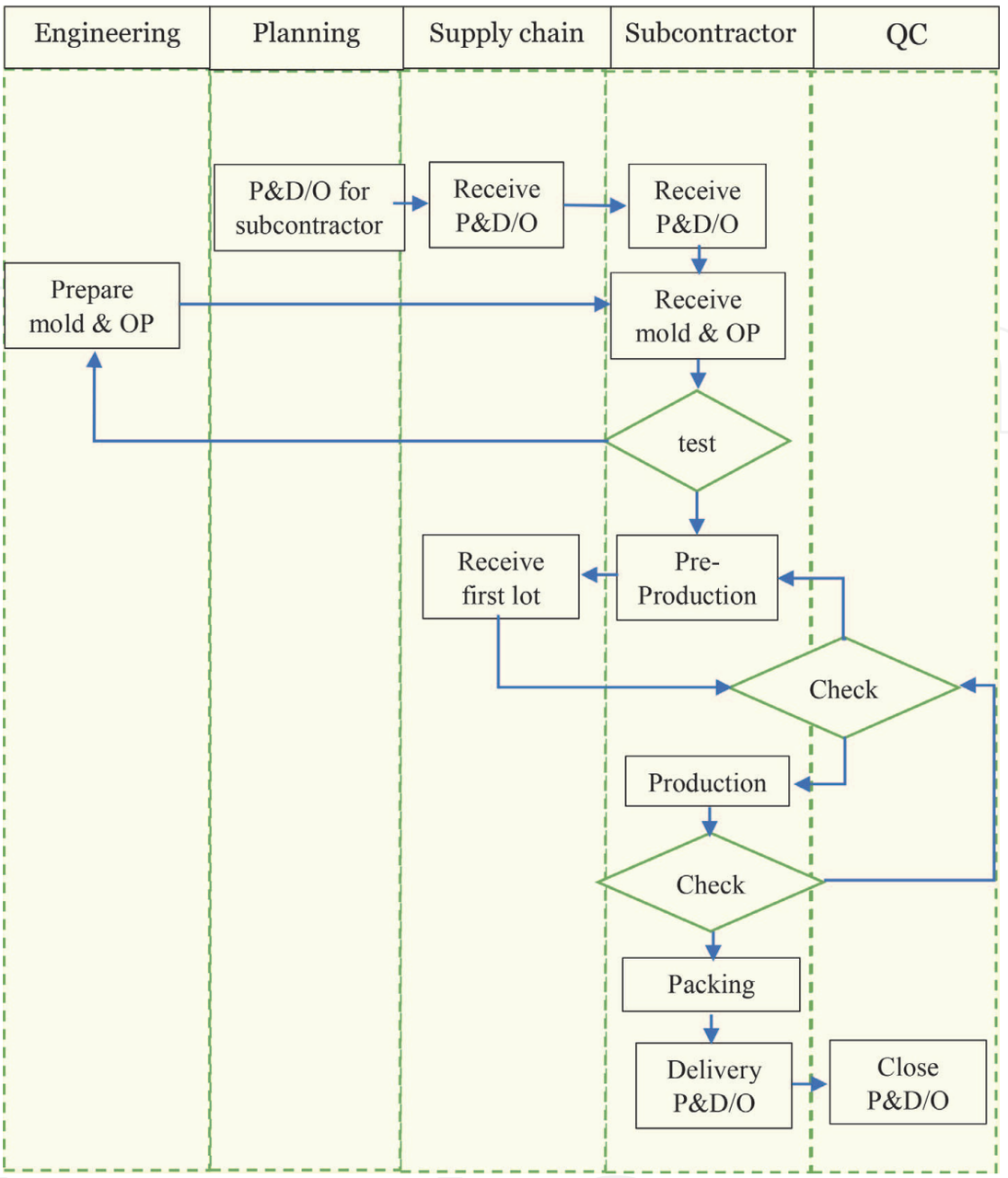

Figure 5.
Production flow for supply chain collaborative of the 1st tier and subcontractor.

QC department at the 1st tier to be approved. The production is continuing if the first lot is confirmed to be acceptable parts. The finished goods are checked by QC and packed before sending to the inventory, and close the P&D order.

4.2 Neuro fuzzy subcontractor evaluation system

This section presents the methodology of Neuro Fuzzy subcontractor evaluation before sending to the cloud production online monitoring (CPOM). This method is successfully validated and workable for automotive rubber subcontractor. The criteria include capacity, availability, quality, delivery, productivity, back order control. This study concerns only the monthly audit and yearly evaluation.
As previous mentioned, the monthly is important because it affects the daily production performance. It is weight 70% of the full mark of the total evaluation procedure. Therefore, the yearly evaluation weight 30%. The subcontractors are

evaluated with the same criteria and get results in 4 levels of satisfaction; A, B, C, and D. The grade A and grade B are passed with satisfaction whereas the grade C and the grade D are fail but they can improve the performance under the time and quality condition. There are 4 criteria are measured; 1. delivery on-time; 2. on quantity of the P&M order; 3. quality of the parts without any defect; 4. Back order clearance. The calculation performance is divided into three categories; delivery (D), back order clearance (B), and quality (Q). The function is shown in the Eq. 1, Eq. 2, and Eq. 3. Each criterion is applied and evaluated by every part. The performance evaluation level is given by score.

$$P(D) = \sum_{i=1}^{i=n} Di \sum_{j=1}^{j=n} Pj.(it1 + it2 + it3 + \cdots itn) \tag{3}$$

$$P(B) = \sum_{i=1}^{i=n} Bi \sum_{j=1}^{j=n} Pj.(it1 + it2 + it3 + \cdots itn) \tag{4}$$

$$P(Q) = \sum_{i=1}^{i=n} Qi \sum_{j=1}^{j=n} Pj.(it1 + it2 + it3 + \cdots itn) \tag{5}$$

When.

P(D) = delivery performance (%), P(B) = back order performance (%), P(Q) = quality performance (%), it = items to be produced (item consists of many pieces), Di = number of items to be delivered, Bi = number of back order to be delivered, Qi = quantity to be produced, Pj = number of pieces to be produced

$$\mathrm{P(D)} = \begin{cases} [\mathrm{x}|\mathrm{x}\ (\text{delivery performance}) \geq 99\%; \text{to get 15 marks}] \\ [\mathrm{x}|\mathrm{x}\ (\text{delivery performance}) = 90\text{-}98\%; \text{to get 12 marks}] \\ [\mathrm{x}|\mathrm{x}\ (\text{delivery performance}) = 80\text{-}89\%; \text{to get 9 marks}] \\ [\mathrm{x}|\mathrm{x}\ (\text{delivery performance}) = 70\text{-}79\%; \text{to get 6 marks}] \\ [\mathrm{x}|\mathrm{x}\ (\text{delivery performance}) < 70\%; \text{to get 0marks}] \end{cases}$$

The function set of P(D) shows the performance calculation of delivery which infers that the subcontractors have capability to handle the routinely received orders. The score is divided into 5 levels. The level 1 is excellent which can deliver more than 99% of the total order and pieces and get 15 marks. The level 2 is very good which can deliver between 90 and 98% of the total order and pieces and get 12 marks. The level 3 is good which can deliver between 80 and 89% of the total order and pieces and get 9 marks. The level 4 is moderate which can deliver between 70 and 79% of the total order and pieces and get 6 marks. The level 5 is fail which can deliver less than 70% of the total order and pieces and get 0 mark. The function set of the back-order release is presented in the next step.

$$\mathrm{P(B)} = \begin{cases} [\mathrm{x}|\mathrm{x}\ (\text{delivery performance}) \leq 3\%; \text{to get 10 marks}] \\ [\mathrm{x}|\mathrm{x}\ (\text{delivery performance}) = 4\text{-}10\%; \text{to get 7.5 marks}] \\ [\mathrm{x}|\mathrm{x}\ (\text{delivery performance}) = 11\text{-}20\%; \text{to get 5 marks}] \\ [\mathrm{x}|\mathrm{x}\ (\text{delivery performance}) \geq 20\%; \text{to get 2.5 marks}] \end{cases}$$

The set clearance of back order P(B) shows the performance score of the back-order clearance. It means that the subcontractor cannot achieve the delivery plan

but can handle the back-order clearance for the next delivery. The less back-order clearance is the more satisfaction. It is divided into 5 levels; excellent, very good, good, moderate and fails. Each level can get different scores. The 1st level is excellent which holds the back-order between 0 to 3% and get 10 marks. The 2nd, 3rd, 4th level hold the back-order clearance by 4–10%, 11–20%, and over 21% which can get the marks of 7.5, 5, 2.5 respectively.

$$P(Q) = \begin{cases} [x|x\ (\text{part defect}) \leq 3\%; \text{to get 10 marks}] \\ [x|x\ (\text{NCR clearance}) \leq 3\%; \text{to get 5 marks}] \\ [x|x\ (\text{part report inspection}) \geq 95\%; \text{to get 5 marks}] \\ [x|x\ (\text{customer claim}) \leq 3\%; \text{to get 5 marks}] \\ [x|x\ (\text{quick respond}) \geq 95\%; \text{to get 5 marks}] \end{cases}$$

The set of quality performance shows above that is x when the x is in the various conditions. If the part defect is ≤3%, then it will get 10 marks. If the NCR clearance is ≤3%, then it will get 5 marks. If the part report inspection is ≥95%, it will get 5 marks. If the customer claim is ≤3%, it will get 5 marks. If the quick respond is ≥95%, it will get 5 marks.

The final evaluation for subcontractor evaluation is combined the three criteria; delivery, quality and back order clearance. The total score and the satisfaction level are shown as the followings.

Table 1 shows the total scores and the evaluation criteria. The total score is 80 marks. This is for the monthly evaluation. The remain score is for yearly audit which gives the total score is 30 marks. However, this paper concerns only the monthly evaluation. Presently, the cluster automotive rubber part is evaluated by manual. It is time consuming, high effort, slow problem solving, and cannot deal with uncertainty circumstances and predict future events.

As mentioned from the literature review that fuzzy logic can deal with uncertainty. This paper adopts the fuzzy logic model to deal with the subcontractor performance evaluation. The set representation selects a membership function. Fuzzy set design is a triangular consisting of crisp subsets. The fuzzy linguistic terms are design in 5 levels; very high, high, moderate, low and very low. The conditional fuzzy rules are as the follows.

1. If delivery is low, then performance is low

2. If delivery is moderate, then performance is moderate.

3. If delivery is high, then performance is high.

4. If delivery is very high, then performance is very high.

Criteria	Marks
Delivery	30
Quality	45
Back order clearance	10
Total	80

Score	Grade	Satisfaction level
70–80	A	Excellent
55–69	B	Good
40–54	C	Moderate
< 40	D	To be improved

Table 1.
The score and evaluation criteria.

5. If back order is very low, then performance is very high.

6. If back order is low, then performance is high.

7. If back order is moderate, then performance is moderate.

8. If back order is high, then performance is low.

9. If back order is very high, then performance is very low.

Figure 6 shows the fuzzy logic model for performance evaluation. It consists of two inputs and two outputs. The inputs are delivery and back order whereas the outputs are performance evaluation of the delivery and back order. The model is performed by using MATLAB which is explained later. Fuzzy logic system is an inference engine using for carrying the results based on the input conditions.

Figure 7 shows the fuzzy inference system for delivery performance evaluation consisting of fuzzy input, fuzzification, and fuzzy output. The input membership function is divided into 4 ranges; Very high (VH), High (H), Medium (M), and Low (L). The Mandani method is selected with a triangular form.

Figure 8 shows the fuzzy membership function of the on-time delivery using triangular form. The divided range is referred to the **Table 1** but it needs to adjust a bit in order to fit with the actual form of the supply chain sample model. The low-level ranges are 69.5,75, and 80. The medium-level ranges are 79, 85, and 90. The high-level ranges are 89, 94.92, and 98.92. The very high-level ranges are 98,100,110.3. The total ranges are designed between 60 to 100%.

Figure 9 shows the membership function of the output delivery. The triangle fuzzy model is selected. The Low-level ranges of 5.25, 5.75, and 6. The Medium-level ranges 8.5, 8.75, and 9. The High-level ranges of 11.5, 11.75, and 12. The Very High-level ranges 11.5, 11.75, and 12.

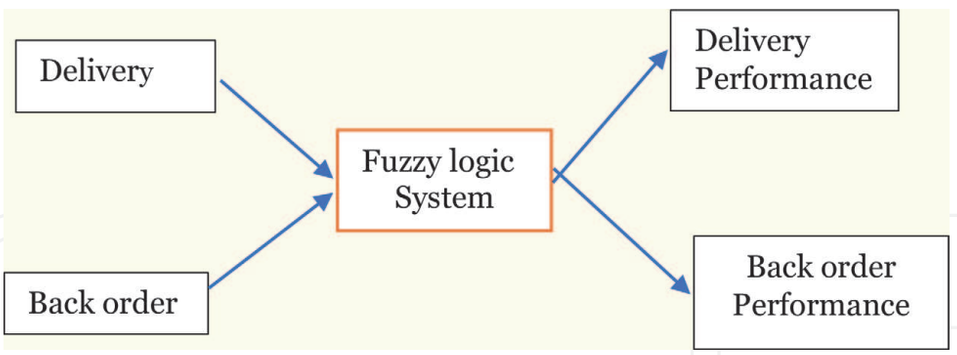

Figure 6.
The fuzzy logic model for performance evaluation.

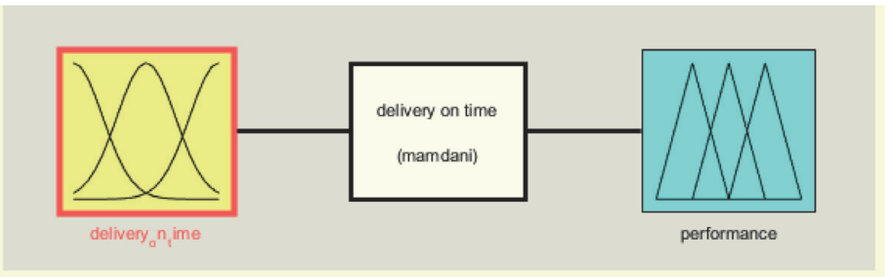

Figure 7.
FIS model for delivery performance.

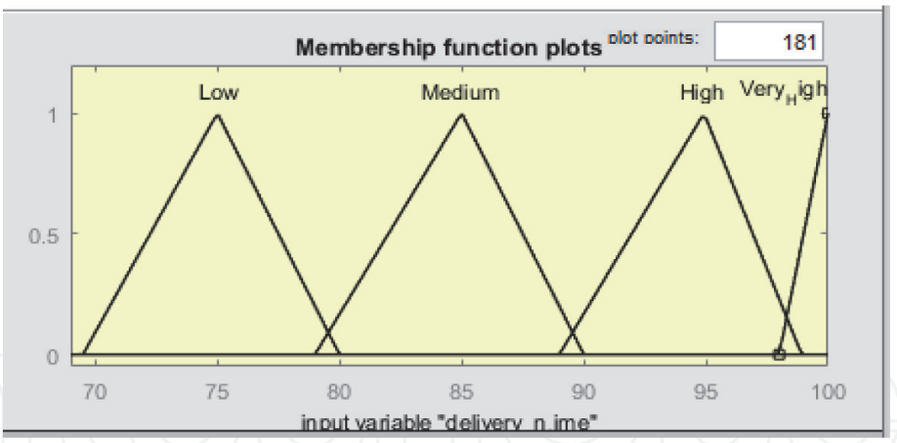

Figure 8.
Membership function input of the delivery.

Figure 10 shows the FIS model for the back-order performance evaluation consisting of fuzzy input, fuzzy inference system and fuzzy output. The model is referred to the **Table 2**. Similarly, **Figure 11** shows the FIS model of the delivery, the back-order clearance membership function which is divided into 4 ranges; Low (L), medium (M), high (H) and very high (VH). The triangular form is selected. The total range is between 0 and 21. The Low range is from 0, 1.5, to 3.99. The Medium range is from 3.95, 7, to 10.99. The High range is from 11, 15, and 20 and the Very High range is from 20.1, 21, to 28.

Figure 12 shows the output membership function, which is divided into 4 levels of Low, Medium, High and Very High. The total range is from 0 to10. The

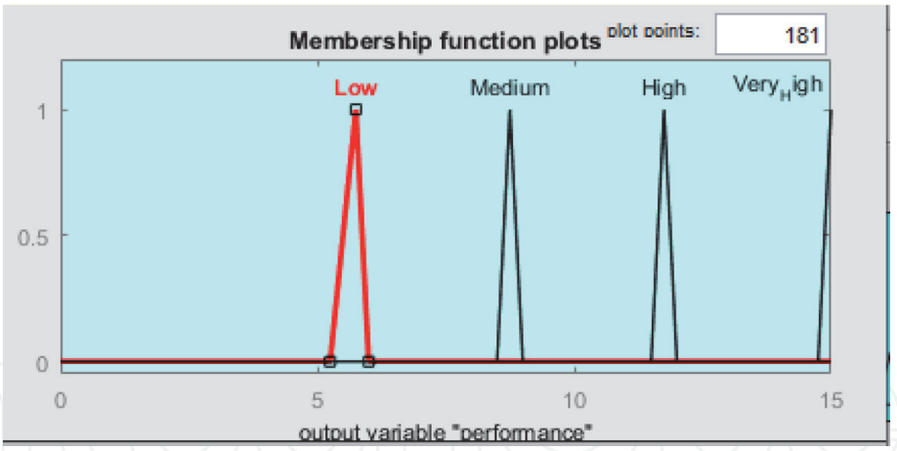

Figure 9.
Membership function output of the performance.

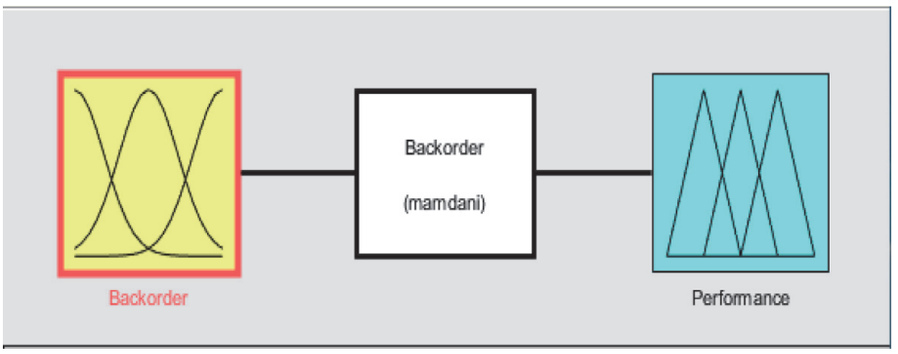

Figure 10.
The FIS model for the back-order performance.

[Input1]	[Input2]	[Input3]
Name = 'input1'	Name = 'input2'	Name = 'input3'
Range = [6 15]	Range = [2.5 10]	Range = [1 40]
NumMFs = 4	NumMFs = 4	NumMFs = 4
MF1 = 'in1mf1':'trimf',	MF1 = 'in2mf1':'trimf',	MF1 = 'in3mf1':'trimf',
[3 6 9]	[0 2.5 5]	[−12 1 14]
MF2 = 'in1mf2':'trimf',	MF2 = 'in2mf2':'trimf',	MF2 = 'in3mf2':'trimf',
[6 9 12]	[2.5 5 7.5]	[1 14 27]
MF3 = 'in1mf3':'trimf',	MF3 = 'in2mf3':'trimf',	MF3 = 'in3mf3':'trimf',
[9 12 15]	[5 7.5 10]	[14 27 40]
MF4 = 'in1mf4':'trimf',	MF4 = 'in2mf4':'trimf',	MF4 = 'in3mf4':'trimf',
[12 15 18]	[7.5 10 12.5]	[27 40 53]

Table 2.
Case of subcontractor neuro-fuzzy performance evaluation.

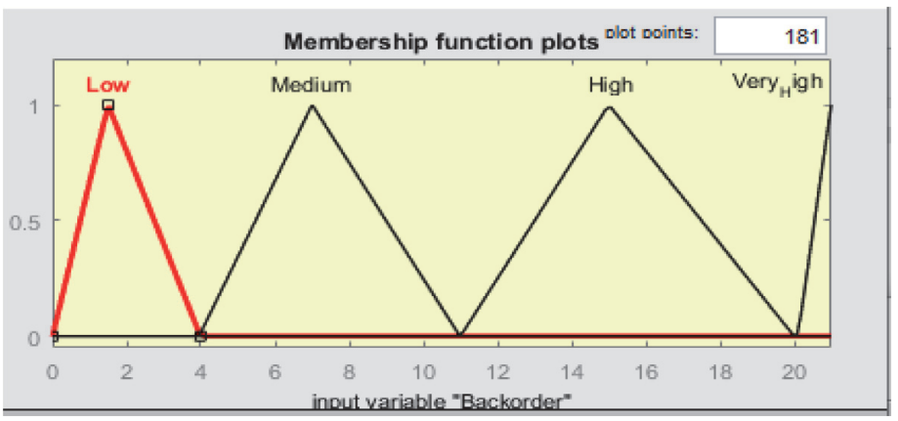

Figure 11.
Membership function input for back order performance.

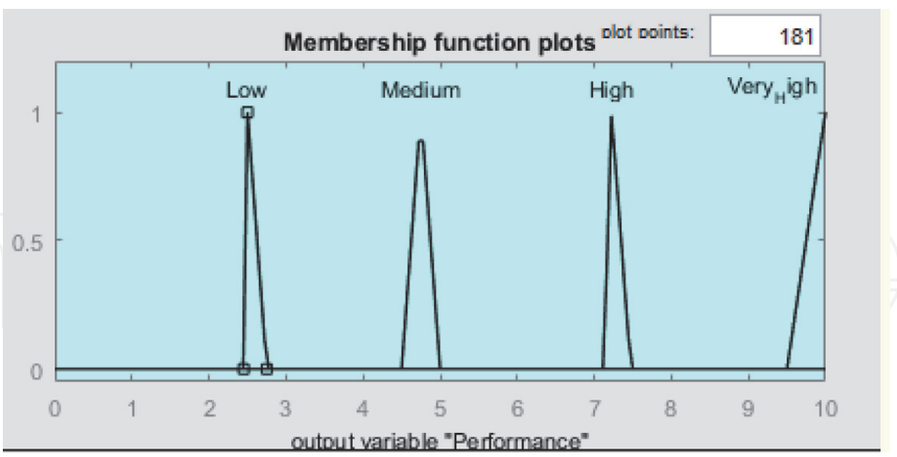

Figure 12.
Membership function output performance evaluation.

membership function of the Low range is from 2.45, 2.5, to 2.75. Membership function of the Medium range is from 4.5,4.75, and 5. The membership function of the High range is from 7.12, 7.22, to 7.47. The membership function of the Very High range is from 9.5, 10, to 13.33.

Figure 13 shows the FIS model is considered and evaluated individually. The ultimate goal of the fuzzy -based system is to get the overall performance evaluation. However, the overall performance has to include quality of the produce part.

Therefore, the model is designed to add quality to be another input membership function and adopt neuro-fuzzy system to solve the problem.

Figure 14 shows the neuro fuzzy inference (ANFIS) system for evaluate overall performance. It consists of 3 inputs; delivery, back order, and quality and one output. The output is overall performance evaluation. The sugeno is selected for the ANFIS rules of inference.

Figure 14 shows the neural training and learning data and the output. **Table 2** shows the overall input membership functions for the ANFIS system. The range represents the minimum and maximum value of the membership function. For example, the range of input 1 (delivery) is 6 to 15. The MF1 (Low range) represents 3 points of the triangle in the base line projection. They are 3, 6, and 9 respectively.

Figure 15 shows input membership functions plots. It consists of 4 levels; low, medium, high and very high. The low ranks between 0 and 2.5. The medium ranks between 2 to 5. The high ranks between 4.75 and 7.5. The very high is fallen over 7.25. The total length is scoped between 0 and 10.

Figure 16 shows the input membership function of the delivery. It is divided into 4 levels; low, medium, high, and very high. The low ranks from 6 to 8. The medium ranks from 8 to 12. The high ranks from 12 to 14 and the very high ranks from over 14. The total length is bounded from 6 to 15.

Figure 17 shows the input membership function plots. It is divided into 4 levels; low, medium, high, and very high. The low starts from 0 to 11. The medium ranks

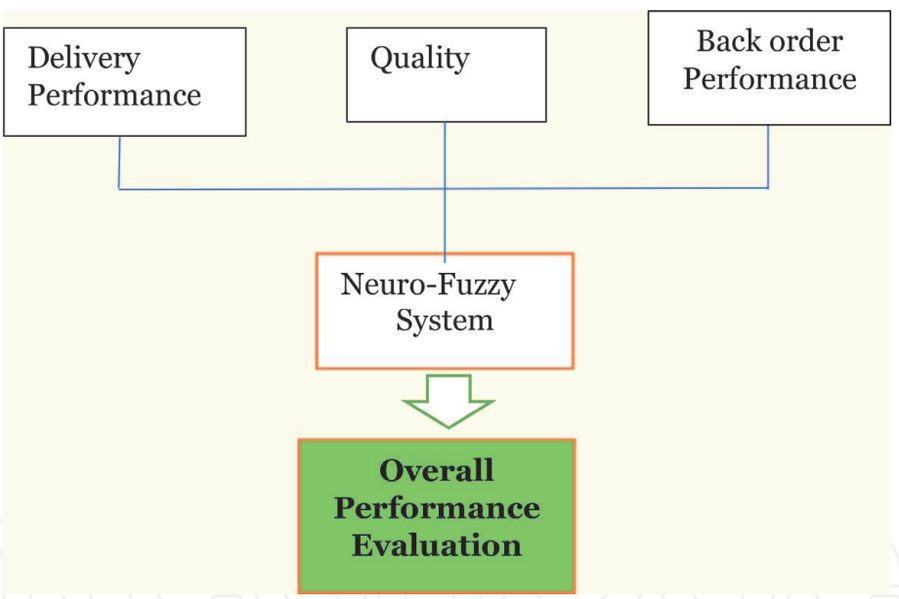

Figure 13.
The neuro-fuzzy model applied for overall performance evaluation.

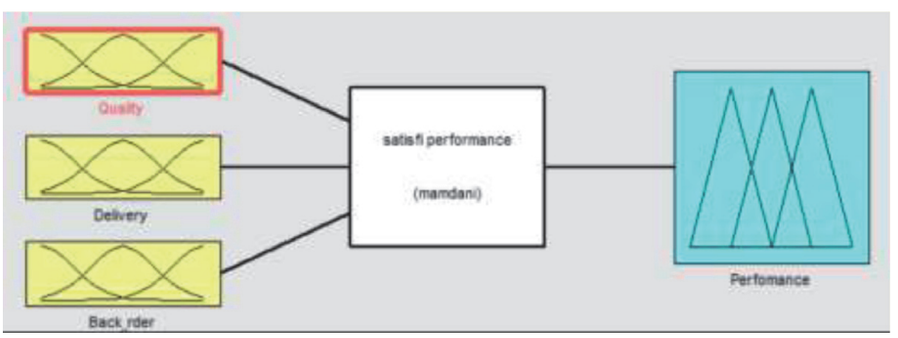

Figure 14.
ANFIS of the neuro-fuzzy performance evaluation model.

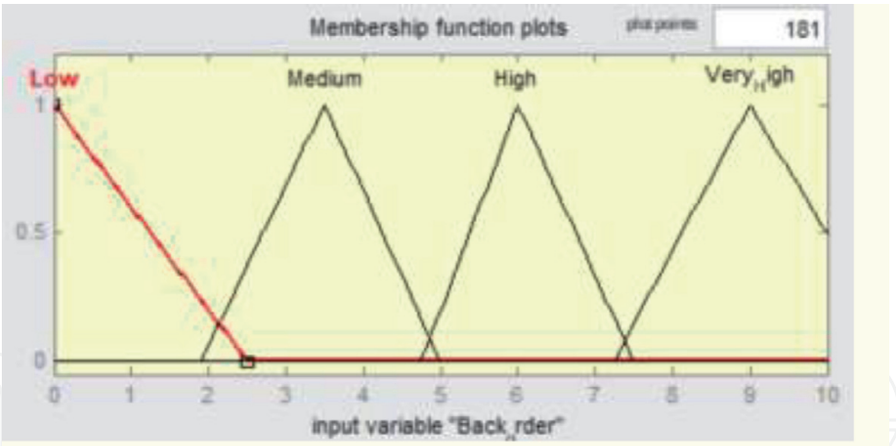

Figure 15.
The input membership function of the back-order clearance.

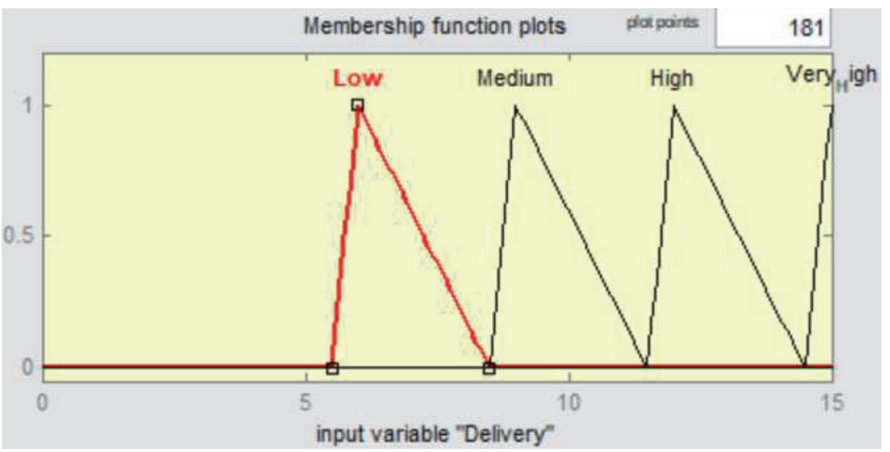

Figure 16.
The input membership function of the delivery.

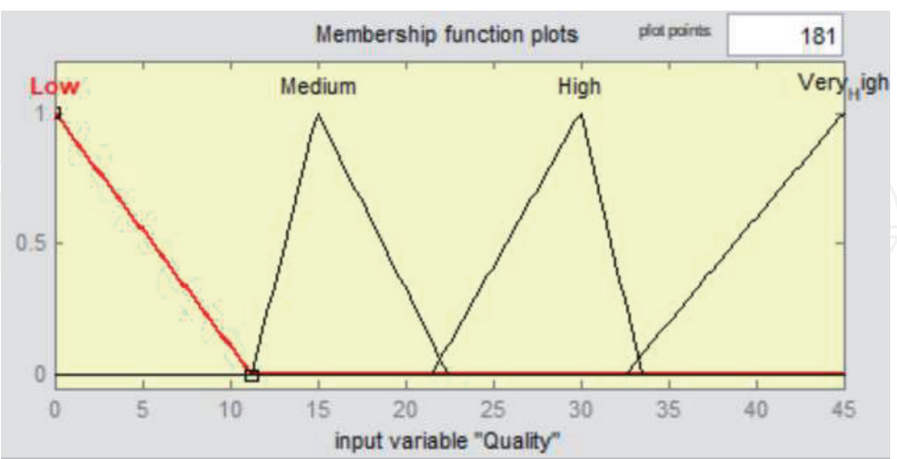

Figure 17.
The input membership function of the quality.

from 11 to 23. The high ranks from 22 to 34. The very high ranks from over 33. The total length bounded from 0 to 45.

Figure 18 shows the rule viewer for the example of the output of the delivery performance. There are four ranges of the input membership function. The example range is in the high which indicates 95.7 and the performance indicates very high. The given score is 11.7 marks in the 15 marks.

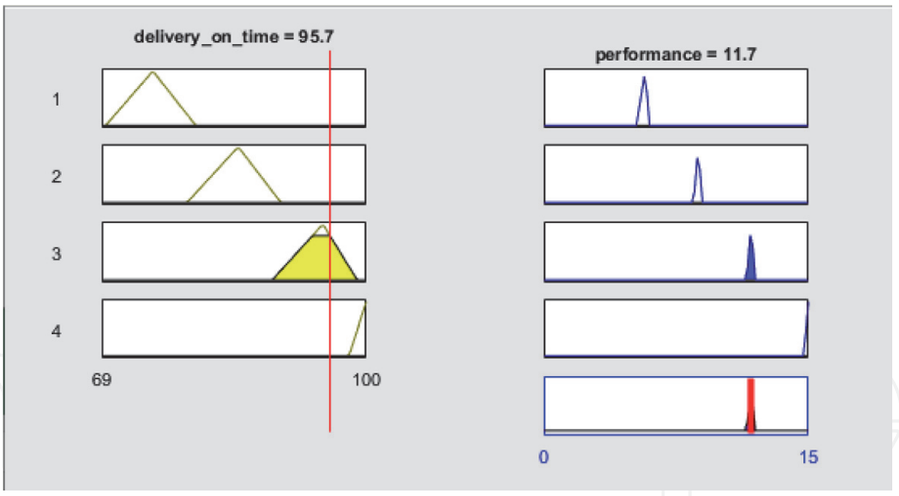

Figure 18.
Rule viewer output performance of the delivery on time.

Figure 19 shows neural training and learning. There are 3 inputs and 1 output. The training is set at 1000 iteration. There are 64 data. The final output is closely 70. The error is 4.546×10^{-6}.

Figure 20 shows the relation surface of the 3 criteria in 3 dimensions. It is found from the relation that the quality is the most influence to the performance whereas the delivery is lower following with the backorder clearance.

Figure 21 shows the rule viewer for the overall performance evaluation model for subcontractor. The data collection from the actual operation. The subcontractor data are inputted into the model and carried out with the result. As the sample above, the score of input 1 (delivery performance) given 15 marks meaning that the delivery performance is very high (99–100%). The 2nd input of the back-order clearance is received 10 marks meaning that this subcontractor performed very well. The percentage of back-order clearance is 1–3%. The 3rd input (input 3) is quality of product and service to the OEM agent and this subcontractor received 40 marks. The quality includes the products delivered quality to the OEM agent.

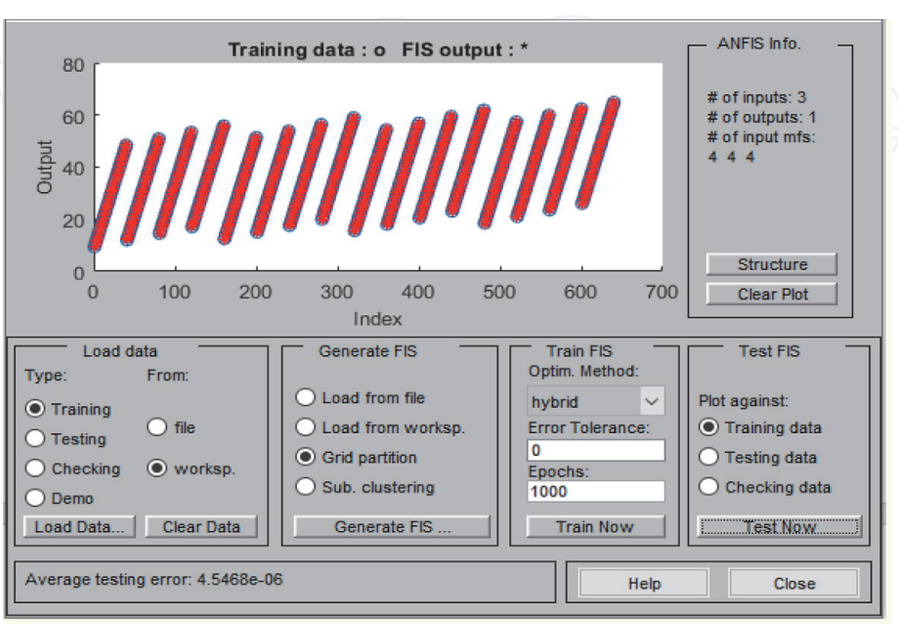

Figure 19.
Neural training and learning.

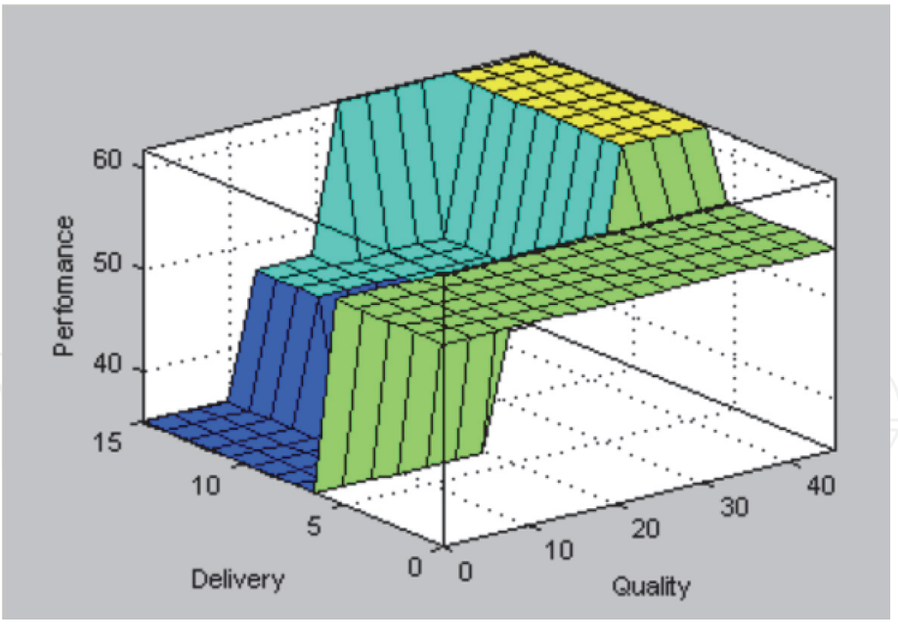

Figure 20.
The relation surface of the 3 criteria in 3 dimensions.

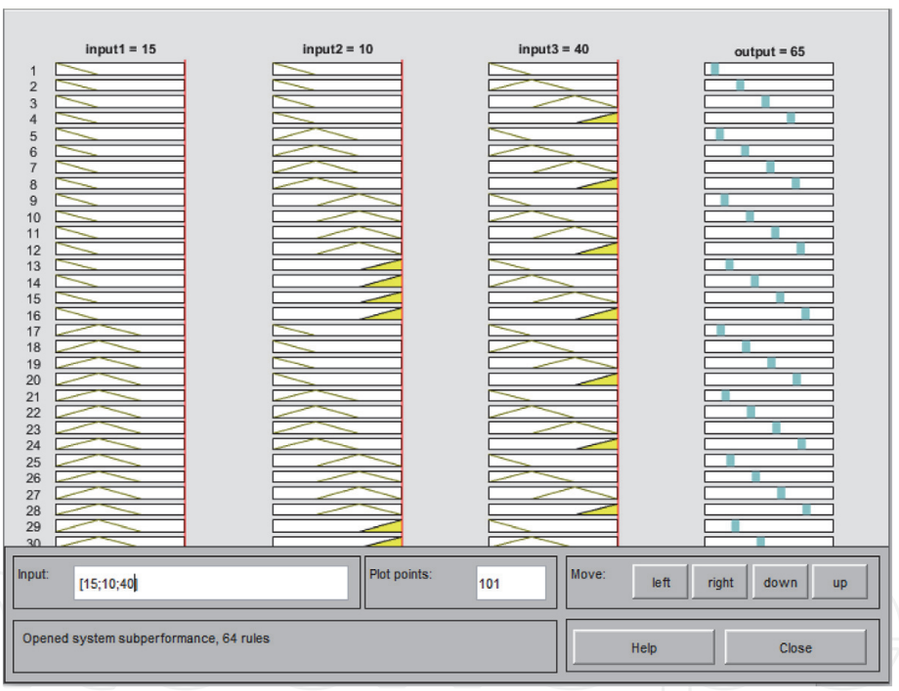

Figure 21.
The rule viewer for the performance evaluation model.

It measures as ppm (part per million). The rank score is A, B, C, D. A is given by the ppm more than 90%. B is more than 80%. C is more than 70% and D is less than 70%. In addition, the quality is measured by defects, NCR (non-conformance record), back order clearance, communication, and claim from customer.

Table 3 shows validation of the ANFIS comparison with actual performance calculation. They are 13 subcontractors are studied (A-K). The column #2 is given marks that calculated by manual. The column #3 and column #4 are also the given marks are calculated by manual. The column #5 and column #6 are determined by the fuzzy inference method. The column #7 and column 8 show the comparison between the actual performance and the neuro fuzzy subcontractor performance. It is found that the neural fuzzy system performs effectively with error 0%.

Subcontractors	Delivery	Back order	Quality	Fuzzy logic delivery	Fuzzy logic back order	Actual performance	Neuro fuzzy subcontractor performance	Error%
A	12	7.5	40	11.7	7.3	59	59.00	0
B	15	10	40	14.9	9.84	64.74	64.74	0
C	15	10	20	14.9	9.84	44.74	44.74	0
D	12	10	40	11.7	9.84	61.54	61.54	0
E	15	10	40	14.9	9.84	64.74	64.74	0
F	15	10	20	14.9	9.84	44.74	44.74	0
G	15	10	35	14.9	9.84	59.74	59.74	0
H	15	10	30	14.9	9.84	54.74	54.74	0
I	15	10	20	14.9	9.84	44.74	44.74	0
J	15	10	20	14.9	9.84	44.74	44.74	0
K	15	10	40	14.9	9.84	64.74	64.74	0
L	15	10	35	14.9	9.84	59.74	59.74	0
M	15	7.5	35	14.9	7.3	57.2	57.20	0

Table 3.
The validation of the ANFIS comparison with actual performance.

Quality	Delivery	Back order	Performance	Quality	Delivery	Back order	Performance
1	1	1	1	11.25	6	2.5	19.75
1	1	2	1	11.25	6	5	22.25
1	1	3	1	11.25	6	7.5	24.75
1	1	4	1	11.25	6	10	27.25
1	2	1	1	11.25	9	2.5	22.75
1	2	2	1	11.25	9	5	25.25
1	2	3	1	11.25	9	7.5	27.75
1	2	4	1	11.25	9	10	30.25
1	3	1	1	11.25	12	2.5	25.75
1	3	2	1	11.25	12	5	28.25
1	3	3	1	11.25	12	7.5	30.75
1	3	4	1	11.25	12	10	33.25
1	4	1	1	11.25	15	2.5	28.75
1	4	2	1	11.25	15	5	31.25
1	4	3	1	11.25	15	7.5	33.75
1	4	4	1	11.25	15	10	36.25
2	1	1	1	22.5	6	2.5	31
2	1	2	1	22.5	6	5	33.5
2	1	3	1	22.5	6	7.5	36
2	1	4	1	22.5	6	10	38.5
2	2	1	1	22.5	9	2.5	34
2	2	2	1	22.5	9	5	36.5
2	2	3	1	22.5	9	7.5	39
2	2	4	2	22.5	9	10	41.5
2	3	1	1	22.5	12	2.5	37
2	3	2	1	22.5	12	5	39.5
2	3	3	2	22.5	12	7.5	42
2	3	4	2	22.5	12	10	44.5
2	4	1	2	22.5	15	2.5	40
2	4	2	2	22.5	15	5	42.5
2	4	3	2	22.5	15	7.5	45
2	4	4	2	22.5	15	10	47.5
3	1	1	2	33.75	6	2.5	42.25
3	1	2	2	33.75	6	5	44.75
3	1	3	2	33.75	6	7.5	47.25
3	1	4	2	33.75	6	10	49.75
3	2	1	2	33.75	9	2.5	45.25
3	2	2	2	33.75	9	5	47.75
3	2	3	2	33.75	9	7.5	50.25
3	2	4	2	33.75	9	10	52.75

Quality	Delivery	Back order	Performance	Quality	Delivery	Back order	Performance
3	3	1	2	33.75	12	2.5	48.25
3	3	2	2	33.75	12	5	50.75
3	3	3	2	33.75	12	7.5	53.25
3	3	4	3	33.75	12	10	55.75
3	4	1	2	33.75	15	2.5	51.25
3	4	2	2	33.75	15	5	53.75
3	4	3	3	33.75	15	7.5	56.25
3	4	4	3	33.75	15	10	58.75
4	1	1	2	45	6	2.5	53.5
4	1	2	3	45	6	5	56
4	1	3	3	45	6	7.5	58.5
4	1	4	2	45	6	10	61
4	2	1	3	45	9	2.5	56.5
4	2	2	3	45	9	5	59
4	2	3	3	45	9	7.5	61.5
4	2	4	3	45	9	10	64
4	3	1	3	45	12	2.5	59.5
4	3	2	3	45	12	5	62
4	3	3	3	45	12	7.5	64.5
4	3	4	3	45	12	10	67
4	4	1	3	45	15	2.5	62.5
4	4	2	3	45	15	5	65
4	4	3	3	45	15	7.5	67.5
4	4	4	4	45	15	10	70

Table 4.
The fuzzy rules of the ANFIS performance prediction.

Table 4 shows the fuzzy rules of the ANFIS performance prediction. The 3 first columns are input and 4th column is output. The column 5–7 are generated by the ANFIS. The last column is the performance prediction. There are 64 cases or rules. If a rule is changed meaning that the performance will be changed. So that, the performance can be predicted.

4.3 Cloud production online monitoring (CPOM) system

This section explains the cloud computing online monitoring system as shown in the **Figure 22**. The CPOM system links the production process and monitor, and evaluation. The production monitoring and control starts at the P&D orders which are received from the 1st tier company every 15 days. It is sometimes that the uncertain orders are given to the subcontractors to increased or decreased quantity of the parts. The production plan is assigned based on the availability of the factory. Capacity is presently checked as well as inventory, back order quantity, and raw material stock on hand. CIM system calculates the availability and actual capacity

for creating aggregate planning, master production scheduling, and job release planning. The plans are delivered to shop floor supervisors including daily production plan, machine used plan, and due date delivery plan. Then, production is operated by serial processes. The compression mold or injection mold is the first operation. The 2rd station is de-flashing and finishing the parts. The last station is quality inspection, counting, recording and packing. Instead of doing so by manual, the research paper presents the novel method which employs the CPOM system to increase productivity of both machines and operators as well as the competitiveness. The system is divided into two main parts; the 1st CPOM system and sub CPOM system which is designed as the private cloud under the company security policy. The 1st CPOM is able to monitor and tracking the production process for supporting rapid decision making of the SCM management team. Besides, the critical control of the 1st tier is the raw material mixing company and mold design company which are supporting resource companies and sharing costs as well as quality standard control under specific customer requirement.

4.3.1 Sensor design and QR code reader

Sensor is a heart of the CPOM system. It works as the interface signal processing from objects to the system input. There are many types of the sensors; fiber optic sensor, photo electric sensor, proximity sensor, area sensor, pressure sensor, multifunctional sensor. Such sensors can be used together with precision measurement, PLC, vision system, laser marker, barcode reader, digital microscope and so on. The CPOM system selects fiber optic amplifier. It can easily set light using automatic mode. It is amplified the light around 250 times. The respond speed is 50 μs. The monitor output can be LED or graph. The output can be single, double or analog

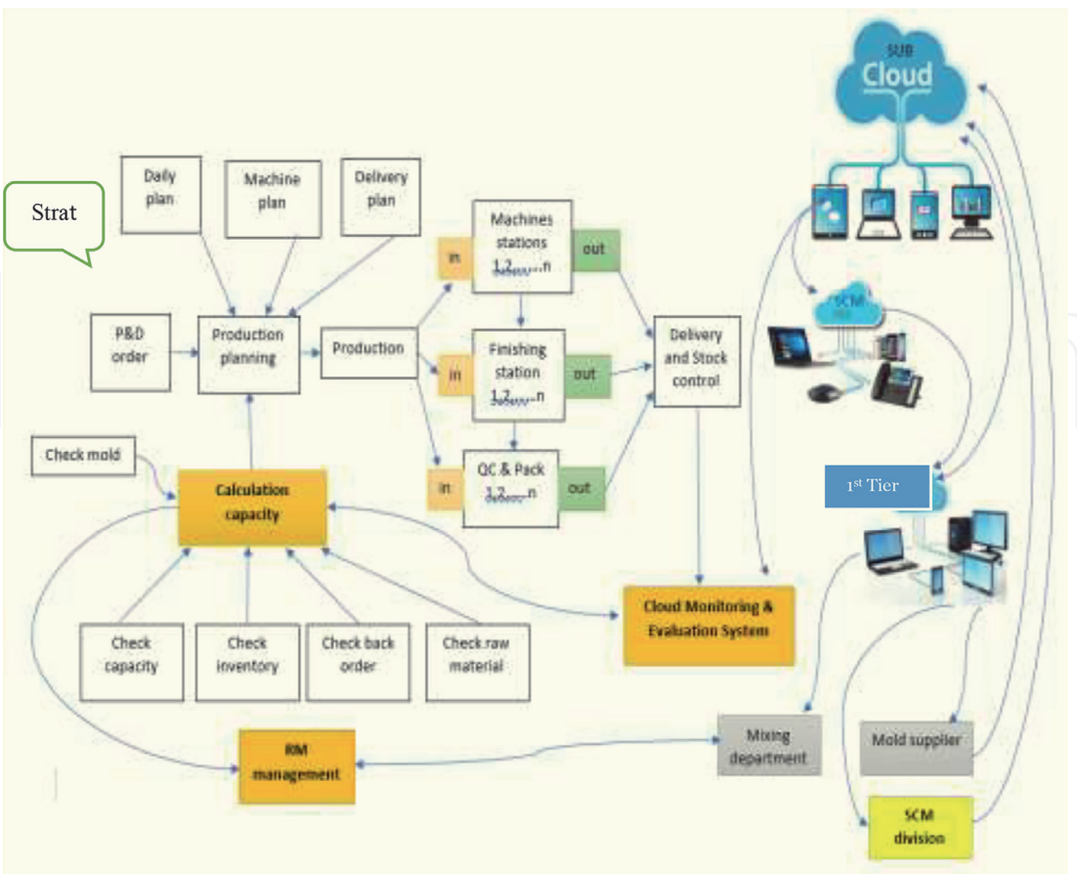

Figure 22.
The CPOM system development.

output. The right **Figure 23** shows the relation of light intensity and displacement. There are different ranges but the effective performance is set on the certain displacement.

QR recorder is used to track a symbolic information of the production process. The QR code generator can be simply done by software and can link to the QR code reader. **Figure 24** shows the QR code reader using a mobile phone.

4.3.2 Conveyor design

The conveyor is designed for delivering the part in the final operation. The conveyor includes sensors, QR code reader, and cloud interface using ESP32. Motor drive is designed for adjustable speed. The displacement between sensor and parts must be effective and eliminate any error.

Figure 25 shows the types of the conveyor system which are used in the factory linked to the cloud management system. They are covered the whole features of the part constraints.

Figure 26 shows the types of the sensor used in the factory. The first sensor type is tracked in the horizontal position while the parts are moved by the conveyor. The second type of the sensor is tracked on the vertical while the parts are delivered through the silo. This is designed and developed for the flat part shape. The third type of the sensor is portable movement which is fit with the large size of the parts. The fourth sensor is called axillary types which is designed to combined with the push button switch and light linked the cloud management system. This type is suitable for the ununiform shape of the parts.

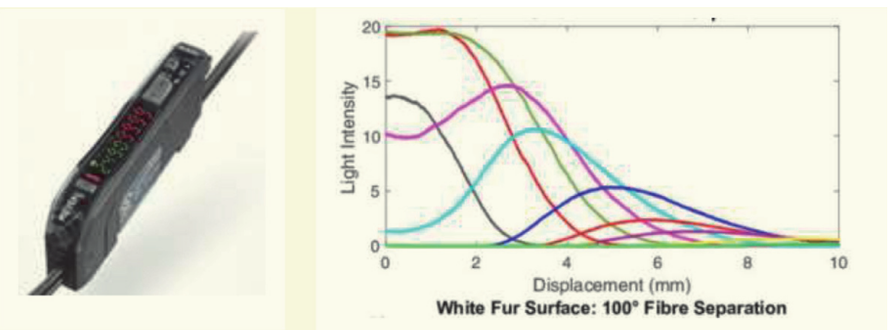

Figure 23.
Fiber optic sensor and characteristic.

Figure 24.
QR code generator and reader.

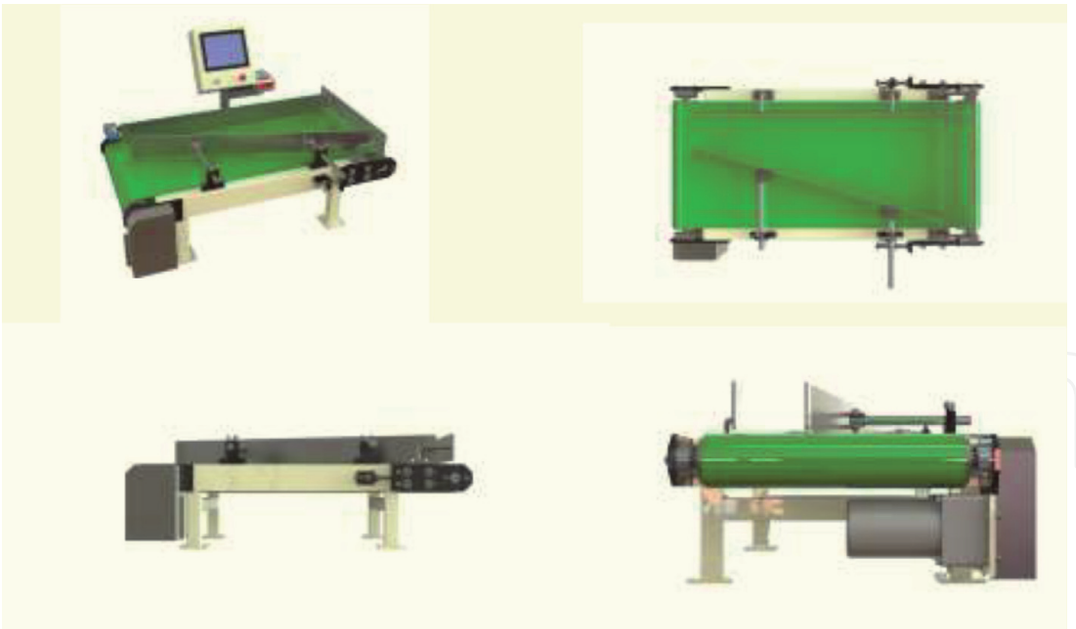

Figure 25.
The conveyor system for delivery finished good.

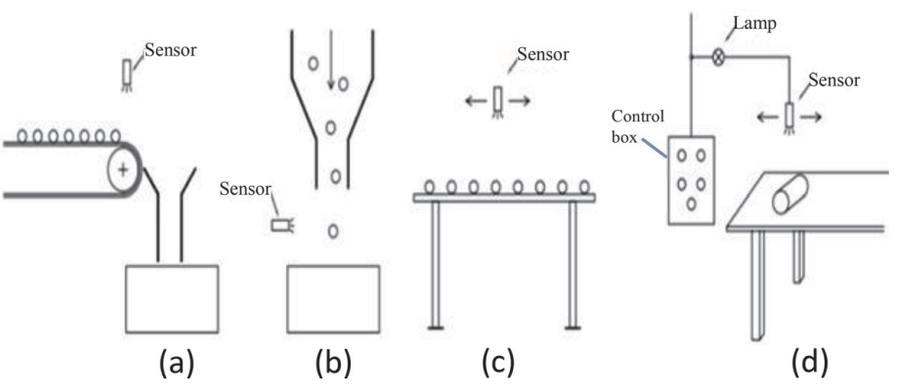

Figure 26.
The types of the sensor used in the factory.

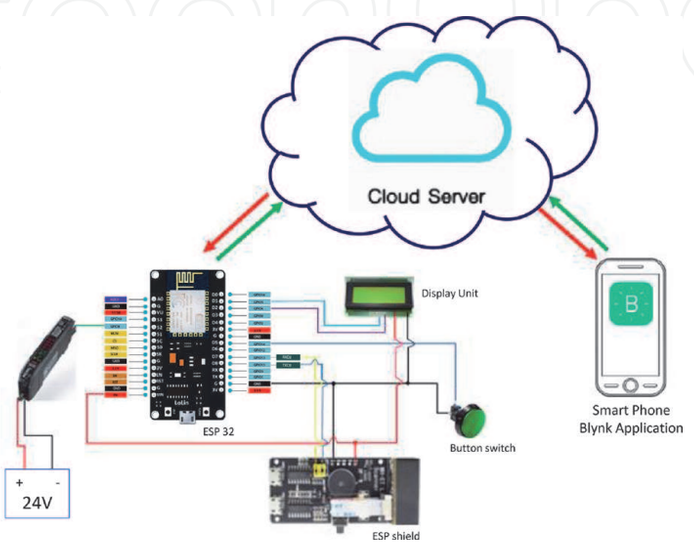

Figure 27.
Cloud interface using ESP32 WiFi.

4.3.3 Cloud interface design

Cloud interface design is used for data tracking and CPOM communication by real-time via WiFi and Bluetooth. It has 18 channels, 3 SPI interface, 3 UART interfaces, 2 12C interfaces, 16 PWM output channels, 2 digitals to analog converter (DAC), 2 12S interfaces, and 10 capacitive sensing GPIOs. **Figure 27** shows the cloud interface using ESP 32 Wifi, Node-Red and blynk application which is linked to a smart phone.

5. Implementation, results and discussion

The section explains the implementation of the CPOM system and shows the result of usages. The example of the P&D order is shown in the **Figure 28** for a month. The delivery date is on the 8, 10,11, 23, 26, and 28. The order # 3 is due on the 8 and parts are completely finished on the 7. It is shown by the green color.

This section explains only one point of the tracking production process system on cloud via WiFi ESP32 micro controller. All production information is tracked and delivered by QR code. The most benefits are to apply the system to the whole supply chain and discuss uncertain situation and collaborative solving problems. This section does not show other dash board for tracking and reporting production progress in every work stations. It is possible to do so via the same CPOM platform with extend the data.

No.	Job No.	Part No.	1	2	3	4	5	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	PlanQty	ActualQty	BadOrder
1	PC6306-0001	17505-20V1-81-25										100																						100		
1	PC6306-0001	17505-20V1-81-25																																		100
2	PC6306-0002	17505-20V1-81-25											250																					250		
2	PC6306-0002	17505-20V1-81-25																																		250
3	PC6306-0003	4W4-Q9259								500																								500		
3	PC6306-0003	4W4-Q9259							500																										500	
4	PC6306-0004	6III3-9L00																										450						450		
4	PC6306-0004	6III3-9L00							100																										100	350
5	PC6306-0005	9D54-YH4-6I00																												222				222		
5	PC6306-0005	9D54-YH4-6I00																																		222
6	PC6306-0006	SR-5051																							120									120		
6	PC6306-0006	SR-5051							100																										120	

Figure 28.
The report delivery monitoring on cloud management system.

6. Conclusion

The paper presented automotive industrial supply chain performance evaluation under uncertain constraints on cloud computing system. The supply chain in rubber part industry is explained in details. The new concept of the CPOM system is developed and tested in the factory. It can enhance efficiency of production control and monitoring as well as decision making under the uncertain circumstance. The CPOM is explained from the design to implementation and the results of application.

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