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SYSTEM DYNAMICS AS A DECISION SUPPORT SYSTEM FOR MACHINE TOOL SELECTION

The worldwide competitive economy, the increase in sustainable issue and investment of new production line is demanding companies to choose the right machine from the available ones. An improper selection can negatively affect the overall performance of the manufacturing system like productivity, quality, cost and company's responsive manufacturing capabilities. Thus, selecting the right machine is desirable and substantial for the company to sustain competitive in the market. The ultimate objective of this paper is to formulate a framework for machining strategy and also provide methodology for selecting machine tool from two special purpose machine tools in consideration of interaction of attributes. A decision support system for the selection of machine tool is developed. It evaluates the performance of the machining process and enhances the manufacturer (decision maker) to select the machine with respect to the performance and the pre-chosen criteria. Case study was conducted in a manufacturing company. A system dynamics modelling and simulation techniques is demonstrated towards efficient selection of machine tool that satisfy the future requirement of engine-block production.

Nomenclature

AHP—*Analytical hierarchal process*
ANP—*Analytical numerical process*
CLD—*Causal loop diagram*
CNC—*Computerized Numerical Control*
COPRAS-G— *Complex proportional assessment of alternatives with grey relations*
FMS—*Flexible manufacturing system*
MADM—*Multi attribute decision making*
MC—*Machining center*
MCWA—*Multi-criteria weighted-average method*
MS—*Machining Center*
PROMETHEE—*Preference ranking organization method for enrichment evaluation*
SD—*System dynamics*
SPM—*Special purpose machine*
SWARA—*Step-wise weight assessment ratio analysis*
TOPSIS—*Technique for Order Preference by Similarity to the Ideal Solution*

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1. INTRODUCTION AND RELATED WORK

In response to new investment and to provide optimal performance, there is a need for reconfigurable production system with a view of introducing defined strategy. However one of the major challenges is how to select the alternative machines that are consistent with manufacturing requirement. Machine tools are one of the most important parts of manufacturing process that could aid companies to achieve the desired part production. Selection of appropriate machine type is highly significant for the quality of the part, the productivity, the efficiency and the cost.

Selecting machine tool type that is suitable for certain part production from among available alternatives is a difficult decision making process for many manufacturers. Improperly selected machine can negatively affect the overall performance of the manufacturing system, such example as the productivity, cost, quality, etc. Furthermore it may cause several problems for the engineer, manger, on the part produced and on the manufacturer. However, selecting or identifying the potential machine that is appropriate to produce the desired part is time consuming, costs much and difficult process requiring advanced knowledge and experience.

There are many different types of machine tool used in industry for the production of specific part. According to specific functional criteria, an appropriate machine tool structure design needs to be found and selected. However there is a lack of consistent methodology deployed for the decision maker for selecting the appropriate machine tool to satisfy the future requirement. Hence, selecting the most suitable machine with respect to the given performance criteria is highly needed.

In the competitive world of manufacturing, when there is demand fluctuation from customers, there is a great deal of pressure on manufacturer to develop strategy to control their production. Companies are experiencing problems to cope up the variation/challenges occurred in the production line and the instability of parameters. A well-defined strategy for their production system is the best solution to handle the situation.

Moreover, in order to make sound decision and to optimize the system parameters, it is necessary to identify and understand the interrelation between the factors characterizing the nature of the machining process. The optimality should be selected with respect to the performance criteria and the current machining strategy adopted in the process. System dynamics (SD) is suitable for this kind of modeling. This paper introduces the system dynamics approach to model and simulate the complex nature of the dynamic interaction between factors characterizing machining processes. On account of SD is suitable for industrial modeling and policy making issue. It has been used to help engineers to formulate (develop) strategy and improve the existing strategy by implementing new policy. The main scope is to oversee the possibility of understanding the machining process and optimizing the process parameters within the manufacturing process by simulating the machining process of each selected machine in the operation of certain part features. The adopted methodology is demonstrated through case study.

Researchers have used different approaches to select the most appropriate alternative machine. The selection problem has been studied mostly for specific type of environment such as flexible manufacturing system and flexible machine tool. It is known that the machining performance relates to the dynamic properties of the whole system of the tool, spindle, and other machine tool parts. But some factors like the machining system parameters effect on the machine tool life span were not considered as well. However the selection approach should be applicable to other type of production system, machine tool type and machine tool part. Different researchers have been using different approach for machine selection problem; Table 1 summarized some of the literature done on this aspect.

Thus, this paper proposes a holistic approach for special purpose machine tool (SPM) selection. Such an approach allows the possibility of controlling machining system parameters and will then evaluate the outcome of machining process in terms of the chosen performance criteria. Here, the main objective is to present a methodology for selecting the efficient machine tool among two SPM for a given product as well as taking into accounts both machine tool characteristics and machining system parameters.

Overall, the ultimate objective is to formulate (develop) a framework for machining strategy and also provide a decision support system for the selection and that help optimize the production system.

Table 1. State of the art on machine tool selection techniques

Authors /Source	Techniques/Tool	Aspect considered/Findings /output
Tabucanon *et al*. (1994) [19]	AHP	Decision support system for the multi criteria machine selection problem for FMS
Lin and Yang (1994) [14]	AHP	-Model was developed to select machine that is appropriate for machining a certain part -Evaluate type of machine that is most appropriate for machining a certain type of part
Atmani and Lashkari (1988) [3]	AHP	-Model is developed for machine selection from fixed number of available machine and operation allocation -FMS
Gerrard (1988) [10]	Step-by-step methodology	A step-by-step approach for selection and introduction of new machine tool is proposed
Wang *et al*. (2000) [22]	Fuzzy multi-attribute decision making model	Decision making for selection of FMS
Goh *et al.* (1995) [11]	revised weight sum method	A decision model for robot selection
Rai et.al (2002) [16]	Fuzzy goal programing concept to model	Problem of machine tool selection and operation allocation considering the objective criteria like minimizing the cost of machining operation, material handling and its set up. The capacity of machine tool and tool life were also included in the model.
Cagdac Arslan et.al (2004) [8]	MCWA	-Select the best machine from possible alternative evaluated with respect to several criteria MS; -Job shop – cylindrical milling as an example /demonstration
Cimren et.al. (2006) [9]	AHP	Decision for selection of machine tool from several alternatives that considers qualitative decision criteria and cost analysis
Ayag (2007) [4]	Hybrid approach—AHP with simulation	Select the best machine among a set of possible alternatives in the market that would meet the needs and expectations of manufacturing companies—then used unit cost investment ratio to determine the best machine
Tsai et al. (2010) [21]	MCDM	Selection of CNC machine considering different selection criteria

Taha and Rostam (2012) [20]	MATLAB based fuzzy AHP and PROMETHEE	To select the best CNC turning center for a FMS
Ayag and Ozdemir (2012) [5]	Used MCDM methods, the modified TOPSIS and the ANP	Present a performance analysis on machine tool selection problems considering some of the factors and the criteria associated with
Ic *et al.* (2012) [13]	A fuzzy MCDM model using the AHP	Evaluating the alternatives machines with some criteria along with other economic and commercial factors
Hasan Aghdaie *et al.* (2013) [12]	Integrated approach—SWARA & COPRAS-G	Eight criteria were considered for evaluation process to assess and choose the best machine for the manufacturing company
Nguyen *et al.* (2014) [15]	Hybrid approach of fuzzy ANP and COPRAS-G with consideration of the interactions of the attributes	Effective decision for evaluating the suitable machine tool to implement the manufacturing system

2. SYSTEM DYNAMICS METHODOLOGY

SD is a powerful methodology and computer simulation modelling technique for framing, understanding, and discussing complex issues and problems. It was first introduced by Jay W. Forrester of Massachusetts Institute of Technology Sloan School of Management to frame, understand and discuss problems in the industrial process domain.

It is a method for studying the world around us. Rather than breaking down the system into sub-system (smaller parts) and investigate them separately, it studies the system as a whole to understand how the parameters interact with each other as a part of a system. In addition, it analyse the possible interaction between subsystem to understand the system big picture [6], [7]. In the analytical method there is no means to capture interdependency [23], it is the nature of system dynamics to capture the interdependencies between all subsystems that made up the whole. The structure of the system determines its behaviour through time. A SD model is useful in illustrating how the real system behaves and to check what will happen if some parameter in the model is changed over a period of time [2].

System dynamics are among a range of techniques for strategy and analytic development for major organization or companies to solve their most important strategy challenges. SD modelling can be helpful for strategy implementation in regards to both strategy refinement and transfer of insight and understanding underlying the process. On account of SD is suitable for industrial modelling and policy making issue and has been used to help engineers to formulate (develop) strategy.

In complex systems like manufacturing, objects often create feedback loops, where a change in one variable affects other variables dynamically, which feedbacks to the original object, and so on. The interplays among objects determine the different states the system can assume in the course of time, which is known as the dynamic behaviour of the system. The dynamic complexity of the system arises not from the amount of the system's component, but from the combination of interactions among system elements over time [6], [7] See an example in Fig. 1, how the dynamic complexity results. An increase in production rate increases the inventory and if inventory increases, then shipment rate also increases. In other case, an increase in shipment rate lowers the amount in the inventory, hence results in higher production rate. That is a change on one factor affect others and feedback each other, it shows how a dynamic complexity observed in the system. This is caused due to system's internal feedback mechanism which can be either negative (also called balancing loop) (B) or positive (also called as reinforcing) (R) loop. The decision making process in this case is significantly influenced by the nature of the mentioned feedback system.

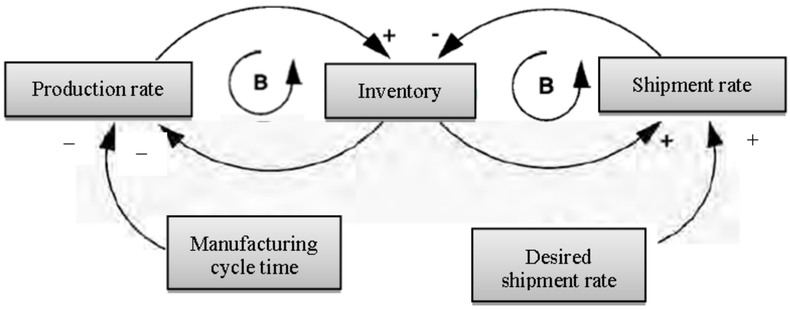

Fig. 1. Example of a causal loop diagram for inventory management [17]

The causal loop diagram (CLD) shown in Fig. 1 is a mental model which captures relationships between parameters (events) and how information from an event is feed back into the system to alter the causes that created the event. Considering the interaction and feedback among different parameters of the model elements, the CLD is mathematically expressed which is then converted to computer simulation for further analysis. The building blocks of SD in the computer simulation models are represented with four elements, following Table 2 are the available building blocks with their definition [1]. It presented in a stock and flow diagram—general structure [1] and as an example the CLD of the inventory management shown in Fig. 1 is also formulated into stock and flow diagram as illustrated in Fig. 2.

Table 2. The building blocks of SD and its definition

Building block	Definition of the term
Stock	Something that accumulates
Flow	Activity that changes magnitude of stock by adding to it (inflow) or subtracting from it (outflow)
Convertor	Stores equation or constant; does not accumulate
Connector	Transmit inputs and information

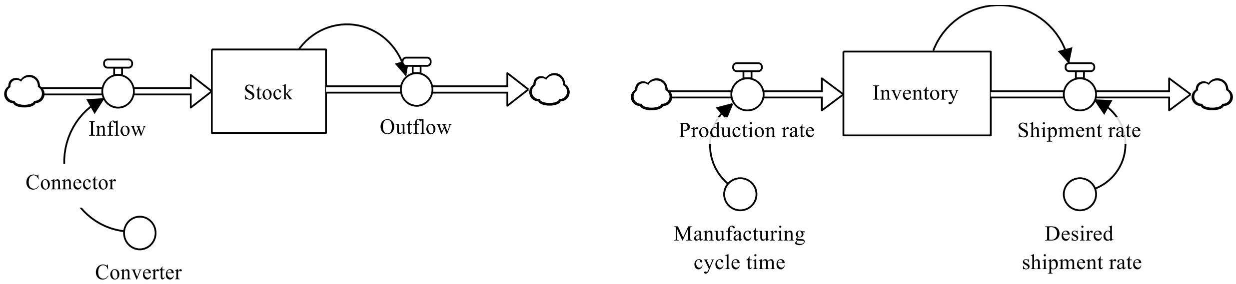

Fig. 2. Stock and flow diagram: (Left) general structure, (Right) Example of Inventory management of manufacturing process

2.1. SD MODELLING APPROACH

Modelling process approach following to building SD model is described as in Fig. 3. The readers are encouraged to go through the book of Business dynamics by Sterman (2000) for detail explanation about the steps for system dynamics modelling approach [17].

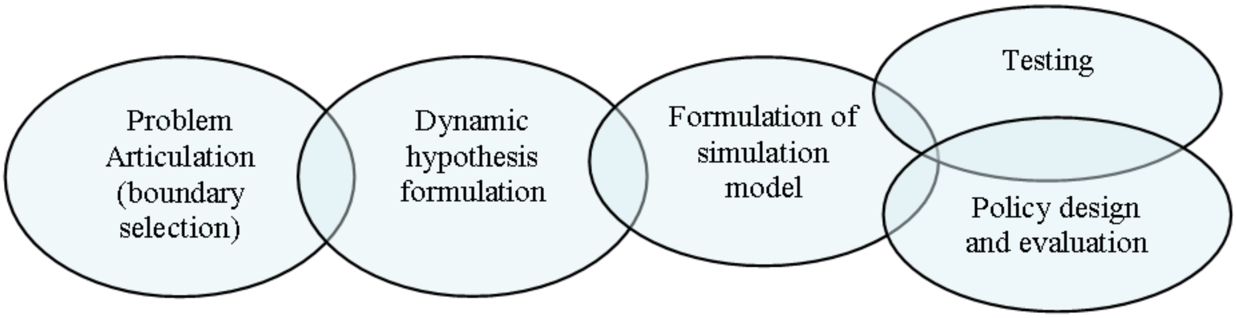

Fig. 3. Modelling process approach to building SD model of the given process

3. EXAMINATION OF THE PRODUCTION PROCESS- CASE STUDY

The proposed methodology for decision making of a machine tool selection was conducted in a real case study of a truck engine-block machining line at a major automotive original equipment manufacturer company. The company manufactures different variant of engine-block. The variant object considered in this paper is grey-cast iron, six-cylinder hole, which manufactures in two autonomous manufacturing line — transfer line (also known as continuous line) and flexible manufacturing system line (also called flexible line). The overview of the configuration of the machining process flow of an ‘’engine-block’’ is shown in Fig. 4.

Based on the current available machining line that is described in Fig. 4 the company would like to invest a new line. To invest a new line that would have a better performance and that could attain the future requirements of an engine-block production, there is demanding to determine/know, which of the existing production line is suitable to choose or any other innovative (proposal) reconfiguration — line evaluation. However there is no defined methodology available to determine the line that is best suit to the manufacturer and that satisfy the future requirement of engine-block production. For line analysis, selecting of suitable machine is one of the major factors that should be considered. On the other hand, studying and comparing all of the machine tool in the production line is complex and time consuming process. However the machine tool that manufacture specific part features from each line can be compared and the best machine that satisfies the given requirements will be selected from each production line. Then the reconfiguration of the overall production line will be analysed. However in this paper only the machine tool comparison and selection for a given part feature production will be considered. The overall production line analysis and selection will be the future work.

3.1. DESCRIPTION OF THE PRODUCTION PROCESS LINE—MACHINING OF ENGINE-BLOCK

The machining line is a complex operation with thousands of features. It consists of about 20 different production stages (steps) with different equipment's like metal removal equipment, quality control (inspection and testing), conveyor system, cooling system, material handling (gantry and robot), heat treatment as well as others. The two layouts —transfer line and flexible line— for the production process of the engine-block is illustrated in Fig. 4. Most of the machine in transfer line are special purpose machine while in flexible line are machining centre (except production stage 16 and 18 which are SPM, the rest are CNC machines). In which these steps significantly machine different features of the part. Some of the major operation types include face milling of the lateral side of the engine block, face milling of the rear, front and top side of the engine, boring of cam and crank shaft, boring of cylinder hole, reaming of dowels and transmission hole, etc.

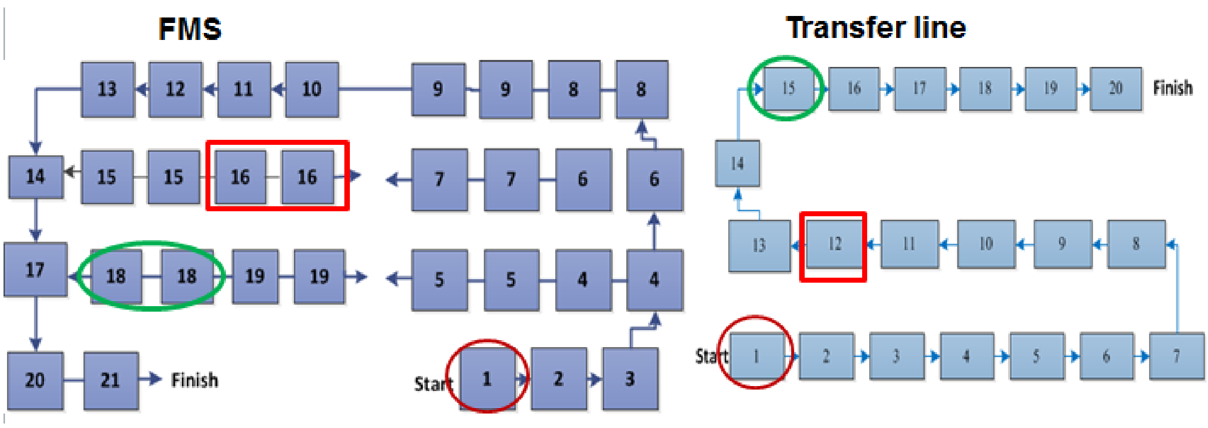

Fig. 4. A schematic illustration of the configuration of machining process: Left- FMS line; Right- transfer line

3.2. IDENTIFYING MOST CRITICAL STEPS—SELECTIONS OF CRITICAL STEPS

The efficiency of the production line is largely drives on the type of machine tool. Although the type of machine tool has a significant effect for the performance of the production line, the manufacturer should choose the best machine that satisfies the needed requirements. In this paper it is unlikely to consider all of the steps in the production line. Considering all processing step is complex, time consuming and infeasible, so selection of critical steps is desirable. Fig. 5 below depicted the steps followed for selecting the parallel critical stations, operations and parameters from both lines. The selection was made with the help of production manager and operators at the respective manufacturing company. The machine tools that produce similar part component and critical for the production process of each line are selected and shown in Table 3 (also highlighted in Fig. 4).

The findings from investigation suggested that the steps mentioned in Table 3 are the prominent critical process in engine-block production. This paper does not consider all of the critical machines (steps) selected on. Instead, the special purpose machine from transfer line—Step12_Old line (SPM1) and the special purpose machine from new line—Step16_New line (SPM2) that has different orientation but machine certain similar part of an engine-block, i.e.—boring of cam-shaft and crank-shaft is considered. The schematic representation (CAD model) of the selected surface for machining is depicted in Fig. 6.

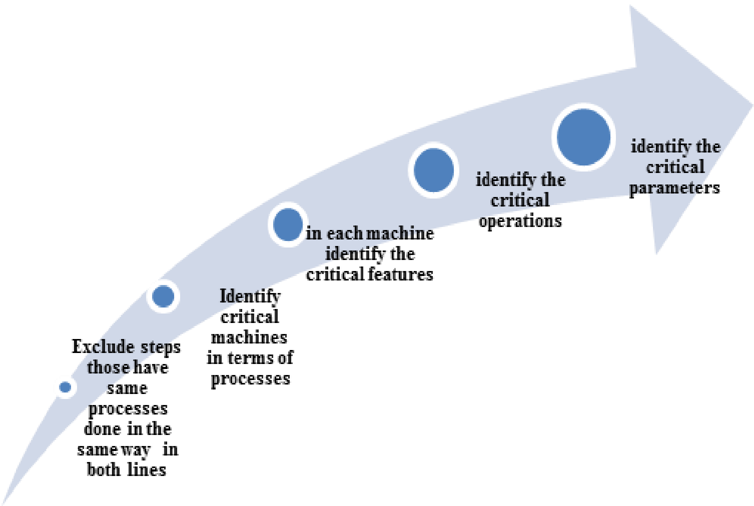

Fig. 5. Methodology for selecting critical operations

Table 3. The critical steps chosen

	Transfer line (old line)	Flexible manufacturing system (new line)	Operations
Critical operations with its corresponding steps	Step1(SPM)	Step 1(MC)	Face milling of the longer side of the engine-block
	Step12(SPM)	Step16(SPM)	Boring of cam & crank shaft, reaming of dowels and transmission holes
	Step15(SPM)	Step15(SPM)	Face milling of the top side of the engine and boring of cylinder holes

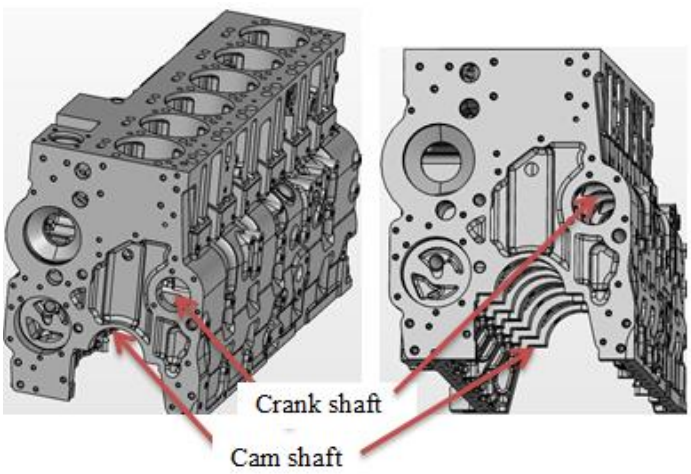

Fig. 6. Cam and crank shaft of an engine block in different views, downloaded from [18]

3.3. MACHINE SPECIFICATION - SPM1 & SPM2

The considered machine tools are different types with distinct arrangement (design and layout) and different capability however they produce the same part. The pre-defined takt time designed to match in the line is X minutes. Hence, to achieve the desired takt time, the cycle time for each steps (machine) should be equal with the takt time or less.

Step12_SPM1: It has two separate stations—roughing and finishing operation— each station has a cycle time of approximately X min, that is, it would meet the pre-designed takt time when producing the specific part.

Step16_SPM2: It has three stations that work independently however they are controlled by the same hydraulic system. The first station is a roughing operation that has a cycle time of X min. and the cycle time for finishing operation is 2X min, hence to produce within the required takt time, there are two parallel stations for finishing operations—the second and the third station.

3.4. DECISION CRITERIA/ PERFORMANCE CRITERIA

Productivity, cost and quality are the most prominent performance criteria considered and they are also the factors where the decision maker used as decision making criteria for machine tool selection problem. However other criteria like foundation depth and width (machine dimension), flexibility, maintenance & service, reliability, safety & environment are assumed the same for both machine types. The criteria chosen and the main machining system parameters (sub-criteria) considered in this paper are shown Fig. 7.

Productivity

Productivity is one of the most important performance criteria dealt for the performance evaluation of machine tool selection. The specific factors incorporated to determine productivity are depending on a number of machine properties such example as, machining time, spindle speed, feed rate, production rate, tool change time, load and unload time, set-up time, pre-maintenance time, time for failures, etc. Such machining time is one of the most crucial factors. Both this factor and other factors interacting with it should be optimized.

Cost

The cost for the operation is modelled as the sum of different cost components that related with machining process. The cost per part is the main factor considered. Components of total cost per part are, principally:

- *maintenance cost per part*— depends on time spent for preventive maintenance, corrective maintenance and scheduled overhaul for the components,
- *capital cost per part* — depends on the machine tool type deployed— in this case SPM1 or SPM2,
- *tool cost per part* —depends on the tool life and therefore on cutting process parameters,
- *spare part cost per part* —this cost occurs when the machine tool components are replaced,

- *overtime cost per part* —depends on the total production time and occurs when operators work overtime,
- *real estate cost* —depends on the factory adaption cost and the floor area used by the specific machine.

Quality

The quality aspect is a fundamental requirement and performance indicator for the manufacturing of the component. In this paper, the machining system capability is to be considered as a constraint and not as a parameter to be monitored, i.e. the parameters are varied (optimized) within the design specification limit. Therefore the parameters related with and their values should be kept with in the design specification limit.

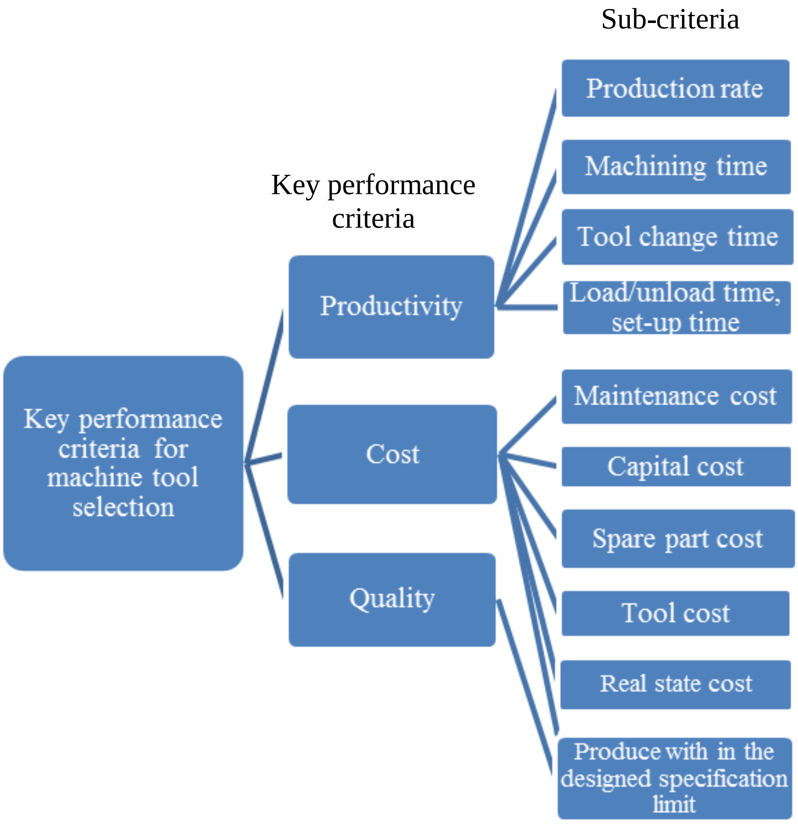

Fig. 7. Performance criteria and the main parameters considered

3.5. PROPOSED MODEL FOR THE CRITICAL MACHINE TOOL /FOR THE MACHINE TOOL SELECTION

SD simulation and modelling techniques is applied as an efficient methodology to model the framework for machine tool selection with explicit consideration of the interaction of machining system parameters and the pre-selected performance criteria. SD accommodates the interaction between parameters and the feedback of the system parameter effect. It has been developed for the purpose of assessing the existing strategy and developing or improving new strategy through comprehensive and effective policy design.

To understand the intricate interaction between the main machining system parameters and performance criteria and to understanding the influence of the effect of the variation of these parameters on the system structure, in general to analyse the machining process, models for existing production system are developed. Model for new policy to improve the existing machining strategy has also proposed. The performance analysis of SPM1 and SPM2 is demonstrated and that could be used for a decision support system for the selection of the best machine tool that satisfies the pre-selected performance criteria. The decision criteria are evaluated as a function of the machining properties of boring operation in engine-block production line.

1. *Model for comparison* - select the type of machine tool that satisfies the future requirement of engine- block production. Model for each SPM tool is developed. A methodology that could be used for comparison and selection of the machine tool type and that could also be used as a decision support system for evaluating and selecting.
2. *Policy design*

For the model develop, a possible new policy (strategy) is proposed. In SD, policy design answers the following questions: "What new decision rules, strategies might be tried in the real world? How can be represented in the model?" Of course, these policies will be aimed at improving the system behaviour: as a consequence, it is worth to first point out the main criticalities and points in which the system should improve. Here is the description of the steps to deploy a policy analysis, shown in Fig. 8.

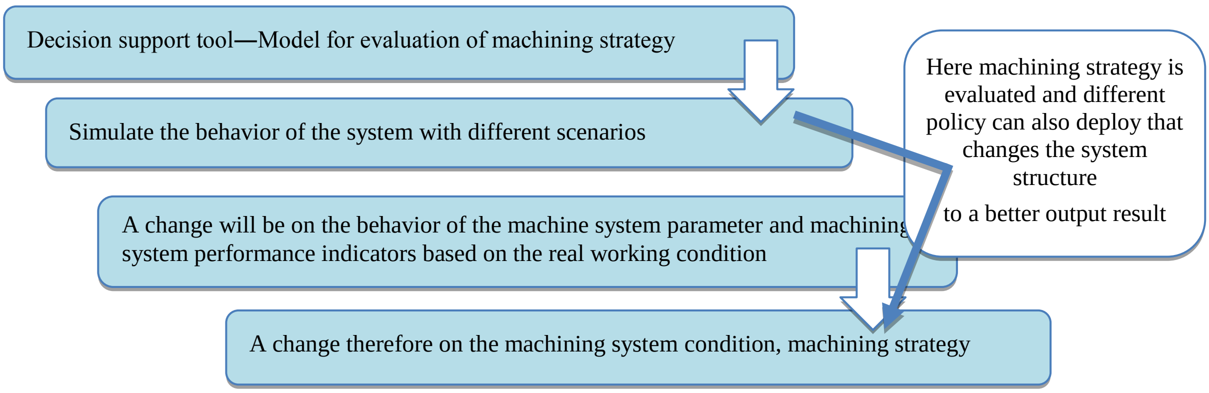

Fig. 8. Steps follow for policy analysis (new strategy)

3.6. CLD—INTERACTION BETWEEN MACHINING SYSTEM PARAMETERS AND KEY PERFORMANCE CRITERIA

The interaction between machining system parameters and key performance criteria in an aggregate level is illustrated in Fig. 9. The machining system parameters are configured to produce the given specific parts considering the productivity, cost and quality. The performance factor – productivity, cost and quality in turn is influenced by the cutting conditions, cutting tool, machine tool and the workpiece and the cutting tool material. The interrelationship for the parameters identified in the case study is described in detail Fig. 10.

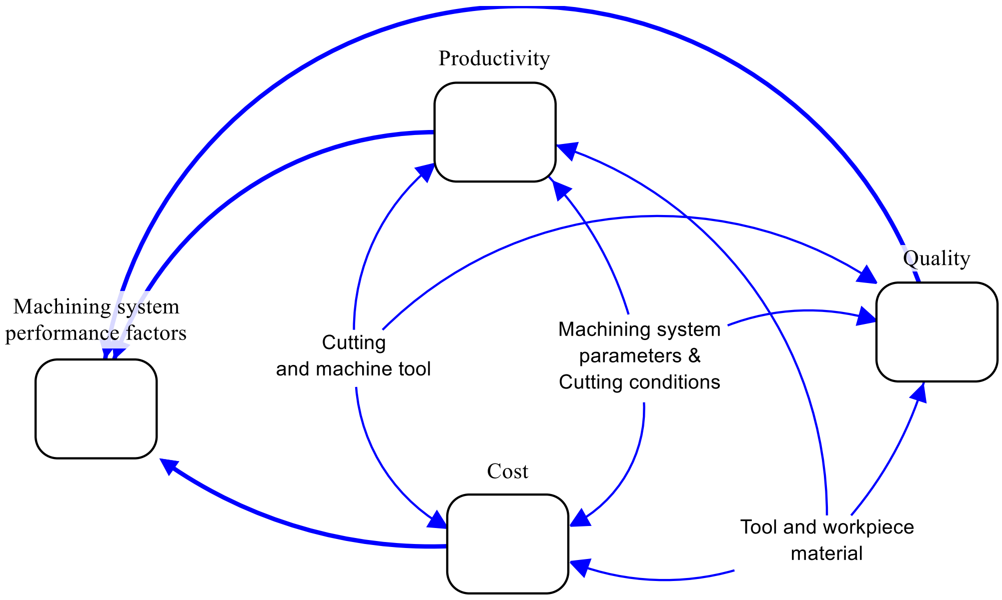

Fig. 9. Interaction between machining system parameters and key performance criteria –aggregate level

The causal loop diagram captures the structure of system main parameters relationship, their interaction, influences and feedback of system. Parameters are related by causal links, shown by arrows, described in Fig. 10.

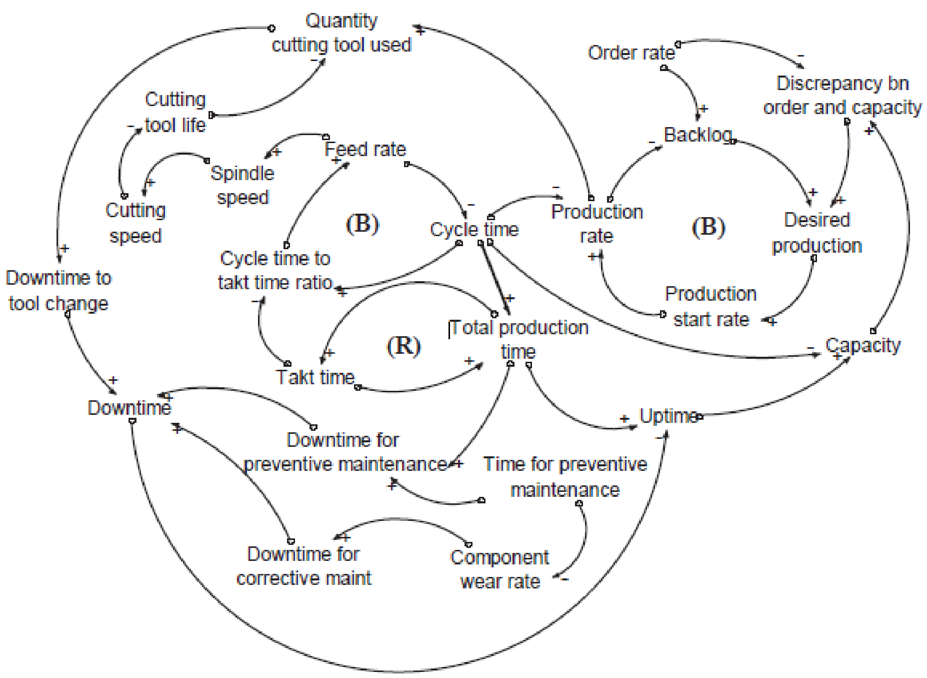

Fig. 10. General causal loop diagram for the main machining system parameter

Each causal link is assigned a polarity, either positive (+) or negative (-). The + and - signs represent the relationships between respective connected parameters either they are in direct or inverse proportionality, respectively. They indicate also how the dependent parameter changes when the independent parameter changes. The two types of feedback loop – negative or balancing loop (B) and positive or reinforcing (R) loop are indicated in the diagram.

3.7. STEPS FOR MODELLING PROCESS

To build an SD model and analyses of the machining process of an engine-block the approach and steps illustrated in Fig. 11 is followed.

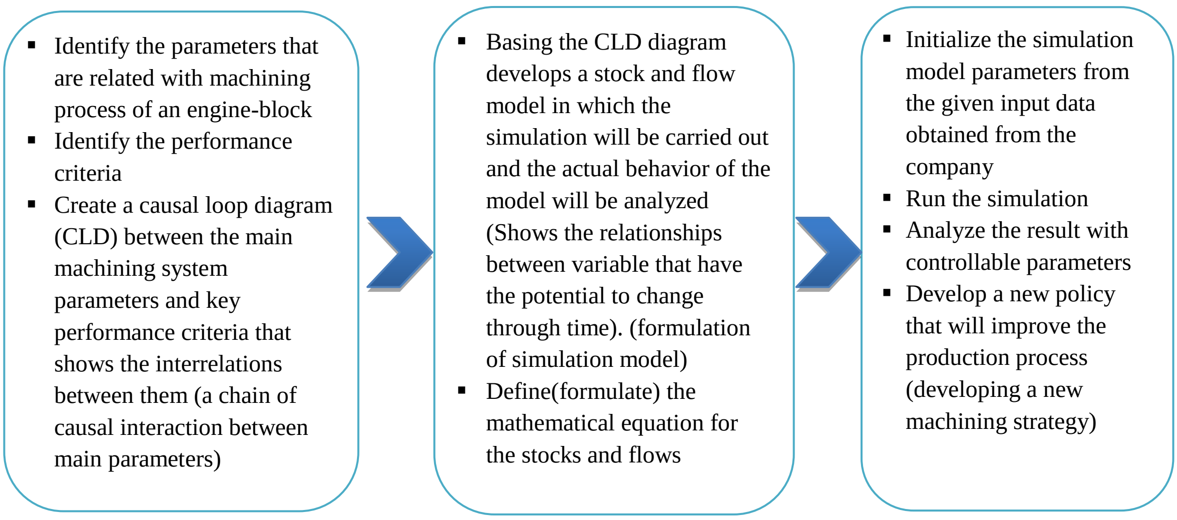

Fig. 11. Steps for system dynamics modelling approach

Basing on the causal and effect relationships loop diagram shown in Fig. 10 the stock and flow model is developed. Some commercial software program are available that were designed to facilitate the building and use of SD models. The most widely used are Stella/iThink, Vensim, Powersim and AnyLogic. Stella/iThink has been used to build the model for this paper [2].The author is obliged to provide detail information about the model if a request from any interested individual reader. The mathematical relationships between stock and flow and the benefits of system dynamics modelling is explicitly described by Adane, T.F. and Nicolescu M., 2014 [2].

4. DISCUSSION

Models are developed using system dynamics simulation and modelling environment. The structure of the model comprehensively subsumes the production process for boring of cam and crankshaft and reaming of dowels and transmission holes of an engine-block that produce a part at every pre-set takt time. The part chosen in this paper has around twenty features that use many different cutting tools as shown in Table 4.

Table 4. The features and cutting tool for SPM1 and SPM2

Machine tool type	Feature	Number/type of cutting tool
SPM1 & SPM2	T801-T807	7 (for each roughing passes)
	T901-T907	7 (for each roughing passes)
	T708 & T709	2 (for finishing process)
	T308 & T309	2 (for finishing process)
	T306 & T307	2 (for finishing process)

Model for SPM1& SPM2- Comparison

To machine of camshaft bore, crankshaft bore, dowels and transmission holes, which of the two SPM machine tool type (SPM1 or SPM2) is the best to use and that could satisfies the pre-selected performance criteria. In order to analyse, an independent model for each special purpose machine is developed. The model structure contains the main machining system parameters that are related with machining process (roughing, semi-finishing and finishing) of cam-shaft, crank-shaft, dowels and transmission holes of the engine-block and its performance indicators; the features are shown in Table 4. Moreover, maintenance activity is included in the model considering the capitalized life of the machine tool and also to maintain the proper quality and to improve the productivity.

It's needless to say the roughing process only considered for optimization―only the feature and the machining system parameters related with T_801-807 and T_901-907 is taken for optimization. Since the other features have one step operation i.e. finishing. So to maintain the quality of the part, the parameters related with finishing is not considered for optimization. The optimality is selected with respect to the performance criteria and the strategy adopted in the machining process.

The step by step approach followed to model, analyse and select the machine type that would achieve the intended performance criteria is shown Fig. 12.

Hence, to achieve the required part productivity there will be a delivery of an output at every takt time value in the production line. In this specific case, if there is demand fluctuation, the production time is adjusted to meet the demand: if the demand grows the machine will produce for longer time, if the demand drops the machine will be used for shorter time. For this case, there is no feedback loop system that optimizes the parameters and limits cost in the system structure. Therefore, in order to improve cost without compromising quality and productivity a new model for policy analysis is proposed.

Model for policy analysis /new strategy/

By finding the leverage points that could improve the performance of the existing working condition a new policy (strategy) is formulated. A policy design is a proposed methodology for the company that would changes the performance of the current strategies on how decisions that regulate machining process are made, by changing parameters and modifying the existing structure of feedback loops. In this report a policy with one scenario is developed and described that has aimed at optimizing the production process and hence improving the system behaviour.

As it has been explained in the aforementioned section the current situation is targeted to achieve the fixed takt time regardless of the order rate (demand). In the proposed policy if there is variation in the system the takt time is rather varied however the machining parameters should always be kept at their optimal condition. For instance, the decrease in order rate than usual will increase the cost per part and hence there is no (system) feedback loop in the model of the current situation that reduces it. Therefore, to alleviate this situation a policy that changes the existing machining strategy is developed and that could also achieve or improve the productivity.

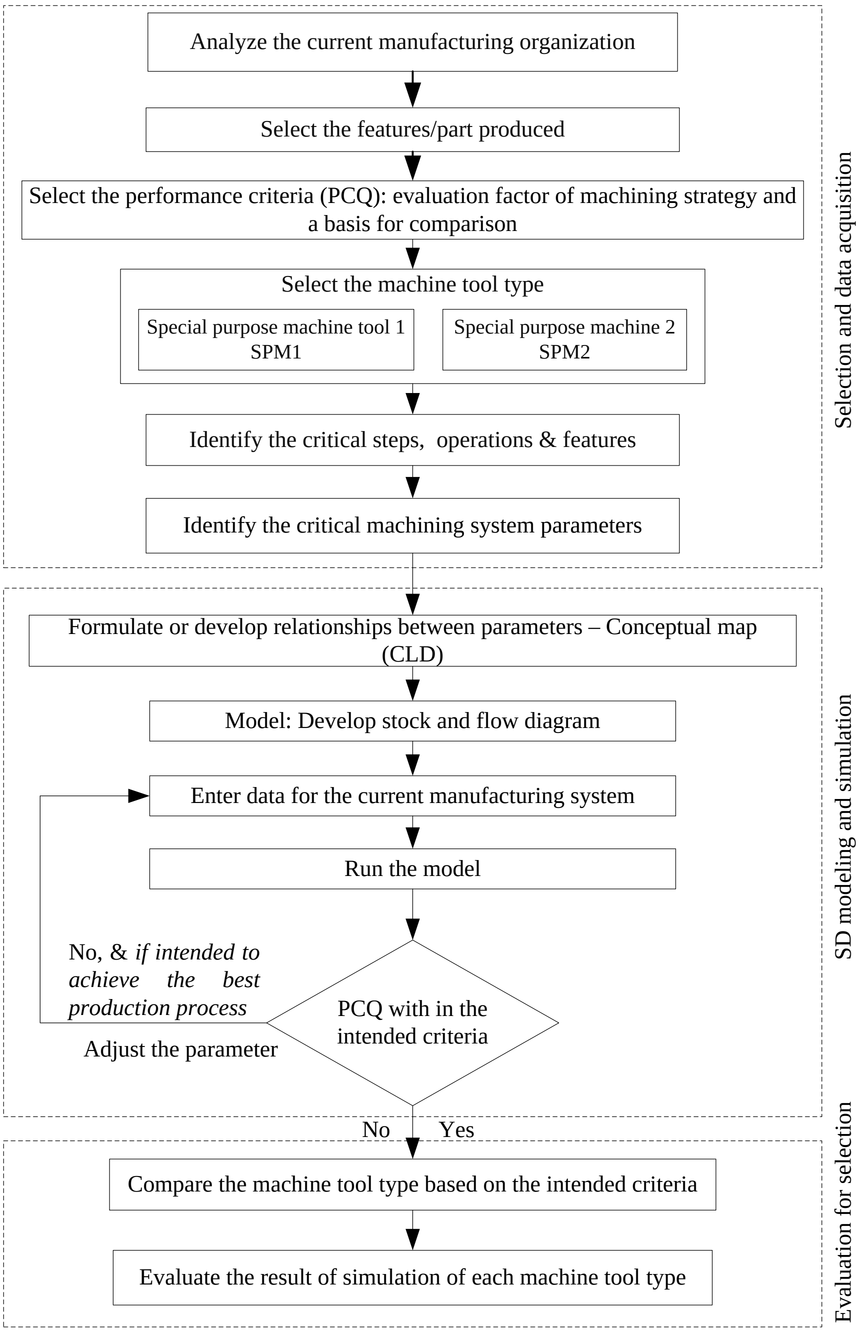

Fig. 12. Approach for machine tool selection problem

5. RESULT

Results are obtained from initialising the simulation model variables and running the simulation with given process input/output data. The data used to define the critical parameters and to run the models are obtained from company's historical data and by measurement during production process with few assumed data. In the modelling environment during simulation, the parameters associated in the machining process are kept within the design specification limit to maintain the quality of the machined part produced. Except demand (order rate) which is considered as a source of variation in the process whereby sample order rates are taken to simulate the system behaviour. The model in both scenarios is run with an increase and decrease in demand that vary between 2000 and 5000 pieces per month, shown in Table 5, the graphical representation for parameters variation during actual situation and new policy strategy is shown in Fig. 13. The simulation is run for 180 months, considering the machining systems have been capitalized over the lifespan of the systems which is estimated to be 15 years.

During demand variation, either an increase or decrease, the performance of the machine to achieve the desired productivity, to produce with the optimal cost and that deliver the required part quality will be analysed. The possible variations in the system are takt time, order rate (demand), and total production time.

Table 5. Scenarios considered

Factors	Demand (piece/month)	Takt time (min)	Cutting process parameter	Total production time
Scenario 1	4000-5000	Fixed	Fixed	Variable
Scenario 2	4000-5000	Variable	Variable	Fixed
Scenario 3	2000-4000	Fixed	Fixed	Variable
Scenario 4	2000-4000	Variable	Variable	Fixed

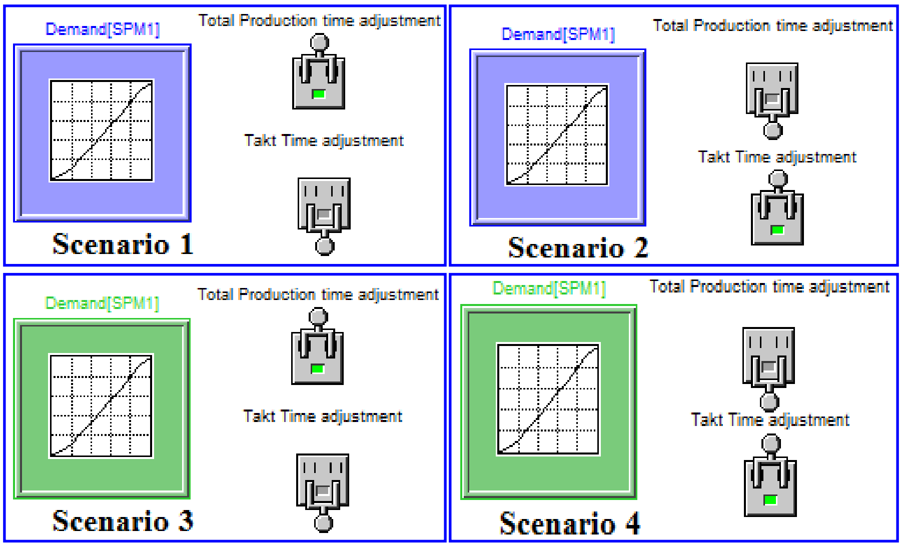

Fig. 13. Parameters variation during actual situation and new policy strategy as graphical representation

To fulfil the required demand of production with the current given data for all the scenarios considered in Table 5 one machine tool was required if either SPM1 or SPM2 used for production. If demand is not fulfilled however either the cutting process parameters or total production time/takt time will be adjusted. Therefore to attain the given demand the cutting process parameters were adjusted. Fig. 14 show the behaviour of the variation of the cutting process parameter —feed rate for SPM1 (special purpose machine 1) and SPM2 for current situation. The higher the feed rate for SPM2 might be from the design specification limit value or due to the production line arrangement to achieve the desired cycle time.

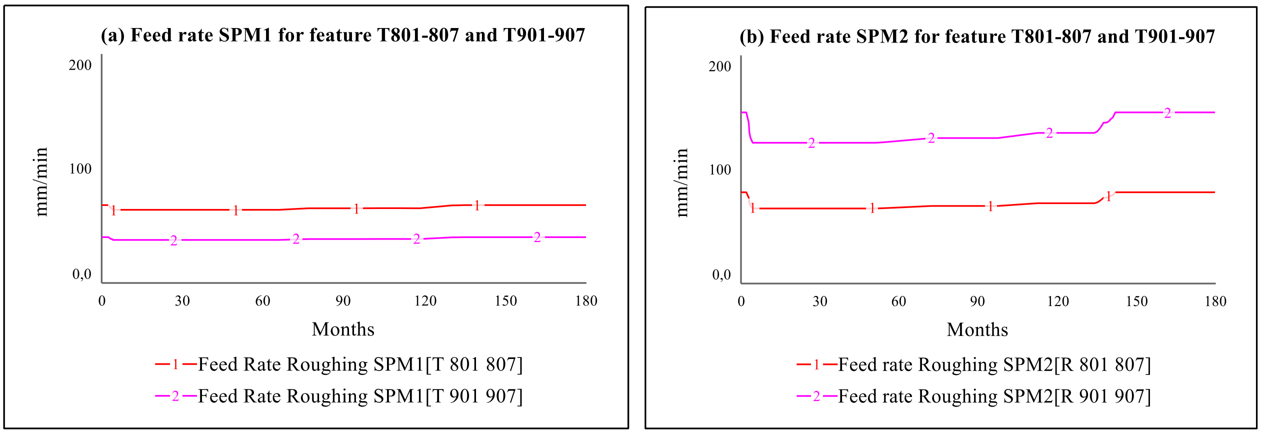

Fig. 14. Feed rate for the respective features and machine

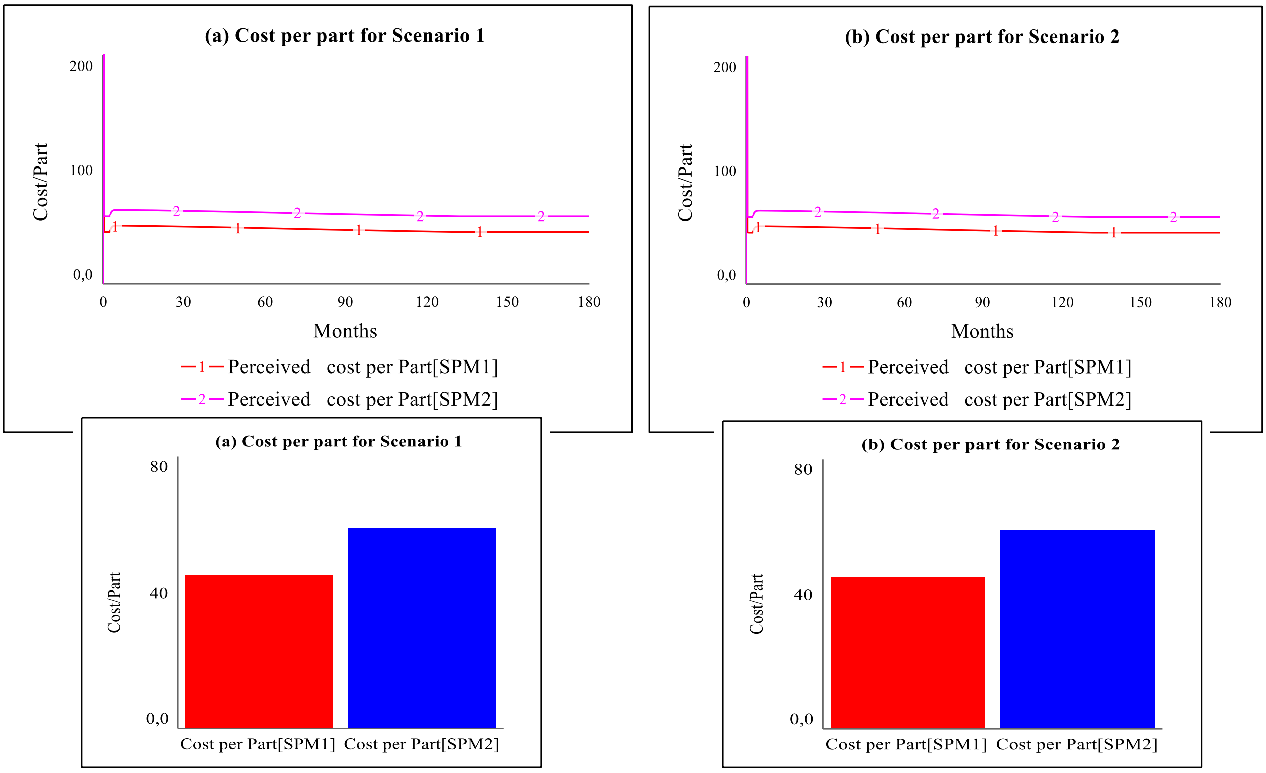

Fig. 15. Comparison of cost per part —SPM1 & SPM2

As it is briefly explained under section 3.4, the values of the cost per part comprises the sum of the cost per part for maintenance, capital cost, tool cost, spare part cost, overtime cost, and real estate cost. For both scenarios: scenario 1 (actual condition) and scenario 2 (proposed policy), the cost per part for SPM 2 is higher than the SPM1 as illustrated in the simulation result Fig. 15. The specific unit for cost is not presented due to confidentiality.

In Scenario 1&2, the SPM1 and SPM2 reached their maximum capacity production and therefore were unable to fulfil the demand above approximately 4750 parts, as shown in Fig. 16. This was due to the settled for the maximum values (designed values) of the cutting process parameters required to produce within the desired quality level. Moreover, to adjust the cutting process parameters for the two cutting tools simultaneously and to find the balance value is challenging. Any change in machining strategies had insignificant difference for the productivity and for the cost per part as well, shown in Fig. 16 and Fig. 17.

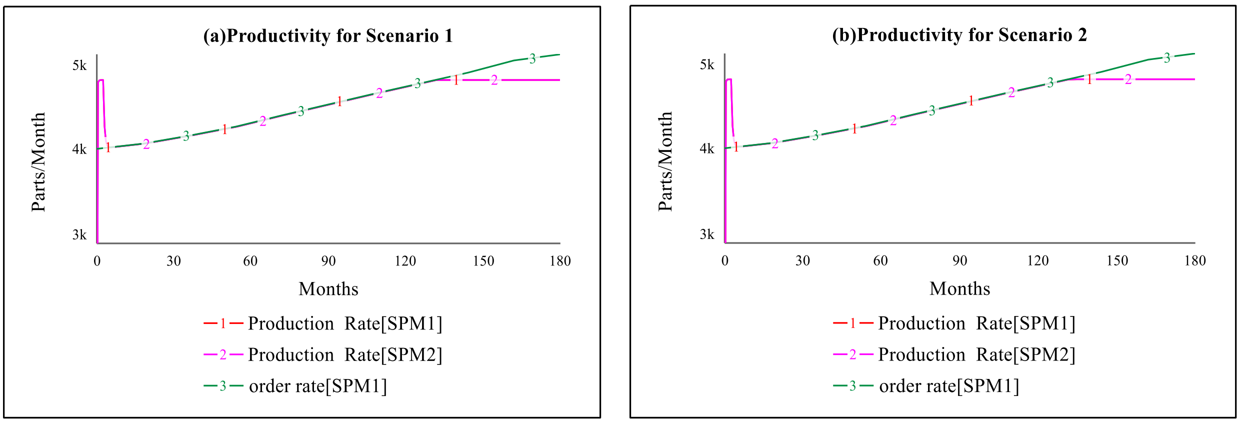

Fig. 16. Comparison of throughput (productivity) for SPM1 and SPM2—Scenario 1&2

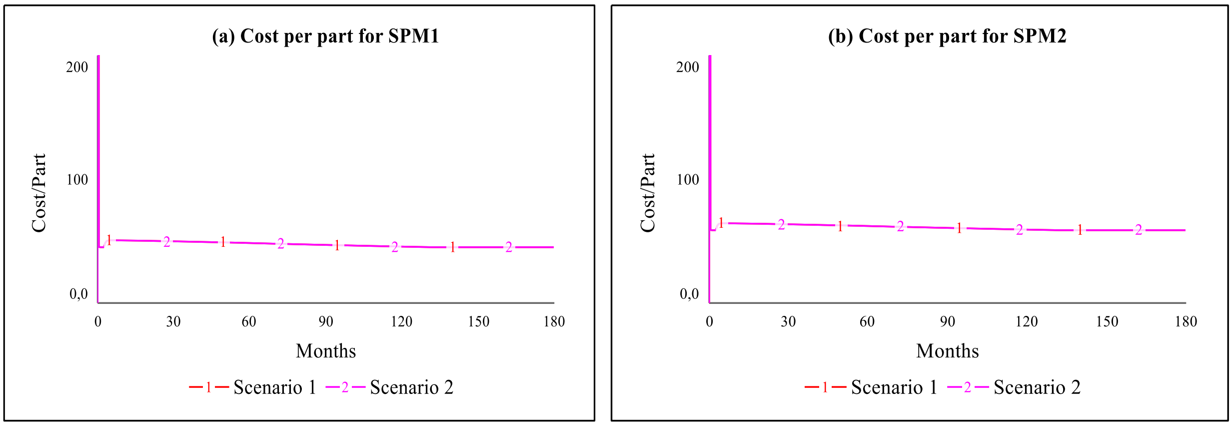

Fig. 17. Comparison of cost per part—Scenario 1&2

The variation of feed rate for scenario 4, for SPM1 and SPM2 for each feature T801-807 and T901-907 is shown in Fig. 18.

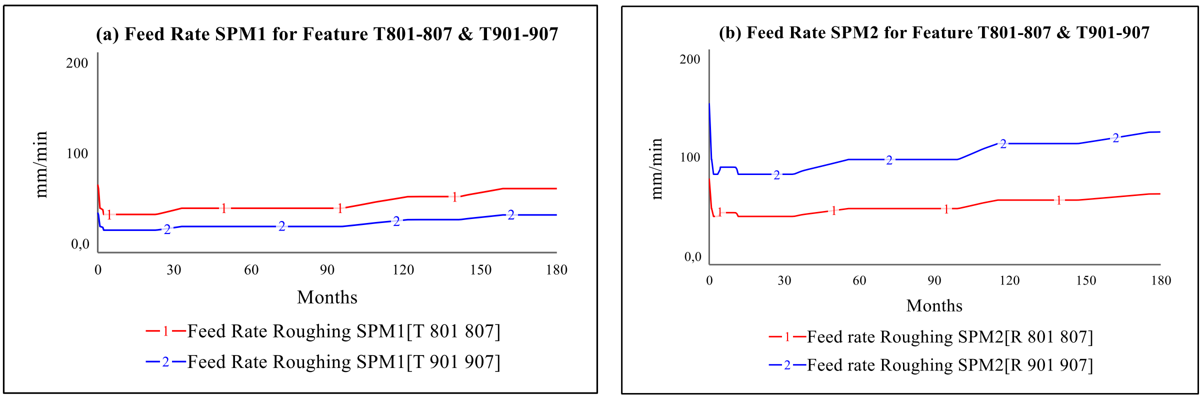

Fig. 18. Variation of feed rate for SPM1 and SPM2—Scenario 4

To produce the given demand of parts the cost per part for the SPM2 is higher than SPM1 in both scenario 3 and scenario 4 as can be seen Fig. 19.

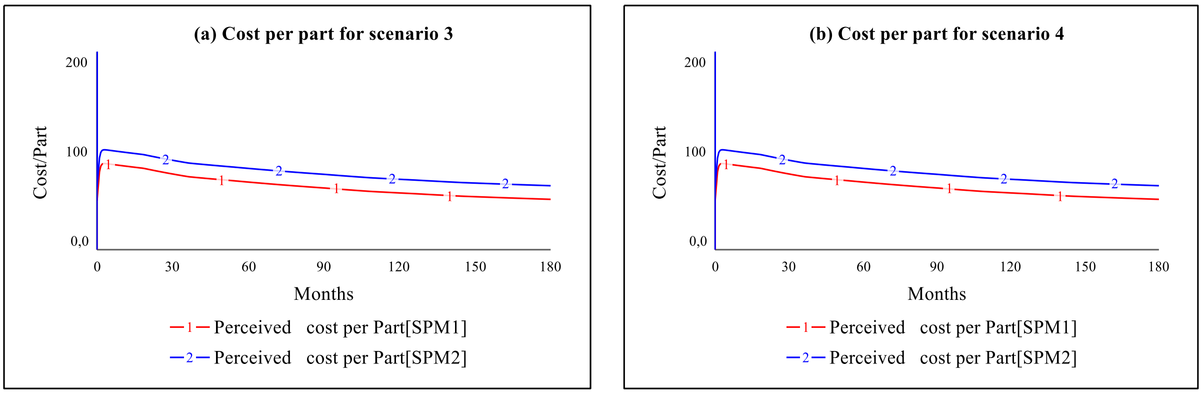

Fig. 19. Comparison of Cost per part for SPM1 and SPM2—Scenario 3&4

For scenario 3 and scenario 4, both machines-SPM1 & SPM2 are capable to fulfil the productivity requirement since they produce the throughput that covers the whole range of demand throughout the life of the machine, the behaviour of the graph is shown in Fig. 20.

Productivity comparison

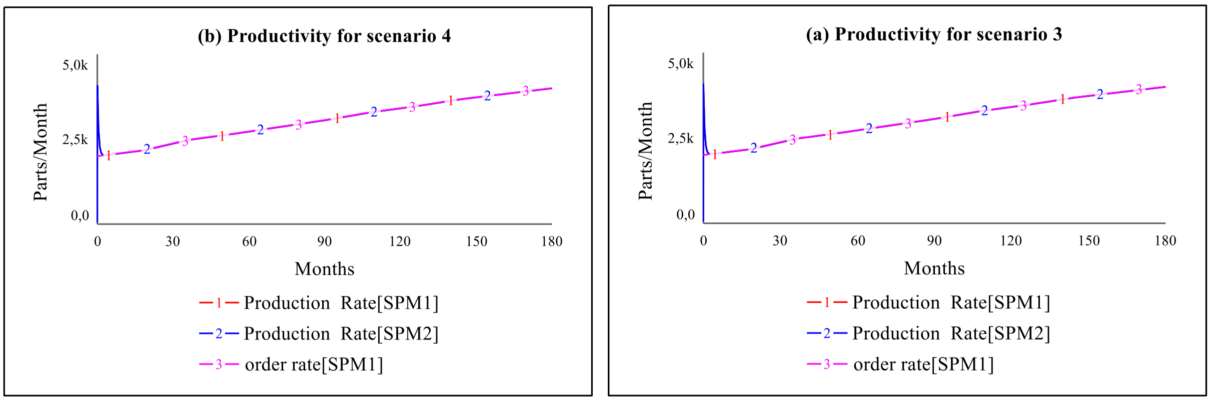

Fig. 20. Productivity for SPM1 and SPM2—Scenario 3&4

As described in Fig. 21, however there is no cost benefit for the new strategy proposed for the SPM1 neither for SPM2.

Cost comparison

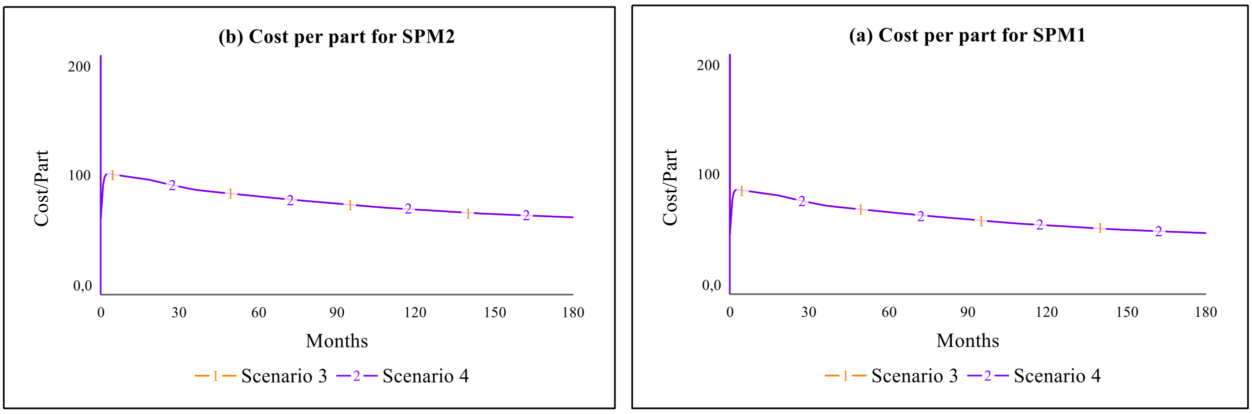

Fig. 21. Cost per part for SPM1 and SPM2—Scenario 3&4

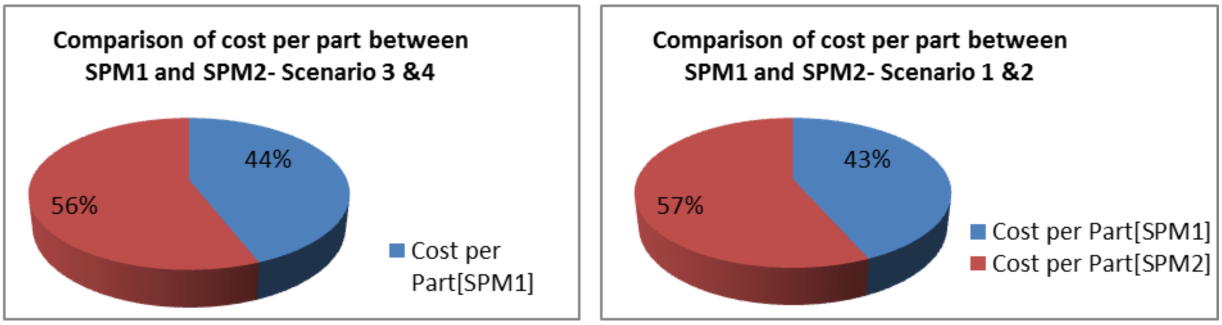

Fig. 22. Comparison of cost per part—SPM1& SPM2—for Scenario 1&2 and Scenario 3&4

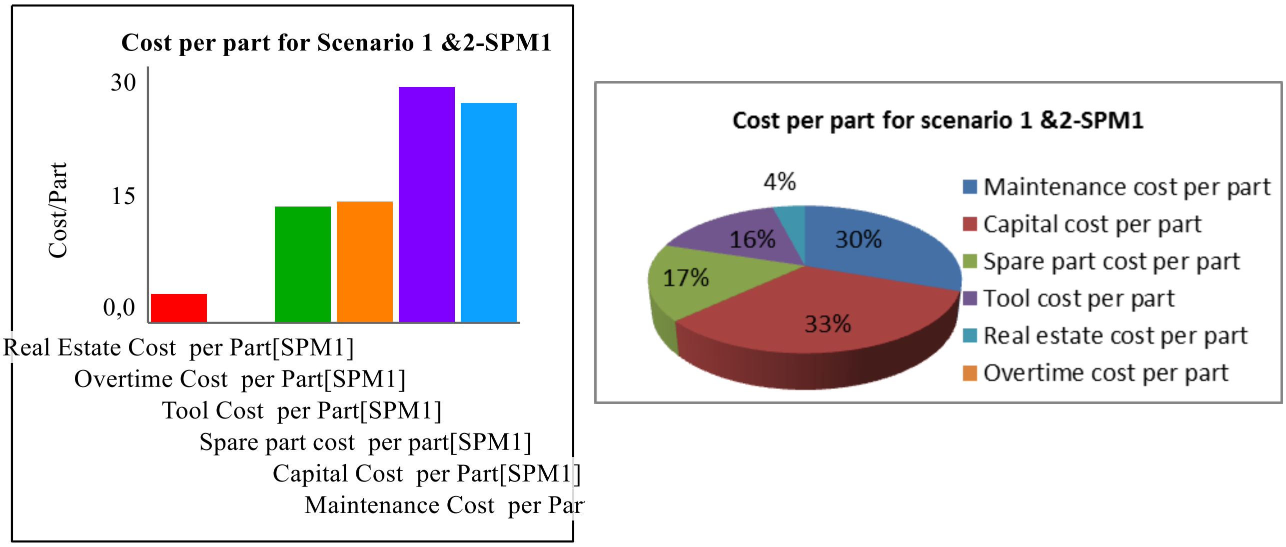

Fig. 23. Left: Cost component for SPM1; Right: Cost component percentage for SPM1—Scenario 1&2

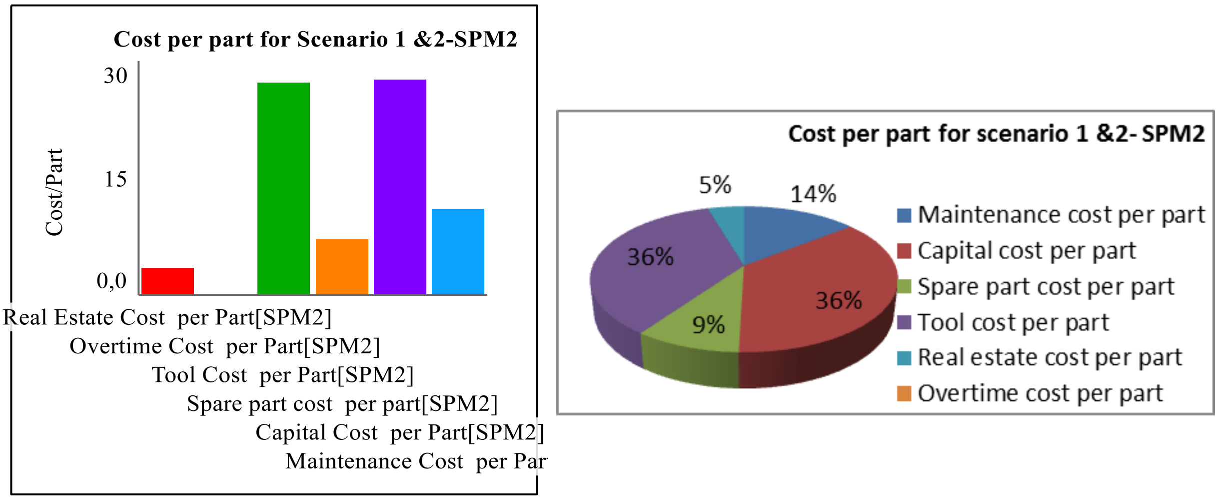

Fig. 24. Left: Cost component for SPM2; Right: Cost component percentage for SPM2—Scenario 1&2

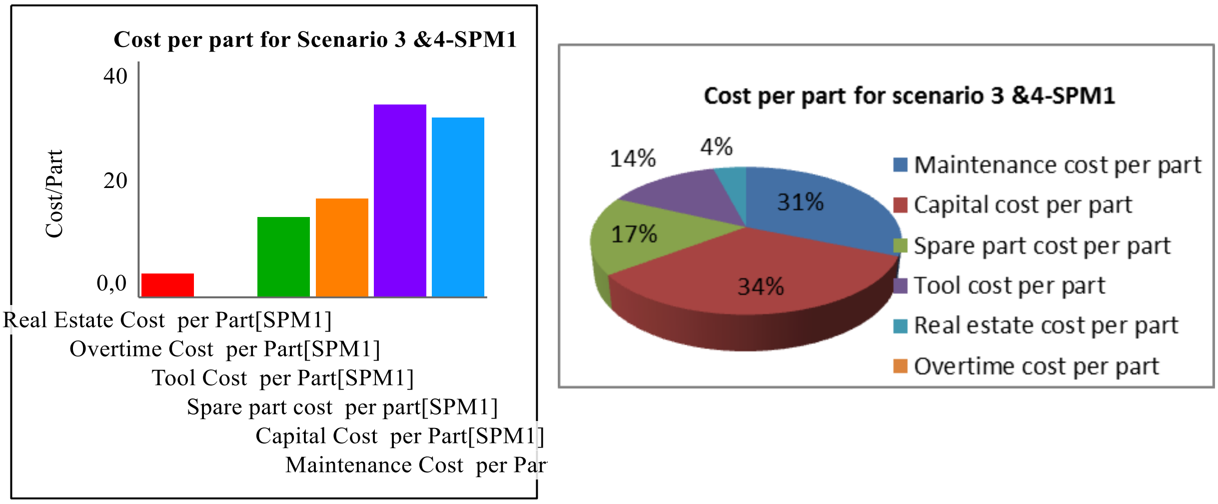

Fig. 25. Left: Cost component for SPM1; Right: Cost component percentage for SPM1—Scenario 3&4

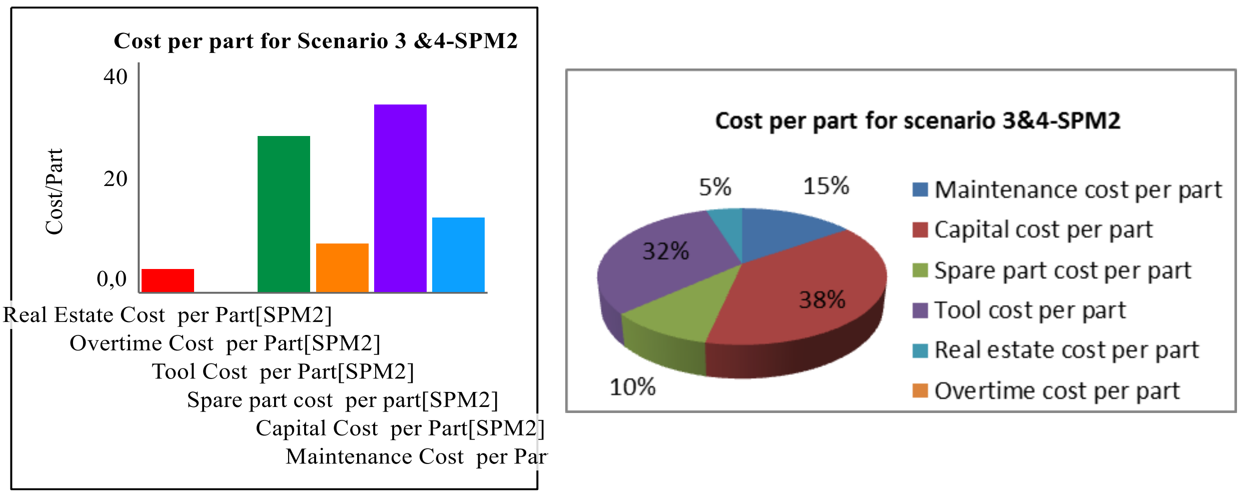

Fig. 26. Left: Cost component for SPM2; Right: Cost component percentage for SPM2—Scenario 3&4

As already explained earlier and as can be seen above Fig. 22, the cost per part for SPM2 is higher than the SPM1. To produce the same amount of demand for the given feature using SPM1 would save approximately 12% of cost per machined part than SPM2.

The percentage of the cost per part that contributes for each component for each machine tool type of the proposed scenarios is illustrated in Fig. 23, Fig. 24, Fig. 25 and Fig. 26.

6. CONCLUSION

Model for performance evaluation

The results from the actual situation and policy analysis have shown that adapting machining strategies to working conditions could enhance machining system performance. The policy developed was useful to improve cost performance by adjusting the takt time and process conditions without decreasing productivity. However, in this case varying and adjusting the cutting parameters for the different cutting tools (T801-807 & T901-907) was not effective, since the cutting process (boring of cam and crank shaft) are done simultaneously unlike for machining centre.

Model for comparison is developed

The result for the case study presented SPM1 had given better productivity performance at a lower cost in comparison to the SPM2 and it was also a robust in both machine tools to the change of machining strategy.

The result for comparison of the two special purpose machines with different orientation (design) shows that SPM1 had produced with a lower cost in comparison with SPM2, SPM1 has a benefit of approximately 12% reduction in cost per machined part. These machines are less sensitive to the change in machining strategy and the new policy proposed had no significant improvement for the cost and productivity of the part being produced.

The selected features and the company in which the case study was conducted both did not have a high variation in product specification and customer's demand fluctuation over time. In the future, (Over time), it would be sustainable to use a SPM. In case of a failure to achieve on productivity due to any increment in customer demand, the purchase of a parallel flexible machine was shown to be beneficial.

Such results found in this paper are intended to support companies in order to provide an evaluation tool for their current working system. Furthermore, it allows for the possibility of predicting the capability of machining performance in order to facilitate effective planning of the machining strategy and attain such benefits as: optimum productivity, quality and cost.

In conclusion, the methodology proposed was allowed to detect variations in the system behaviour and could aid in machine tool selection. Taking into account the precise feature that was to be manufactured from a life cycle perspective – rather than only being considered at the time of purchase. Furthermore, since it was flexible to simulate the system response to different sources of variation, the selected method can be useful as a decision support tool to make sustainable choices in machine tool selection and machining strategy evaluation. Furthermore, the methodology can also be applied for any similar engine-block production company by adjusting the parameters relationships in the system and modifying the system behaviour.

Of importance here is this case study model's own limitation, the major challenges:

- It's only the variation of demand from customer is considered. However, the variation related to workpiece material, design changes (introduction of new components to be manufactured in existing system) is not accounted due to the unavailability of historical data from the company.

- Since only demand fluctuations were considered as a source of variation, excluding other situations. Nevertheless, this methodology allows to easily modify the model and to include other aspects that can be taken into account. As a matter in fact, the major advantage of this method is the possibility to re-use blocks or parts in other circumstances, which will be considered later on in the model.

- Due to the unavailability of data, quality is considered as a constraint. Part accuracy should be incorporated in the model and has to be seen as a performance factor to improve, more than only a constraint. That is the machining system parameters and other factors are set within the design value to produce the required quality limit.

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