Critical Analysis of Scalability of Reconfigurable Manufacturing Systems

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Abstract - Due to the rapidly increasing industrial competition in the globe, it has now become fundamental of engineering firms to implement fundamental industrial approaches, which promptly and reliably focusses on sudden transformation of the design of engineered products. Emergent strategies, which might allow forms to cope up with the quickly transforming changes of product specification is centered on Reconfigurable Manufacturing Systems (RMSs). This research contribution discusses the significance of the presently available scalable Manufacturing Systems (MSs) that allows engineering firms to meet the demands of the market quickly. RMSs have to be designed on the outset of the futuristic scalability to allow its cost-effective and prompt expansion according to the demands of the globe. As such, this research contribution provides the principles to given manufacturing systems' design to enhance scalability.

Keyword - Manufacturing Systems (MSs), Reconfigurable Manufacturing Systems (RMSs), Flexible Manufacturing Systems (FMSs), Dedicated Manufacturing Systems (DMSs).

I. INTRODUCTION

The aspect of manufacturing applies to the chemical and physical processes that alter the appearance, geometry and properties of a particular raw or semi-complete material to create product. This process is normally done in operational sequences with every process drawing materials closers to the final phase. Facility arrangements to create operation sequences are known as Manufacturing Systems (MSs). Other than the above definition, MSs can be defined as the operations and arrangements of different elements of manufacturing e.g. information, people, materials, tools, and machines to produce value-added physical service products and informational products whose costs and success is featured by the measured parameters of system design.

Elements of MSs have to be arranged in a systematic manner, which allows smooth operation of the complete system to allow for the achievement of organization goals and objectives. This has to be projected and addressed in the design process of MSs. Reconfigurable Manufacturing Systems (RMSs) are one whose subsystem or subsystem reconfiguration can easily be modified or changed after the process of fabrication for a particular purpose. W. Wang and Y. Koren in [1] have defined RMSs as MSs made from the outset of quick transition in structure and hardware/software components to transform the production functionality and capacity, based on a sudden transition of regulatory requirements and market conditions.

Since the Industrial revolution, Dedicated Manufacturing Systems (DMSs) have facilitated mass production and many engineering firms in the globe make use of it significantly Mass production amounts to low product unit pricing. Considering to the condition of traditional dedicated MS, any potential slight transition in product design may make more production of novel engineered products on line challenging, if not difficult. This is because, DMSs, based on its design, is considered rigid to facilitate mass production for cost-effective and profitable purposes. However, these forms of MSs can only be applicable in a more stable market. The current market is highly customer-based, dynamic and competitive, since it is a market case featured by more consumer demand for a wide-range product in random quantities.

Flexible Manufacturing Systems (FMSs) represent the alternatives, which come in mind focusing on the shortcomings of DMSs; however, FMSs have their own disadvantages. Lower throughput and higher costs of equipment due to redundant flexibility and more complexity in the designing of FMSs are the major shortcomings, stopping it from effectively replacing the DMSs. Consequent to that, it is fundamental to consider the most recent approaches, such as RMSs to allow easy switching between engineered products as conditions arise. Reconfigurability in manufacturing ecosystems to modify its critical elements (machine tools, assembly workstations and material handling systems) reliably and rapidly to accommodate sudden and planned changes in the designing of product or specifications without costly set-up costs and shutdown periods.

The aspect of scalability in MSs denotes to the capacity to change its production capacity to possible adapt to the needs of production. It is a fundamental system design feature, which evaluate ease of affordable transformation in a particular MSs' throughput to meet the changes in the demands of the market. As of early 1990's, there were not high volume manufacturers known to enjoy stable developing markets with long product lifetimes based on fixed transfer lines. Stimulated by global competition, manufacturing firms in the 21st century are faced with an enhancing unpredictable changes in the market, incorporating rapid introduction of novel products, constantly varying demands of productions. To maintain competition, firms have to design effective MSs that produce high-quality products at an affordable price, and enhance their chances to responding to market changes in an economical manner.

Y. Koren and M. Shpitalni in [2] have considered RMSs as a remedy that addresses the need to rapidly transforming demands of products. Based on the perspective of RMSs, MSs are formed to be affordable and self-reconfigurable to particular precision essential for matching novel demands in the market. E. Johri, D. Sarkar, K. Shah and M. Mota in [3] started addressing the issues of system scalability since early 1990s and provided patent, which handles strategic changes and production capacity in RMSs. These researchers developed algorithms, which focus on scalability capacity; however, the algorithms have been restricted to upgrades of capacities of serial lines.

C. Kan, M. Breteler, E. Timmermans, A. van der Ven and F. Zitman in [4] presented a more comprehensive approach where the aspect of scalability was evaluate as a critical problem in the designing of massive and complex machining systems. Capacity scalability can be attained through the scale of the capacity of individual equipment. However, the most practical methods of system scalability is incorporating or eliminating machining from the present MSs. In this instance, original layout of system design is fundamental for attaining cost-effective scalability. A. Deif and W. ElMaraghy in [5] introduced dynamic framework for capacity scalability evaluation in RMSs. The dynamic framework is based on the minimization of the potential delays in scaling the capacity of systems and hence enhancing RMSs performance with respect of sudden demand changes.

In this research contribution, we focus on the optimization of the original layout of the system i.e. removing or adding machines whenever required by the market promptly and cost-effectively. Simultaneously with the removal and addition of machines, the aspect of material handling scheme has to be adapted to the layout of new systems. There are instance in which Autonomous Guided Vehicles (AGV) create material transport schemes. Even though AGV stimulates part transfers in the motors; however, they are slower and costly, and therefore viewed as an affordable solution. With the development of machines and machining initiatives for many decades, the productions of medium to higher volumes, larger mechanical segments, such as locomotive power trains mechanical parts etc. have undergone significant changes.

Dedicated transfer line with dedicated stations of machines is replaced by schemes that have highly flexible CNS tools of machining. System architecture comprises of many parallel CNS machining tools at every phase, with the machines completing similar machining tasks. The configuration of more parallel identical machines in every phase, with material transfers between different phases (i.e. crossovers) enhance throughput, minimize the work-in-progress inventory, and are easier to reconfigure. Each MSs is properly designed with a particular capacity to potentially fulfill any projected demand. Nonetheless, for instance, it the projection for annual product sale in about 230K to 300K units, marketing normally dictates a building capacity for about 300K units. In that case, every when systems are optimally structured, capacity might still be wasted whenever the actual demand is fundamentally lower compared to the completely planned capacity. Contrasted against the complete lifecycle of MSs, times in which schemes can be operative at higher capacities, are normally shortened. The investments in surplus capacity (e.g. 700K units) may possibly be delayed until it is essential; thereby making the lifetime of these systems to be minimized fundamentally. The design of systems for scalability implies that it is designed in a manner, which allows rapid capacity transformations to meet large or small demands with required. The major focus of this paper is on the aspect of scalability of rapidly transforming production capacity of MSs based on the removal or addition of machines. This paper will define the various system scalability concepts of incrementally scaling scheme capacity and identify the relevant principles for attaining incremental scalability. This paper will also define the inputs required for the planning of scalability, incorporating formulas to possibly reduce the general number of motors through concurrent reconfiguration and rebalanced systems. Finally, this paper will focus on a case study of an industry to validate the proposed methodology. In that case, this research has been arranged as follows: Section II presents detailed definition of scalability. Section III reviews the relevant literature texts. Section IV presents a critical analysis of the paper: scalability planning formulation and case study. Finally, Section V present a discussion and conclusion.

II. SYSTEM SCALABILITY DEFINITION

The dedicated lines are not known for scalable capacity and might not potentially cope with the significant changes in the demands of products. This issue can be met through reconfigurable and flexible MSs that are composed of CNC motors and configurable motors because these are considered to be those schemes that are more scalable in minor increments attained through the removal or addition of individual machines when the need arises. It should be noted the overall stage number is constant during the whole scalability process. Scalability of systems is known as a percentage i.e. 100% focusing on smaller capacities as well. Whenever minimal transformations of capacities by which the throughput of systems can be changed to meet the demands of the market is considered lower, the scalability of these systems is significantly higher. For instance, in case the serial line requires an increment in production capacity to potentially fulfill the demands of the market, a new line has to be added (see Fig 1).

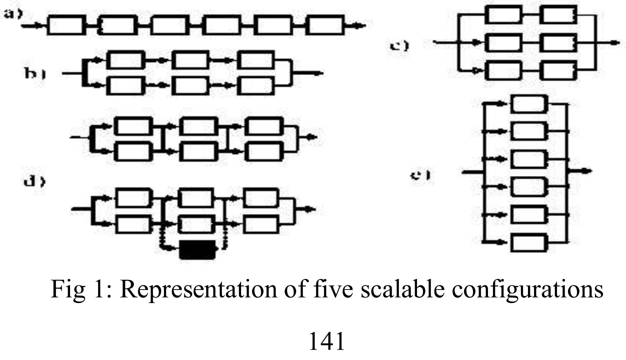


Fig 1: Representation of five scalable configurations

Mathematically, minimal incremement of addition the production capacity in the serial lines is 100% of this systems, which denotes to the addition of completely new line, forming scalability of 0% serials lines. Dual application of the lines' capacity (if dual capacity is non-essential) would be expensive because of the lack of assurance that more capacity will ever be used completely. This therefore risks sunstantial fiscal loasses. In that case, zero percent scalability shows that for an increment of capacity to be attained in a particular sustem, complete production lines have to be dublicated. Whenever the markets are volatile, the designing of MSs with 0% scalabilty is not effective as a engineering remedy. The same form of scalabilty for system in Fig 1 indicate that:

- Configuration b has 50% scalability
- 50% scalability in configurability of b
- Configuraiton c has 68% scalability (which shows that two machins have to be incorporated to increase the system capacity)
- Configurations d & e scalability are 84% and this is a higher form of 6-motor configuration.

Minimal increment of 15%, in this instance, a single machine is incorporated to enhnace system capacity eg machines could be included in the 2nd phase of configurations 'd' according to Fig 1. As such, configurations in Fig 1c of the dual phase systems that has three machines in a single phase might be a compromize between reasonable investment costs and scalability. In that regard, if the product necessitates machining on the side surface and upper surfaces, 3 motors in the 1st phase could be a 3-axis verticle machine used for mills, and three machiines in the 2nd phase could be a 3-axis milling machine that is horizontal.

Conversely, in more parallel schemes, 6 machines (as seen in Fig 1e) need to be 5-axis millers that increases the overall cost of the system. In this system, Fig 1 (C) represents the need to perform scalability in phases of 34% through the incorporation of a single verticle machiines and a single horizontal machine, in stead of in phases of 16% like the corresponding configurations. Incoproating more phases of 16%, in Fig 1e implies to the practical additon of a single five-axis machines with larger tool magazines, which comprises of every tool required for the complete-part processing, and this is expensive. Generally, the smallest form of scalability phases of adjustment can be attained whenever the original schemes is completely parallel (Fig 1 (e)). Nonetheless, initial costs of the parallel scheme is a higher system configuration. In the corresponding configurations, every form of machine has to perform all the manufacturing obligations required to finish the parts. In that case,

In that regard, every machine should have full sets of tools essential for productions of full parts and has to be capable of performing multiple functions, whereby more motion axes are required. Resultantly, a capital cost in every additional increment of volumes in the corresponding configuration is a higher form of configurations. The example below evaluates the method of including a minor form of incremental capacity.

Example: Referring to the system with 6 different machines, it is fundamental to process parts, which necessitate about 20 machining tasks of half a minute each, and which totals to about 600 seconds or 11 minutes, required to machine every part. Essential demand is 274 parts in every eight-hour shift i.e. 480 minutes.

Hence, the essential cycle duration is 480/275= 2.74 minutes for every parts. (i) For the designing of scalable system configurations and (ii) after a single year, the demand has increased and about 300 parts in every shift is required, hence minimizing the cycle duration in a single part to 1.5 minutes in every part. Therefore, what is the number of machines that have to be incorporated considering the kinds of novel configuration to include? Affordable scalable system configuration have been indicated in Fig 1d. As such, every machine completes seven talks in half a minute, each totaling to 210 seconds for a single machine. Whenever the demand increases to 320 parts in a single day, 7 different machines are needed.

Configuration d presents a pocket-friendly remedies through the incorporation of newer machines in the second stage. The final tasks, which was completed in the first stage is shifted from the first stage to the second stage, in that case, every machine in the first stage operates for about 180 seconds on the part and the first tasks, which was completed on third stage to the second stage. Two different tasks were incorporated to the second stage. In that case, every machine in the second stage will now work for 270 seconds on every part, and the entire cycle of the system will be operative for 90 seconds in a single part. Whenever the demand increases, the initial scheme is cost-effectively scaled to configurations, and potentially meets new market demands.

The initial investment of the capital in the configurations of the system is more than the serial lines because of the material-handling system, which is viewed to more complex. As such, we have reserved a position for the 2nd phase that allows the incorporation of the 7th machine in case it is required. Nonetheless, more capital investment is the same as buying insurance premium for events in the future and this is what is likely to happen. If the demands increase, systems can be scaled easily and novel demands can be supplied without a very short duration and at minimal additional investments. If the demands are not changeable during the complete system lifecycle, minor capital investment on sophisticated systems for handling materials are lost.

So, 21 tasks, which are treated equal, are required to finish the part. The systems with three phases and two machines in every phase were balanced and effectively scalable. The same form of scalability findings are achieved through the additions of (r) machines to the configurations with L phases and M machines in every phases, in case the number of the same tasks are required to finish the parts is (L. M + r) L. It should be noted that, r = 1, and particular task duration (i.e. half a minute) does not influence the solution.

Based on the example above, we can identify the four principles for MSs to enhance scalability:

- Systems have to be reconfigurable. In this case, RMSs are structured for cost-effective transformation of production capacities, which respond to more imminent need.
- RMSs capacities are formulated to be more scalable in optimal increment.

- To enhance scalability, RMSs may incorporate economic equipment mixes of more reconfigurable and flexible machines.
- To be rapidly and significantly scalable, RMSs necessitate more investment on its infrastructures.

The example used above signifies an idea instance to demonstrate the concepts of scalability. To apply the concept practically; various constraints have to be considered e.g. unequal task durations, stage features and task precedence. All these concerns have been discussed in the below sections.

III. LITERATURE REVIEW

P. Cichosz in [6] evaluate the works done in reconfigurable machining tools, reconfigurable-engineered products, reconfigurable manufacturing cell, reconfigurable procedural planning and reconfigurable control schemes among others. Nonetheless, as it is a manufacturing system with reference to the above definition, i.e. aggregation of the elements of manufacturing. The scientists have not focused much attention as long as it is a reconfiguration type. Literature survey reveal that, little has been done regarding this segment.

A. Kusiak in [7] focused on the knowledge of three concepts of manufacturing, Bionic MSs (BMSs) and Fractal MSs (FrMSs) and Holonic MSs (HMSs). These MSs are a good development of RMSs. What should be noted is the contrast between three concepts of manufacturing. The scientists focused on the underlying principles regarding the concepts of manufacturing and compared their various operational and design features. The knowledge achieved from these concepts was of immense value in the development and design of RMSs as evaluated in this research paper.

P. Telek and Á. Cservenák in [8] argued that RMSs signify the aggregation of RMSs such as material-handling schemes, machine systems, measuring devices and control systems among others. Nonetheless, this research contribution provides the motivation for considering novel paradigm in the designing of MSs i.e. RMSs. Presently, RMSs have not been addressed; however, based on this research contribution, reconfigurability of MSs have been evaluated. Reusability evaluation of MSs focusses on various forms of configuration, which could assist futuristic configurations of MSs.

P. Renna in [9] evaluated the challenges of reconfiguration of MSs and introduced novel approaches to properly reconfigure cellular MSs based on the application of the concept of virtual cells. The scientists argued that MSs can effectively be reconfigured through dynamic restructuring procedures to mitigate the issues of disturbance. Even though dynamic reconfiguration procedures are not properly documented in literature, the principles utilized in the development and design of RMSs presented in this research.

P. Smith in [10] focused on the works on RMSs for agile-mass customization manufacturing. The assumptions are similar to the ones presented on the manner that various RMSs and elements that are highlighted; however, how they can be made configurable as MSs is not viewed. The scientists focusses on the manner in which reconfiguration can be utilized in dealing with the breakdown of MSs. They considered a method based on reconfiguration characteristics e.g. the ones in this research of RMSs for dealing with errors in scheduling schemes. It was also projected that high-level object-based control systems are used to error handling using reconfigurations and presently using unified modelling language notations. Researchers in [11] assessed the present FMSs and DMSs and new MSs (RMSs) through the trade-offs among both tangible and intangible designing parameters. This assessed was done based on the application of analytical hierarchy procedure. They indicated that, in long-term, the present MSs have to be incorporated using RMSs so that they can effectively cope up with the developing product varieties and uncertainties in the demands of the market based on variety and volume. The ideology of mobile manufacturing is considered as assistance to reconfigure MSs.

P. Barash in [12] presented the definition of MSs Mobility as the capacity to switch promptly and effortlessly between different engineered products since they indicate that the concept is the same as reconfigurability. In their research, the ideology of mobile manufacturing is evaluated through the description of five different demonstrators in the factory-in-box research projects. MSs Design based on the demonstrator I & 3 (i.e. mobile robot cells and reconfigurable cells for foundry applications will make it completely reconfigurable with a short time and comparatively cost effective. The main issue with many designs for RMSs is the necessity that the elements of manufacturing have to be mobile. Actually, the works illustrated in this research is based on making MSs more reconfigurable without the feature of MSs' mobility.

IV. CRITICAL ANALYSIS

Scalability Planning Formulation

In this paper, we propose a practical approach that determines a cost-effective system reconfiguration that potentially meets new demands of the market. To undertake scalability planning of systems, various factors have to be considered. The factors include comprehensive planning processes, structured set-up planning, higher machine capacity, spots' numbers that have been maintained for the systems at every stage of additional machine. In the reconfiguration of the present MSs, more simultaneous configuration arrangement and scheme balancing are mandatory for proper maximization of system capacity. This also minimizes the general number of machines needed. This section focusses on the introduction of an optimization framework for scalable planning.

Assumptions

The assumptions provided below have been made with respect to the present manufacturing practices in energy train industry.

- Multi-phase system with configurations that are similar to Fig 1. Parts are shifted from a single stage to the other using conveyors that are given to different types of machines with phases using different gantries
- Phase number has to be constant during any process of reconfiguration. This maintains the system setup plans to eliminate major changes of the process plan, hence reduce the overall impact of system's configuration on products' quality.

- The machining in the same phase performs the same task sequences.
- There normally reserved space for incorporating novel machines in phases and the handlers of machines might be transformed to produce parts of the machines that have just been added.

Input

Configuration data

Phase number = L, machine numbers in every phase = Ni, whereby I = 1, 2, ….L; Maximum machine numbers permitted in every phase Mi, I = 1, 2,…..L.

Phase features

Every manufacturing phase has the capacity, which is described using the sets of features of the phases. These incorporate the features of machining tools e.g. machining ranges, accuracy, power, functionality and fixture characteristics, which describes the various faces, which can be accessed using the cutting tools. Whenever the set of tasks have been assigned to every stage, the essential capacity has to fall in the segment of features of every phase. Taking for instance, the number of features in every phase is K, the capacity matrix S stores all the potential features of every phase. S (i and j) = d: d represents the jth key feature of the i phase; whereby represents less or equal that i is not the same or less than L, i is the same or less than j and equal or less than k.

Manufacturing task

Manufacturing tasks that are precedent have to be completed following a particular order. Every tasks can be completed following the various initial tasks and their times of completion. 2D binary matrix (Pre-il, N, jN, N) , whereby N denotes the task number, which being processed, is used to represent precedent trees, '1', in case the 'I' task has been finished before 'j' tasks. Then, Pre ij is the same or equal to "#".

Task features

These incorporate the various types of tasks, accessibility directions, accuracy, dimensions and energy required to complete various tasks. for a tasks to be allocated in a certain phase, its characteristic has to be included in certain features of the phases. With respect to the overall number of features of different tasks 'R', the features of the tasks K (i and j) = f: whereby f denotes to the jth task I feature, whereby is the same or less than i and equal or less than N and 1 is equal or less than j and equal or less than R.

Machine reliability

Reliability of machines can be expressed using two parameters: Mean Time to Repair (MTTR) and Mean Time Between Failure (MTBF).

Demand

Systems have to be configured since its new capacity can accomplish novel demands (Dnew).

Decision's Variable

Two critical decision's variables have to be considered in this case:

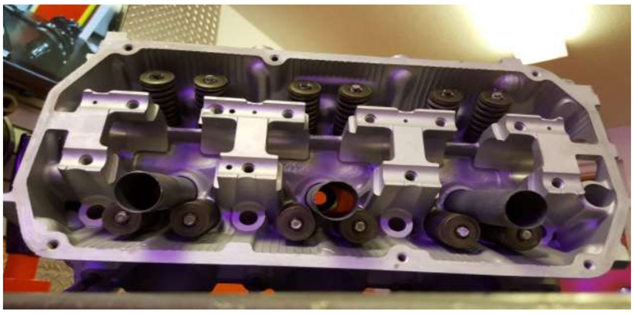
- Arrays for machine assignment (m-i) that controls the manner in which machines have to be incorporated into systems and where to integrate them, and;
- Tasks allotment arrays (T-i) defining the way in which different tasks are assigned whenever novel machine is integrated or eliminated from systems. M-I denotes to the overall machine number to be added in the i stage. I is the same as i and L. M-I is more than zero when it comes to the addition of more machines.

$$minimum\left[\sum_{i-j}^{l} N_i + M(i)\right] \tag{1}$$

With respect to precedence constrains, feature constraints, throughput constraints and space constraints has to be considered. Genetic algorithm (GA) optimization tool was structured based on eq. 1 below. This was used to determine the optimal system reconfigurations during the changes in the market demands.

Case Analysis

The elaborate the approach being proposed, a case analysis by industrialists has been considered in this paper using a rough procedure of machining of mechanical V6 Cylindrical Heads of NSF Engineering Group of RMSs' In this case study, 140 elements on the segment, which could be divided into forty different mechanical tasks, integrating milling, borings, tapping, spot facing and drills. The overall timeframe fundamental for dissimilar mechanics is approximately is 1020s. Due to its complexity, this part is the best for this research since it allows many procedural design remedies to be presented for various system configurations. Machines utilized for all the various phases are 4-axis CNC machining points capable of completing different tasks in machining. Fig 2a signifies the segment whereas Fig 2b is the configuration of machining MTTR and MTBF of CNC machine are 15 minutes and 180 minutes.



a) V6-cyclinder head

b) Four-axis horizontal machining centre

Fig 2: Parts and machining configurations

Standard Configuration

For every configuration (see Fig 3), reconfigurations for the three system configurations ie 6 by 2, 4 by 3, and 3 by 4, are utilized as the standards to evaluate the aspect of scalability plan. Fig 4 represents three systems' configuration and their respective balancing findings.

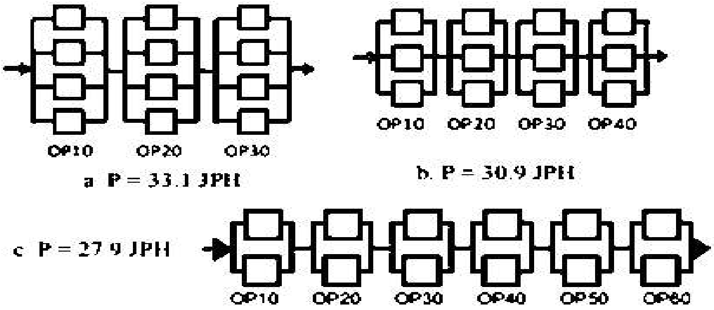
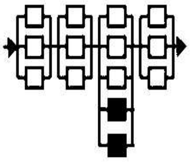


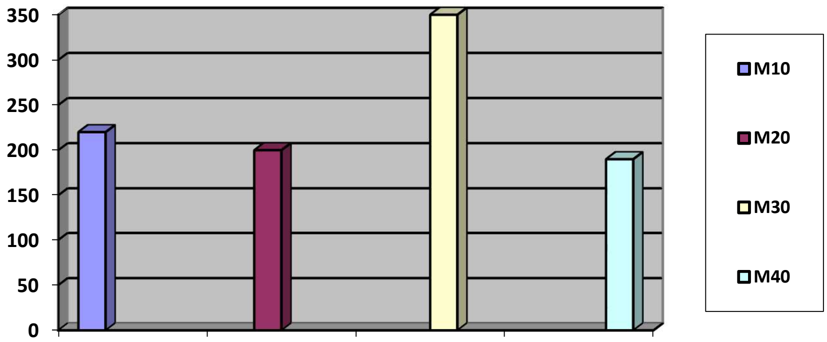
Fig 3: Different system reconfigurations and their various line-balancing findings

Scalability Findings

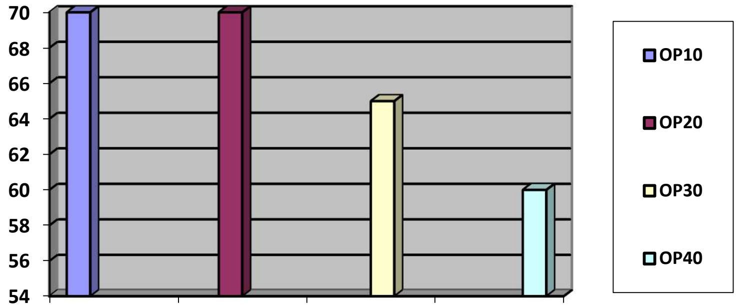
Taking for instance, '4 by 3' configuration as shown in Fig 3, is being utilized to accomplish the production demands of 30 JpH (Jobs per Hour). Moreover, taking for instance about two different machines can be integrated to each available phase while the planning approach used is the same. In case the new demands of production changes to 34 jph, this projected form of scalability algorithm is viewed that two different machines have to be integrated in these schemes according to Fig 4 (a). Rebalancing findings in every machine and in every phase are indicated in Fig 4b and 4c, This follows the incorporation of dual machine system's capacity that is boosted to 36 jPh. Considering the duplication of 4-machine serial lines, novel configuration types require two different machines to attain current demands of the market.



a) Novel system configuration



b) Balancing in every machine



c) Balancing in every phase

Fig 4 (a, b, c): Scalability planning samples for improving productivity by 5 JpH

Fig 4 also indicates that other than adding two various phases, two motors are integrated to similar stages. This is because of tasks of machining that are undistributed in an even manner on every accessible phase in the chosen set-up distributed on every accessible phase in the chosen set-up plan. Machines are added to phases with the set-up that permit accessibility to additional tasks. In this manner, system throughput is effectively exploited and fundamental machine number reduced.

In each configuration as shown in Fig 3, configurations for incorporating approximately five machines to the present systems can be evaluated. Fig 5 indicates the reconfigurations for 3-stage system. Moreover, Fig 5 indicates that for a particular instance, machines are not integrated in every manner at every phase. Some of the phases tend to necessitate more machines compared to other to effective maintain its workload balancing in the system. The overall machine number and their different locations have to be integrated in the system to enhance optimization using the projected approach.

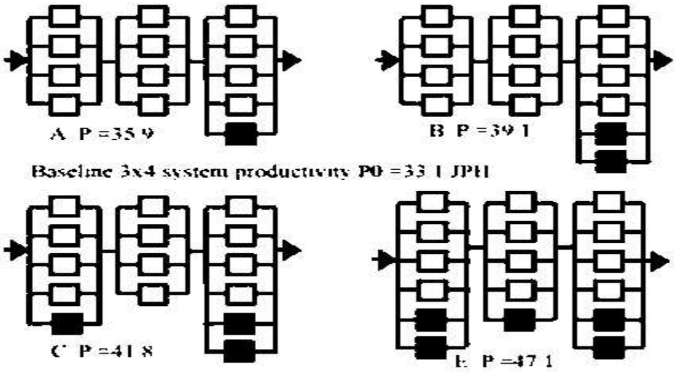


Fig 5: Reconfigurations for 3-stage system

When viewed from a cost-effective perspective, we recommend scalability planning, which is done concurrently based on the designing of novel MSs. As such, optimal location where futuristic machines have to be incorporated can be noted prior. Thus, handling of machines and systems can effectively be optimized for planning in the future durations to reduce the lifetime costs of investment. Table 1 shows a summarized data for configurations' productivity and new productivities when one to five machines are integrated to current systems.

Table 1: Summarized data for configurations' productivity

Machines integrated		**3 by 4**	**4 by 3**	**6 by 2**
Throughput of the system	0	33	31	28
	1	36	33	30
	2	39	37	32
	3	42	39	35
	4	43	42	37
	5	46	44	39
Mean throughput		39.83333333	37.66666667	33.5

From Table 1, it is evident that systems of '3 by 4' configurations provide both the largest throughput and highest original system throughput gains in every newly added machine. This is due to system balancing and system reliability aspects, which tend to diminish with the improving number of system phases. Whenever the demands of production increases for a particular system, Table 1 is fundamental to help in determining how various machines are applicable and where new machines should be installed.

V. CONCLUSION AND DISCUSSION

This research contribution has analyzed the concept of scalability and presented a novel approach of the system utilized for scalability plans i.e. addition or removal of machines to fulfill the required demands in the market. The approach in this paper uses the process of scalability planning, which simultaneously transforms the system rebalances and configuration of RMSs. Optimal remedy using GA was structured for the process of scalability planning, which is based on realistic constraints. The projected approach has been validated using an actual industrial case study. The experimental findings indicated that the proposed methodology could mitigate potential issues in scalability due to its efficiency and affordability. The paper suggests that the scalability planning process has to be viewed in a concurrent manner based on the design of new MSs. With respect to this methodology, material-handling schemes need optimization to be used for scalability planning in the future and to potentially reduce costs of investment. For simplicity, this research contribution applied the overall number of machines as its optimized objectives. Nonetheless, in real-life production, various cost factors have to be considered. These incorporate material handlers, costs of operation, floor spaces, utility, tooling and labor. Moreover, because reconfiguration process typically necessitates closing down production systems, extra expenses will be incurred because of the production loss during the process of reconfiguration. When viewed from an economical angle, the factors are entitled to the scalability of a system. Reconfigurability has various meanings according to different researchers and these definitions demand o the subjected. Some researchers have defined the concept as the capacity of MSs to be reconfigured cost-effectively and timely. NSF Centre of Engineering for RMSs considered it as the ability to change the capacity of production and MSs functionality to newer conditions by changing and rearranging components in a system. Others have defined it as an operative capacity of assembly system and manufacturing systems to potentially switch with minimal delay and effort to a certain family of workpiece and assemblies through the removal or addition of functional elements

Reconfigurability essence is to allow manufacturing responsiveness to transform marketing conditions i.e. the capacity of production systems to act according to disturbances, which may be influenced by technological and social changes. The need for reconfigurability is essentially from the company due to relevance. In some cases, an industry might be required to review its products, or to help improve completion based on the production of the same products in the market. As such, this may stimulate the incorporation of RMSs. The need for reconfigurability can be visualized from the perspective of improved customer demands, hence increasing supply. Typically, if this need has to be accomplished, it may be essential to procure sophisticated tools to replace or add to the present tools. Nonetheless, this might be time-consuming and costly, hence limiting potential expansions. Operations might be staged out of the systems due to lack of reconfigurability due to reasons discussed above.

From the above definitions, it can be seen that the main objective of reconfigurability is to attain the projected functionality and capacity needed. Reconfigurability is attained with 6-basic features: Customization, Diagnosibility, Convertibility, Integrability, Scalability and Modularity. Many researchers focusing of RMSs typically recommend MSs reconfigurations e.g. relocating machines, replacing machines, bypassing or adding machines and procuring machines, which can be reconfigured to structured MSs. Based on all these provisions, reconfiguration is possible, and it is fundamental to focus on feasibility and economic perspectives of doing so. There are special instances where movable machines are either not economical or feasible; actions cannot be commensurated with respected to profitability. As such, this contribution projects a remedy for such special instances.

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