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Process Configuration For Product Quality Enhancement Using Multi-Syntax Combinatorial Manufacturing Capabilities

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***Abstract*—Dimensional inaccuracies have been known to pose manufacturing challenges with respect to design and precision problems during production. This often results products with different degrees of structural inefficiencies that are often the source of many litigations resulting financial loses of significant proportions to the manufacturing concern. In view of this situation, this study investigated current manufacturing systems and practices and their outputs in terms of product quality frameworks and future programs for future sustainable quality delivery. The study found that most manufacturing concerns treat product quality as an external factor to the manufacturing process. This attitude results same product from same manufacturing system and conditions, but with varying and complicated dimensional mismatch at the point of service integration or parts coupling. More findings indicate the need for manufacturing capabilities with process configurations that are consistent with the retention of quality level and future prediction of uninterrupted quality stan- dard in operation; as to ensure structural compliance with design templates over a fixed period of operation. The study proposes a scale-up in manufacturing strategy and quality delivery by the application of multi-syntax combinatorial manufacturing possibilities where individual components of a machine are produced simultaneously and concur- rently within the logic of their in-service operation using any of the three proposed typologies. The significance of this venture is to reduce or eliminate issues of dimensional inaccuracies resultingfrom misalignments on accounts of vibration and motion transients due to unleveled ground surfaces and process inclinations.**

Keywords—automated manufacturing, processes control, quality strategy, innovative re-engineering, subtractive manufacturing, predictive evaluation, Modulo-N Binary counters, logical controllers

I INTRODUCTION

Manufacturing is defined as a processes of converting raw materials into finished products in such a way that consumer or user satisfaction is guaranteed. Thus, manufacturing deals with the technical and industrial capabilities required to enhance
the national productivity of a country. This imply that manufacturing is a form of creative and innovative treatment of raw materials within some pre-determined specifications, under well-structured additive or subtractive conditions [1]. In all, manufacturing as a transformative process is commenced at the point where a product or system is conceptualized and progresses into architectural, configuration and parametric designs where part geometry, tolerances, material choices, planning, etc. become the basis of the production process [2].

In the foregoing regard, manufacturing process configuration is crucial in the determination of quality output for all range of products. Hence, cutting edge manufac- turing processes deserving of significant investment must be promising at least to instill confidence in the investors of such projects.

This imply that such projects must be designed with some level of flexibility in terms of adaptability to new products without total redundancy or discarding of such projects on the basis of obsolete condition of operation. In this regard, the plants and equipment should be designed to maintain a continuous flow of products that meets or supersede consumers' quality benchmarks; without any opportunity for rejection of such products on account of technical or dimensional inconsistency. Studies have shown that manufacturing processes that are capable of achieving this feat are designed to maintain some level of flexibility while structurally designed to achieve specific standardization with significantly high productive index [2]. Such systems are compulsorily automated with minimum opportunity for human interference given the nature of their tasks.

Consequently, the active technologies required for this level of automated manufacturing are constantly facing challenges of upgrades and operational parameters redefinitions instituted to ensure newly discovered materials match appropriate conversion technologies [3].

Notwithstanding the foregoing, the unit or multiple operations of such manufacturing cells commences with product planning activities. This scoping stage produces the required or intended processes, machines and methods of converting the identified raw materials. Accordingly, the design of a product requires a proper understanding of the functions and level of performance required of that product [2].

Consequently, manufacturing functions encompasses a number of activities directed towards design and production to the distribution of the finished products and feedback assessment from consumer responses. Thus, the study observed that life cycle support for manufactured items is crucial to product standards, process standardization, product reviews and redesign, which is a complex activity involving, (i) product design (ii) machinery and tooling (iii) process planning (iv) materials management (v) production control (vi) support services (vii) sales and marketing (viii) shipping etc.

In view of the foregoing, automated manufacturing operations can be analyzed into six critical aspects, namely,

(i) the nature and structural composition of the materials being processed,
(ii) process equipment (machines and assembly lines),
(iii) manufacturing methods applicable to the nature of material and type of product,
(iv) equipment calibration, control and maintenance,
(v) skilled workforce and technicians,
(vi) other relevant and enabling resources.

This paper thus view the main categories of traditional manufacturing as follows:

(a) Discrete item or process manufacturing: - these are manufacturing processes that impact pre-determined physical shapes and structures on materials during the transformative process. This is achieved either as a material additive process or a subtractive process. They are further referred to as unit manufacturing operations.

(b) Continuous materials processing: - dealing with pre-processing of materials for other applications in other manufacturing conditions, as in the case of metals processing.

(c) Micro- and Nano-fabrication with mechatronics: - this borders on very tiny parts defined in millionths of a meter, with very magnified capabilities which refers to the creation of small physical structures which in in the near future would be the basis of most advanced manufacturing.

Consequent on the foregoing, it can be safely said that manufacturing is the process of converting raw materials to finished products using well defined processes and production systems. Thus, materials constituents and compositions are impacted upon on the basis of the specific design and production syntax; which may be an additive or subtractive process that meets customer satisfaction and other manufacturer's objectives[4]. Accordingly, manufacturing process takes place when there are materials or energy input into a concept which causes a change in the structural characteristics of the original material or concept. This input achieved by means of a production system may be additive or subtractive in nature and results production output that provides the needed result in the form of a product [5].

MULTI-SYNTAX COMBINATORIAL MANUFACTURING PROCESS

It should be stated that, combinatorial manufacturing represents an interacting integration of combination of multi-level manufacturing complexities including labor, raw or processed materials, tools, machines, automation, software facilities, and procedures designed to work together or in combination with other processes or systems, for the purpose of producing items of the type of quality which meets manufacturer's objectives and customer satisfactions.

Thus, multi-syntax combinatorial manufac-turing process is designed to provide the production strategy which enables the production of the specified products on a concurrent or simultaneous basis. This specialized approach of multi-scale manufacturing provides the needed technology for enhanced production output thus magnifying the efforts of individual workers in turning raw materials into finished ready to use products at very competitive and cost effective condition. Hence, production is achieved within time with standard quality touch on the basis of computer aided manufacturing (CIM) which generally increases the required manufact- uring flexibility [6].

This paper thus posits that there is a close link between the quality of the product and the choice of manufacturing process to implement the design strategy for the product. In view of the foregoing, an appropriate manufacturing technology as this, is normally needed to generate products of high structural dimensional precision and quality since the deployed or applied technology is the principal quality determinant [7].

Consequently, multi-syntax manufacturing process as proposed in this paper, should possess capabilities to engender products of predictable quality and conformity and must at the level of productivity keep the production cost under feasible control as to determine the future conditions of those products. Thus, combinatorial manufacturing must be unique and has to be developed by innovative re-engineering of existing production processes[8].

In the foregoing view, the choice of manufacturing process plays very significant role during the process of raw materials conversion into finished goods on the basis of the desired quality. Consequently, multi-syntax combinatorial manufacturing process consists of operations which involves flow of materials and conversion procedures, design of the processes including the layout, use of the appropriate and necessary equipment, and cost of the end product. It also includes the machines, equipment, tooling, monitoring and inspection instruments, and devices which contribute to an operation transforming the input materials to the specified products based on the specified manufacturing processes and procedure intended for the expected outcome [7].

Thus, multi-syntax combinatorial manufa-cturing delivers value to the input materials and subsequently provides the customers the desired products within specified tolerances, standards and specifications. As an advanced manufacturing strategy, it diminish manual labor and human interference which are generally involved during the process of manufacturing [8, 9].

In view of the foregoing, it should be noted that manufacturing process is mainly used to impact the desired quality in the product and it is of more benefit to the process when it:

(i) predicts product quality based on the nature of the materials and the operational conditions of the production process, [10]

(ii) is dependent on scale-up operating conditions and priorities with the intendment of improvement in the product quality, and [1]

(iii) detects faults or malfunctions in the process and/or equipment for preventing undesirable operation and production of the products which have been identified and eliminated and as such, the process runs within the technical specifications. [2].

CATEGORIES OF PROCESSESFOR MULTI-SYNTAX COMBINATORIAL MANUFACTURING

As opined above, multi-syntax operational conditions of combinatorial manufacturing can be applied or implemented to production process where the needed manufacturing activities are related in terms of general attributes and materials processing requirements. These are as follows:

i *subtractive manufacturing and material removal operations:* - these includes sawing, drilling, milling, turning (lathe), and all forms of abrasive machining, and dependent surface finishing, unconventional machining such as wire EDM, etc.

ii *deformation manufacturing or materials shaping through heat or pressure*: - these processes include, casting, rolling/ forging, extrusion/drawing, sheet metal forming, etc.

iii *additive manufacturing and material shaping by surface deposition*: - these processes utilize materials addition at defined parameters and dimensions. They include operations such as powder metallurgical processes, 3D printing, specialized precision control welding services and unconventional manufacturing such as chemical machining.

iv *materials joining technologies*: - mechanical fusing of two or more materials: - these processes include, welding, brazing, soldering, adhesive bonding, fastening, etc.

APPLICATION OF MODULO-N BINARY COUNTERS IN MULTI-SYNTAX COMBINATORIAL MANUFACTURING

The use of *Modulo-N Binary Configuration* in the enhancement of quality production activities consider the integration of the various manufacturing conditions into a single manufacturing cell with each manufacturing type referred to as a *sub-manufacturing cell* under this strategy, the sub-manufacturing cell are structurally integrated to a central control hub where each operation is digitally assigned, under a *Modulo-N Binary Configuration* which serves as the control interface for signal generation and transfer. In that regard, equipment grouped into the following distinct forms of manufacturing can be simultaneously deployed within their assigned time frame and energy resources input. This invariably imply that the central hub is the control platform for energy and operational signal transfer.

In view of the foregoing, manufacturing systems are broken into;

i. subtractive manufacturing and material removal
ii. deformation manufacturing and material shaping
iii. additive manufacturing and material shaping by surface deposition
iv. material joined technologies

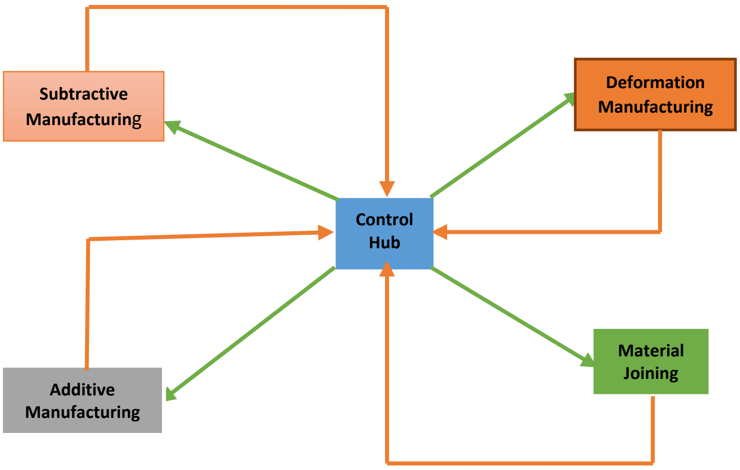


Fig 1: multi-syntax combinational assembly of various manufacturing system

In view of Fig 1 above, advanced manufacturing with integrated modern open control capabilities allow access to internal signals in the numerical controller with respect to operational signals such as current and power [11]. Thus, appropriate software can be integrated into the CNC terminal at the machines and linked to the *central control hub* through human machine interface (HMI) [12]. Thus, the internal control parameters and strategies have been designed to synchronize with Adaptive Control Optimize (ACO) and Adaptive Control Constraint (ACC) which are activated by the use of internal control signals and additional sensor implants [13] for high quality signal information acquisition for decision. This proposed manufacturing template utilizes the high sensitivity conditions of internal signals that were returned to the hub as feedback and signal compensation resources [14].

The foregoing implies that high quality signal information for manufacturing processes of this nature can be obtained real-time by the installation of high sensitivity signal sensors at the operational nodes of the manufacturing facilities [15]. Studies have further indicated that thesensitivitycapacity of these sensors are designed to precisely define the characteristics of the signals as to determine the compensation strategy that is required in situations of operational low output or complicated signal structure. The imperative of this investigation from the view point of this study is significant since such predictive evaluation of real-time component behavior has been applied in motor and drive train dynamics. [16,14] to demonstrate the possibility of optimizing and operationalizing of signal relativities with the view to enhancing their remote controllability based on feedback signals from implanted sensors [16].

CONTROLLER BASED MULTI-SYNTAX MANUFACTURING

It should be stated that the proposed multi-syntax manufacturing is operable on the basis of process connectivity. Thus connectivity under integrated manufacturing conditions is defined as the ability of each system element to communicate with every other system element within the framework of the particular integrated system of manufacturing [6].

Hence integrated manufacturing is intended to be made operational by high level of co-ordination and efficiency of operation, utilizing high speed extensive and interactive local area network (LAN) composed of software interlaced on approximate hardware. This communication connectivity utilizes logically arranged signal flow sequence which brings the various phases of the multi-syntax capability into a unified operation [17].

In view of the foregoing, it has been observed that local network could be substantially large, connecting hundreds and thousands of machines and devices that are located within several facilities into one central control hub [17]. Connectivity for such manufacturing operation using network layouts of fiber optics or copper cables can be inter-connected in a single framework.
Thus various manufacturing networks can be arranged in forms of simultaneous production activities; such network of manufacturing functions could be linked through gateways and bridges, in order to prevent access control collision in terms of feedbacks and compensation signals. However, the transmission of input signals can be done simultaneously under well-defined LAN arrangement.

With respect to the proposition of this paper, three characteristic equations namely; R-S type Configuration, D-type Configuration and T-type Configuration shall be used alongside their truth tables and excitation tables. These logic control resources are defined within *Modulo-N Binary Counters* and follows from the logic that where there are 2^N combinatorial syntax of *0s* and *1s* consisting of *N bits*, then the input *0s* and *1s* are arranged to mirror or follow each other in such an up-and-down array of logical counting.

(i) STAR NETWORK MULTI-SYNTAX MANUFACTURING OUTLAY

This manufacturing cell typology can be deployed under conditions where the structural outlay and signal logics are configured to some extent of permanence. Implying that such designs are not subject to frequent changes. Control sequence for this type of manufacturing outlay is transmitted from a central station where all input signals are processed and feedback are analyzed to indicate the operational health of the machine and all range of sensitivity [13].

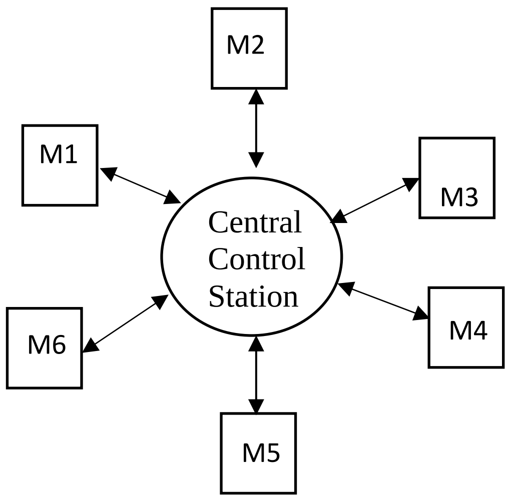


Fig 2 schematic of star network multi-syntax manufacturing outlay

To illustrate the operation of the *Modulo-N Binary Counter* under the star network multi-syntax manufacturing the following D-Type truth table and excitation table is designed in line with equation (1), thus:

$$Q_{t+1} = D \qquad (1)$$

Table 1: Truth table and Excitation table for the D-type Flip-Flop

Truth Table

D	*Q_t*	*Q_{t+1}*
0	0	0
0	1	0
1	0	1
1	1	1

Excitation Table

Q_t	*Q_{t+1}*	*D_i*
0	0	0
0	1	1
1	0	0
1	1	1

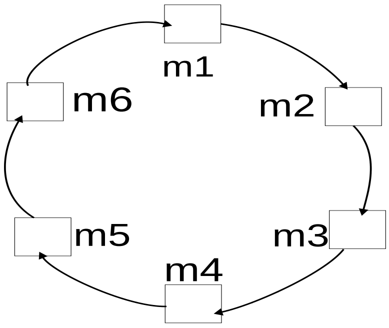
where D = process input Q_t= current state, Q_{t+1}= next state

Thus, under multi-syntax manufacturing application, star typology could be deployed to respond to production situations where the process modality requires intermittent interjections in work flow; this situation mainly occur where logically based process switching is required to be activated. With respect to the proposition of this paper, multi-syntax manufacturing and production template rely on the signal transmission of integrated logical controllers.

(ii) RING TYPOLOGY MULTI-SYNTAX MANUFACTURING CELLS

The proposed ring typology multi-syntax manufacturing cells could be designed for manufacturing situations where different and divergent machining operations are connected in a continuous ring of production sequence of individual component or part manufacture for assembly or integration.

This imply that all components for a given item or machine are designed and manufactured in sequence of their logical operations; implying that the suitable manufacturing cell for this typology should be encased in a ring form for which each component's method of manufacture differs from the other but they are all synchronously and simultaneously combined and components integration is achieved in the direction of the arrows from machine m1 to m6 as shown in Fig 3.



User Station for control

Fig 3: schematic of ring typology multi syntax manufacturing cells

Thus under this multi-syntax manufacturing, the parts or units are processed or operated upon from the user station located outside the ring. It is important to note that the user station is a CNC enabled facility with full access control on the operational conditions of the machines. Thus, machine parameters can be altered for new set of manufacturing from the external control point. Using the flip-flop type of R-S for ring typology of multi-syntax manufacturing, we have;

$$R - S \rightarrow Q_{t+1} = S + R\overline{Q_t +} (SR = 0) \qquad (2)$$

This characteristic equation (2) is deterministic for a parallel manufacturing function distribution of the ring typology for which a truth table and excitation table could be stated thus;

Table 2 Truth Table for R-S flip-flop and Excitation table for R-S flip-flop

Truth Table

S	R	Q_t	Q_{t+1}
0	0	0	0
0	0	1	1
0	1	0	0
0	1	1	0
1	0	0	1
1	0	0	1
1	0	1	1
1	1	*x*[a]	*x*
1	1	*x*	*x*

Excitation table

Q_t	Q_{t+1}	S	R
0	0	0	d[b]
0	1	1	0
1	0	0	1
1	1	d	0

Note: [a]-not allowed, [b]: don't care

where, S= state of the unit cell
Q_t= current state
R= output data or signal
Q_{t+1}= next State

The logical sequence above operates as signal input and output counter and indicative of control framework for the ring typology multi-syntax integrated manufacturing cell. Thus, each *0s* indicate data values in *bit* that may signify a particular action for a fixed duration. On the other hand, *1s* indicate another opposite state of the unit machine which is in consequence of the previous state.

The condition of these up-and-down state is thus reported as a feedback signal which can be reviewed or sustained for the particular unit cell to either follow the internal operational control configuration or change the signal.

Thus, the signal flows from one-unit cell to another until it reaches the targeted cell. Since signal transmission from cell to cell is simple, a breach of one cell can bring the entire process to a halt.

(iii) BUS MULTI-SYNTAX MANUFACTURING TYPOLOGY

The design of bus multi-syntax manufacturing typology requires that all manufacturing cells have independent access to the bus.

Using the Truth table and Excitation table to illustrate the foregoing, the signal processing for the bus multi-syntax manufacturing typology produces the following table for the T-type syntax, based on equation (3), thus;

$$Q_{t+1} = TQ_t = \mp Q_t \qquad (3)$$

Table 3: Truth Table and Excitation Table for the T-type Flip-Flop

Truth table   Excitation table

where T= process input (for T-type), Q_t=current state, Q_{t+1}= next State

This typology is relatively simple in terms of maintenance when compared to the two previously proposed models in this study. As could be seen, between the original process input condition, T and the process input condition at the excited state T_i, we could notice that while $T = 01 \ldots 1$, $T_i = 11 \ldots 0$ implying that the unit machines or plants are independent of each other as they individually derive signalsor energy defined for the specific task they are required to undertake. Although their signal or energy are from the same stream of source (bus), but at different signal frequencies. Thus, the signal for machine *m1* is useless formachine *m2* application or any other machine in the syntax.

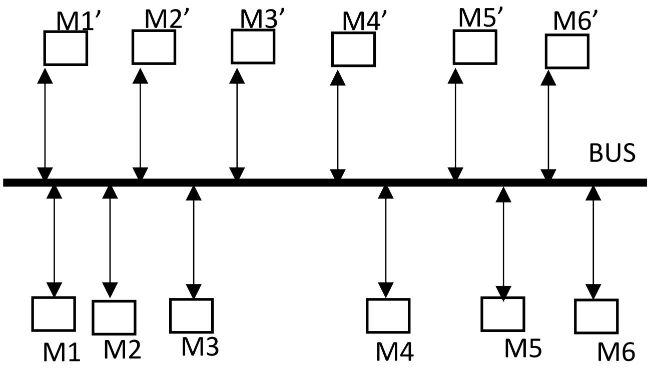


Fig 4: schematic of bus multi-syntax manufacturing typology

DISCUSSIONS

The three typologies under consideration for the multi-syntax manufacturing capability has largely depended on the possibility for concurrent or simultaneous manufacturing of various components of a system where signal instructions are transmitted from a central terminal that can be effectively located at any point depending on the manufacturing syntax typology adopted for the manufacturing process. In this regard, the application of high level machine language, algorithms and codes are necessary for implementation of such strategies. Consequently, these digital programs and codes would assume the platform of logic controllers and systemic logic gates for signal transmission, interpretation and implementation.

In furtherance of the foregoing, it should be

T	Q_1	Q_{t+1}
0	0	0
0	1	1
1	0	1
1	1	0

Q_t	Q_{t+1}	T_i
0	0	0
0	1	1
1	0	1
1	1	0

noted that the up counter has a sequence of $00\ldots0_2$ to $11\ldots1_2$ for which its *Modulo-N Binary* equivalent is $(2^N-1)_{10}$, while the binary down counter is expressed as an opposite sequence of $11\ldots1_2$ to $00\ldots0_2$. The design of this counter in support of the proposed multi-syntax manufacturing, took into consideration, this identified three flip-flop types proposed for the (i) star manufacturing cell typology (ii) ring manufacturing cell typology (iii) bus manufacturing cell typology.

In view of these typologies, it is imperative to state that intra- multi-syntax manufacturing of various parts or components of machine can be simultaneously achieved taking cognizance of the peculiar features of the part and the synergies between appropriate machines.

Additionally, combinatorial manufacturing in this regard can take into consideration various advanced manufacturing tools, such as machines vision [17,18], expert systems and artificial intelligence [19] in addition to the conventional CAD/CAM applications. Thus, the logical controller under this specialized manufacturing strategy would integrate all these resources and more through a user friendly interface.
Further, a careful observation of the Truth table and Excitation table for the specified manufacturing cell typology indicates a common pattern between the current state, Q_t and the next state Q_{t+1}, in the sense that if the current state of the counter is *2*(i.e. 11), an addition of *1* will cause the counter to change to 3 (i.e. $11…1_2$) while an input of *0* will cause the counter to count down to 1, $(10)_2$.

CONCLUSION

In view of the discussions on the design for various models of multi-syntax manufact- uring, it is important to state that a summary of tables 1 to 3 would therefore yield the state transition diagram that can be used to indicate the *modulo-4 binary up-and-down counter*, representative of the multi-syntax manufacturing control for sim- ultaneous manufacturing of the components of a machine with different manufacturing system requirements. The implication of these models to modern manufacturing capabilities is that they promote efficiency of scale in the manufacturing of products with varying technical challenges.

This imply that design for machines with this type of capability must be made in line with the structural conditions and orientation of the materials and workpiece that they are to process. This concurrent machine-material interface is capable of producing items that have a direct copy impact of the machines. Hence, subsequent manufacture of such items using these machines after the first run would continue to increase the efficiency of scale due to better understanding and internal adjustment of the machine during its learning process within the manufacturing life cycle.

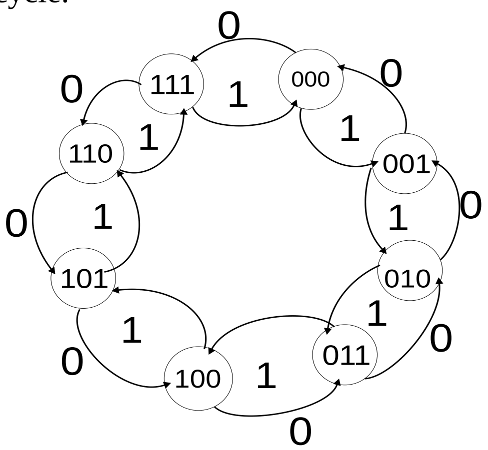


Fig 5: state transition diagram for an up down counter

In Fig 5 above, the manufacturing cell show combination of logical sequence of operational signals; such that each *0s* or *1s* represent instructional data with operational values in terms of expected behavior of a particular machine at any point in time. Secondly as should be noted, the manufacturing cells can be operationalized to heuristically learn from its independent operations or in association with other machines and also perform such tasks that, it has been self-taught within defined limits and resources.

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