Similarities between Manufacturing and Biological Cell and its Impact on Development of Autonomous Control

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Abstract— For timely response to the rapidly changing manufacturing environment and markets, future manufacturing systems tends towards flexibility, adaptability, and selforganising. Bionic, holonic and fractal manufacturing systems have emerged as potential candidates for the next generation manufacturing systems. In this paper, these methods are used to show how biological systems have inspired control methods in manufacturing.

Index Terms— Manufacturing Systems, Bbiological Cell, Scheduling, Autonomous System, Fflexible Manufacturing,Job Shop, Assembly/Disassembly System, Reconfigurable Manufacturing System, Flow Lines

1 Introduction

The paper will illustrate the manufacturing system as an objective-oriented network of process activities through which flow of material occurs [1]. Manufacturing is concerned with the transformation of materials into items of greater value by means of one or more processing and/or assembly operations [2].

Many recent studies in manufacturing systems have reported continuous changes in the production processes caused by variability of many kinds [3]. The inclusion of variability in scheduling in manufacturing and service work environments may be improved further by adopting some principles of biological control providing highly autonomous decision-making functionalities, as founded in gene transcription and translation processes.

Scheduling is a core manufacturing tool both on strategic and operational levels. Each manufacturing activity exhibits a level of variability, which may be taken into consideration during the scheduling process. Future scheduling of manufacturing activities will have to adopt strategies and methods founded outside manufacturing as in biological systems.

Biological processes have been found to display a number of similarities with manufacturing systems and in particular, production lines. Because of these similarities, attempts have been made to learn the structures and behaviours of biological systems with the aim of establishing the possibility of adopting biological control principles into manufacturing.

This paper presents the useful similarities between biological systems and manufacturing systems. Some basic principles of biological control are underscored in line with the fundamental principles of autonomous decision-making functionalities of these systems with a possible application to manufacturing is presented.

2 Types of Manufacturing Systems edure for

Wide range of products manufactured hence several different types of manufacturing systems are identified each meeting unique demands and characteristics of the product.

A number of manufacturing systems based on the physical layout of the manufacturing resources and, hence, the types of material flow in the systems as follows:

1. **Job Shop System:** a process structure where small batches of many custom products are made. Job shop process flow has most of the products produced that require unique setups and sequencing of processing steps [4].
2. **Flexible Manufacturing System:** a manufacturing system that has some amount of flexibility presents to react in the case of predictable or unpredictable changes. It consist of automated machines and material handling system and controllers to control the machines and the material handling system [5, 6].
3. **Assembly/Disassembly System:** characterised by parts waiting for the resource to become available and for the other parts of the assembly to arrive before processing can begin [7]. It is associated with a set of input and output buffers. The station becomes starved if one of the input buffers is empty, and it is blocked if one of the output buffers is full.
4. **Reconfigurable Manufacturing System:** a machining system which can be created by incorporating basic process modules, both hardware and software, that can be rearranged or replaced quickly and reliably [8]. It allows adding, removing, or modifying specific process capabilities to adjust production capacity in response to variability of whatever kind.
5. **Manufacturing Flow Line:** consist of stations with buffers where parts route in specified sequence. Kha-

lil [4] identified three types of flow lines in manufacturing based on the type of parts transfer method: (a) synchronous, (b) asynchronous and (c) continuous. Flow lines with synchronous part transfer are called transfer lines and flow lines with asynchronous parts transfer are called production line. Flow lines are high-volume production systems, and layout of the machines and buffers is dedicated to a few families of products. Flow lines are affected by the reliability of machines and buffer sizes.

6. **Cellular Manufacturing System:** a methodology for organising the design and operation of a wide range of manufacturing systems so that the advantage of mass production and flexibility of job shop manufacturing can be derived from the production system.
7. **Agile Manufacturing System:** a dynamic manufacturing setting which allows rapid reconfiguration and is highly adaptive to quick market changes through widespread use of information technology [9]. This requirement for manufacturing to be able to respond to unique demands moves the balance back to the situation prior to the introduction of lean production, where manufacturing had to respond to whatever pressures were imposed upon it, with the risks to cost, speed and quality.
8. **Sustainable Manufacturing System:** creation of goods and services using processes and systems that are nonpolluting, conserving of energy and natural resources, economically viable, safe and healthful for employees, communities, consumers and socially and creatively rewarding for all working people

This paper is more concerned with the manufacturing type of interest is flow lines because it exhibits similarities with biological processes in gene transcription and translation processes and in this flow lines operations lead to a final product in terms of goods or services.

3 MANUFACTURING AND BIOLOGICAL PROCESSES ECTIONS

The structure and behaviours observed in biological processes from the cell level to the whole system expose some important principles of control applicable to manufacturing. For example, flow production can be likened to biological systems, where each machine will have certain abilities and functions to make its only decisions independently, but, with cooperation with other machines, can achieve the overall goal of the manufacturing systems (intermediate goals or finished products) responding to variability at all times [10].

Raw materials, parts and control information circulate in predefined ways, and the products and information from the processes are sent again by corresponding mechanisms to the machines that initiated the need. The properties of biological systems and manufacturing units uncover a lot of similarities [11].

Two groups of similarities have been identified between biological and manufacturing systems:

1. Structural
2. Operational

Some structural similarities between manufacturing and biological cell have been identified [12, 13, 14, 15]. Figure 1 and 2 shows the structure of a basic manufacturing system and biological cell. Similarities between the two systems are tabulated in Table 1.

The operational similarities between biological and manufacturing systems comprise the control features that run the structures identified to achieve the set goals.

i. Flow of information and material among different machines in production flow lines [16]. In biological system, this translates to systematic series of actions directed to the achievement of a goal
ii. In manufacturing, there is a structured measured set of activities designed to produce a specified output for a particular customer or market. Biological systems, generate highly ordered and complex structures from simple options, stores information for making choices between different options, and transmitting adequate instructions to the correct places;
iii. Comprise of a large number of different machines (as enzymes for biological systems) where many events take place such as assembling, processing, breakdowns, planned and unplanned maintenance. This can be presented as sources variability which include, mean time to repair (MTTR), mean time to failure (MTTF), and % rework and change over [12];
iv. Ability to measure completed job represented as throughput, equivalent to metabolic flux through a certain pathway in biological systems [15];
v. Degree of flexibility to manufacture mixed products which is the need of nowadays successful manufacturing system [17]. Gene transcription and translation regulatory proteins can have different roles for different genes, and this is one mechanism by which cells can coordinate the regulation of many genes at once;

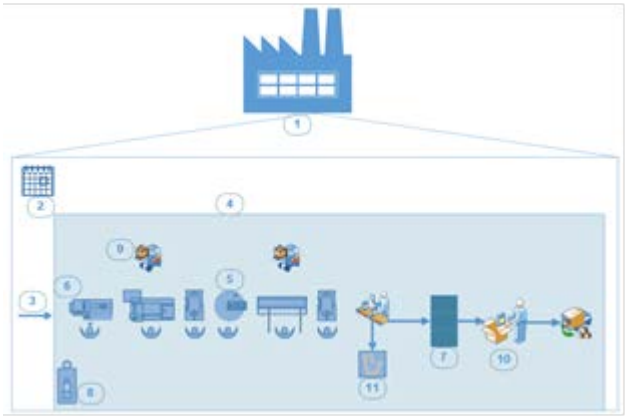

Figure 1. Structure of manufacturing system

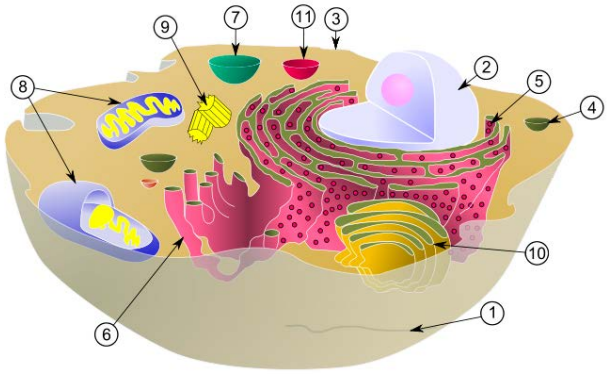

Figure 2. Structure of animal cell

Table 1. Structural similarities between manufacturing **and biological cell**

	Manuf. Element	Function	Biological Element	Function
1	**Plant**	Factory premises	**Cytoskeleton**	- Provide shape - Give structural support - Transport substances around the cell
2	**Planning and scheduling logic**	- Manage and control activities - Initiate production	**Nucleus**	- Coordinate activities including growth and reproduction
3	**Entry Point**	Receive goods	**Cell membrane**	- Define and compartmentalise space - Regulate flow of materials - Detect external signals
4	**Shop floor**	Factory floor where products are assembled, finished and shipped	**Cytoplasm**	- Hold the cell organelles which control all the activities of the cell
5	**Machine/working area**	Machines which can include conveyor belts and robots	**Ribosomes**	Produce Protein for the cell
6	**Assembly Line**	Machines, tools and operators	**Endoplasmic reticulum**	Used in the manufacture, process and transport of chemical compounds
7	**Storage area/ buffer**	Store different levels of inventories of finished products or WIP	**Vacuole**	- Maintain fluid - Remove waste - Store ingested food
8	**Energy producer/ Generator**	Produce energy for the plant	**Mitochondrion**	Generate energy required for cellular activities
9	**Transport**	Move the materials among different machines/working areas	**Centrioles**	Organise cell organelles by moving or pulling chromosomes.
10	**Packing and Dispatch**	Packs products for distribution	**Golgi bodies**	- Sort proteins - Packs proteins into membrane wrapped structure called vesicles
11	**Scrap area**	Scrap parts that are out of specifications	**Lysosome**	Breakdown unwanted cell organelles

4 Manufacturing Control Methods Adopting Biological Reorganisation

In recent years, manufacturing systems have changed significantly in order to synchronise with the rapid changes in manufacturing environment and markets. Researchers have investigated adapting biological reorganisation in manufacturing systems in order to make them more adaptive and responsive to the dynamic changes in manufacturing environment. Bionic, holonic and fractal manufacturing systems have therefore emerged as potential candidates for the next generation manufacturing systems.

Biological processes can be considered at many levels of detail, ranging from molecular mechanism to general processes such as cell division and transcription and translation.

The representation of hierarchical process knowledge in biology has been approached by a variety of methods:

a. Bayesian Network – this method represents independence and dependence relationships between variables and the links represent conditional relationships in the probabilistic sense [18]. Bayesian network method assumes that expression of some entity is a function of only expression of level of other entities in the system. However, this is not always the case since some entities do not interact directly with each other, instead they do so by means of mediating factors or agents are represented by the introduction of hidden variables, making the method hard to explain and follow [19].

b. Neural Network – unlike the Bayesian networks, neural networks have no relationship, dependent or independent between variables and in fact the intermediate nodes are discovered features, instead of having any predicate associated with them in their own right [20].

c. Stochastic Network – provides an intelligent design and control method to describe the potential for coherence among several processes and characterise the control strategies that achieve it [21].

d. Boolean Logic – Boolean logic is a building block for modelling complex, large-scale and dynamical networks of genetic interactions where the expression level of each involved factor in the process is functionally related to the expression states of some other entities using logical rules [22]. The expres-

sion of an entity corresponds to the entities being expressed with the required inputs being present. Time is viewed as proceeding in discrete steps; the new state of a node is Boolean function of the prior states of the nodes together with other required inputs. Boolean network are in the form G (V, F) defined by a set of nodes (gene) V = {x1, …,xn} and a list of Boolean functions F= (f1, …, fn). Each xi ∈{0, 1}, i = 1, …,n is a binary variable and its value at time t + 1 is completely determined by the values of other nodes or products at time t by means of Boolean functions.

Table 2 highlights the comparison aspects of FrMS, HMS, and BMS. The three systems are examples of systems adopting the functionalities of biological systems but tend to be very hierarchical in operation. Although the control is easy to understand and has less redundancy, they are not fast responding to variability affecting all levels in the hierarchy. Furthermore, these methods face difficulties in handling the ever-changing customer needs, since the hierarchical control architecture is not flexible in reconfiguring the shop layout.

Table 2. Comparison of Fractal, Holonic and Bionic Manufacturing Systems [23]

Feature	Fractal Manufacturing System	Holonic Manufacturing System	Bionic Manufacturing System
Basic unit	fractal (BFU): autonomous	holon: autonomous & cooperative entity	cell (Modelon): biological entity using DNA and Enzyme concepts
Creation of unit	predefined but dynamically reproduced or reorganised by the self-organisation	predefined and dynamic but limited to rule & functional decomposition at design time	predefined but dynamically reproduced by the evolution & self-organisation
Unit function	predefined but can be dynamically reassigned as new functions during operating time	predefined, new holons (or set of holons) with functions can be defined at design time	new modelons with required functions can be defined at design time, or can be divided or merged during operating time
Flexibility of unit	flexibly react to the environmental status through the dynamic restructuring process, self-optimisation, and self-organisation	flexibly react to the change of status of other holons through cooperation and negotiation	flexibly react to the changes in operating environment following the biological approach
Group creation	dynamically redefined as a fractal (an individual or a set of fractals)	holons in holarchy to support specific functions are define	as an organ through cell division to support required functionality dynamically
Reconfiguration	change fractal structure by constructing new fractals or reassigning new functions to existing fractals	change resources by re-allocating resources to holons subject to fixed canons with stable intermediate forms	change process flows by re-arranging flow lines of live (available) cells

In gene transcription process decisions are taken autonomously based on prevailing circumstances by, (i) evaluating the process' own performance, (ii) adjusting accordingly and (iii) sending synchronisation signals to other units of the mechanism. This is done to ensure that the gene expresses at the right time thereby not causing any harmful effects to the biological cell. Autonomous decision-making processes as evidenced in gene transcription and translation are characterised by a shift of control capabilities from the total system to its elements (distributed control) [24].

In developing a finite capacity Scheduling control logic based on biological control concept, some of the abilities of autonomous system are used so as to aid in reducing the excessive use of highly skilled manual input in manufacturing planning and scheduling. Some of the additional capabilities of autonomous systems may include:
a) Improvement of performance through learning; and
b) Coordination with other autonomous systems in collaborating to execute a wider objective.

Biologically inspired control methods are characterised by sets of rules for autonomous decision-making and indirect communication of the machines and other resources. Figure 3 shows the idea of this regulated finite capacity scheduling approach. In this approach, every machine or resource is autonomous and has limited knowledge of the whole objective of manufacturing system; the control emerges, as a whole, from the interaction among the distributed machines and resources of the system with each contributing with its actions based on local optimisations.

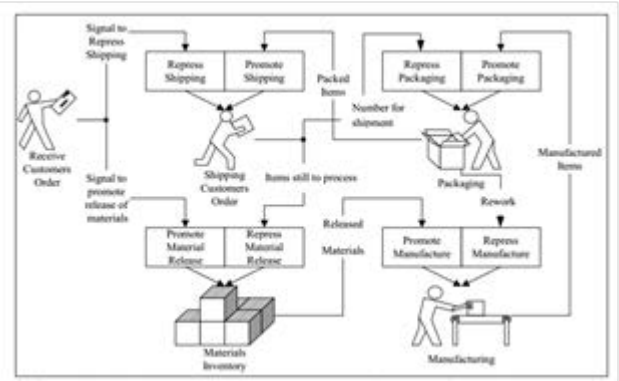

Figure 3. Regulated Finite Capacity Scheduling Approach (Stockton et al., 2008)

5 Results And Discussion

Modelling of finite capacity scheduling assumes that all the production requirements (such as cycle time, setup time, inter-arrival times, etc.) from customer orders are available to contribute to an optimal solution with consideration of the variability in these requirements. In this paper, the variability of production requirements or factors is taken into consideration to determine the process variability of machines which contribute to the determination of the whole system set performance measurements. Also from the process variability the finite capacity availability of the processing machines was determined.

By adopting biological control principles, three different interaction mechanisms are identified:
a) determination of variability in input finite capacity control factors;
b) determination of machine variability, such as % waiting, % blocking, % stopped and % working, caused by variability of input control factors; and
c) estimation of the recovery time (which in this case is the mean time to repair (MTTR)) from the disturbance that caused the variability and hence taking the appropriate processing action.

These interactions are modelled using Simul8. The variability in scheduling factors is simulated in the model to determine the process variability of the machines. This information together with principles learnt in biological control can be used to develop an autonomous finite capacity scheduling control logic to be used to manage resource allocation to manufacturing activities, thereby reducing excessive manual input involved in scheduling.

4 Conclusion

The systems have been considered as a good illustration of systems operating with high uncertainty due to variability of orders that are not easy to predict..

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