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Agent Based Model for Complex Flow Shop Manufacturing Systems with Customer-Related Production Disruptions

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***Abstract*— There have been number of frameworks and approaches proposed for the study of complex flow shop manufacturing systems. However, due to the continuous effects of customer disruptions such as cancellation, change in sequence and due time on flow shop production, there arise need to develop an adaptive system to respond to the effect of such disruptions. In this ongoing PhD work, we develop a Framework and Agent-Based Model to simulate flow shop production line and investigate the disruptions consequences and recovery strategy. An experimental case study using an Original Equipment Manufacturer (OEM) factory for automotive parts is adopted to verify and validate the proposed system. The new understanding presented in this work offers informed decision-making policies for manufacturing production activities**.

Keywords—agent-based modeling; manufacturing systems; production disruptions

I. INTRODUCTION

Modelling complex system such as manufacturing systems operation can be a challenging task as specific system entities' attributes, behavior and how they interact is crucial to understanding complex system requirements. Developing a model habitually requires a high level of details relevant to study interest, in which the choice of representative model solely relies on.

Manufacturing system is an important part of supply chain network, considered as one of the driving forces and significant contributor to national economic growth [1]. In automotive manufacturing sector, Original Equipment Manufacturer (OEM) serve as the main source of parts and components supplies [2]. OEM in itself is a manufacturing system whose finished products constitute material components for automotive manufacturing. In most cases, automotive manufacturer depend on OEM, and OEM production processes are triggered by customer (automotive manufacturer) orders. In actual sense, OEM production processes are not only controlled by customer orders but customer order irregularities, causing various types of disruptions in the production flow shop. Manufacturing production disruption types such as: change in order sequence of production, order cancellation by customer and change in the delivery due time collectively and individually constitute huge impact on manufacturing flow shop, with significant consequences on the entire manufacturing system operational performance. In the light of these disruption problems, system entities (agents) suffer over-utilization or lack of utilization of available resources and other risks as a result of changes in the system environment.

In the recent time, Agent-Based Modeling (ABM) is gaining attentions as a technique in the area of complex system modelling [3]; [4]; [5], especially in a rapidly changing complex system environment [6].

Using ABM approach, this paper presents the proposed framework and simulation modelling of the behavior and operations of complex manufacturing systems in response to production disruptions.

The rest of the paper is organized as follows: section II presents some selections of relevant and related works in the area of manufacturing disruptions, and the application of ABM in manufacturing system context. Section III discusses the problem statement focusing on the use of case study to illustrate the applicability of ABM in the specified manufacturing disruption problems. Section IV brings to light the proposed framework and its integration with ABM model.

The actual ABM system development is the focus in section V while the discussion of results of the developed system is given in section VI. The paper ends with conclusion and recommendations for future research in section VII.

II. Previous Related Workd

In the literature, numerous studies have been carried out about the disruption in manufacturing production and various recovery plans and strategies employed through different modelling approaches. We discuss manufacturing production disruption problems and the implementation of ABM approach.

A. *Manufacturing Production Disruption Problems*

There are number of disruption associated with a typical supply chain network. They are classified in terms of supply disruption, transportation disruption, demand disruption and production disruption [7]. Production disruption is very common situation in the manufacturing environment. Disruption can happen as a result of financial problem, loss of reputation, [8] and can even be from the outside source. This can create a more difficult problem for the entire manufacturing establishment causing shortages, delays and unfulfilled customer demand [8]. Machine breakdown is an example of disruption to the production line. The impact of this was analyzed in a single stage manufacturing system [9]. Other categories of breakdown, random production disruptions are recorded in [10]; [11]; [12]. Sometimes, disruption on the production line can be caused from outside the actual manufacturing facility, as it is the case in OEM manufacturing systems. OEM manufacturing systems face uncontrollable situation emerging from customer-imposed disruptions on production line. Production disruption in this manner becomes difficult to manage when it is been orchestrated by the customers. In this ongoing study, three production disruption types were identified, which ABM system experimentation is conducted upon. These disruptions are: i.) Change in sequence of production, ii) Order cancellation, and iii) Change in order delivery due time.

B. *Agent-Based Modeling (ABM)Approach*

The choice of ABM is rationalize by the nature, attributes and behavior of the problem under study. ABM offers flexible, adaptive, robust, and autonomous platform for manufacturing system challenges. The approach evolves to accommodate complex problem in manufacturing operations compare to other traditional simulation methods such as Discrete Event Simulation (DES) and System Dynamics (SD) [13]. ABM has been applied as a platform for many manufacturing system modelling [14]. In a changing shop floor environment, [15] modelled an internet-enabled agent-based intelligent shop floor to control systems implemented to respond quickly to change. Disruption in terms of manufacturing system failure was modelled by [16] to simulate repairable manufacturing system. The ABM model has been used to determine system failure rate, based on machine age as a factor influencing disruptive behavior. In [17], adopt agent-based modelling and simulation for production management systems problem of unplanned disruptive events and disturbances such as arrivals of rush orders, shortage and delays of raw material as well as equipment breakdowns. ABM method is used in production scheduling problem in [18] in a framework for distributed manufacturing scheduling framework at the shop floor level. The modelling framework includes the multi-agent system modelling of work cells, service oriented integrated of the shop-floor, distributed shop floor control structure and dynamic distributed scheduling algorithms. In a simultaneously loaded station, [19] develop a simulation based priority rules for flow shop scheduling.

Having explored the production disruption problem situation and the possibility of ABM implementation with the proposed framework, it is the aim of this of this paper to apply integrated ABM and the adaptive framework to simulate complex manufacturing systems and examine the impact and consequences using OEM manufacturing flow shop located in Coventry, UK as a case study. The ABM will simulate the system with different combinations of the disruption problem-related scenarios. The study does not intend to provide a perfect prediction of the expected favorable outcome from the system, but to offer reasonable understanding of the emerging production system behavior, to provide critical insight to help manufacturing production decision making on disruption recovery plans.

III. Problem Statement

In this section, we discuss a flow shop production line with sequential operations of multiple product types. We consider the problem of customer-imposed OEM production disruptions in terms of i.) Change in sequence of production, ii) Order cancellation, and iii) Change in order delivery due time.

OEM manufacturing systems is faced with production disruption emanating from customer order demand. Disruption occurs from customer when there are production uncertainties affecting the flow process of the assembly line. The uncertain situation affects how, when and what customer demand from the OEM. This is because customer operates sequential assembly line in their production processes.

Form the OEM perspective, manufacturing production processes, plans and schedules are based on customer requested demand information. These demands come in different and sequential order splits to suit customer's assembly line operation. In as much as OEM production process depends on customer orders, and they are restricted by time. Disruptions still need to be managed to keep smooth running of the system while equally fulfilling customer demand in due time.

The sequence change occurs when customer's assembly line sequence changes due to uncertainties experienced [20]. Since order splits are processed in the system sequentially by flow line machines, a change in this sequence significantly disrupts planned production schedule.

Cancellation disruption occurs when customer decides to cancel order(s) that have been initially requested [21]. This type of disruption, even though disrupt planned production schedule, it can also reduce the entire process time as well as setup time since cancelled order or order split will no longer be processed and required no machine setup.

Order delivery due time can be changed by customer to accommodate urgent need on their assembly line. Change in the order delivery due time affects already planned production schedule. And when this happens, the order or order split in question will be made first priority on production line with the aim of achieving the due time for delivery

Disruptions that increase number of setups, causes prolonged processing time which cannot be accommodated by the daily production cycle time constraint. This results in requesting support from the inventory to complete orders that cannot be completed in the daily production cycle. When this continually happens, maintaining an optimum inventory policy is challenging, as the system is at risk of stock-out. For this reason, an effective measure to tackle this problem is significant to smooth running of the entire system.

IV. METHODOLOGY

In this study, we proposed simulation-based Production Disruption-Inventory Replenishment framework incorporated into Adaptive Agent-Based Model (Fig. 1). The idea of the proposed framework is for the manufacturing systems to adapt to production flow shop disruption caused by customers.

A. The Framework

Several types of framework have been developed in an attempt to solve complex problems. They are set of steps, procedures, rule, tool, components or material purposely put together to target particular problem domain. The use system framework in simulation project to solve problem is not new, especially in supply chain, logistics and manufacturing [22],[23],[24].What is new is the guided inter-relationship between framework entities trained to solve unique problem in a unique way. In this study, we proposed Production Disruption Inventory Replenishment framework to facilitate definitive solution to specific industrial related problem. And more importantly, the framework is experimented using a real life data for manufacturing production system case study

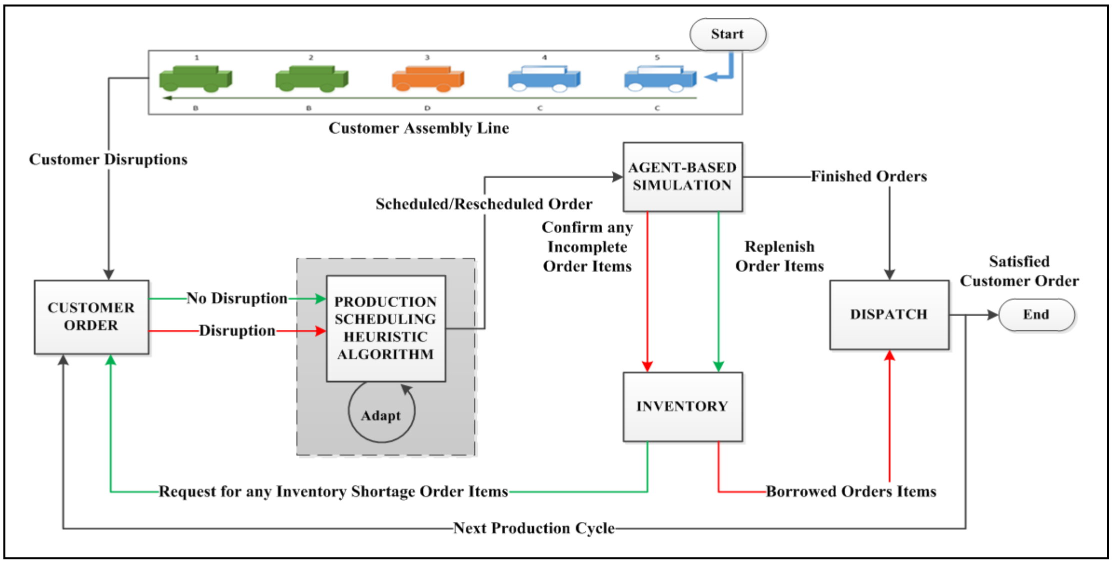

Figure 1: Production Disruption-Inventory Replenishment framework

In the framework, productions of manufacturing system are triggered by customer assembly line conditions, which is uncertain and sequential in nature. The sequential process on customer assembly line is the basis for order demand. However, uncertainties on customer assembly line force a change in initial order. The changes mean some order demand might not be satisfied in due time, causing shortages, and delay as it disrupted the original planned production schedule. In other to respond to the disruption, production scheduling adaptive heuristic algorithm is suggested to reschedule production processes in face of disruption. The heuristic algorithm will not only reschedule the process, but also help determine the system on number of order item completed or not completed. Through ABM module, order item not completed can be requested from inventory storage, which represent a backup plan for a successfully implementation of the framework, in case of disruption in this way, all order demand ca be completed in time to fulfill customer demand. But then, inventory storage requires to be replenished of item taken from it. Again, heuristic algorithm schedules replenishment order items to be fixed in 'available time' as the next production process progresses. The 'available time' is defined as the time saved on the production line as a result of disruption. For example, random cancellation which reveals time gap in between process or change in sequence, which can cause order of the same type to follow each other on the production line as opposed to original planned schedule, meaning the supposed setup time is now saved. The repetitive process continues in a daily production cycle.

The proposed framework represents significant contribution to knowledge such that it provide a platform for OEM manufacturing system to adapt to customer production disruption, maintain the smooth running of the slow shop while fulfilling customer demands in the right quantity and in due time.

B. *Agent-Based Modeling (ABM) module*

Agent-Based Modeling tool allows the simulation of complex adaptive system [13]. The approach has been used to solve manufacturing related problems [14], [25], [17], [26]. ABM method is adopted in this study to take advantage of entity interaction capabilities, as well as operational flexibility, which crucial to the complexity of the problem domain. We incorporate ABM module into the proposed framework to actualize the reality of the system entities (agents).

V. SYSTEM DEVELOPMENT

A. *Data Collection*

Real life simulation data was collected from OEM manufacturing case study as well as the simulation criteria and parameters. The ABM system is developed using Excel VBA to code and represent the three identified agents. The agents are: Order, Machine, and Operator. These three agents interact within the system environment to execute system rules and strategy (Fig. 2).

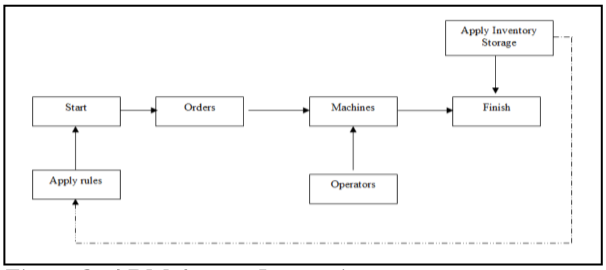

Figure 2: ABM Agents Interaction

B. *Simulation System*

We show in (Fig. 3), the system user form for set of rules for individual agents and the disruption types. Agent rules are applied during simulation experimentation to determine the key performance indicators (KPI) that is crucial for analysis and decision making. The rules for customer disruption types are applied to observe the system behavior through combination of disruption scenarios. Other tabs like parameter apply for system input; machine, order and operator apply to agent interaction and dependencies during system run (Fig. 4).

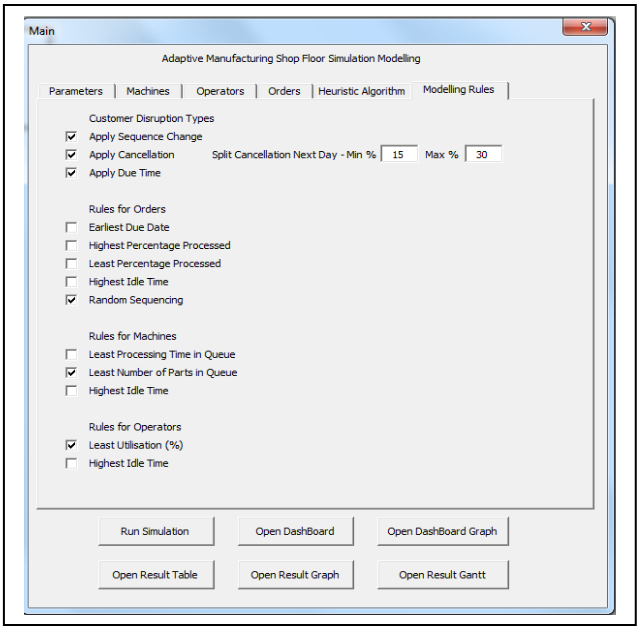

Figure 3: System Modeling Rules Tab

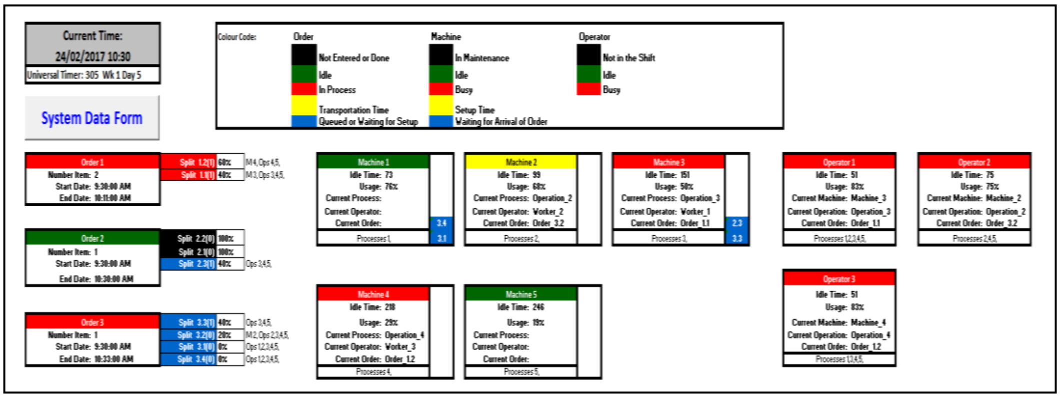

Figure 4: ABM Simulation Interface

Some of the relevant functionalities of ABM approach which have been implemented in the model are that; it allows orders to be assigned to machine, operators to be assigned to machine with individual agent attributes and behavior. In our model, we set order process time and machine setup time randomly. Using the actual data for order quantity, we proportioned each order quantity with daily production cycle to give the system flexibility and avoid unrealistic numbers.

While system is running (Fig. 4), agents (order, machine, and operator) status is visualized based on completion rate for orders, level of utilization and idleness for machines and operators.

The simulation interface (Fig. 4) is embedded and run in MS Excel spreadsheet. The idea that makes it user-friendly since MS office package is a common used platform in majority of manufacturing establishments.

VI. Results and Discussions

The simulation result shown in (Table 1) represent the three problem scenarios; change in sequence, cancellation and change in due time.

The three scenarios have been experimented and the result of one week disruption is shown in Table 1. We experiment initial number of order with random sequential splits before and after disruption. As a result of disruption, only first four order splits have been complete. Cancellation disruption also affects four orders (Order_2.2, Order_3.2, Order_2.4, and Order_3.4).

The system generated production scheduling chart (Fig. 5) represents corresponding production sequence, showing the setup and idle time. From the chart, we visualize sequence of operation before and after disruption. Variation in different disruption scenarios is revealed to clearly determine 'available time' from the total production cycle time.

Table 1: Result Table

Week 1 - Day 1

Order	Initial Number of Items	Disruption	Number Items	Items Not Completed	Total Time	Processing Time	% Idle	Planned Start Date	Planned End Date	Entered Start Date	Left End Date	Processes
Order_1.1	41	Order_1.1	35	35	481	466	3.12	9:00:00 AM	10:11:00 AM	13/02/2017 09:00		1,2,3,4,
Order_2.1	19	Order_2.1	20	20	481	167	65.28	9:00:00 AM	5:00:00 PM	13/02/2017 09:00		1,2,3,4,
Order_1.2	3	Order_1.4	2	2	481	10	97.92	9:00:00 AM	10:11:00 AM	13/02/2017 09:00		1,2,3,4,
Order_3.1	18	Order_3.1	48	48	481	152	68.4	9:00:00 AM	10:33:00 AM	13/02/2017 09:00		1,2,3,4,
Order_2.3	22	Order_1.5	2	2	481	0	100	9:00:00 AM	10:11:00 AM	13/02/2017 09:00		1,2,3,4,
Order_3.2	1	Order_3.2	1	1	481	0	100	9:00:00 AM	10:38:00 AM	13/02/2017 09:00		1,2,3,4,
Order_1.3	1	Order_1.3	1	1	481	0	100	9:00:00 AM	10:16:00 AM	13/02/2017 09:00		1,2,3,4,
Order_3.3	11	Order_3.3	1	1	481	0	100	9:00:00 AM	10:33:00 AM	13/02/2017 09:00		1,2,3,4,
Order_1.4	2	Order_1.2	7	7	481	0	100	9:00:00 AM	10:16:00 AM	13/02/2017 09:00		1,2,3,4,
Order_3.4	22	Order_3.4	2	2	481	0	100	9:00:00 AM	10:33:00 AM	13/02/2017 09:00		1,2,3,4,
Order_1.5	2	Order_2.3	1	1	481	0	100	9:00:00 AM	5:00:00 PM	13/02/2017 09:00		1,2,3,4,
Order_2.5	2	Order_2.5	16	16	481	0	100	9:00:00 AM	5:00:00 PM	13/02/2017 09:00		1,2,3,4,
Order_1.6	1	Order_1.6	3	3	481	0	100	9:00:00 AM	10:11:00 AM	13/02/2017 09:00		1,2,3,4,
Order_2.6	1	Order_2.6	6	6	481	0	100	9:00:00 AM	4:55:00 PM	13/02/2017 09:00		1,2,3,4,
CANCELED												
Order_2.2	5		4									
Order_2.4	2		4									

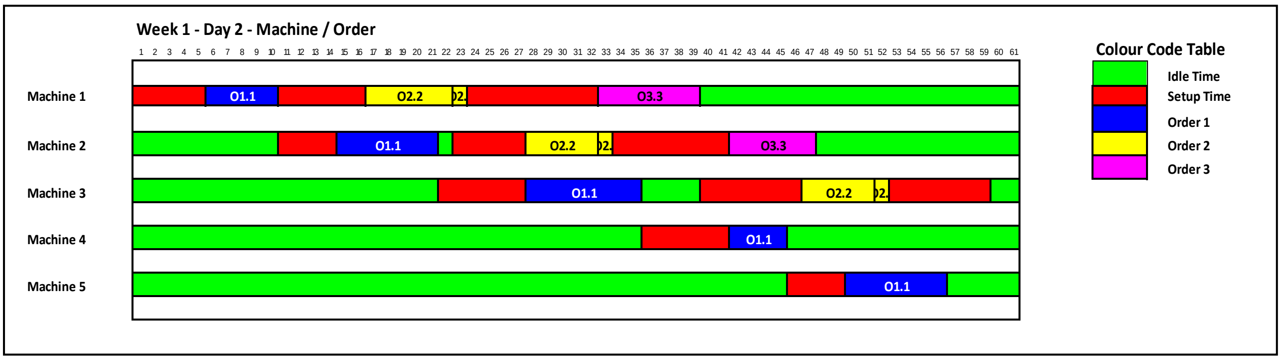

Figure 5: Production scheduling chart

The simulation result so far showed that disruption not only causes disorderliness in the flow shop production schedule, but create opportunities for responding to future disruptions. We also identified and established the following sets of consequences of the three disruption types [27].

The consequences of change in sequence disruption include:

- Production and delivery delay
- Minimises or increases total production setup time
- Increases total production time
- Renders some orders incomplete within the planned production schedule
- It could save more production time
- It requires significant inventory support

The consequences of cancellation disruption include:

- Create more available production time and keep inventory level stable
- Enables available time utilisation
- Has no effect on inventory
- Decreases production service level
- Result into loss sales

The consequences of change in due time disruption include:

- The production consequence of change in due time is reduced number of setup since order of the same type is brought together for emergency production.
- Delivery delay of order products
- Reliance of inventory support

VII. Conclusion and Recommendations

This paper presented integrated ABM approach to proposed framework, to respond to production disruption on the flow shop. The simulation of the OEM manufacturing case study helps to shed light on the significance of inventory storage and the setup time utilization. This has shown a promising opportunity to adapt to production disruption

The ABM system has been developed to adapt the production disruption. Also, inventory replenishment strategy has been the key enabler for the implementation of the proposed framework. However, adaptive heuristic algorithm which is the major contribution in this ongoing PhD research is currently in the development stage, as this model is part of a bigger research project. The aim of developing the heuristic algorithm is to help manage the disrupted processes and ultimate reduce to the minimum, the sets of consequences cause by these disruption on the production flow shop.

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