SIMULATING THE INTEGRATION OF ORIGINAL EQUIPMENT MANUFACTURER AND SUPPLIERS IN FRACTAL ENVIRONMENT

Sameh M. Saad[(a)] and Julian C. Aririguzo[(b)]

[(a)(b)] Department of Engineering and Mathematics,
Sheffield Hallam University, City campus Howard street Sheffield S1 1WB

[(a)]S.Saad@shu.ac.uk, [(b)]Julian.C.Aririguzo@student.ac.uk

ABSTRACT
Partnerships and collaborations between companies (OEMs) and suppliers are not new. Many companies rely on partnerships with key suppliers to improve operational effectiveness through minimized inventory, information and culture integration to boost their lean/ agile credentials. The Fractal Manufacturing Partnership (FMP) is new manufacturing strategy, whereby OEMs form relationship with key suppliers. The former cede autonomy of non-core activities to tried and tested suppliers, while concentrating on their core competencies. The latter become assemblers of their components with heightened sense of responsibility while co-owning the OEMs' facility. The objective of this relationship is maximization of flexibility - ability to respond swiftly and robustly to changes in environment, requiring physical network and more importantly, cultural network linking the people rather than their machines. In this paper, integration of OEM and suppliers is modeled and simulated to highlight critical factors in this partnership and quantifying and harnessing benefits of this new approach.

Keywords: OEM and Supplier partnerships, FMP, Supply chain managements.

1. INTRODUCTION
Partnerships and close relationships between OEMs and key suppliers and customers are not new. OEMs increasingly outsource the manufacture of auto parts and this purchasing practice not only affect direct costs, but also impact quality, lead-time, technology, over head costs and most importantly, market success (Cross and Gordon 1995; Lewis *et al*. 1993). Many companies especially in the automotive industries rely extensively on important partnerships with key, time tested suppliers. It has been established that the cost of purchased parts and products make up to 30% to 50% of the final selling price of finished product (depending on the firm's vertical integration strategy) (Dyer *et al*. 1998; Dyer 1996; Cross and Gordon 1995). Close collaboration with suppliers from initial product design to final assembly, reduces product development time, manufacturing expense and improves quality (Noori and Lee 2000; Lewis *et al*. 1993). This logical and more recent progression from single sourcing has been the development of long-term supply agreements (LTSAs) between OEMs and their key suppliers. The partnership is marked by great motivation and synergism and requires cooperation, commitment, trust, teamwork and information sharing between parties and complete integration of parties involved to facilitate effective product lunches and competitive pricing (Simonian 1996; Cross and Gordon 1995). FMP is a revolutionized manufacturing method whereby OEMs go into close relationship with their key suppliers. Conceptually from the fractal system, it elevates the operation of sub-factory within a factory and enhances close links within members. This practice is necessitated by swift technological developments and by the need to take cost out of their operations. Companies examine their internal strengths, focusing their efforts towards achieving excellence in their core capabilities (Noori and Lee 2000; Dyer *et al*. 1998). These trusted suppliers then take responsibility for non-core activities. They design, manufacture, and assemble their parts on the assembly line directly to the product while sharing and co-owning the OEMs' facility. In the case of automotive companies, the OEM concentrate on the vehicle concept which includes envelop size and weight and assembly, relinquishing parts and components that have been undertaken by them in the past to trusted suppliers in a long term relationship (Cross and Gordon 1995). An increasing shift to modular component purchasing e.g. seats, belts, instruments panel and headliner may be integrated into an interior module that is undertaken by a single supplier - such as a tier-one supplier (Dorrell 1996). This results in fewer, but larger tier-one suppliers that are taking responsibility for the system design, development, assembly and management of the supply chain (Simonian 1996). OEMs need to consider which core competencies they are maintaining and which ones they will need for the future and ensure that sufficient investment in these continue. Given the long lead-term in development, failure to invest in a key area now may make it difficult later. However, de-integrating certain functions out of the organization does not have benefits for the OEM, instead capital investment requirements ,

operational costs and the logistical costs of maintaining product balances are all transferred to the supplier, while flexibility and the ability to concentrate on core competencies is enhanced (Cross and Gordon 1995). FMP is designed to maximize the logistical attribute of a lean production system and configured to provide strategic merging of engineering network capabilities (Phelan 1996). It combines logistical attributes of lean production methods with strategic configuration of agile network capabilities (Dyer *et al.* 1998; Phelan 1996; Noori and Lee 2000). The organizational structure of the FMP is based on series of highly coordinated production silos arranged side by side to each other to promote high degree of cooperation, communication and integration of operation and managerial activities, culminating in further reduction in work in process (WIP) inventory and instantaneous communication amongst parties involved. The communication and 'open book' information system present allows complete flexibility and an information enriched manufacturing atmosphere. There is also better service and product quality especially when suppliers feel part of the team. The degree of integration between OEM and these key suppliers is of great significance. Studies carried out by (Dyer 1996; Dyer *et al.* 1998; Lewis *et al.* 1993; and Cross and Gordon 1995) highlighted that this integration leads to improved operational effectiveness through reduced inventory, improved communication, quality, faster product development, design for manufacture and productivity. All parties must weigh the costs against the relative benefits in establishing their integration policy. Cost, control, communication, organizational climate, operations management and competitive differentiation must be analyzed exhaustively (Dyer *et al.* 1998; Cross and Gordon 1995). It is imperative to point out and highlight how OEM - supplier partnerships have evolved in recent years from an arms length relationship - just-in-time or bulk delivery, JIT (11) (Issacson 1994), through modular sequencing (Dinsdale 1996) and supplier parks (Feast 1997; Kochan 1996) to a 'hands on', proximate FMP (Friedland 1996; McElroy 1996). As the evolution progresses, there is increased responsibility on the part of the supplier for design, assembly, higher value added contribution and increased integration. However, FMP has both higher degree of integration as well as complex supplier responsibility. The focus of this paper is the determination of an optimal representation of the FMP. This facilitates achievement of flexibility and swift response to uncertainties in the manufacturing environment, the realization of a host of other benefits as listed in (Noori and Lee 2000) and most importantly a harmonious cultural and technological integration of the parties involved in the long-term FMP relationship. However, culture integration, union philosophy that is resistant to radical changes and costs all pose a challenge in implementation of the FMP configuration. The rest of the paper is organized as follows; section two details the methodology employed for the modeling and experimentation and software used in the study. Section three elaborates on the model development, including the tricks and turns involved in such exercises. Section four studies and discusses the results and section five concludes the paper.

2. METHODOLOGY

A comprehensive computational representation of the FMP is made using modeling and simulation. This aids in evaluating its performance in dynamic conditions. The structure, resources, behavior, strategic objective, values and constraints of the FMP is captured in Arena software (Kelton *et al.* 1998) through enterprise design, analysis, and operation. Understanding of the nature and working of FMP before conducting statistical experiments is also crucial in the final results of the modeling. The output data of the simulation is used to identify system bottlenecks and to generate alternative states that may provide the desired performance improvements for the system. Arena is designed to describe, model and analyze an existing or proposed application accurately and gives maximum flexibility to systems. It integrates all simulation related functions; animations, input data analysis, model verification, and output analysis into a single simulation modeling environment (Kelton *et al.* 1998). Its flexible flowcharting objects will be used in this project to capture the essence of the FMP system being considered and compare different competing manufacturing scenarios, so as to select one that best meets the objectives. Visual Basic for applications (VBA) is a technology used to write custom program codes that argument Arena model logic. VBA is embedded directly in Arena to enable writing codes (via the visual basic editor) that automate other applications such as excel, auto cad or Visio. VBA code will be used in this project to automate Arena, such as to get values of a simulation output statistics, change values of module Operands or add animation variables (Kelton *et al.*, 2004). Opt quest for Arena is an optimization tool and will be used to analyze the results of the simulation runs. It includes sampling techniques and advanced error control to find better answers faster (Rathmell *et al.* 2002). This package combines the metaheuristics of Tabu search, neural networks, and scatter search into a single, composite search algorithm to provide maximum efficiency in identifying new scenarios (Kelton *et al.*, 2004; Kelton *et al.* 1998). Finally the Arena Output analyzer will be used in fitting confidence intervals on expected output performance measures, and statistical comparison of alternatives (Sweet and Grace-Martin 2003). These applications will be used in; (i) building and developing a virtual scenario for the proposed FMP. (ii) finding the best fit and balance for the OEM/ supplier partnership to ensure a harmonious collaboration (iii) calculating the best mix of resource capacities to maximize throughput in the integration of lean production / agile network capabilities (iv) finding the optimal balance for the system in a volatile environment while meeting the conceptual benefits of the FMP. An organized set of procedures and guidelines are used for specifying the structural and quantitative parameters and relationship between the factors affecting the output performance. These factors are varied systematically with a view to finding and identifying the optimal conditions that most influence the results. Important variables are identified and investigated. These are defined, measured and controlled during the simulation with a view to tracking their level of variation.

3. MODEL DEVELOPMENT

3.1. System Description

The system under studies is a truck assembly plant. To keep things simple, only major modular components have been represented in this model. In total there are eight sub-models that represent eight distinct operative activities. These include; Body in white, Chassis Trim supplier, Motor Engine builder, Electrical / Electronics supplier, Motor Transmission supplier, Paint supplier/ shop, OEM (Dealership) Inspection, and the Exit logic (see figure 1). As mentioned earlier, these suppliers have been vested with the responsibility of designing, building and assembling their modular components in close proximity to the OEM's assembly line. The suppliers rent production silos side by side to each other on the assembly line in a highly coordinated arrangement. The layout of the FMP assembly line allows complete flexibility in its operation and essentially shows the physical link with the different suppliers involved in this partnership. The OEM concerns with the brand concept which includes the envelope size and the weight of the finished truck, and is fully represented on the assembly line, eyeballing these different suppliers and supervising the overall assembly process.

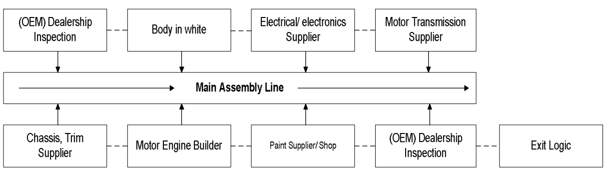

Figure 1: FMP assembly line (Noori and Lee 2000)

3.2. Sub-factory within a factory

The FMP operates on the conceptual philosophy of the Fractal Manufacturing system (Ryu and Jung 2003 & 2004). The fractal is an independent acting corporate entity whose goals and performance can be described precisely (Warnecke 1993). The idea of 'assembly within assembly' is applicable to organizational structuring of distributed manufacturing systems (Shin *et al.* 2008). (Strauss and Hummel 1995) in their work on industrial engineering, say that a fractal is a partial system of an enterprise which offers opportunities for entrepreneurship to all employers, and it has a relation with other fractal units as a service centre. Each fractal is a customer as well as a supplier within the enterprise, and plays the role of an individual service centre within other service centre, i.e. 'a design within design' or 'pattern within pattern'. Each business unit of the factory acts as an autonomous factory which is integrated within a communication network (Sihn and Von 1999). In the FMP, the suppliers are incorporated as assemblers, working within the manufacturing facility alongside the OEMs' employees. Every fractal unit has or is inherently equipped with the fractal specific characteristics. This include; self-similarity, self-organization, self optimization, goal orientation and dynamics (Warnecke 1993). These are congenital attributes of fractals.

3.3. Decentralized hierarchical structure

The fractal structure is characterized by constant evolution with respect to its partners and environment (Tharumarajah *et al.* 1996). The administrative functions in the FMP are distributed over a less concentrated area, decentralizing the structure and highlighting the evolution from a vertically integrated enterprise to a network of integrated core competencies (Noori and Lee 2000). This structure is subject to a constant dynamical process of change, making them more suitable and adaptable to turbulent environment. It is also more flexible because it is susceptible to modification or adaptation and more responsive to change. Every fractal in the FMP has the same functional modules which are well-defined interfaces to the other components. In terms of job processing, this is carried out through the goal-formation process. Component relationship also exists, whereby there is a coordinative higher fractal and an active lower fractal. The fractal model manages the structural complexity and coordination of a flexible manufacturing system by maximizing local functionality and minimizing global control (Tirpak *et al.* 1992).

3.4. Modeling of FMP

The top-level model for the layout of the FMP is shown in figure two. The system to be modeled is a truck assembly facility. Shots of 'body-in-white', dealership (OEM) inspection and paint shop sub-models during the simulation have been included in figures three, four, and five respectively. It consists of part arrivals, manufacturing cells with different machines and part departures, eight major sub-factories represented by sub-models located adjacent to each other. The suppliers design, build and assemble their modular components while residing on highly coordinated production silos. This representation not only allows flexibility and ease of organization but also shows the physical link with the participants. Transfer of parts and components is by a loop conveyor system following the concept of pre-defined entity-dependent sequences. The time between a part's arrival and that of the next part is called inter-arrival time of parts. The assembly operation starts at the 'body in white' sub-model where the metal frame arrives and within which threads and supports, doors, hoods and deck lids are assembled. On completion, this is transported by the loop conveyor to the chassis, trim supplier where seats, upholstery and windshield are coupled. After undergoing a quality check this is conveyed to the electrical and electronics supplier where the electrical aspects of the assembly operation are done, including the airbags and sensors. The motor engine builder is next on the assembly line, and he mounts the engine which was pre-built at his sub-factory. The transmission supplier follows, and here both the gear box and crank case are assembled and coupled on, followed by elaborate greasing of different movable parts. From this sub-model, nearly completed truck is conveyed to the paint shop which is manned by the paint supply who organizes the priming, initial coating and finishing of the painting. Trucks that pass the painting quality check proceeds to the Dealership (OEM) inspection. Here there is continuous eyeballing of the entire assembly progression and trucks undergo an elaborate inspection for overall envelop size and weight. There is also room for rework for trucks that don't make it through the inspection. This final inspection rolls the fully built truck off the loop conveyor and production line. All process times (the time a part spends processing in a particular cell) are triangularly distributed, inter-arrival times between successive parts arrival are exponential distributions. Load and unload times unto the loop conveyor are 2 minutes each. Information is considered from the output performance measure of 10 statistically independent and identically distributed (IID) replications, of length 480 hours, to study the system's average Work in Process (WIP) and to get statistics on the system's behavior, utilization and turnarounds. Statistics is gathered from the long run (steady state) behavior of the system, hence there is a warm-up period of 240 hours to clear the statistical accumulators from

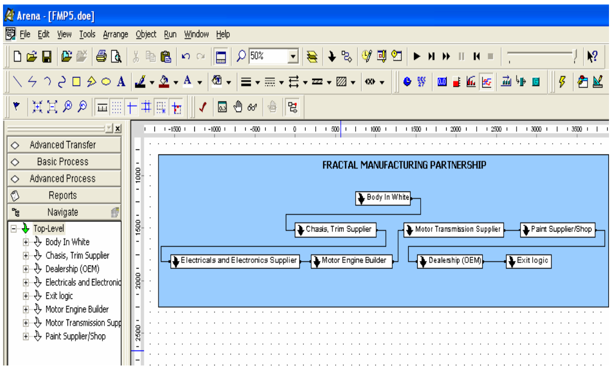

Figure 2: Top-level of FMP model

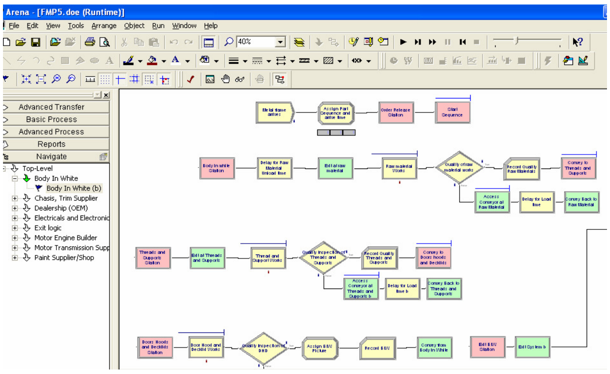
Figure 3: The ‘Body-in-White sub-factory

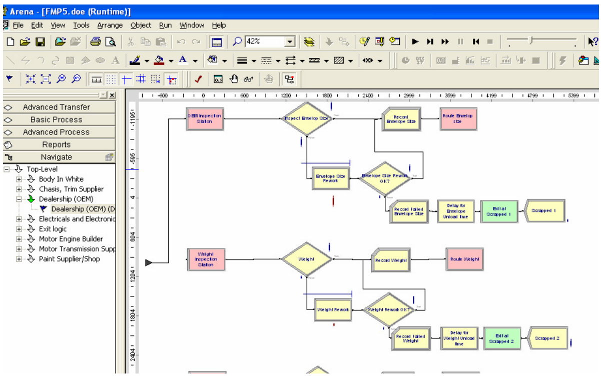
Figure 4: Dealership (OEM) Inspection

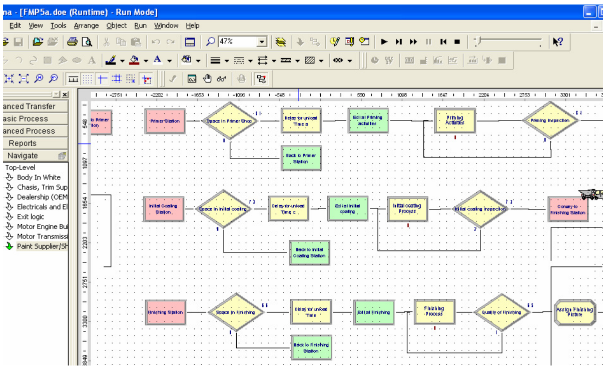
Figure 5: Paint Supplier/Shop sub-factory (taken at simulation time, 1243 minutes)

biasing initial conditions. The steady state is tracked from the plot of the curve of WIP vs. Time when the effect of the empty-and-idle initial conditions appear to settle or wear out. The base time unit is in minutes. We will be interested in collecting statistics in each area on resource utilization, number in queue, time in queue, and the cycle time (total time in system). The work in process (WIP) inventory is very important to the FMP. Obviously the OEM eyeballs the entire assembly process, but to establish a single overall output performance measure for the WIP, we tracked the history of the WIP over time and summed this for the individual activities in the different sub-models and found an average. We also created an entry (Figure 6) labeled Total WIP in the statistic module which shows in the category overview as 'user defined', giving the time average and maximum of the total number of parts processing in the system.

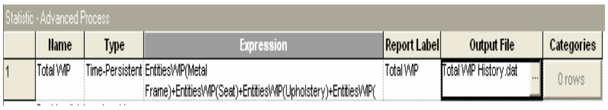

Figure 6: The Total WIP Entry in the statistical data module

The significance of this is to show the compatibility of the different partners and their activities and the harmony in their intra- and inter- operations. The model has taken into account the similarity requirement in organization and orientation of different sub-assemblies present. This has been built from bottom up. The sub-factories are similarly organized both internally and in their goal system. Similarity of goals means conformity of objectives in each organizational unit to the overall corporate goal (Shin *et al*. 2008; Sihn and Briel 1997).

3.5. Model verification and validation

The validity of the developed simulation model was evaluated by comparing the performance of the model to the conceptual system. Separate experiments were carried out, to investigate how robust the system is and how it can recover from uncertainties like equipment breakdown and unforeseen delays from sub-factories. The output values obtained (Tables 1, 2, &3) from the simulation model were found to be very similar to the estimated values of the conceptual system, differing at most 7.9%. Therefore the tests are suitable for system analysis and experimentation. The Output Analyzer provides one way of quantifying the imprecision in the parameter estimates through a 95% confidence interval. This is achieved by forming intervals with endpoints that cover the target with high probability. Half width of the output performance is the half width of a (nominal) 95% confidence interval on the expected value of the output result. These resulted in reliable and precise statistical conclusions.

3.6. Model Debugging

The model of the FMP is a particularly large model, going into great depth on the lower-level modelling constructs as well as correspondingly detailed statistical requirements, comprising essentially eight sub-models as has been established. The sub-models were ran separately for a start and huge amount of time was spent debugging the model and making sure that it runs without errors.

4. EXPERIMENTATIONS AND RESULTS

The fractal concept advocates adaptability and the ability of the system to recover from failures and uncertainties. To study this capability of the system, we looked at three key scenarios. First we observed the system under normal conditions. Then we watched how the system managed without grinding to a halt to cope or adapt when;

- there is surge/ drop in demand of the product.
- when a machine breaks down or there is delay in meeting with a pre-scheduled operation in a sub-factory.

We managed the practical mechanics of making the model changes for these alternatives, and that involves lots of parameter changes in the model especially the process times for different machines at different sub-factories. These model variants from changes in the model's input parameters were ran in an efficient and organized way using Arena Output Analyzer.

4.1. Output Statistics

Table 1: Surge in demand

Performance measures	Conveyor velocity			
	15 Feet/m	20 Feet/m	25 Feet/m	30 Feet/m
Throughput	834	844	857	867
Cycle time	20708.75	20699.53	20679.86	20676.19
WIP	224880.80	224902.85	224889.93	224923.00
Scheduled Utilization	0.700	0.699	0.700	0.701
Wait time in queue	19909.46	19906.51	19897.09	19901.97
Number in queue	6307.01	6306.24	6308.10	6306.88

Table 2: Drop in demand

Performance measures	Conveyor velocity			
	15 Feet/m	20 Feet/m	25 Feet/m	30 Feet/m
Throughput	190	192	191	190
Cycle time	20832.66	20916.64	20939.78	20904.20
WIP	83981.26	83873.78	83823.29	83860.25
Scheduled Utilization	0.626	0.624	0.625	0.625
Wait time in queue	17434.44	17579.11	17587.30	17491.06
Number in queue	2194.61	2192.99	2192.35	2192.25

Table 3: Equipment breakdown in sub-factory

Performance measures	Conveyor velocity

	15 Feet/m	20 Feet/m	25 Feet/m	30 Feet/m
Throughput	823	827	829	835
Cycle time (mins)	19646.98	19632.93	19639.06	19621.39
WIP	112667.61	112657.91	112642.00	112654.70
Scheduled Utilization	0.685	0.685	0.685	0.685
Wait time in queue	18578.52	18567.86	18575.01	18564.19
Number in queue	2977.84	2977.77	2977.35	2977.93

4.2. Discussions

Comparing different versions or alternatives of FMP model, there isn't huge differences in the output statistics between different replications. What makes the alternatives differ more significantly is more of a fundamental change in logic rather than simple parameter variations. During a surge in demand, the number of trucks produced (Figure 7), after 480 hour long replication, increased directly with increase in conveyor velocity and peaks at 867 trucks for conveyor velocity of 30 Feet/minutes.

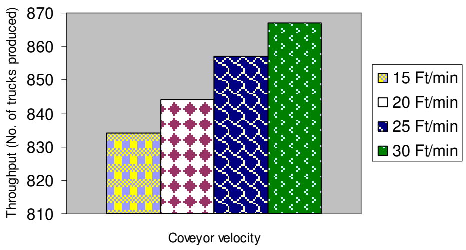

Figure 7: Average number of trucks produced during a surge in demand

Conversely, the average cycle time i.e. the total time parts spend servicing in system (figure 8) dropped with increase in conveyor velocity. This figure was maximum at just above 20708 minutes at velocity, 15 Ft/min and least at about 20676 minutes.

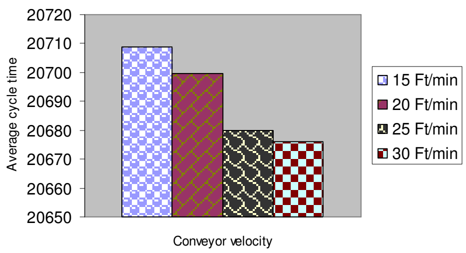

Figure 8: Average cycle time (in minutes) during a surge in demand

Figure 9 shows the amount of parts servicing in the system or work in process (WIP) during a drop in demand of the product. This was least at a conveyor velocity of 25 Ft/min at just above 83823 parts and most at 15 Ft/min conveyor velocity.

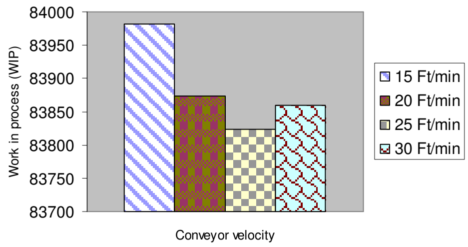

Figure 9: Average number of parts in system (WIP) during a drop in demand

The amount of queue seen in the system during a drop in demand (Figure 10) dropped with increase in conveyor velocity. There were at least 2192 parts at velocity of 30 Ft/min. Expectedly, the system was not exploding with parts in service since there weren't too much activities going on.

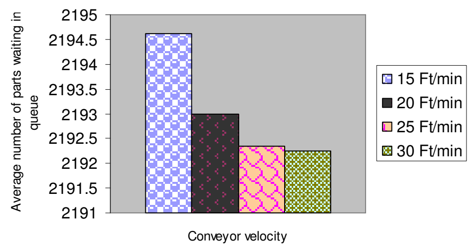

Figure 10: Average number of parts waiting in queue during a drop in demand

The system's behavior was investigated during some five hour equipment breakdown in two sub-factories. Parts spent the least time on average (figure 11) at the 30 Ft/min conveyor velocity at 18564 minutes.

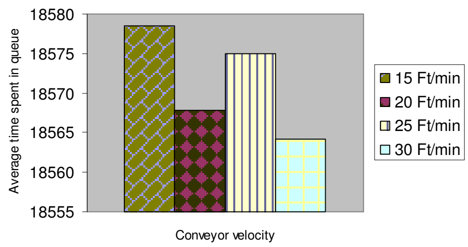

Figure 11: Average waiting time in queue (in minutes) during equipment breakdown

The average scheduled utilization during equipment break down (figure 12) stayed marginally displaced at just under 69% throughout, not minding an increase in conveyor velocity.

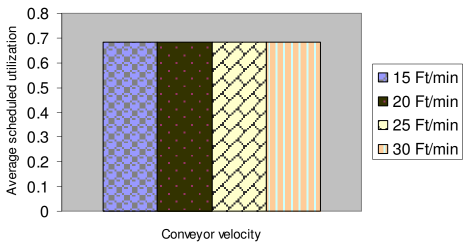

Figure 12: Average scheduled utilization during equipment breakdown

5. CONCLUSION

The paper has reported on the simulation model development of the integration of automotive OEM and their key suppliers. The modeling and simulation focus was on harmonizing as well as synchronizing the operations of these different parts suppliers, who have now become assemblers of their modular components while residing side by side with each other on the assembly line, and harnessing the synergic effects of such 'hands on' collaboration to boost lean production and provide agile capability for rapid response to competitive markets. Hence the truly agile manufacturing framework/ structure formed in the FMP is ultimately used to carry out production with a sense of shared or mutual dependency, motivation and a heightened sense of responsibility between OEMs and this web of suppliers that provide all the elements required in the production process perhaps under one roof.

REFERENCES

Cross, B., and Gordon, J., (1995), Partnership strategies for market success, *Business Quarterly, Autumn*, pp. 91-6

Dorrell, K., (1996), Auto industry prepares to weather the storm, Plant, Canada's Industrial Newspaper

Dyer, J., Cho, D. S. and Chu, W, (1998), Strategic supplier segmentation: the next 'best practice' in supply chain management, *California management Review*, Vol.4, No. 2, pp.57 - 77.

Kelton, W.D., Sadowski, R. P., Sadowski, D. A., (1998), Simulation with Arena, The McGraw-Hill companies, inc. USA.

Kelton W., Sadowski R., Sturrock D., (2004), Simulation with Arena. 3rd Ed. New York: McGraw-Hill Companies.

Noori, H., and Lee, W. (2000): Fractal manufacturing Partnership: Exploring a new form of strategic alliance between OEMs and suppliers, logistics information management, Volume 13, No. 5 pp.301-311.

Phelan, M., (1996), Stalking the elusive 5-day car, Automotive industries, November, Vol. 176, p.62.

Rathmell, J., and Sturrock, D. T., (2002), The Arena product family: Enterprise modeling solutions, proceedings of the 2002 winter simulations conference.

Ryu, K. and Jung, M., (2004), Goal-orientation mechanism in a fractal manufacturing system. International Journal of Production Research, 42, 11, 2207-2225.

Ryu, K. and Jung, M., (2003), Agent-based fractal architecture and modeling for developing distributed manufacturing systems. International Journal of Production Research, Vol. 41, No. 17, pp. 4233-4255.

Shin, M., Mun, J., Lee, K., and Jung, M., 2008, r-FrMS: a relation-driven fractal organization for distributed manufacturing systems, *International Journal of Production Research*, pp. 1-24.

Sihn, W. and von Briel, R., (1997), Process cost calculation in a fractal company. *International Journal of Technology Management*, 13, 68-77.

Simonian, H., (1996), Alliances forged in the factory binding carmakers to parts firms. The financial post, 9 November, pp.102. (The Financial Times).

Simonian, H., (1997), Car making joint ventures takes radical route. The financial post daily, 11 July, pp.49. (The Financial Times).

Strauss, R., and Hummel, T., (1995), The new industrial engineering revisited - information technology, business process reengineering, and lean management in the self-organizing fractal company, proceedings of the 1995 IEEE Annual International Engineering Management Conference, Theme "Global Engineering Management: Emerging Trends in the Asia Pacific", ed. F.S. Wei, pp. 287-292

Sweet, S., and Grace-Martin, K., 2003, Data analysis with SPSS, a first course in applied statistics, 2nd ed., *Pearson education*, Inc. USA.

Tirpak, T.M., Daniel, S.M., Lalonde, J.D., and Davies, W.J., (1992), A note on a fractal architecture for modeling and controlling flexible manufacturing systems. IEEE Transactions on Systems, Man and Cybernetics. Vol. 22, No. 3.

Warnock, I., (1996), Manufacturing and business excellence, Strategies, techniques and technology, Prentice hall, Europe, pp.120.

Warnecke, H.J., (1993), The fractal company- A revolution in corporate culture, Springer- Verlag.

AUTHORS BIOGRAPHY

Professor Sameh M. Saad, BSc (Honours), MSc, PhD, CEng, MIET, MILT, is Professor of Enterprise Modelling and Management, Postgraduate Research Coordinator and MSc/MBA Course Leader, in the Department of Engineering, Faculty of Arts, Computing, Engineering and Sciences, Sheffield Hallam University, UK. His research interests and experience include modelling and simulation, design and analysis of manufacturing systems, production planning and control, reconfigurable manufacturing systems and next generation of manufacturing systems including fractal and biological manufacturing systems. He has published over 130 articles in various national and international academic journals and conferences, including keynote addresses and a book.

Julian Aririguzo C. BEng, MSc**,** MIET**,** is final year PhD. student in Manufacturing Systems at Sheffield Hallam University. He has an MSC. in Automatic Control and Systems Engineering from University of Sheffield and a BEng. Degree in Mechanical/ Production Engineering from Enugu state University of Science and Technology, Nigeria. He has published various research papers based on his research. He is passionate about resource efficiency in facility developments, innovative technologies in efficient use of resources and his research interests also include sustainability, sustainable developments and environmental protection/ clean energies.