Exploring the Influence of Flexibility on Readiness to Deploy Manufacturing Process Innovation

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Abstract

It is important to attain an appropriate state of deployment readiness when implementing process innovation. That is, ensuring that deployment will run smoothly and relatively problem free. Essentially, deployment readiness is a feature of pre-implementation phase and it represents the state of preparedness for something about to happen. Of increasing interest in the literature is finding ways of achieving the highest degree of process innovation deployment readiness. Whilst methods of assessing deployment readiness are emerging, the influence of flexibility on deployment readiness is yet to be ascertained. This paper focuses on the influence of flexibility on readiness to deploy process innovation in manufacturing. In particular, the emphasis is on how flexibility mediates deployment plans for implementing manufacturing process innovation. Deployment plan is conceptualised as the approach, scope, and execution planned for the deployment of an innovation initiative. The interrelationships of flexibility and deployment plans is studied using simulation of a job shop with routing flexibility and results show that deployment plan is significant to innovation deployment readiness performance and its significance is moderated by flexibility.

Keywords
Manufacturing, Process Innovation, Deployment Readiness, Simulation

1. Introduction

In increasingly competitive global markets, manufacturing companies are looking towards flexibility and innovation amongst others to achieve their desired goals. Innovation is now widely accepted as a condition for survival in manufacturing (Cefis and Marsili, 2006; Gonçalves Silveira Fiates et al., 2010; Maier et al., 2014; Naji al., 2016). Ability to compete over time is now not only determined by efficiency increases but with appropriate capacity to simultaneously innovate (Abernathy, 1978; Stalk and Hout, 1990; Park et al., 2014). Continuous innovation alongside productivity improvements has therefore come to the fore. There are several definitions of continuous innovation (e.g. Teece and Pisano's, 1994; Teece et al, 1997; Soosay, 2005; Davison & Hyland, 2006); central to the definitions are ideas of 'timely responsiveness, rapid product and process innovation'.

Product innovation, process innovation, and a combination of the two are fundamental dimensions of innovation in manufacturing. Product innovation entails creating and introducing goods and services that are either new or offers substantial improvement to previous versions. Process innovation is the implementation of a new or significantly improved production or delivery method, including significant changes in techniques, machines and/or application software. Process innovation has been compared with product innovation and the relations between them well studied. As in product innovation, implementation methodology and acceptance is central to successful delivery of innovation initiatives.

Continuous innovation and manufacturing flexibility are intrinsically linked. Innovation offers manufacturing companies mechanisms for adapting to demands of dynamic environments (Hurley & Hult, 1998). Manufacturing flexibility complements with ability to respond effectively to changing circumstances and to better handle a wider range of possibilities under uncertainty (Gerwin, 1987). Manufacturing flexibility is a capability of manufacturing companies to deploy and redeploy its resources effectively in response to changing situations (Gerwin 1993).

To successfully implement innovation initiatives, manufacturing companies needs to be prepared and understand the risks involved. The state of preparedness for the innovation initiatives about to be actualised is referred to as deployment readiness. It can be visualised, retrospectively, as the extent to which a deployment has run smoothly and relatively problem free (Ahmadi et al., 2015), and it is an important issue in the pre-implementation phase of innovation implementation models (Papinniemi, 1999; Kwahk and Lee, 2008). The benefits of deployment readiness in manufacturing include addressing potential risks at the early stages leading to better deployments that minimises unforeseen problems in production. Following an appropriate deployment plan is a condition for realizing these benefits and achieving successful implementation. The role of flexibility in achieving successful deployment of process innovation in manufacturing is the focus of this paper.

This paper investigates how flexibility mediates deployment plans for implementing manufacturing process innovation. Deployment plan is conceptualised as the approach, scope, and execution planned for the deployment of an innovation initiative. The interrelationships of flexibility and deployment plans is studied using simulation of a job shop with routing flexibility and results show that deployment plan is significant to innovation deployment readiness performance and its significance is moderated by flexibility. The remainder of the paper is structured into four sections. Section 2 presents an overview of the two main bodies of research relevant to this paper i.e. manufacturing flexibility and process innovation. Approaches to assessing deployment readiness in the context of manufacturing process innovation are briefly reviewed in Section 3. The simulation experiments conducted and its results are reported in Section 4. Finally, the paper ends in Section 5 with concluding remarks and recommendations for future work.

2. Manufacturing Flexibility and Innovation

This paper relates to two main bodies of research in the context of manufacturing, namely flexibility and innovation. The literature has established manufacturing flexibility as a key strategic objective of many manufacturing companies. Alongside flexibility, the core content of a manufacturing strategy includes: quality, cost, and technology (Adam and Swamidass, 1989). Several aspect of manufacturing flexibility has been reported in the literature covering, for example, the definition, dimensions, and taxonomies of manufacturing flexibility (Slack, 1987; 1991; Duguay et al., 1997; Koste and Malhotra, 1999; D'Souza and Williams, 2000), advantages and disadvantages of manufacturing flexibility and its link to performance (Gerwin 1993), characterise the concept and nature of flexibility (Upton, 1994; Beach et al., 2000), accommodation of uncertainty and leveraging with technology. Whist there are several definitions of manufacturing flexibility, a common thread is the recognition of the ability to respond or adapt to change and use of flexibility to accommodate uncertainty (Beach et al., 2000). Uncertainty can arise in a variety of ways e.g. changing circumstances or instability caused by the environment. The type of uncertainty to address by manufacturing companies can vary, contingent on the manufacturing plant as a whole or its components such as its processes and operations.

Swamidass and Newell (1987) introduced flexibility in the context of manufacturing strategy. Based on this viewpoint, manufacturing flexibility represents ability to adapt or change in response to uncertainty or unexpected changes with little penalty in time, effort, cost, or performance (Boyle, 2006; Upton, 1994). Reinforcing the relevance of uncertainty, manufacturing strategy, and change regarding manufacturing flexibility, Boyle and Scherrer-Rathj (2009) provided evidence in support of the following most important practices for ensuring manufacturing flexibility: 'incorporating the role of manufacturing flexibility into the manufacturing strategy; identifying the major potential sources of uncertainty faced by the manufacturing department; and identifying the general capability of the manufacturing department to address these potential sources of uncertainty'.

Day (1994) asserted that organisations achieve customer satisfaction by building capabilities on a set of competencies. Upton (1995) made a distinction between internal flexibility as what the firm can do (competencies) and external flexibility as what the customer sees (capabilities). In terms of internal flexibilities, competencies covers machine flexibility, labour flexibility, material handing flexibility, and routing flexibility. Volume flexibility and mix flexibility define flexible manufacturing capability (Zhang et. al., 2003), representing external flexibilities. Sethi and Sethi (1990) describe volume flexibility as the ability of the organisation to operate at various batch sizes and/or at different production output levels economically and effectively and mix flexibility is ability of the organisation to produce different combinations of products economically and effectively given certain capacity. According to Zhang et al (2003), customers value the visible capabilities, volume flexibility and mix flexibility, rather than the internally oriented competencies because customers see how these capabilities can be used to increase their satisfaction. However, volume flexibility and mix flexibility cannot be achieved directly; they are attained through the implementation of flexible manufacturing competencies.

The significance of labour and routine flexibility is also worth noting. Labour flexibility is ‘the ability of the work force to perform a broad range of manufacturing tasks economically and effectively’ (Zhang et al., 2003). The primary source of labour flexibility is cross-training or multi-skilling (Oke, 2005). As Zhang et al. (2003) noted, the work force actually plays an important role in the production process and its consequences on system flexibility and performance has been the subject empirical studies (Upton, 1995; Jack and Raturi, 2002). Routine flexibility is the capability to use alternative processing routes to make a product. By providing the capability of alternative processing paths, routine flexibility allows better handling of unexpected imbalances in demand for specific resources. In addition routine flexibility enhances ability to unexpected changes or variations in product mix allowing the impact to be dampened through alternative process routes over a variety of resources.

The influence of manufacturing flexibility on performance is well studied and it is generally believed that manufacturing flexibility has a positive influence on operations performance (Camisón & Villar-López, 2010). Studies have also reported positive influence of different types of innovation on performance (Camisón & Villar-López, 2010). Attempts has also been made to study the link between manufacturing flexibility and innovation (e.g. Nemetz and Fry, 1988; Bolwijn and Kumpe, 1990; Duguay et al. 1997; Camisón and Villar-López, 2010). Bolwijn and Kumpe (1990) noted that flexibility is a required component for innovation. Nemetz and Fry (1988) explained that manufacturing companies that are flexible should give greater weight to process innovation as their principal ‘distinctive competence’ for gaining competitive advantage, as in the case of product innovation. Duguay et al. (1997) insist that manufacturing flexibility may simply be accomplished when the company has both a flexible workforce as well as equipped with versatile machinery. This would then facilitate the quick adaptation in any variations within all aspects of manufacturing processes (Camisón and Villar-López 2010).

In the context of technological innovation, Purwanto and Raihan (2015) reported that manufacturing flexibility offers a mediating role through which manufacturing flexibilities positively contributes to operation performance. Oke (2013) found that the interaction of mix flexibility and labour flexibility positively predicts product innovation in manufacturing plants. It seems logical to extend this assertion to manufacturing process innovation. According to Nemetz and Fry (1988), manufacturing flexibility can have more influence on process innovation in comparison with product innovation. Higher manufacturing flexibility would allow supporting evolving requirements, adapting to environment or system configuration changes, simplifying maintenance and repair, and improving the efficiency in resources utilisation (Ferreira et al, 2006). Camison and Vilar- Lopez (2010) suggested that manufacturing flexibility influences product, process, and organisational innovations, has a positive effect on innovation capability, which consequently contributes positively to firm performance. This efficiency is expected to impact positively on innovation deployment readiness.

3. Assessing Process Innovation Deployment Readiness

Deployment readiness has a measurable outcome; this estimates the risk of the project and is often shown as a percentage of readiness. A higher level of readiness to innovate is identified thorough a number close to 100%. On the other hand, a number close to 0% means a higher risk of failure. The overall readiness estimate of an organisation is a function of the readiness estimates of the individual influencing factors. To model the interrelations between the individual influencing factors methods such as analytical network process (ANP) (Razmi et al., 2009), fuzzy cognitive maps inference (Ahmadi et al., 2015a), and a combination of fuzzy cognitive maps (FCMs) and the fuzzy analytical hierarchy process (FAHP) (Ahmadi, Yeh, Papageorgiou, & Martin, 2015b) have been used. A simulation approach to readiness assessment has been taken in Alireza and Sunmola (2017) to more easily capture the complexities involved in modelling manufacturing processes and its operations. It is a powerful technique for analysing manufacturing systems (Mourtzis, Doukas, & Bernidaki, 2014) and, in general, for appraising innovation deployment strategies in organisations (Wang & Moon, 2013).

In Alireza and Sunmola (2017) a sequential decision process framework is adopted in which the manufacturing system develops through transitions from one state to another. The transition is expected to be influenced by the implementation of the continuously innovation initiatives. The implementation is created on a deployment plan P_k that covers a pre-specified set of innovation initiatives. By having the deployment planP_k, the problem is to assess the extent how the plan will effect in a deployment smoothly and problem free. In the manufacturing system each state will have a degree of readiness related. For instance, set of features like deployment influencing factors, or risks may have associated with it could degrade system performance and for which there is no appropriate mitigation establishment in the deployment plan. This will result in reducing the degree of readiness compared to those whose features are entirely consistent with those that will deliver smooth and problem free deployment.

4. Simulation Experiments

This section contains a description of the simulation experiments conducted to study the influence of flexibility on deployment readiness. The simulation experiments focused on a job shop adapted from Alireza and Sunmola (2017).

4.1 Set Up of the Simulation Experiments

There are 11 machines in the simulated job shop as shown in Figure 1. Eight are non-specialist machines i.e. Machines 1 – 8. The non-specialist machines processes jobs which are randomly assigned a sequential series of operations such that there is a random machine visitation order, subject to a constraint that no machine is revisited. Each of the non-specialist machines has a constant capacity, they are always available and no breakdowns. Machines 9, 10, and 11 are specialist machines primarily for the purpose of quality assurance.

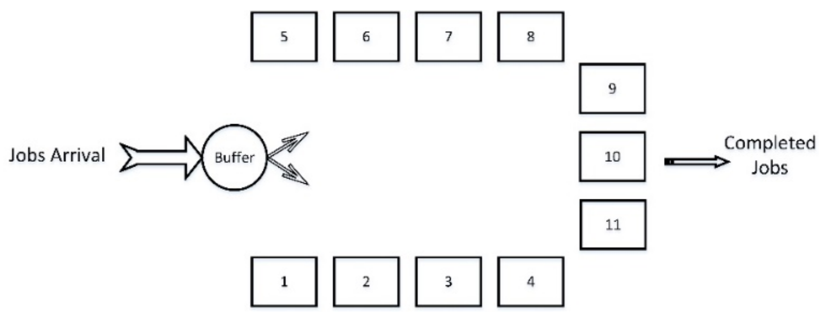

Figure 1. The simulated job shop.

In addition to the normal operations performed on Machines 1-8, there are three specialist operations performed by the specialist machines. The specialist machine can be configured in three ways to signify three levels of routing flexibility: no flexibility, limited flexibility and full flexibility; offering three possible scenarios for the job shop. In the first configuration, each specialist machine is able to perform one operation in a dedicated configuration (Fig. 2a), offering no routing flexibility. In the second configuration, there is limited routing flexibility with each specialist machine able to perform two operations (Fig. 2b). Finally, in the third configuration, there is full routing flexibility with each specialist machine able to perform all the three specialist operations (Fig. 2c).

A job visits one or more of the specialist machines i.e. Machines 9, 10 and 11, depending on the set of specialist operation(s) required by the job, in addition to the operations performed on the job at some or all of the other machines. When jobs arrive the job shop they are placed into a pre-shop pool and released for processing according to a workload bounding release mechanism (Bergamaschi et. al. 1997). Jobs are selected from the pre-shop pool on first come first served (FCFS) basis and FCFS rule is applied when sequencing the jobs for processing on the non-specialist machines. Jobs inter-arrival times are exponentially distributed with a rate parameter of 8mins.

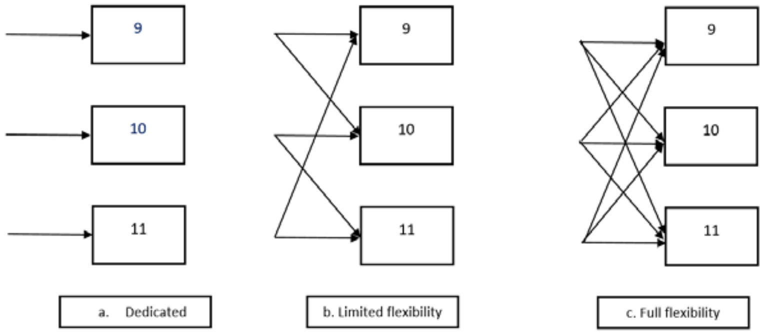

Figure 2. Configurations of the Specialist Machines.

The operation sequence for each job is uniformly distributed between 4 and 10 inclusive of visitation to either Machine 9, 10 or 11. The operation times on the machines follow a uniform distribution between 10mins and 50mins for the non-specialist machines and between 10mins and 40mins for the specialist machines. The operation processing times include machine set-up times. Due-date for each job is determined internally based on the total work-content (TWK) method (Blackstone et. al., 1982) with allowance factor of 5 and a job is completed on completion its operations sequence.

The job shop is considering whether to deploy a set of process innovations using two types of deployment plans, Deployment-Plan-A and Deployment-Plan-B that are of low and good quality respectively. Three scenarios were conducted. In the first scenarios there is no requirement for process innovation hence no deployment plan. In the second scenarios there is a requirement for process innovation and deployment is to be carried using a bad quality deployment plan i.e. Deployment-Plan-A. In the third scenarios, there is a requirement for process innovation and deployment is to be carried using a good quality deployment plan i.e. Deployment-Plan-B.

For each scenario, three experiments were conducted using the job shop characteristics described above and for each of the three configurations – No, limited, and Full flexibilities. Under conditions of limited and full flexibilities, a decision must be made as to which alternate machine's queue a job will be routed as each preceding operation is finished. The setup of the experiments are summarised in Table 1.

Table 1. Set-up of the Experiments

Scenarios	Deployment Plan	Configuration of Specialist Machines		
		No Flexibility (Dedicated)	Limited Flexibility	Full Flexibility
A. No Requirement for Process Innovation.	None	A.1	A.2	A.3
B. Requirement for Process Innovation	Low Quality	B.1	B.2	B.3
C. Requirement for Process Innovation	Good Quality	C.1	C.2	C.3

In Scenarios B and C, process innovation initiatives cover locally innovative and structural process innovations (Yamamoto and Bellgran, 2013). There were two main innovation initiatives: a) integration of RFID into shop floor operations, and b) replacement of the specialist machines, i.e. Machines 9, 10, and 11 with smart specialist machines. In both scenarios, deployment is phased out as shown in Tables 2 and 3 resulting in seven deployment states.

Processing times on the innovative smart specialist machines are lower than the old specialist machines replaced, and it is derived from a uniform distribution with values between 12mins and 25mins. The implementation of the RFID starts at 12500mins in Plan A and much earlier in Plan B at 3000 mins. The RFID implementation has an immediate disruptive effect on the shop floor with a learning rate (Wright, 1936) of 80% that initially increases job processing times. This disruptive effect lasts up to 13000 minutes under Plan A and 4000 minutes under Plan-B; from then onwards there is a reward for implementing the RFID with job processing times reduced by 25%.

Table 2. Deployment-Plan A (Low Quality Plan)

State	Machine 9			Machine 10			Machine 11			RFID	Activity Times (mins.)	
	Old On	Old Off	New On	Old On	Old Off	New On	Old On	Old Off	New On		Start	End
1	✓			✓			✓					5500
2		✓		✓			✓				5500	6000
3			✓	✓			✓				6000	9000
4			✓		✓		✓	✓			9000	9500
5			✓			✓	✓		✓	✓	9500	12500
6			✓			✓			✓	✓	12500	13000
7			✓			✓			✓	✓	13000	15000

* On = Machine is Online; Off = Machine is Offline.

Table 3. Deployment-Plan B (Good Quality Plan)

State	Machine 9			Machine 10			Machine 11			RFID	Activity Times (mins.)	
	Old On	Old Off	New On	Old On	Old Off	New On	Old On	Old Off	New On		Start	End
1	✓			✓			✓					1500
2		✓		✓			✓				1500	2050
3			✓	✓			✓				2050	2500
4			✓		✓		✓	✓			2500	3000
5			✓			✓	✓		✓	✓	3000	3500
6			✓			✓			✓	✓	3500	4000
7			✓			✓			✓	✓	4000	15000

* On = Machine is Online; Off = Machine is Offline.

Simulation starts with an empty shop and runs until 15,000 minutes with 100 trials. Data on the first 800 minutes is discarded to allow for a warm-up period and attainment of steady state conditions. Deployment readiness is based on the service levels recorded up to 15,000 minutes.

4.2. Results and Discussion

The simulation results are presented in Figure 3 and Table 4 below. In all the three experiments, an average of at least 70% machine utilisation was recorded. There is a noticeable difference in the average utilisation of the machines over time both in no-deploy and deployment scenarios. There is a lower average machine utilisation in deployment Plan A compared with no-deploy scenario and much lower average machine utilisation under deployment Plan B. The noticeable difference is more pronounced with increasing flexibility. Deployment Plan B permits increased capacity at a much earlier time than Deployment Plan A and this contributed to the decreased level of average machine utilisation recorded. The increased capacity would allow the shop to take on more jobs.

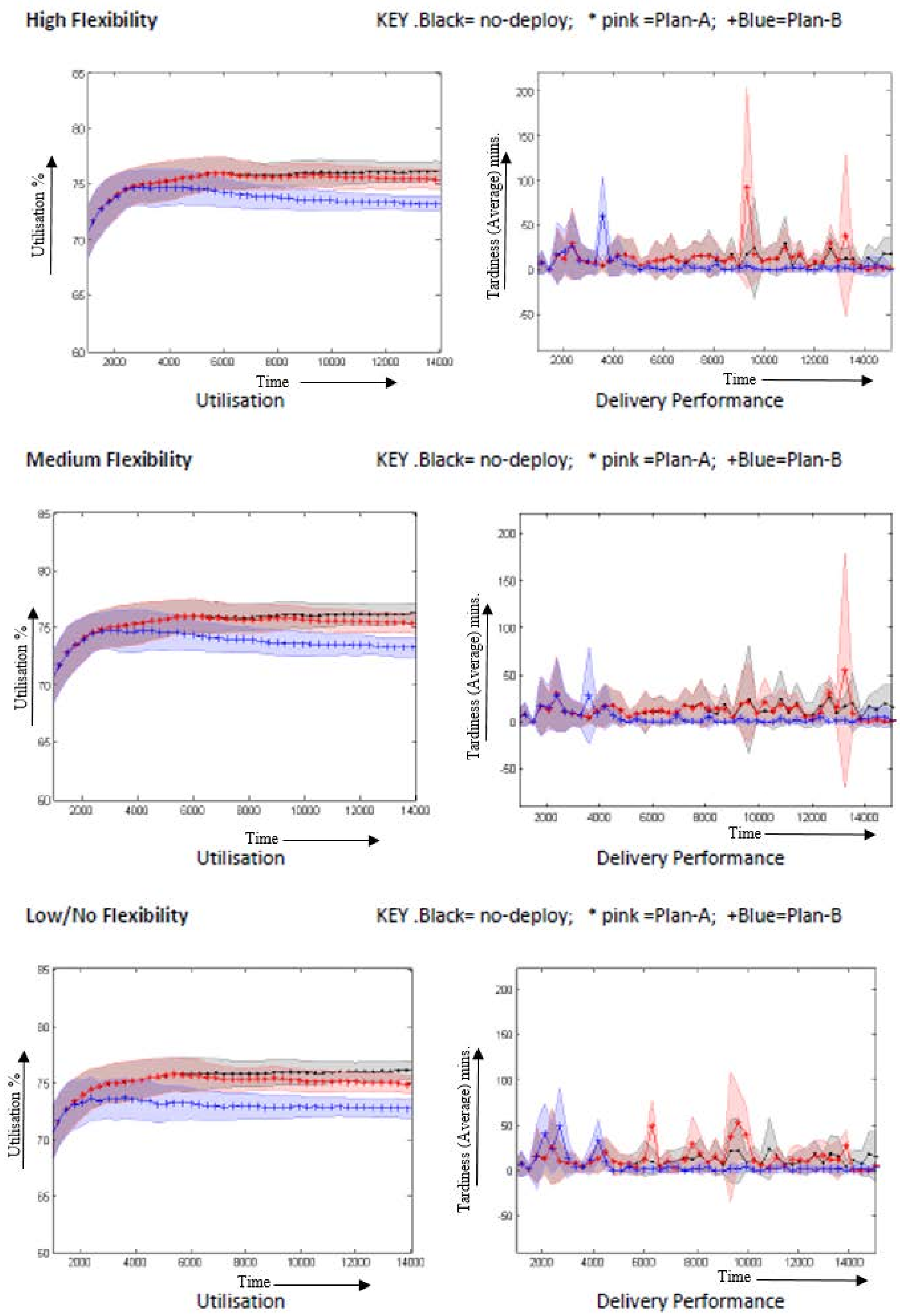

Figure 3.

In terms of the service level performance, the results shown in Table 4 shows that the quality of deployment plans have an influence on deployment performance. Deployment Plan B has a higher deployment readiness value than deployment Plan A. The quality of the deployment plan may in cases result in service levels that are worse than situations in which changes has not been made to the system. For example, in Table 1, the service level in terms of tardiness is lower under deployment Plan A compared to no deployment for the no flexibility configuration. This performance result is reversed with increased flexibility. This indicates that flexibility can mediate the influence of deployment plans on implementation performance.

Table 3. Deployment Readiness Values

Flexibility	Deployment Plan		No Deployment
	Plan A	Plan B	
Low	91.987383 [91.670450,92.304316]	96.753051 [96.599353,96.906750]	92.196027 [91.928727,92.463327]
Medium	93.047331 [92.726043,93.368618]	97.328555 [97.173442,97.483668]	92.252077 [91.935841,92.568312]
High	93.083751 [92.774522,93.392980]	97.359536 [97.199234,97.519838]	92.278283 [91.981109,92.575457]

*[] 95% Confidence Interval; Plan A – lower quality plan; Plan B – higher quality plan.

With no flexibility, tardiness is more spread compared with medium and flexibilities under the two deployment plans. The spread of tardiness overtime is much reduced for deployment Plan B compared with deployment Plan A. Which also accounts for the deployment readiness values shown in Table 4. Having a less spread out tardiness values is ordinarily good particularly of jobs are of relatives equal in value.

5. Conclusions and Future Work

Getting prepared for deployment is an important step when implementing manufacturing process innovation. The level of preparedness, captured through measures of deployment readiness index, is a useful indicator for managing implementation of process innovation. There are several factors than can influence deployment readiness and they include the deployment plan and manufacturing flexibility. This paper focused on these two factors and found that flexibility can influence deployment readiness. In addition, flexibility is found to mediate the impact of deployment plan quality on deployment readiness. These results were obtained based on computer simulation of a job shop and for a specific routing rule FCFS. Areas of future work should look more closely at the role of manufacturing flexibility more generally such as flexibilities other than routine flexibility, the criticality of machines and jobs, the effect of alternative rules of routing jobs to the alternative machine's queue and other range of performance measures beyond service level performance. Work is also required in validating and extending the findings to other types and manufacturing processes and environments.

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Biography

Alireza Javahernia is currently a PhD student in the School of Engineering and Technology, University of Hertfordshire UK. He worked and experienced in various fields such as engineering, managing, coordinating and controlling projects. This gave his the abilities to find problems and analyse situations and confident to make right decision and judgement.

Funlade T. Sunmola is currently a Senior Lecturer at the School of Engineering and Technology, University of Hertfordshire UK. He is also the programme leader for MSc Online Engineering and Technology programmes at the institution. His teaching activities include tutorship and leadership on a variety of undergraduate and postgraduate modules with emphasis on manufacturing, enterprise systems, operations and supply chains. He earned his PhD in Computer Science, with emphasis on applied artificial intelligence and robotics, from University of Birmingham UK. He has over 35 years of experience in the industry, in a variety of capacities, and currently leads a variety of research projects including supervision of a current KTP funded project on smart manufacturing.

Leslie Mitchell is the Head of Division for Manufacturing, Materials, and Biomedical, School of Engineering and Technology. He has many years of experience both in teaching and in the industry, with over 20 years in manufacturing and service industry especially for small-medium enterprises. He has higher education experience in teaching, research, and consultancy on many aspects of manufacturing operations and performance measures. He has research publications both at international conferences and in international journals. He is involved on many high-profile committees for performance measures, especially in the provision of quality learning and teaching, and sustainability as a corporate social responsibility. Gained legal qualifications and legal experience, to help with the quality of working life. His present position has demonstrated his proven ability to make educational and management decisions, and that ability to exercise judgements on matters affecting strategic decisions both in higher education and manufacturing industry.