An Intelligent Manufacturing System: Agent Lives in Adhesive Slice

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Abstract

Mobile Agents represented as adhesive slices are developed for production control and optimisation. These agents termed Agent Slices are adhered to both large-sized objects such as machine tools, large workpieces, pallets, etc. and small-sized objects such as cutting tools, small workpieces, etc. The abilities of Agent Slices to make decisions and establish wireless communication have shifted the production control principle away from traditional centralised manner into autonomous distributed manner. With the aid of Agent Slices, a flexible, autonomous, distributed production control system is developed. Due to the complexity of the proposed control system, a comprehensive discussion on the system cannot be fully presented within a paper, hence, this paper is mainly focused on the communication network of the Agent Slices. Discussions in this paper will include the agent's architecture, working principle, abilities, communication architecture and platform, as well as the integration of Agent Slices forming an Intelligent Manufacturing System.

Keywords*:* Bluetooth technology, Communication protocol, Intelligence agent, Production Control and Optimisation, Intelligent Manufacturing System.

1.0 Introduction

Intelligent agents are autonomous software entities whose behaviours tend towards satisfying their design objectives, taking into consideration the information and capability they possess, as well as depending on their perceptions, representations, and communications they receive. Agents are capable of responding to stimuli, analysing the perceived stimuli, and making decisions that satisfy their design objectives. These unique capabilities of agents have driven the application of agents in different research field recently. Within the manufacturing context, Agent Technology is widely and mainly applied in product design, robotic control system, supply chain management, and production control and optimisation.

Within a production shop floor, all manufacturing resources (e.g. machine tools, workpieces, production lines/cells, etc.) are represented as agents. More specifically, workpieces are often represented as mobile agents while other production resources such as machine tools and cutting tools are represented as non-mobile agents. The functions of these agents are depending on their roles within a production shop floor. Agents perform negotiation, bidding, and voting to obtain contracts for various tasks.

As physically connecting production resources to computers is impractical, the idea of using mobile adhesive slice i.e., Agent Slice emerges. An Agent Slice is created by transferring a piece of software code onto an adhesive slice and attaching the slice to a physical workpiece. As an Agent Slice is attached to a physical workpiece that is physically not link to any computers, a network of wireless communication is established to enable inter-agent communication and to update/store data produced during communication within irrespective host computers. The wireless communication is accomplished using Bluetooth technology. An Agent Slice attached to a physical part is reusable. This is simple achieved by stripping off the Agent Slice from a finished workpiece and re-adhered it to a new workpiece. As an Agent Slice has the self-learning ability, it becomes more and more intelligent as time passes.

A collection of agents controlling and optimising production within a shop floor has created an intelligent and flexible manufacturing environment.

2.0 Bluetooth Development Kit

In recent years, Bluetooth Technology has made a great impact in communication and is regarded as one of the newest technologies in the latest ten years by Network Computing[11]. Performing wireless communication and automatic search within a compound of approximately ten meters are two key characteristics of the Bluetooth technology. Once connection is established, data are transmittable with respect to program instead of artificial interference.

Bluetooth technology, which is used for short distance wireless communication has the following features:

(1) ***Small-sized module***
Bluetooth device usually has a size that is small enough for convenient use. For instance, the Cambridge Silicon Radio (CSR) module is a surface mounted device with the size of 27.0 x 14.5 x 2.3mm.

(2) ***Universal operating frequency band***
It uses 2.4GHz to 2.48GHz, unlicensed Industrial, Scientific, Medical (ISM) band, with an open system designed for wireless communication.

(3) ***Strong stability and anti-interference***
The use of technology with fast frequency hopping, frequency spreading, and automatic mistake correction minimises external noise and interference to enhance Bluetooth system's stability.

(4) ***Low power consumption and radiation***
It is a highly integrated technology that constrained Bluetooth chip within ten millimetres square. This has contributed to low power consumption and feeble radiation with various embedded units. Till now, there is no proof from World Health Organisation (WTO) and Institute of Electrical and Electronics Engineering (IEEE) which manifests the danger of Bluetooth radiation to human body.

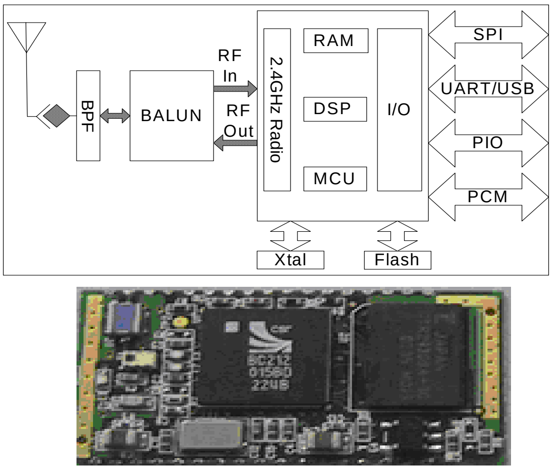
(5) ***Low cost***
Many years back, products with Bluetooth technology are relatively expensive. Pursuant to the increase of demand and the improvement on Bluetooth technology, more suppliers are able to provide better Bluetooth products with lower costs. According to Bluetooth Special Interest Group (SIG), the price of Bluetooth chip will fall to USD$5 and will continue to fall in the future. CSR's Bluetooth development kit is one of the solutions that is fully compliant to the Bluetooth specification and protocol. Users of the kit will only need to compose the application software using C language.

3.0 An Agent Slice and the Bluetooth module

3.1 Bluetooth module

Bluetooth module is the core hardware for an Agent Slice. It is a highly integrated module that consists of an antenna interface, a Bandwidth Pass Filter (BPF), a balun, a Random Access Memory (RAM), a Digital Signal Processor (DSP), a Microcontroller Unit (MCU), an Input/Output (I/O), a Serial Peripheral Interface (SPI), an Universal Asynchronous Receiver Transmitter/Universal Serial Bus (UART/USB), a Parallel Input Output (PIO), and a Pulse Code Modulation (PCM). The function blocks of the Bluetooth module are shown in Fig.1. The Bluetooth module has an interface (i.e. UART) for data exchange, and embedded DSP, MCU for data processing. It is able to support Piconet (up to 7 slaves) and full data rate (up to 723.2/57.6 kbps).

The main parameters of Bluetooth module include: input voltage of DC（Direct Current） 2.7V-3.6V; input current of 90mA; operating voltage of 3.3V; power consumption of 140mw for master and 110mw for slave under active mode; Radio Frequency (RF) output power of 1.5dBm; efficient transmission distance of 10m; data rate up to 732.2kbps via Recommended Standard-232 (RS-232) or UART; UART, RS-232and SPI interfaces; operating frequency band of 2.4GHz ISM.（Industrial.Scientific.Medical）



Size: 27.0 x 14.5 x 2.3 mm

Fig.1. The function blocks of a Bluetooth module

3.2 An Agent Slice – a Bluetooth Device

The main parts of a Bluetooth device are the Bluetooth module, an antenna, a display unit, a latch unit, and a switch unit as depicted in Fig. 2. Among these modules, Bluetooth is the core module. It holds a 16Mbit ROM（Read Only Memory）that has more than sufficient capacity to satisfy a basic need for data processing. It is fully compliant to the Bluetooth development kit. The display unit, latch unit, and switch unit are used to enable a distributed and intelligent workshop control and to fulfil mutual communication among Agent Slices (representing workpieces and machine tools).

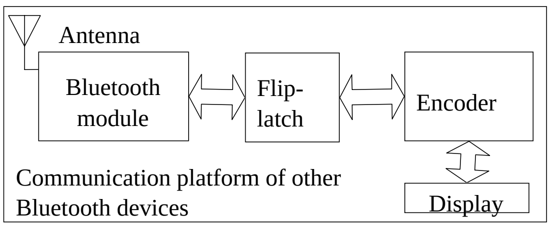


Fig.2: An Agent Slice – the Bluetooth device

3.3 Architecture of An Agent Slice

The internal architecture of an Agent Slice is depicted in Fig.3. There are three control modules which are the Computer and operating unit, a controller and a Learning and Reasoning module; a Goal Library; a Knowledge Library; and a Data Library.

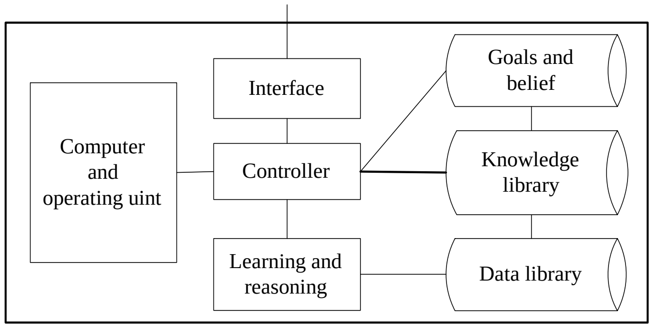


Fig.3: The internal architecture of an Agent Slice

Belief enables an Agent Slice to achieve its local goals and global goals for the whole control system. Based on these goals, agents adjust their actions accordingly making them more versatile to changing scenarios. *Knowledge Library* encapsulates basic principles and rules such as process plans which will be automatically updated via the self-learning ability of the Agent Slice. *Data Library* is a database encapsulating real time information which mainly consists of external received information and final or semi-final results. *Knowledge Library* and *Data Library* support the reasoning and learning modules of the Agent Slice. Whereas the learning and reasoning module support message processing, which means the Agent Slice is able to perform self-control. *Controller*, the core element of the Agent Slice governs the behaviours and actions of the slice. *Interface* is a gateway for the Agent Slice to have contact with its environment. It could be a human-machine interface, a physical interface or data linkage among agents, where information is received from or transmitted to the working environment. A *Computer and the operating unit* are the operating systems of the Agent Slice. Pursuant to results achieved from learning and reasoning, the *operating unit* (under the supervision of *Controller*) will execute the desired action.

3.4 Working Principle and Abilities of an Agent Slice

Initially, only the basic and universal rules are documented within the *Knowledge Library*. These rules are obtained from experts and/or experience accumulated throughout the life of an Agent Slice. These rules include the working principles of an

Agent Slice, process plans and process quality of parts. When data are received from human-machine interface or wireless interface, the data are first stored. Learning and reasoning module will analyse the data by matching them with rules residing within he *Knowledge Library*. With the supervision of the *Controller* and the decision made by the learning and reasoning modules, signals are generated and transferred to the *operating unit*, which executes the desired actions. The completion of one working cycle (i.e., from receiving data to the execution of actions) produces new rules and facts which are stored within the *Knowledge Library*. In other words, it is through learning and reasoning that new rules are generated and added into the *Knowledge Library* as time passes. As a result, the Agent Slice will become more and more intelligence, just like human being. The degree of autonomy of the agent is directly proportional to rules stores within the *Knowledge Library*.

An Agent Slice is able to perform Data Receiving and Transmission as long as the communication architecture of the slice conforms to the Bluetooth specification. Data link can be established easily and information can be transmitted between Agent Slices. Agent Slice are versatile enabling it to adapt responsively to the changing situation. This is accomplished via self-learning and self-adjustment abilities of the Agent Slices.

3.5 Wireless Communication Architecture for an Agent Slice

Using a Bluetooth module alone to fulfil a wireless communication in workshop is not sufficient. Hence, extended circuit and its corresponding software are required for data receiving and transmission. The wireless communication architecture for an agent slice is shown in Fig.4.

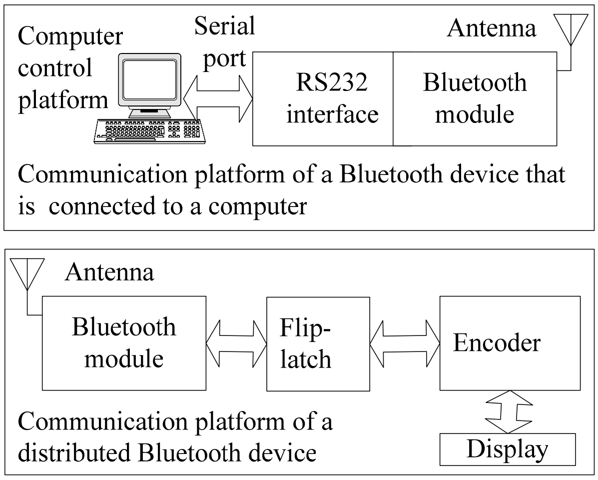


Fig.4. The Wireless Communication Architecture of Bluetooth Devices

4.0 An Intelligent Manufacturing Shop Floor: A Distributed Multi-Agent System

The use of intelligent Agent Slice for workshop control has created an intelligent manufacturing environment. which is also regarded as a distributed multi-agent system. The idea of the distributed multi-agent system is to decentralise and distribute the controlling tasks of a manufacturing shop floor to multiple intelligent controllers i.e., Agent Slices. Such principle is particularly vital for a complex and dynamic workshop where nimble decisions are required.

Within a multi-agent system, Agent Slices serve as masters or slaves at different times. Their role changes accordingly with response to different production scenarios. Generally, agents that provoke communication serve as masters, while the requested agents serve as slaves. Fig. 5 illustrates the roles of a master in the multi-agent environment. The only different between the roles of a master and a slave is that the slave does not initialise a communication.

Wireless network within workshop is established when Agent Slices are adhered to production resources or workpieces. During production, information such as the state of machines should be transmitted to Workpiece Agents (representing workpieces). This information is used by Workpiece Agents to perform free searching through the network to determine the most suitable Machine Agents (representing machines). Within the production shop floor, Workpiece Agents and Machine Agents negotiate to gain the opportunity to process individual workpieces. Management Agent (which normally is the host computer) is the general supervisor responsible for resource registration and logging process, conflict solving which might arise between Workpiece Agents and Machine Agents.

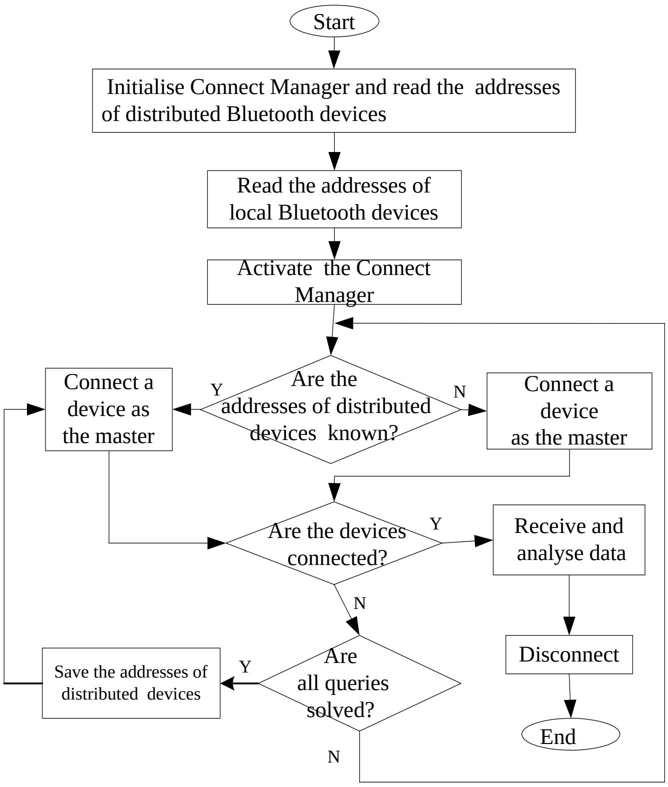


Fig.5: The flow chart illustrating the roles of a master

Fig. 6 shows that a Bluetooth device that connects to a computer via serial port proposed in this research is capable of having a maximum of seven data links, connecting to seven Bluetooth devices respectively. This forms a communication network termed as Piconet. The main functions of a Computer Controlled Platform (CCP) are: data receiving and transmission, system controlling, collaborating and supervising. Data received will be analysed to solve problems, whereas requests, commands, or information will be transmitted to production shop floor to control, harmonise and supervise production activities. Meanwhile, Agent Slices in field analyse received data and generate signals to drive the operating unit. On-line production information such as the state of machines and workpieces will also be feedback to the CCP in time. In this research, the Machine Agents and Workpiece Agents constitute a Piconet. Among these agents, the same frequency hopping sequence is adopted to enable synchronise communication. Within a manufacturing shop floor, there are several Piconets with each Bluetooth device can be a part of more than one Piconet and plays different roles respectively.

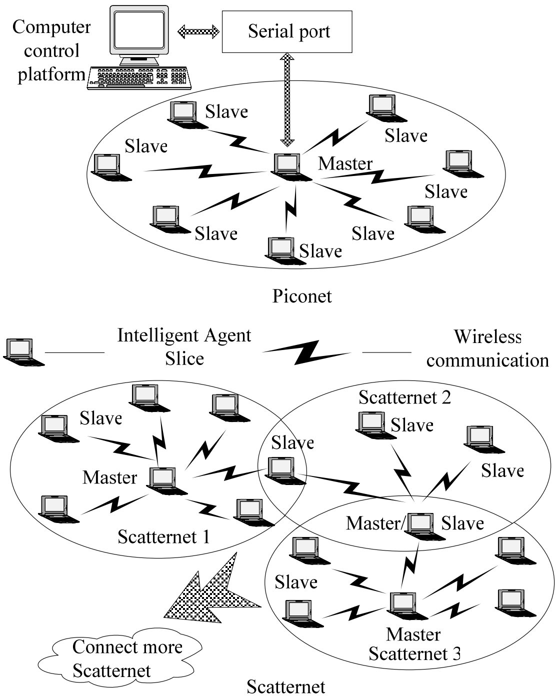


Fig. 6: Piconet and Scatternet

Fig. 4 also shows how would a network be established via Bluetooth technology. The network is regarded as the control system for the production shop floor. Generally, eight Bluetooth devices form a Piconet and several Piconets forms a Scatternet. With these Scatternets a network is established.

4.1 Computer Controlled Platform

The Computer Controlled Platform is a software handling data receiving and transmission, system controlling, collaborating and supervising. The window of Computer Controlled Platform that consists of three display areas is shown in the upper part of Fig. 7. The top part of the figure shows results obtained from self-learning. The learning function is a subprogram written using the principle of fuzzy-neural network. The middle part of the figure shows the data transmission process, whereas the bottom part of the figure shows the data receiving process. Data can be used to perform real time analysis to obtain the states of various distributed Bluetooth devices or be saved for later use. The lower part of Fig. 7 is the window for parameter settings for the serial port.

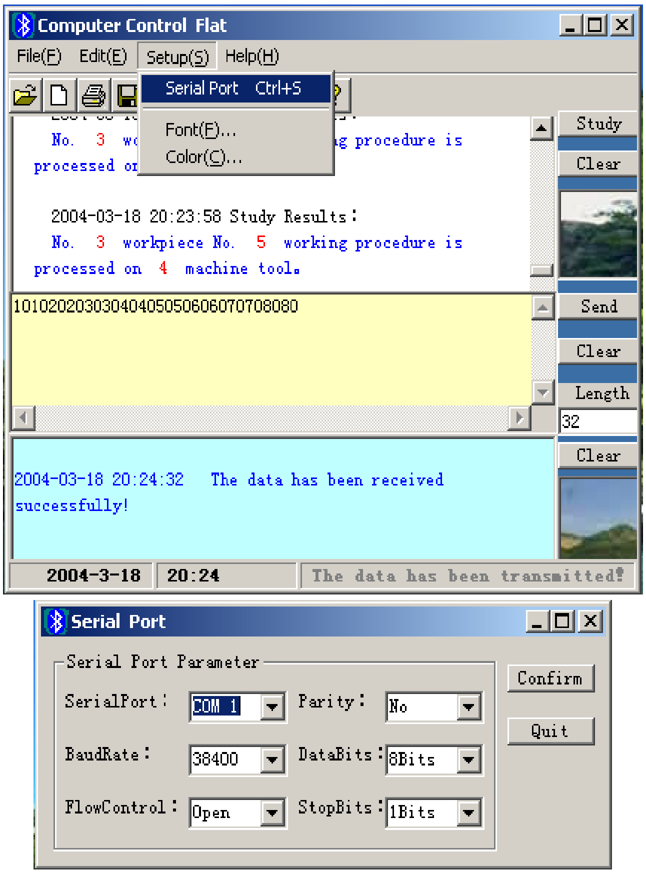


Fig. 7: Windows for Computer Controlled Platform and the Serial Port

Communication process of the serial port is illustrated in Fig. 8. Prior to the execution of learning subprogram, data pertaining to process plans, product quality, and scheduling should be known in advance. All these information will be used to conduct succeeding operations, which are reasoning, decision making, final or semi-final result analysis.

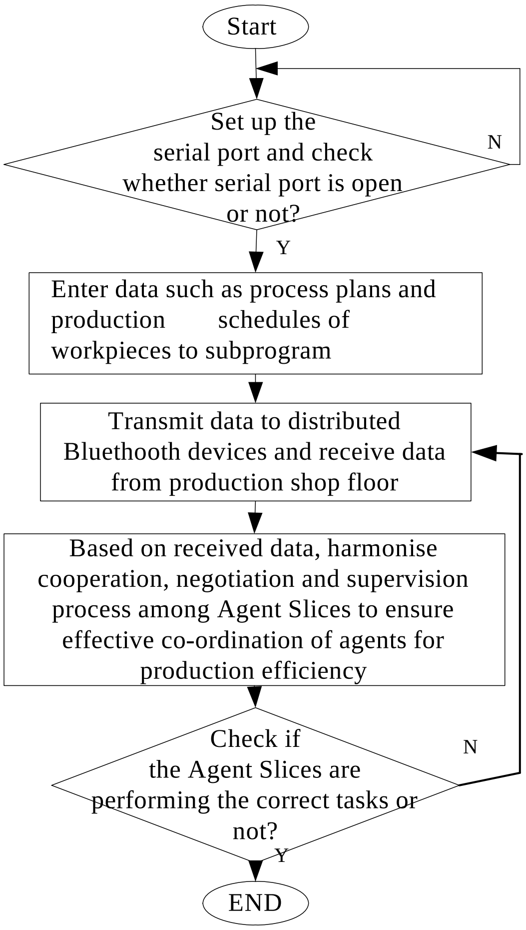


Fig.8: Communication Flow Chart of a Serial Port

5.0 Test case

Experiment was conducted to validate the feasibility of the developed planning and scheduling methodology in this research on a production shop floor (refer to Fig. 5) with four lathes, two milling machines, two drilling machines, two grinders, two automatic guided vehicles (AGV), and some pallets (P). There was a Control Unit responsible for the overall supervision of production operations in the shop floor.

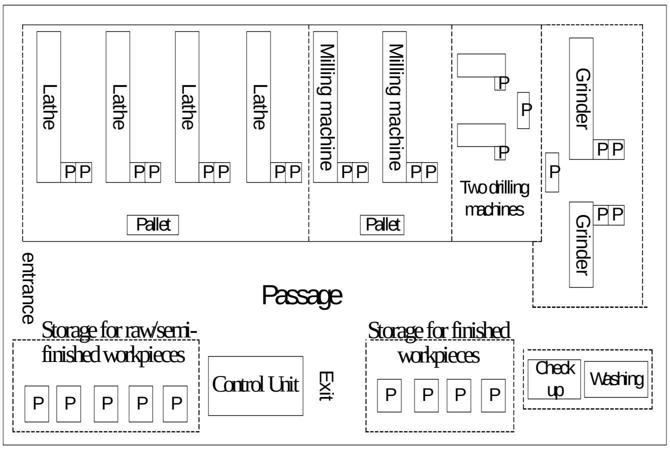


Fig.9: Physical Layout of the Plant

Agent Slices were attached to mobile resources such as workpieces and AGVs making them mobile agents termed Workpiece Agents and AGV Agents. Agent Slices were also attached to non-mobile resources such as lathes, grinders, etc., making them non-mobile agents termed Machine Agents. All workpieces were identical to one another, and each had a number of features to be processed. Individual Workpiece Agents negotiated with Machine Agents as discussed in Section 3.0 and 4.0 to determine the appropriate process plans for the workpieces. The performance of a generated process plan was measured using production lead time. The shorter the lead time, the better the process plan.

5.1 Discussions

The straight line curve in Fig. 10 is a benchmarking line. It indicates a constant and proportionate increase in production lead time as production volume increases. More specifically, this curve shows no improvement in lead time throughout the production cycles. Conversely, results produced from the experiments, which are represented by another curve in Fig. 10, shows improvement in lead time. Lead time decreases when production cycle increases. This indicates Agent Slices are able to co-ordinate with one another and use their knowledge (preset and/or learnt) and experience (gained through the simulation cycles) to determine cheaper and cheaper process plans as production cycle increases.

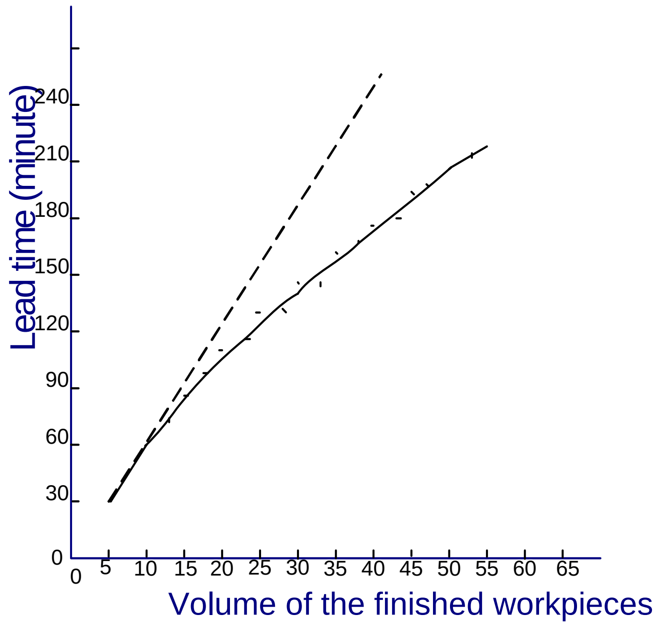


Fig.10: The plot of production volume versus production lead time

6.0 Conclusions and future work

This paper has presented a novel methodology that uses Agent Slices to control and optimise production operations. Promising results produced on site trial have validated the feasibility of the developed methodology. Besides, the use of Agent Slices has promoted the creation of an adaptive and dynamic shop floor control system capable of aptly addressing changing production requirements.

In order to fully explore its capability, the developed methodology will be used in real time dynamic production environment in the future.

Acknowledgements

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