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Intelligent Business Process Engineering:

An Agent Based Model for Understanding and Managing Business Change

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Abstract—**This paper advances the hypothesis that a business can be regarded as a collection of interacting rule based processes, that are analogous to a set of rule based coordinating pervasive computing agents that make up intelligent environments. In this paper we explore this hypothesis and, in particular, investigate the application of directed graph theory, normally used in determining the stability of systems of pervasive computing agents, to business systems. In doing this we present an account of interaction networks, business process reengineering, show how they are both based around the use of 'process' abstractions and illustrate how they can be integrated using a representative example. This paper represents a first step in our longer-term goals to explore the full potential for AI to create smart business monitoring and management tools.**

Keywords- intelligent environments; intelligent agents; business process reengineering, business management, smart business

I. INTRODUCTION

Henry Ford once said, "You can do whatever you like except stay as you are". Change is an intrinsic part of our world and can be found everywhere ranging from our own private lives, through politics and businesses to our technologies. Change can occur in societies, organizations, people and technological systems [1]. Change can have positive or negative effects on systems. Understanding the effects of change and, if possible managing it has the promise to allow change to work to the advantage of the stakeholders.

Managing change is critical to enabling a modern business to adapt to a shifting market place and business environment. The Business Process Reengineering (BPR) tool has become an important methodology for deliberating and managing such organizational change in businesses [2]. Likewise, change or adaptation is an essential part of intelligent environments with most useful functionality stemming from managed change [3].

Fundamentally, both business and intelligent environments are composed of collections of interacting agents. In the case of businesses, the agents are both people and companies (companies being legal identities in most countries) whereas in the case of intelligent environments the agents are appliances and managed spaces. Each system operates by executing rules that are subject to regulations set by policies originated from the stakeholders.

In this paper we explore a unified model of agents, that allows the theories developed for agents in intelligent systems to be applied to understanding and managing business behaviour, raising the hypothesis that "*a business is effectively another form of intelligent system*". This paper is part of the author's interest in exploring novel ways to bring together business and engineering [4].

II. THE ROLE OF POLICY, RULES AND REGULATION IN AGENT SYSTEMS

We define agents as autonomous self-managing entities and examples include people, companies, robots and even intelligent buildings. Common characteristics of intelligent agents include their ability to reason, plan and learn. They generally operate according to rules, some of which they inherit from a regulatory environment (fixed) and other they deduce through their operation (dynamic) [5]. In the 1920's Le Corbusier, an architect of some renown, famously remarked that, "*A house is a machine for living in*". Later, in the early millennium, Callaghan extended this view by declaring "*A building is a robot we live inside*" [6]. In this paper we extend this metaphor further by hypostasising that "*a business is an intelligent environment*" (ie "*a company is a machine for doing business*"). In particular, a company is a special kind of machine in that it is both an agent (a company has a legal identity similar to a person) and is made up of multiple agents (job roles, processes undertaken by people). Both Le Corbusier and Callaghan's views were instrumental in forcing people to think about their disciplines in a new way, bringing novel approaches to the design of buildings and pervasive computing systems. For example Corbusier's views led to a new 20th-century style of architecture, modular in nature and drawing on engineering technology using materials such as ferro-concrete and sheet glass while Callaghan's analogy with mobile robots led to the application of behaviour based AI methods to building and environmental control. In this paper we postulate further on the integration of engineering with other disciplines, suggesting that businesses are analogous to intelligent environments and may benefit from the applications of related engineering theorems; in this case, Interaction Networks (INs). The rationale behind this proposal is that both intelligent environments and businesses are composed of numerous collaborating autonomous agents, some of which take biological form, others taking electronic or software form. At the heart of computational systems is the notion of a *process*, an autonomous execution thread that takes inputs, produces outputs and communicates with other processes. In a similar way, businesses can be deconstructed into a set of collaborating processes with inputs, outputs and inter-process communication (see figure 3). Thus, in this paper we seek to set out the initial groundwork needed to explore the proposition that "*a business is an intelligent environment*" (aka "*a company is a machine for doing business*".

III. Interaction Networks (IN)

Modern Intelligent environments are composed of numerous coordinating distributed intelligent agents. Understanding and designing behaviour in such systems is crucial to their success. Tools that assist engineers understand and design effective intelligent environments as especially valuable. One such mathematical tool is the interaction network which is a directed graph (also known as *digraph*) that captures the interactions between rule based agents. In more formal terms a *directed graph* G consists of a finite set V of vertices or nodes, and a binary relation E on V. The graph G is denoted as (V,E). The relation is called the *adjacency* relation. If w is relative of v, i.e. $(v,w)\in E$, then w is adjacent to v [7].

An agent A_k is an autonomous device consisting of a triplet $[s_k,r_k,w_k]$, where k is the agent number for $k=1,2,3,...n$, n the total number of agents and:

s_k: Binary state of the *k*-agent defined over $\{0,1\}$
w_k: Importance or weight over $\{Low, Medium, High\}$
r_k: Set of time-dependant Boolean rules of the *k*-agent $\{\varphi_k,\psi_k\}$ defined as:

$$s_k = 1 \text{ If } \varphi_k \quad (1)$$
$$s_k = 0 \text{ If } \psi_k \quad (2)$$

With

$$\varphi_k,\psi_k : S\times t \rightarrow \{0,1\} \quad (3)$$

It is important to notice that in general terms, the weight associated to the pervasive devices is a function of time, as a device could have higher importance or priority during certain periods of time:

$$\omega_j = \omega_j(t) \quad (4)$$

If we have n autonomous devices $A_1,A_2,...,A_n$ the state of the system is $S=(s_1,s_2,...,s_n)$.

The rules defined in (1) and (2) are consistent in the sense that $\varphi_k=\psi_k^{-1}$. With this, the case of contradictory rules (e.g. one device ending up with two different states simultaneously) is avoided.

The set of rules defined over the agents can be used to build a network able to capture the functional dependencies between the agents, as will be shown in the next section.

The factor of importance corresponds to the inherent weight of the agent, taking into account the following aspects [8]: inherent importance (devices can have different importance according to the services or functionality provided) and user's preferences (users could have different preferences). As it can be seen, this model is very similar to a state machine, in particular, Boolean networks [8]. However, in the case of Boolean networks the rules are homogeneous, and the connections are symmetric and time-independent.

An *Interaction Network (IN)* is a digraph (V,E) in which the vertex $v\in V$ is an autonomous agent A and $(v_i,v_j)\in E$ if the Boolean functions φ_j or ψ_j of the pervasive autonomous agent A_j depends on the state s_i of the agent A_i.

Let $U\subseteq S$ be a subset of S. Because of the dynamics of the system, the system will produce a sequence of states $U_1,U_2,U_3,...,U_p$. If this sequence of states is periodic, then the subsystem U is said to be periodic.

The functionality of a node in a digraph is defined as the number of descendants in the Interaction Network. This characteristic of a node is very important, as it shows the impact of a process on the wider system, in terms of the number of processes whose activity rules could be triggered.

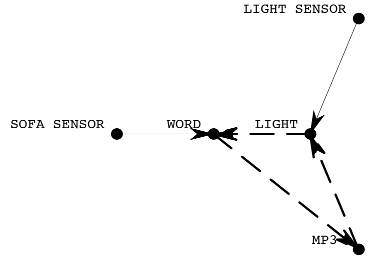

Figure 1. Example of the IN showing the dependiencies of 5 services in an intelligent computing environment

Figure 1 provides an example of an Interaction Network in an intelligent environment (the sort of system that might be used in an intelligent building or smart home), showing the dependencies of 5 network services: Sofa Sensor, Light Sensor, MP3 Player, Light, and Word. The *light* depends on the state of the *light sensor*, and in the state of the *MP3 player*. The software application *word* depends on the state of the *light*, and in the occupancy of the sofa (*sofa sensor*). Additionally, and accordingly to our formal definition, each agent A_k has been assigned a weight: sofa sensor (*High*), word (*Low*), light (*Medium*), light sensor (*Medium*), and mp3 player (*High*), In order to avoid the instabilities we must find the set of agents that stabilizes the system and minimizes the total cost W. If unitary weights for the agents are considered, the number of agents is minimized, and in general the optimum is calculated using

$$\min\{W = \sum_{A_i \in \Delta} w_i\} \qquad (5)$$

where $\Delta = \{A_i\}$ is the set of agents that stabilize the system. In figure 2 we illustrate the high-level algorithm.

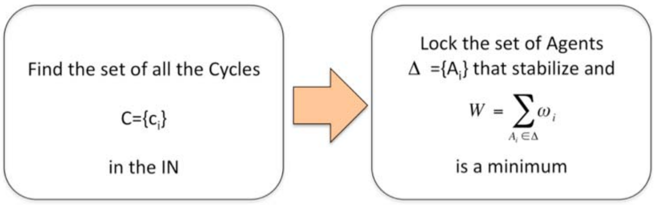

Figure 2. High level algorithm

One of the goals is minimizing the number of agents locked, in order to have a less-disabled system. The concept of weak and strong coupling cycles has been proven to be valuable tool on analyzing and understanding complex systems [8].

A. *Multidimensional Model for Task Representation*

In more generic terms processes are equivalent to tasks (either single or multiple). In order to visualize the effects of process / task interactions we have developed a multidimensional representational model. In this model a *temporal allocation* is a tuple (d, T, t_i, t_f), where d is a simple device, T is a simple task, t_i is the initial time and t_f is the final time. In other words, the device d will be performing the task T during $t_f - t_i$ units of time, beginning on the instant t_i.

So, a temporal community, denoted by C_t, is a non-empty set of temporal allocations:

$$C_t = \bigcup_{j=1}^{k} \{(d_j, T_j, t_{ji}, t_{jf})\} \qquad (6)$$

This definition allows us to locate the entities in a 3-axes graph: device, task (or state) and time [9]. This model is used in our example in order to show the dynamics of business process interaction

IV. BUSINESS PROCESS REENGINEERING

Business Process Reengineering (BPR) is a socio-technical approach which aims to redesign and implement broad, cross-functional business processes using information technology and social enablers to create improvement in organisational performance, such as quality, cost, flexibility, delivery time, and profitability [10, 11, 12, 13, 14]. The roots of BPR belong to the previous managerial schools, which were developed in the 20th century. The pioneer of the scientific management school, Frederick Taylor, used the methods of reengineering to discover the best way for organisations to work so as to maximize their productivity. Henry Fayol, at the onset of the 1920s, referred to the same concept as a means to guiding organisations to rebuild workflows for the purpose of improvement and maximization of profits from all available resources [5]. Many other people adopted the same idea. For example [16] asserts that BPR is actually a collection of four much older concepts; process redesign, structural reorganisation, information measurement and value refinement. He claimed that process redesign could be traced all the way back to Frederick Taylor in the nineteenth century whereas restructuring goes back to Henry Fayol and Peter Ducker. The modern onset of the BPR concept was in 1990 via two articles published simultaneously the first by Hammer “*Reengineering Work: Don’t Automate, Obliterate*” and the second by Davenport and Short “*The New Industrial Engineering: Information Technology and Business Process Redesign*”. The crucial idea at the heart of reengineering is that the obsolete rules and discontinuous thinking have to change [17]. In this approach the business is defined as a set of processes or tasks that, taken together, produce an outcome and a process perspective as a means of looking at the collection of tasks and the outcome from the customer's view [17, 10]. This then is the basis of our approach in this paper, as we regard a businesses as a set of connected processes, see figure 3.

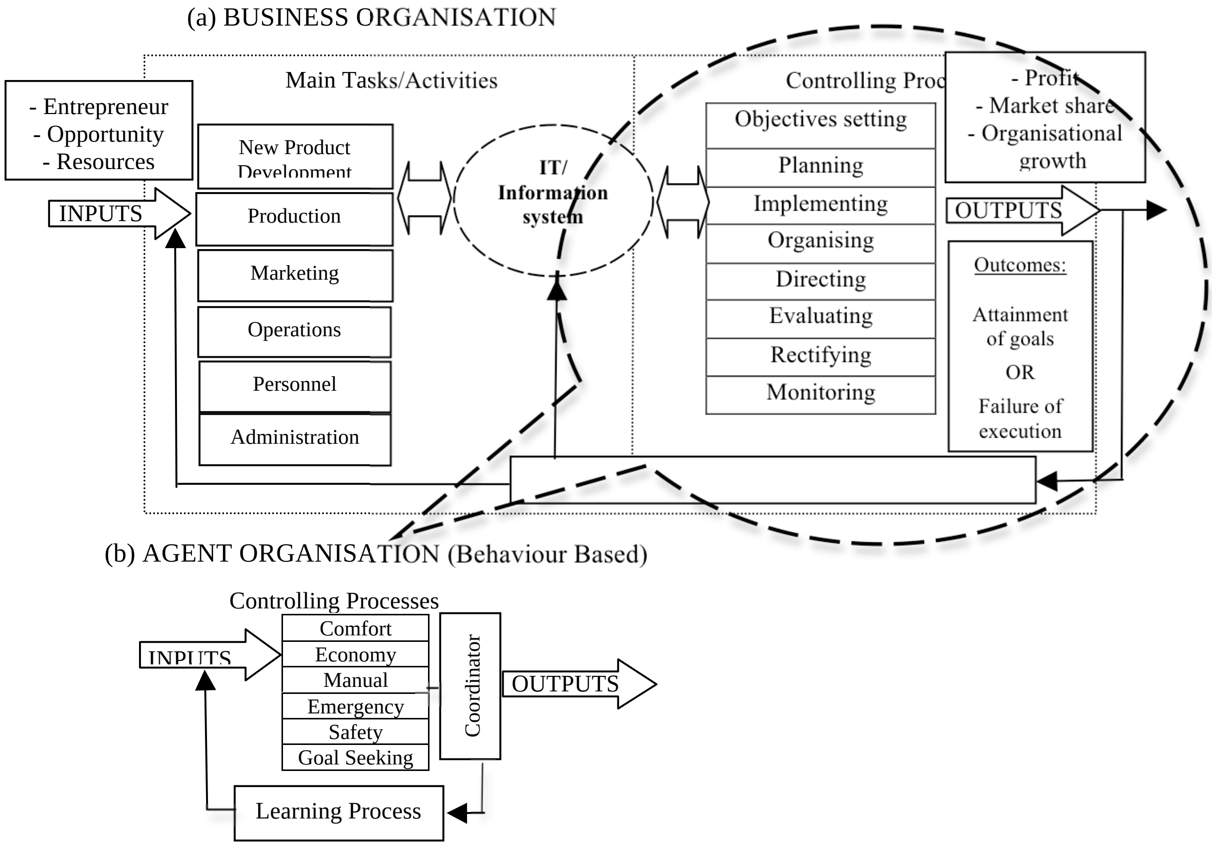

Figure 3. Business organisation & agent organisation as a set of processes

The description of business by a set of connected processes leads to building a business process model (Figure 3). An organisation is a complex system involving a varied range of main tasks and activities, such as new product development, production process, marketing, operations and personnel management that are being organised and controlled within the organisational process [18, 19, 20]. The entrepreneur is the individual who lies at the heart of the organisational process that drives the whole process forward [21]. It is the entrepreneur who recognises opportunity and manages resources (e.g. finance, labour, networks, facilities etc.) to start the value creation process and to achieve the outputs, such as profitability, increase in market share or organisational growth. Thus, entrepreneur, opportunity and resources are the key inputs which lead to the outputs through organising and controlling the interactions of connected processes and activities. In this cycle, controlling process is crucial part for the process reengineering and redesign. Therefore, it is likely that BPR is more effective and feasible in a highly controlled environment, similar to an computer controlled intelligent environment.

Information technology (IT) plays a key role in analysing the data of transactions and activities, which facilitate and leverage the controlling processes [22] For instance, it helps to find out the habits of customers and improve core operations to better meet customer needs (see [23]). By collecting and analysing the orders and sales from suppliers, distributors and retailers, managers can better plan and optimize the inventory turnover and reducing cost [24]. Therefore, a company can improve its business process efficiency by IT integration and information sharing. It enables resources and the interactions of activities to be effectively planned, monitored and controlled [19, 20]. However, the contingencies could happen, human errors may be inevitable [25] as computing is sometimes distributed and fragmented, as are the human agents managing the work processes creating a highly complex system in which outcomes of the holistic business process are not wholly predictable and can lead to either attainment of goals or failure. Such outcomes could cause either growth in profit, market share and organisational size or decrease vice versa. The business processes are connected and interacted as a cycle since the outcomes feed back to the processes for rectification and improvement. As in computational agents, the learning process is critical in the whole operation, which dovetails and completes the cycle. An effective organisation must be a learning organisation, that is, it must not only respond and adapt to the opportunities and changes, but also reflect on the outcomes that result from the processes in order to modify the future responses in the light of experience and knowledge accumulation [26, 27]. This directly mirrors the operational characteristics of agents in intelligent environments [28].

V. Agent Architectures And Processes

There are numerous ideas for the design of intelligent autonomous agents. With respect to our research in this paper we are especially interested a type of autonomous agent architectures referred to as a behaviour based approach [28]. Essentially this type of agent functions by decomposing the overall organisational structure into a set of horizontal processes known as behaviours (see figure 3a). Typically these behaviours are implemented as independent concurrent processes. In this model the system can be regarded as a set of concurrent processes, vying for control or influence of the overall system (or, in other words, a set of inter-related processes that combines to give the agent its overall functionality and behaviour). In that respect it is analogous to a company. When comparing the architecture in Figure 3a and 3b, the architectural similarities of the process structure are striking, which provides the basic rational for this work. By viewing each agent as part of a higher-level set of distributed (but coordinating) agents the system similarities are further amplified. Thus, in this paper we explore this relationship and the commonality of techniques used to reason and manage the interrelated processes. In our view the “process” is a common abstraction between intelligent environments and businesses.

A. A Unified Model of Agents & Processes

In terms of business models a process is defined as “*a set of logically related tasks performed to achieve a defined business outcome*” ([29], p. 12). Processes do that by adding value to some input(s) to providing output(s) for some internal or external customer” ([30], p. 718). According to Dilworth’s idea, a process perspective gives the organisation a base to recognize all the interrelated stages that must be planned and then reengineered. Thus, the business process is a set of activities that contain one or more types of input devoted to create valuable output for the customer [31, 32].

In computational terms processes are an architectural construct in that they are independent execution units that contain their own state information, use their own address spaces, and interact via inter-process communication mechanisms. They can be thought of as being software equivalents of hardware processors (there being a duality between processors and processes). Processes (as with processors) can run concurrently and are often used to create an instance of a computer program that is being executed (eg supporting multi-tasking) or for parallelizing an application. Agents can be implemented as processes making it possible to create complex systems of intercommunicating entities, akin to a business. By equating computational processes to business processes it is possible to set up graphical simulations or mathematical representations of a businesses, or some sub-part of it. In this paper we are using the mathematics of Interaction Networks to model aspects of a business and to provide a tool to understand the behaviour of interacting processes, or to manage changes to them. Figure 3a and 3b diagrammatically illustrate how a business and computational processes can be regarded as synonymous.

B. Phantom Work

System Dynamics Methodology was originally developed by Forrester [33], in order to model complex system that include feedback loops, delays and nonlinear relationships between systems variables all features of the new product development environments. This theory has enabled analysts to gain valuable insights into redundant activity within businesses.

1) In companies

In companies overlapping Design-Build-Test cycles can lead the creation of unnecessary work. This phantom work arises in situations where different component and subsystems that are developed in parallel iterate through the design-build-test at different speeds. The amount of phantom work generated is a function of the individual iteration speeds of the various subsystems, the speed imbalance between them, and the timing of the iteration cycles [34].

Phantom work is a real challenge for companies focused on innovation and new product development, as engineer’s time (and resources) is wasted with the consequent direct cost. Improving and eliminating unnecessary design iteration cycles will reduce cost, and resources expended on phantom work might be better utilized [34].

2) In Nature

Collective goal-directed activities are not just the prerogative of human created companies but have analogies in nature such as colonies of ants and termites that can be seen as organisations where members have roles and work within distinct interconnecting processes. Studies on such colonies have revealed that the operate rich structures composed of differing sub-systems (processes), which interact in complex ways. One remarkable finding is they display a type of “phantom work” phenomenon that manifests itself in periodic behaviour of redundant physical activity (with a observed periodicities in the order of a quarter to half an hour) [35].

These are interesting finding as they suggests that the phantom work phenomena is an intrinsic part of a distributed complex organisations where they are termites, intelligent environments or businesses.

VI. Example – Discovering “Live Locks” within Business Processes

Internal competition is often used as a driver for increasing organisational productivity. Competition implies making reactive changes to gain advantage over neighbouring (sub)business units (physical or logical neighbours). Typical actions are imitating or doing the opposite of neighbouring units. Such actions have been shown by Zamudio to be capable of leading to ‘live locks’ in a system [3]. In a business a ‘live lock’ would manifest itself as pockets of wasted internal resources such as person-power (or process) being consumed in endless cycles of adaptation and counter adaptation (change for the sake of change!) or, as we refer to it, phantom work (or thrashing). These are particularly hard to spot in a business as, superficially, people seem to be busy, consumed with vigorous activity helping the company (or their unit) adapt to changing conditions or needs. In the following example, we illustrate how a digraph and multidimensional model graphs can form a tool to help a business identify such redundant activity loops. To illustrate how this tool would work we have imagined a large (but simplified) company comprising some 64 internal business processes with a flat structure (see Figure 4). Processes are regarded as rule following activities which we simplify to AND /OR logical operations. In our simulation we generated a random inter-process topology and rules of interaction for the business system. Boolean functions were assigned randomly, as rules of behaviour, to each business process, represented as a binary string, where 0 and 1 would be interpreted as an OR and AND gates respectively. In the case of our example the rules of interaction were:

{0,0,0,0,1,0,1,1,1,0,1,1,1,0,0,0,0,1,1,0,0,1,0,0,0,0,0,1,0,0,0,1, 0,0,0,1,1,0,1,1,0,1,1,0,1,1,0,1,0,1,0,0,0,0,0,0,0,1,0,0,0,0,1,0}

The experiment was implemented using Mathematica® 6, a programming language with powerful tools for quick prototyping. In particular, the package Combinatorica proved extremely useful, as it provided tools for graph theory, graphics and combinatorics. Using the simulator it was possible to control a number of parameters, such as the number of business processes involved, probability of managerial perturbations, generation of random company topologies and random rules of interaction, amongst others. We used the digraph theory in section 2 to find that there were 14 phantom work cycles

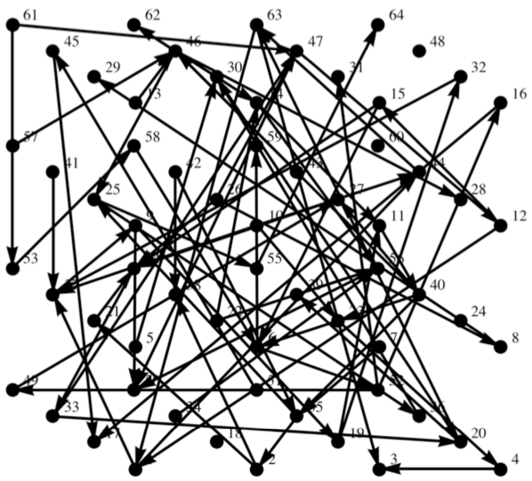

Figure 4. Grid with 64 business processes (nodes) and random inter-connections. The system had 14 cyclic processes.

By representing the processes as binary states (with 1 representing activity, 0 representing inactivity) it is possible to graphically illustrate the dynamics of the business process system, in this case the phantom work (cyclic processes) that are shown in Fig. 5.

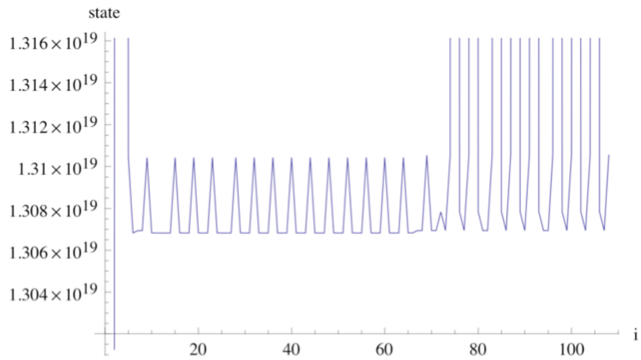

Figure 5. Dynamics of a business process system with 64 nodes and 81 cyclic processes.

Using this analysis data, and with some thought by the management, it is possible to stabilise the dynamics of the business processes by carefully disabling or reorganising some cyclic processes. Of course, the decision on which business processes to alter is critical and there is a future opportunity that by designing the tool to be intelligent we would hope to be able to learn such decisions which, when used in combination with the live lock algorithms would produce a more intelligent business tool. For the example, by way of an example we have applied the disabling vector: {1,1,1,1,1,1,1,1,1,1,0,1,1,1,0,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,0,1, 1,1,1,1,1,1,1,1,1,1,0,1,1,1,1,1,1,1,1,1,0,1,1,1,1,1,1,1,1,1,1,1} which has stabilised the company cyclic processes (Fig. 6).

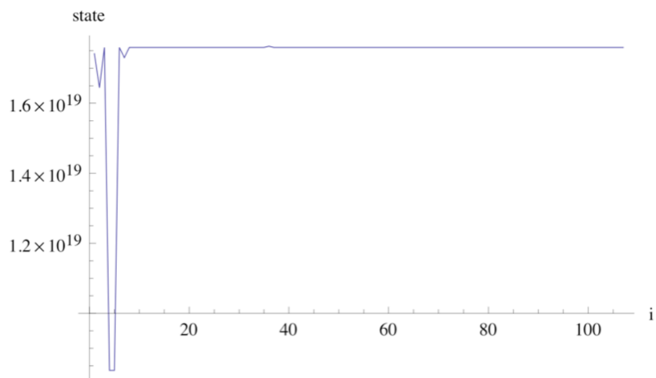

Figure 6. Response of a system with 64 nodes and 14 cycles when stabilising action was taken.

An alternative (pictorial) view based on an MDM is shown in Figure 7, which is very useful for analyzing individual behaviour due to its expressiveness and simplicity. Focusing on a small part of the interactions can help to simplify and analyze the dynamics of business systems.

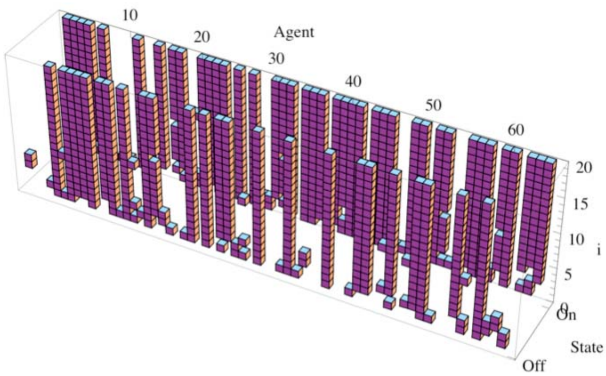

Figure 7. This graphs shows cyclic processes for 64 nodes using an MDM

These findings, particularly the destructive and undesirable characteristics of phantom work cycles, are consistent with complex interactions observed in intelligent environments [36]. From Zamudio's observations, and the findings of our work we surmise that, in business processes, Design-Build-Test cycles are necessary for new product development, and in the case of intelligent environments cyclic and coupled interactions can provide specific services to the final user. Extrapolating the results of Zamudio's earlier work suggests that in both domains there is a threshold point Θ from which the system performance decreases dramatically: in the case of intelligent environments the system will self-lock, and hence become unusable; in business process redundant innovation cycles can lead to the creation of phantom work (see Fig. 8).

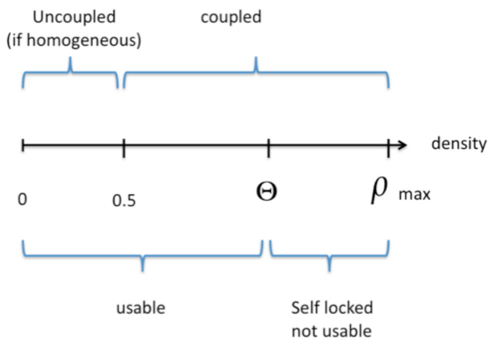

Figure 8. Density and usability of a system

Finally, before this work there was no framework for analysing and eliminating problems of phantom work cycles related to the interaction of rule-based business processes.

VII. Concluding Discussion

In this paper we have raised the hypothesis that *"a business is an intelligent environment*". We have argued this by making an analogy between the way intelligent environments work and those of business organisations (by seeing both as being composed of sets of collaborating rule based agents). .

Having made that case, we then illustrated the principles by applying an interaction network theorem (that can analyse and manage behaviour in intelligent environments) to address a Business Process Reengineering problem (phantom work cycles), which is found in organisations which seek to use an internal competition approach to increase productivity and adaptability. Whilst the example we used was entirely fictional our intention was to demonstrate the principles involved, and to support our assertion that businesses are amenable to engineering methodologies, and especially those from intelligent environments.

We have presented a method that can both identify process (and work flow) relationships that are susceptible creating phantom work which can then be highlighted to business managers for monitoring or even workflow (or management) redesign. In our earlier work in digital homes, we developed automated mechanisms for eliminating such problems. If a more formal tool for designing managing business process engineering was created, it would be possible to consider integrating such mechanisms into it. In writing this paper we also highlighted an area of business that are especially susceptible to such phantom work behaviour, namely business processes design-build-test cycles which are a fundamental part of new product development,

While our approach is relatively primitive, being a simplification of a more sophisticated tool we have used for analysing behaviour in complex intelligent environments, we hope that it was sufficient to demonstrate the principle and open up the possibility that there may be synergies between business and intelligent environments tools. Clearly this work is just at a beginning but we hope by encouraging multi-disciplinary work between business and engineering schools it will be possible to undertake novel and worthwhile research. Our ultimate aim is to provide business practitioners with more effective business management tools that can reason, plan and learn and give business a competitive edge, while advancing our vision for creating increasingly pervasive intelligent business environments.

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