MONASH
UNIVERSITY

FACULTY OF BUSINESS AND ECONOMICS

THE EDGE OF CHAOS: A SIMULATION OF A KANBAN SYSTEM

Tim Haslett

Working Paper 77/03
December 2003

WORKING PAPER SERIES

ISSN 1327–5216

Abstract

A widely discussed notion in the field of non-linear theory is that of the Edge of Chaos where systems, and in particular organisations, are presumed to be at their most creative. This paper presents evidence from a simulation model of a Kanban system that improved its performance as the system became less predictable and less stable. The results from spectral analysis indicate that the system moves towards a chaotic regime under certain input conditions while at the same time improving performance on one of the key performance measures of a Kanban system. This paper suggests that movement towards a chaotic regime is accompanied by improvement performance.

This paper is a work in progress. Material in the paper cannot be used without permission of the author.

DEPARTMENT OF MANAGEMENT

THE EDGE OF CHAOS: A SIMULATION OF A KANBAN SYSTEM

INTRODUCTION

This paper discusses data from a computer simulation which supports the contention that systems become more creative or efficient at the "edge of chaos". This idea was developed by Kauffman (1995) in the work on computer simulations of lattices and nK landscapes. The "edge of chaos", which is a point somewhere between total stability and chaos, where biological and computational systems are capable of the greatest flexibility, adaptability and creativity. The edge of chaos has important implications for organisational theorists. If organisations are able to evolve and adapt as they move along the continuum towards chaos, it would be highly useful to developed measures to enable theorists and managers to understand this process.

The research reported in this paper describes a computer simulation of a Kanban system in a factory. The simulation was designed to examine impact of managers' interventions on the performance of the Kanban system. These interventions were responses to pressure and criticism from senior management. The managers' behaviours were designed to deflect the pressure and criticism. It was found that the managers' behaviour improved the overall performance of the system but in the process made it less stable and predictable. In other words, performance improved as the system moved towards chaos.

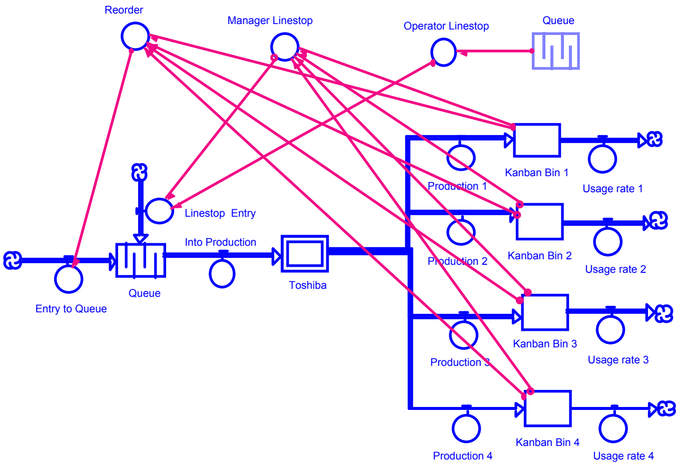
LOCAL RULES

The behaviour of the managers was interpreted as local rules behaviour. Local rules develop on landscapes (Kauffman, 1989) which contain fitness peaks where adaptive behaviours, termed local rules, can be optimised. Successful local rule adaptations have been observed in computer simulations of interactive processes (Feldman and Nagel, 1992; Huberman and Hogg, 1993; Epstein and Axtell, 1996; Grover, 1997; Arthur, 1989)) suggested that local rule adaptations produce optimal efficiency in economic systems. Organizational applications have been observed in mail sorting centres (Haslett et al 2000) and manufacturing (Haslett & Osborne 2000).

THE SIMULATION

The simulation was built using the System Dynamics modelling package "ithink". Roberts et. al. (1994). Morecroft and Sterman (1994), and Vennix (1996) report on this methodology. Just-In-Time and Kanban systems are widely used and reported in the literature. (Singh, Shek, and Meloche (1989), Monden, 1983, Schonberger, 1982, Ohno, 1988). The system described here was first noted by Coghill (1990). Figure 1 shows a simplified version of the model.

Figure 1: Simplified ithink Model of the Kanban System

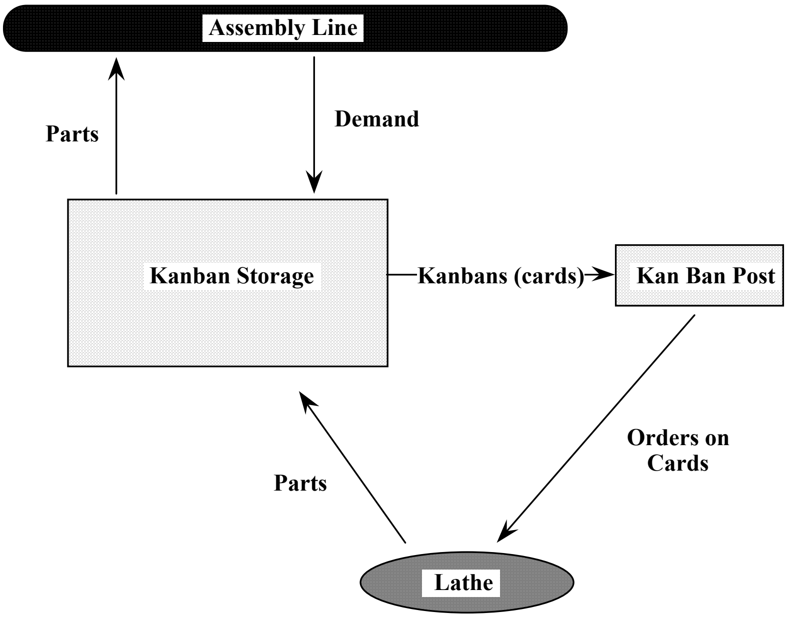


Three simulation were run: the first was the original calibration to settings, the second impact of queuing (referred to as "normal ") and the third with impact of queuing and of the managers local rule (referred to as "local rule"). The importance of decision rules, in this case the local rules, in Kanban systems was developed by Gravel, Martel, Nadeau, Price and Tremblay (1992) and specific simulation analysis of Kanban systems has been reported by Watts, Hahn and Sohn (1994), Singh and Brar (1992) and Gupta and Gupta (1989).

THE SETTING

The company was a medium-sized high-technology manufacturer in Victoria, Australia. The company used a Kanban system to minimise inventory holdings for assembly line. The Kanban system is part of the JIT system and has been widely reported in the literature (Monden, 1983; Schonberger, 1982; Ohno, 1988; Haik, 1989; Chan and Smith, 1992). Figure 2 provides a highly simplified picture of such a system.

Figure 2: Layout of Kanban System

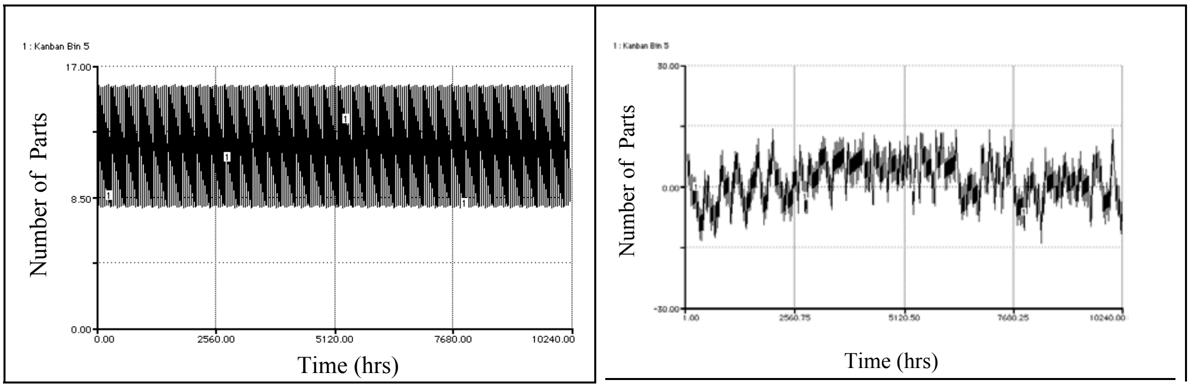


Parts for the assembly line are held in bins in the Kanban storage area. Each bin has a card, called a Kanban, which specifies the amount and time at which extra parts must be made. At the appropriate time, the cards are placed in a queue awaiting manufacture. This system aims to have the manufacture parts delivered the bin before the bin empties. This insures minimum stock holding and minimum down time through parts stockouts. When the Kanban system was originally set up and calibrated, it was done so on the basis of following rules:

1. The rate at which the parts will be used during the year given projections of demand (Annual Forecast).
2. The Economic Order Quantity (EOQ).
3. The time to produce the EOQ (Total Lead Time).
4. Total Standard Cost for each part.

What these calculations had failed to include is the time that the cards spent a queue. This is natural as it is impossible to predict what these times will be. It was clear from the simulation, that the effect of queuing made the inventory levels of all the parts less stable and less predictable. Figure 3 shows the impact of queuing on one part. It can be seen that the part does not perform in the way that the original calibration of the system predicted it would.

Figure 3: Comparison of Part Behaviour, without Queuing (Left) and with Queuing (Right)



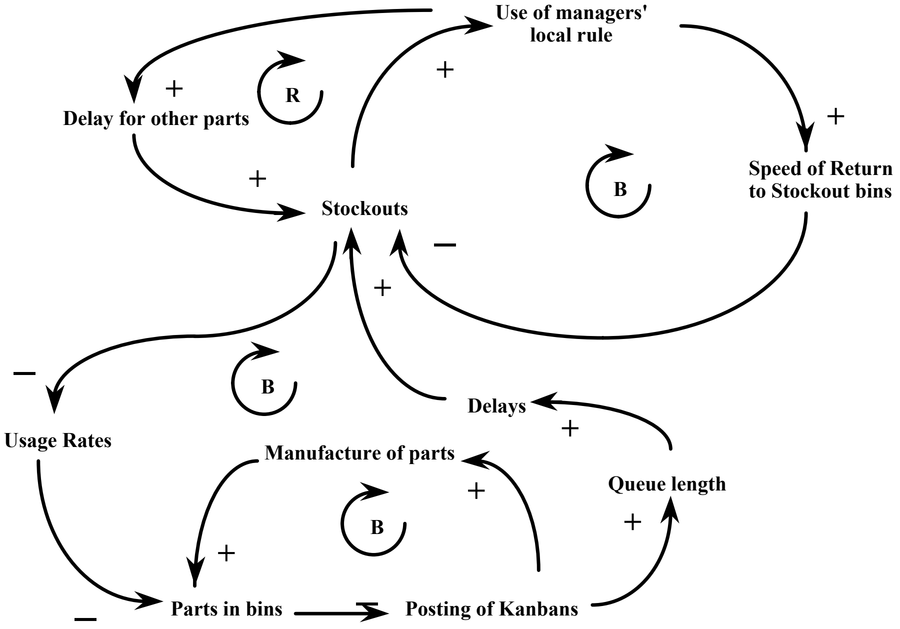
In an effort to control the stockouts, managers developed a rule of behaviour, termed a " local rule ". The rule was that if a bin emptied, its card would be moved to the front of a queue to ensure that the empty bin would be filled as quickly as possible. The managers wished to understand whether this local rule improved the performance system. Sterman (1988:172) justifies the use of computer simulation in such situations.

> "The discovery of nonlinear phenomena such as deterministic chaos in the physical world naturally motivates the search for similar behaviour in the world of human behaviour. Yet the social scientist faces difficulties in that search which do not plague the physicist....aggregate data do not exist...social systems are not easily isolated...controlled experiments on the systems themselves [are] difficult at best...the laws of human behaviour are not as stable as the laws of physics"

Sterman (1988) suggests that one method of analysis of such systems is to "develop laboratory experiments with simulated social systems" which can explore the decision making heuristics of real people.

Two things were observed. The first was that the simulation demonstrated that only one part should have suffered stockouts. The second was, that in reality, the managers were confronted by stockouts for a large number of parts. The reasons for this are set out in Figure 3 which is a causal loop diagram of the interactions set up by the application of the managers' local rule. Every time a manager intervened and applied the local rule, all the cards in the queue, which had been in front of the card which was "queue-jumped" were effectively delayed, increasing the chances of their bins going into stockout.

Figure 4: Causal Loop Diagram of the Effect of the Local Rule



The bottom section of the diagram shows the working of the system. Usage decreases parts in bins, manufacturing increases them. The more cards in the queue, the greater the likelihood of stockouts. As the managers apply their local rules, some bins fill more quickly while others fill more slowly. Each time a card is shifted, it increases the delay for other cards and the chances of another stockout and another card shift. Thus the more cards are shifted, the more cards need to be shifted.

One other reason why the managers were continually intervening was that the system never worked perfectly. Machines would break down, staff would be absent or cards would not be delivered on time. In one case, an operator put the card in his pocket and took it home overnight. The managers decided that computer simulation be a good way to examine the operation the system free from these imperfections.

METHOD

The first measure was of the stability and hence predictabilty of the inventory levels of the parts with and without the manager's local rule. Spectral analysis was used to determine and then compare the stability of the inventory levels. (For a technical description of spectral analysis of time series see Baker and Gollub, 1990 pg 28- 36). The use of Fourier transforms in the analysis of sawtooth functions such as found in the data in this research can be found in Kaplan, (1973) and Çambel, (1993).

The other two measures were of a more practical nature. The first was the number of hours a part was in stockout. This is important at a practical level because it is indicative of the potential for the assembly line to stop. In fact, the system could tolerate short periods of stockout because operators often had some parts at their workstations. The second measure was the cost of holding stock. This was calculated from the number of machine hours held in inventory. As the machine in question was a lathe where raw materials were standard across the parts, the hours of work was an effective measure of the cost of inventory.

RESULTS

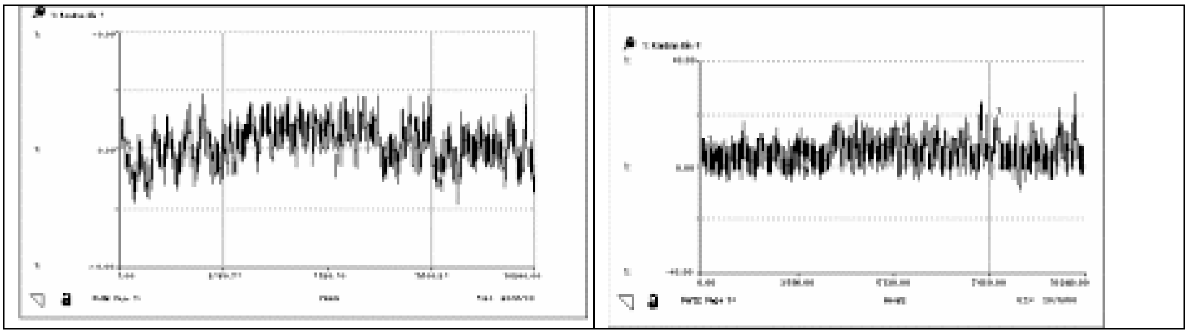
Spectral Analysis showed changes in the stability of 12 of the parts. Table 1 shows that 9 became less stable and 3 became more stable. The overall impact of the managers' local rule interventions was to increase instability in the system.

Table 1: Spectral Analysis of Part Numbers

Part	Beta	Standard Error	Lower limit	Upper limit	Stability
2 N	-.493	.022	-.536	-.450	
LR	-.560	.022	-.604	-.516	↓
3 N	-.513	.024	-.559	-.467	
LR	-.580	.022	-.622	-.537	↓
4 N	-.557	.022	-.560	-.515	
LR	-.627	.022	-.670	-.585	↓
5 N	-.575	.021	-.617	-.533	
LR	-.525	.021	-.566	-.484	↑
6 N	-.618	.022	-.662	-.575	
LR	-.684	.021	-.725	-.644	↓
7 N	-.590	.023	-.635	-.546	
LR	-.670	.021	-.712	-.629	↓
8 N	-.551	.023	-.596	-.507	
LR	-.468	.026	-.519	-.418	↑
9 N	-.525	.022	-.567	-.482	
LR	-.594	.022	-.636	-.551	↓
13 N	-.529	.022	-.573	-.486	
LR	-.583	.022	-.627	-.540	↓
14 N	-.494	.022	-.538	-.450	
LR	-.608	.022	-.650	-.565	↓
15 N	-.615	.023	-.660	-.570	
LR	-.678	.022	-.722	-.634	↓
17 N	-.795	.021	-.837	-.753	
LR	-.750	.024	-.797	-.703	↑

Figure 5 shows the impact of the local rule on Part 5. The inventory levels have stabilised and the stockouts are less frequent. The impact of this change is demonstrated in Figure 5 which shows the destabilised behaviour of Part 5.

Figure 5: Impact of the Local Rule on Part 5 Stabilised on Left



This was the part that the managers paid most attention to and the effect of their interventions is shown in Table 2. Stockout times for Parts 5 and 10 have decreased while Parts 8 and 9 are now having stockouts. While more parts are now having stockouts, the overall stockout time has decreased by over 60%.

Table 2: Comparison of Stock Out Times

Part	Stock out (hrs) Normal	Stock out (hrs) Local Rule	Interventions
5	3,809	1,349	135
8	0	79	25
9	0	61	27
10	606	186	56
Totals	**4,415**	**1,675**	**243**

Table 3 shows the improved cost performance of the system under the manager's local rule. The cost of parts was calculated on the amount of machine time invested.

Cost of Parts = Total number of parts in bin * Machine time per part

There was a 10% improvement in the total cost of inventory. Only Part 5 shows an increase and this is a result of the interventions decreasing stockout time and consequently, the number of parts held. As a consequence of the shorter queuing time for the parts where the managers intervened, there were longer queuing times for the other parts. Table 4 shows how the longer queuing time meant that inventory ran down but not to critical stockout levels bringing about an overall improvement in inventory costs.

Table 4: Cost of Inventory Held by Machine Hours.

Part	Time Cost of Inventory (hrs)		Part	Time Cost of Inventory (hrs)	
	Normal	**Local Rule**		**Normal**	**Local Rule**
1	99695	98837	10	85177	72337
2	238764	232657	11	192446	186752
3	74970	72865	12	37537	20347
4	82741	81193	13	212794	190811
5	26797	39085	14	83007	80587
6	192902	191613	15	129424	128458
7	67130	66236	16	116554	115265
8	228561	81545	17	146132	150418
9	100534	97357	18	157264	153877
			Totals	**2272428**	**2060241**

DISCUSSION

The interventions of the managers had two effects. The first was to introduce greater instability into the system. The second was to improve the performance of the system on two key measures, inventory costs and stockout time. The stability and predictability that is central to a Kanban system does not appear to be necessary for improved, if not optimal, performance. This improved performance derives from the fact that the system has the flexibility and redundancy to cope with the managers interventions. In this simulation improved performance and a decrease in stability of the system appear to go together. The system is capable of absorbing the increased instability because the original settings allowed adequate buffer stock in most bins and thus avoided stockouts. With any given level of buffer stock, there would be a point where instability would push the system into widespread stockouts and declining performance. It is possible that this point is just beyond the edge of chaos where system performance is optimal.

CONCLUSION

This simulation suggests that improved performance and increased instability may be linked. The direction of the causal relationship is not proven but it may be that increased instability is a necessary condition for improved performance. The increase in instability lends support for the suggestion that system performance improves the system moves towards the edge of chaos. This research does not define where the edge of chaos may be but there is tentative support for the idea that the edge of chaos may be defined by redundancy in individual systems.

REFERENCES

Arthur, W. Brian (1989) *The Economy and Complexity* Lectures in the Sciences of Complexity, (ed Stein, D.). Addison Wesley Longman

Baker, G.L. and Gollug, J.P. (1990) Chaotic Dynamics: an introduction CUP., Cambridge.

Çambel, A. B. (1993) Applied Chaos Theory: A Paradigm for Complexity Academic Press, Boston

Chan, F.T.S. and Smith, A. M. (1993) *Simulation aids JIT assembly line manufacture: A case study.* International Journal of Operations and Production Management Vol. 13(4): pp 50 - 74.

Coghill, John, M. (1990) *Implementation of JIT/KANBAN in a low volume, high variability environment* Paper presented to the Pacific Conference on Manufacturing, Australia.

Feldman, B. and Nagel K. (1993) *Lattice Games with Strategic Takeover* 1992 Lectures in Complex Systems (eds. Nadel, l. and Stein D.): SFI Studies in the Sciences of Complexity, Lect. Vol. V. Addison-Wesley.

Gravel, M., Martel, J. M., Nadeau, R., Price, W. and Tremblay, R. (1992) *A multicriterion view of optimal resource allocation in job-shop production*. European Journal of Operations Research Vol. 61(1,2): pp 230 - 244.

Gupta, Y. P. and Gupta, M. C. A (1989) *A system dynamics model for a multi-stage multi-line dual-card JIT-Kanban system* International Journal of Production Research Vol. 27 (2): pp 309 - 352.

Haik, L. (1989) *A simple framework for understanding JIT.* Production and Inventory Management Journal, Fourth quarter, pp. 61 - 63.

Haslett, T. & Osborne, C. "Local Rules: Their application in a KanBan system." International Journal of Production Management, (forthcoming 2000)

Haslett, T., Moss, S., Osborne, C., & Ramm, P. "The Application of Local Rules in Self Ordering Systems." Nonlinear Dynamics, Psychology and Life Sciences.

Huberman, B. A. and Hogg, T. (1993). *The emergence of Computational Ecologies* 1992 Lectures in Complex Systems (eds. Nadel, l. and Stein D.): SFI Studies in the Sciences of Complexity, Lect. Vol. V. Addison-Wesley. pp 185-205.

Kaplan, W. (1973) Advanced Calculus. Addison-Wesley, Reading, MA, Chapter 7

Kauffman, S.A. (1989) *Adaptation on Rugged Fitness Landscapes*. Lectures in the Sciences of Complexity, (ed. Stein, D.): Addison Wesley Longman pp 619-712.

Monden, Y. (1983) *Toyota production system*. Industrial Engineering and Management Press, Norcross, Georgia.

Morecroft, D.W. and Sterman, J. D. (1994) Modelling for Learning Organizations Productivity Press, Oregon.

Ohno, T. (1988) Toyota production system: Beyond large scale production Productivity Press, Cambridge.

Schonberger, R. J. (1993) *The human side of Kanban*. Industrial Engineering Vol. 25(8): pp 34 - 36.

Singh, N. and Brar, J.K. (1992) *Modelling and analysis of just-in-time manufacturing systems: a review* International Journal of Operations and Production Management. Vol. 12(2): pp 3 - 14.

Singh, N., Shek, K.H. and Meloche, D. (1989) *The development of a kanban system: a case study.* International Journal of Operations and Production Management. Vol. 10(7): pp 29- 36

Sterman, J. D., (1989) *Misperceptions of feedback in dynamic decision making.* Organizational Behaviour and Human Decision Processes, Vol 41: pp 301 – 335

Watts, C. A., Hahn, C. K. and Sohn, B-K, (1994) *Monitoring the performance of a reorder point system: A control chart approach*. International Journal of Operations and Production Management Vol. (14):2: pp 51 - 61.