Local Rules: The theory, the application and the chances of success.

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Abstract

This paper report on results for a simulation of the “local rules” used by managers in a manufacturing setting. Local rules are similar to what Forrester termed *implicit* decisions which are the “unavoidable result of the state of the system”. The theory of local rules is developed further using the work of Kauffman and Holland on fitness landscapes. Local rules are those rules that are repeatedly used by individuals or agents to increase the “payoff” for them in a given situation, this equates to Kauffman’s “fitness peak”. In this case, the payoff was to deflect senior management criticism of potential stockouts in the system.The simulation model is of a Kanban, or Just-in-Time system, in a linked assembly and manufacturing system. The operation of the system and the effect of the local rules interventions are modelled, individually and separately. The success of the managers’ rule and unintended consequences are reported. Some tentative questions about the effectiveness of local rules are advanced.

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Overview

This paper discusses the results of a System Dynamics model of a set of “local rules”. Local rule theory arises primarily from work in evolutionary biology, in particular the work of John Holland (1989) and Stuart Kauffman (1989), which points to the development of rules designed to maximise an agent’s chances of survival. Local rules were similar to what Forrester (1961) termed *implicit* decisions which were the “unavoidable result of the state of the system”. It has been argued that these local rules were specific to the demands and pressures of the agents immediate environment.

The application of the idea of local rules in biology to organizations implies that individual agents may develop local rules to achieve a number of ends, the maximisation of their chances of success, the stabilisation of their immediate environment, minimisation of threat from outside. All these behaviours were focussed at the local level. The importance of local rules lies in the possibility that when one individual’s local rules were highly successful, they will be adopted by others and their “locality” will be broadened. The structure of an organization can be seen as sets of localities operated on the basis of adaptive local rules. Organizations think locally and act locally. This suggests that organizations may consist of localities seeking to optimise local payoffs. If this is the case, such behaviour raises an important question: What impact do local rules have on the overall performance of an organization?

The Theory of Local Rules

Holland (1989) believed that many organizations do not have repetitive or easily recognised patterns of behaviour. This was because they were intrinsically dynamic, far from global optimum (always room for improvement) and continually adapting. He termed such organizations ANNs (adaptive non-linear networks) which use a “classifier system” as their means of adaptation. In his description of the classifier system, Holland refered to “rules” which were attempts at adaptation to environmental demands. These rules were the local rules of behaviour that were used by agents in their specific locality to maximise payoff or chances of survival. The classifier system tests the fitness of each rule in the ecological landscape where the fittest rules ultimately survive.

Thus, the emergence of successful payoff-optimising agents was based on their ability to adapt to specific and local conditions. There was not a central management decision process and no overall organizational structure imposed on the system. Agents operated on a landscape which has fitness peaks (Kauffman, 1989) where agents maximise their chances of survival.

A similar system was suggested by Arthur (1989) in economic systems. Here agents act, not simply in relation to environmental demands, as would be the case on a Kauffman landscape, but on the basis of expectations and strategy. Mitchell (1993) supported the case for using such evolutionary and ecological models for investigating complex adaptive systems. Survival was based on simple local rules capable of generating extremely complex structures and behaviours.

Forrester (1961:102) classified managers' decisions into two categories. The first was *overt* decisions which were "conscious decisions as part of the management and economic process". These decisions were those that were part of the planning or system design process and which will laid down as the ongoing conditions under which the system will operate. The second category of decisions was *implicit* decisions which were the "unavoidable result of the state of the system". Like local rules, implicit decisions were a response to the dynamics of a system, they were recurrent, as well as being flexible in their application. Local rules differ in that they were designed as an adaptive process which seeks to stabilize the environment or to maximise the payoff to the agent using the rule.

Haslett et al (1997) demonstrated the application of local rules in Australia Post mail sorting centres. Here mail sorters developed local rules which effectively adjusted workrates to ensure payment of overtime penalty rates. These local rules were found to exist independently in six geographically dispersed centres giving support to the idea that such rules persists across broad localities when they are effective at maiximising pay-offs for the local agents.

This paper examines the effects of local rules generated by managers in a manufacturing setting. The research involved the design of a computer simulation of the local rules used in a manufacturing and assembly process at Varian (Australia) in Melbourne (Coghill, 1990). The manufacturing system used in this company was a Just-in-Time system incorporating a Kanban inventory control methodology.

Of particular interest was the extent to which the use of the local rules affect the overall performance of the system. While the Kanban system was designed to produce stability and predictability in manufacturing systems, imperfections in the original set up (the overt rules) of the system meant that it never worked in the expected manner. This led to constant adjustments by the managers responsible for the day to day operations. This was through the application of a set of ad hoc decision rules, termed local rules by Holland, or implicit decisions by Forrester, which were designed to reduce senior management pressure over perceived inefficiencies in the system.

Forrester (1961:98) identified this type of discretionary judgement as managers relying

> "for lack of anything better on certain formal statistical decision procedures with respect to some of the most subtle an difficult decisions. In dealing with the dynamics of information-feedback systems, the human was not a subtle and powerful problem solver"

The verbal and mental models that managers use as the basis for these computations were immense over simplifications. Nonetheless, decisions were made on the basis of limited computational power and the inadequate models that managers carry with them. The impact and operation of the mental process of managers was later developed by other writers in terms of misperceptions of complex feedback (Sterman 1989a, 1989b, 1989c, Sterman and Paich 1993). It was found that dysfunctional behaviour was caused by misperceptions of feedback which was defined as the failure to account for and distinguish feedback that was critical to the functioning of the system, time delays and non-linearities. Decision making performance of managers was poor relative to potential especially when feedback complexity was high. This was often seen as failure to see the relevance of a "critical cue...often because even with perfect information the equation solving implicit in the problem was too difficult for humans." The functioning of the Kanban system at Varian involved "feedback that was critical to the functioning of the system, time delays and non-linearities" of a level of complexity only understandable through simulation and the behaviour of the managers confirmed the findings of Sterman and Paich.

There are two possible views of how local rules may operate. First the evolutionary view says that agents develop rules for survival at a local level. These rules are tested and the fittest survive. Unfit rules do not survive. Therefore rules which persist must be successful at delivering pay-offs. Second, the misperceptions of feedback view says that managers cannot compute complex feedback and their adaptive behaviours or local rules will be sub - optimal. This paper investigates these two propositions

Varian (Australia)

The system at Varian that was modelled was a JIT / Kanban system in a high-tech manufacturing plant in Melbourne, Australia. The Kanban system, which was part of a JIT system, was designed to maximise the cost efficiency of the system through maintaining minimum inventory levels pioneered at the Toyota plant in Japan. (see Monden, 1983, Schonberger, 1982, Ohno, 1988). It has been implemented widely, with surveys of its application in Hong Kong (Cheng, 1988), USA (Im and Lee, 1989, Gilbert, 1990) and the UK (Voss and Robinson, 1987). The system was described as a "pull" system as distinct from the traditional "push" systems (Kitney, 1994).

The system used in this study has been described by Coghill (1990) and consists of two systems with shared interdependence; an assembly line and a machine shop. The Kanban system was designed to achieve the minimum inventory holdings through just-in-time delivery of manufactured parts. In operating terms, the system consisted of a series of bins which hold manufactured parts for the assembly process. Parts are taken from the bins as required in the assembly process. When the level of parts in the bin reaches the re-order point as spsecified on a card or Kanban, the kanban is used to request the re-order quantity. Once the re-order quantiy has been manufactured it is placed in the bin, which, all things being equal, had not yet emptied. In theory, this process minimises the cost of holding inventory and minimises the chance of a stockout.

The re-order point and re-order quantity are fundamental to the operating of the system. Each one of the 10,000 patrs used has its own re-order point and re-order quantity. The re-order point is calculated to be the minimum amount of stock that can be held without running out before the next batch can be manufactured. The re-order quantity is the effectively the economic order quantity for that part. (For a description of the theory for these calculations see Price, Gravel, and Nsakanda, 1994). The managers' observations were that in practice the calculations for these figures were a mixture historical data, rules of thumb and guesswork. The basis calculation involved: the rate at which the parts will be used during the year given projections of demand, the Economic Order Quantity, total lead time, and total standard cost for each part. This data was used to calculate the re-order point which allows sufficient time for the re-order quantity for the part to be made before the Kanban bin becomes empty. The calculations were as follows:

Re-order point = Annual Forecast / 230 * Total Lead time.
Annual value = Total Standard Cost * Annual Forecast

This allows the part to be allocated one of three "class factors" based on annual value. The re-order quantity is then based on the lower of the following calculations:

Kanban Quantity (option 1): 3 * Total Setup Hours / Total run Hour
Kanban Quantity (option 2): Annual Forecast * Class Factor

These calculations, with all their imperfections, one of which was the failure to include variations in quue length which had a major influence of lead time, were what Forrester called overt decisions. The reported method of their design supports Diehl and Sterman's (1994) view that "people's mental representation of complex tasks are highly simplified tending to exclude side effects, feedback processes delays and other elements of dynamic complexity". The simulation demonstrated that calculations of re-order points and quantities, the overt rules calculated for each part in isolation, did not achieve the goals of the system when the parts were in the complex interactive queuing system.

Application of local rules

As the system approached maximum capacity the following dynamic came into play. There are two balancing loops. Loop B1 is kept in balance through the manufacture of the parts but as maximum capacity is reached loop B2 keeps the system in balance through stockouts which effectively slow the system down. The operators perception that there may be stockouts accelerates the process but while their actions lead to stockouts they do not necessarily lead to linestops.

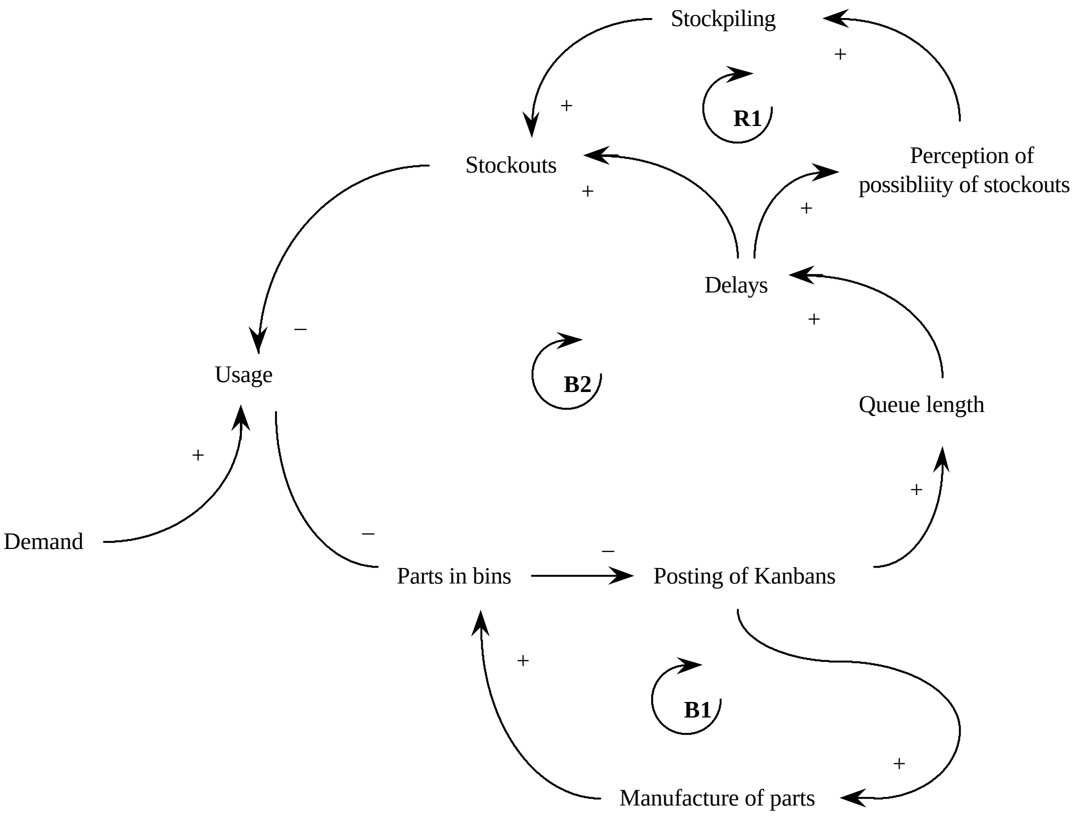

Figure 1: Causal loop diagram of the Kanban system

The problem that managers faced was that of stockouts or linestops, as they were termed by senior management. Senior management were extremely concerned about stockouts which they defined as situations where a bin was empty and hence likely to stop the assembly line. However, empty bins did not necessarily lead to line stops. The assembly operators would often stockpile parts at their work stations and therefore were capable of keeping the line operating despite the fact that a bin may be empty. Their behaviour, in effect their local rule, exacerbated the problem of empty bins and the corresponding senior management concern about the possibility of line stoppages.

Nonetheless, one of the important measures of the manager's performance was the number and duration of stockouts. As empty bins were the key informal measure by which managers' performance was assessed, a local rule was developed to ensure that the bins did not empty. The rule was " If a bin empties while the Kanban was still in the queue awaiting manufacture, then move the card to the front of the queue". This local rule is shown in Figure 2.

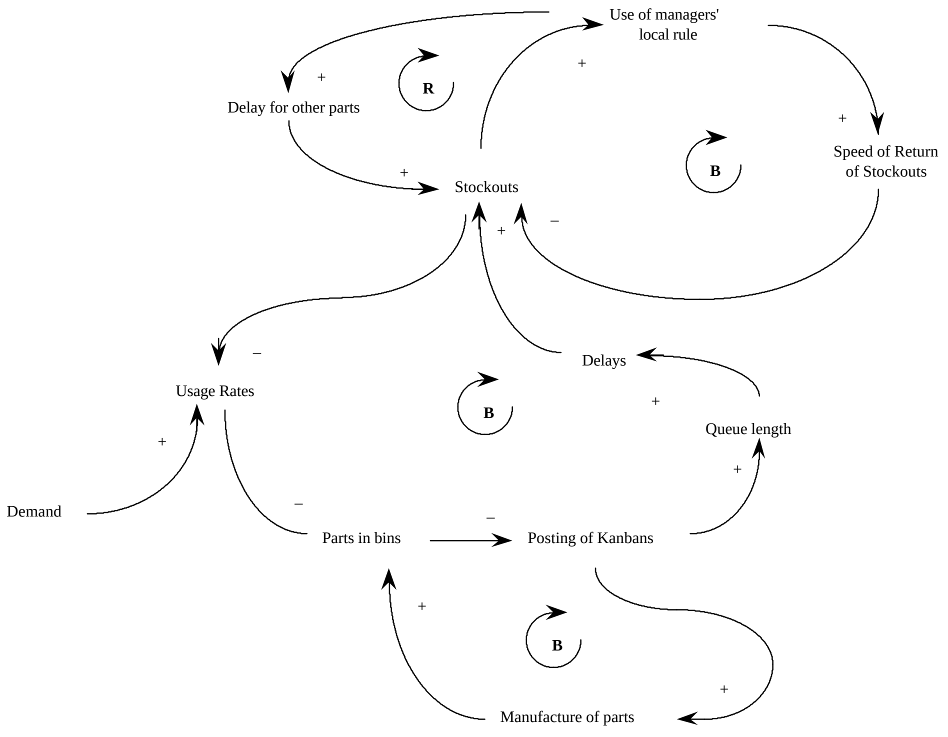

Figure 2: Causal loop diagram of the managers' local rule.

The local rule is in the balancing loop in the top right of the figure. The unintended consequence of giving Kanbans from empty bins priority was to delay other cards and create the potential for more empty bins.

The managers were well aware of the potential impact of stockouts on the production line and were also well aware of senior management's reaction to this situation. What the managers were less aware of was the impact of their decisions on the dynamics of the operation. Without the application of a simulation model, which allowed the testing of their rules free from the day to day perturbations in the system, they were unable to verify that they were, in fact, getting the relief from senior management pressure that they wanted.

Modelling the use of local rules in the Kanban setting

System Dynamics modelling has been used in a wide range of situations (see Morecroft and Sterman, 1994, Vennix, 1996, Roberts et al. 1983) and for Kanban systems in particular by Ebrahimpour and Fathi (1984) and Gupta and Gupta (1989) and has been reviewed by Singh and Brar (1992). The managers at Varian were aware that the performance of the system had large, possibly chaotic, variances. Sterman (1988:172) commented:

> "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 suggested that one method of analysis of such systems is to develop laboratory experiments where the decision processes of managers, such as those at Varian, can be simulated. This allows the isolation of single variables and the gaining of a deeper understanding of their impact .

To this end a model of the system and the rules used was built in iThink (Richmond, 1993). The Kanban system was used in all aspects of the company's operation. The simulation looked at one machine, a lathe, which manufactured 18 parts used in the assembly process. While this was a small part of the total operation it embodied all the feedback aspects of the larger system. This machine was simulated over 10000 hours. A simplified model of the Kanban system is shown in Figure 3 and demonstrates the nature of the feedback system.

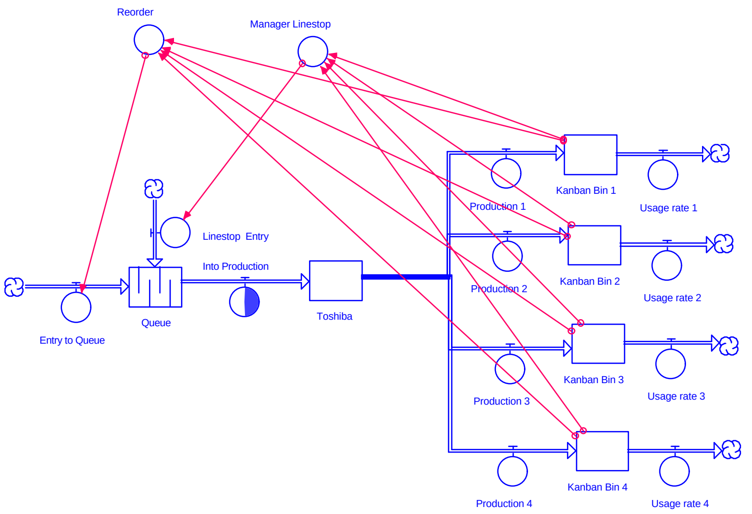

Figure 3: Simplified model of the Kanban system.

Each part was simulated without queuing, namely without any dynamic interaction with other parts of the system . This set of simulations indicated the most stable possible behaviour of each part and was referred to as the overt rules simulation. Once the expected operation of the system had been established to serve as a base for comparison with the parts interacting through the queuing system, two parallel sets of four simulations were run. The effectiveness of the local rules was tested with the machine running uninterrupted (an unlikely situation in real life) and with a 200hr breakdown factored in, both situations were tested withand without the application of the local rules. Tayur (1993) highlighted machine failures as one of five sources of randomness in systems along with process time variation, tool unavailability, poor yields and worker absenteeism. Machine breakdowns were also identified by Muckstadt and Tayur (1995) as one of four main sources of system variability, process time variation, rework requirements, machine breakdowns and yield losses highlighting similarities and differences in their impacts.

Method

There were two measures used. The first was on the number of parts in each bin. This done plotting the logarithm of the amplitude of the Fourier spectrum against its frequency to determine the line of best fit (β). This parameter was used to determine the degree of stability of each part. (For a technical description of spectral analysis of time series see Baker and Gollub, 1990:28- 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. See also Çambel, 1993). The second measure was the total number of hours that Kanban bins were empty.

Results

A comparison between the predicted performance, based on overt rules, and the performance of the parts once they were queuing indicated that the behaviour became less stable (indicated by an increase in β values) in 16 of the 18 parts with significant stockouts in the case of two parts. Two examples are shown in Table 1. Increasing negative gradients (indicated by β values) show increasing instability, and hence unpredictability, in the number of parts in the bins. This increase in instability is a result of the delays in the queue. These delays mean that the re-ordered parts arrive less regularly leading to inceasing variation in the number of parts in each bin at any given time.

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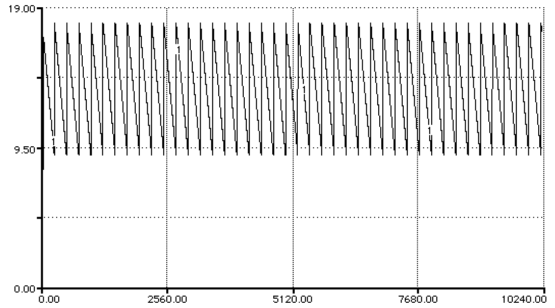
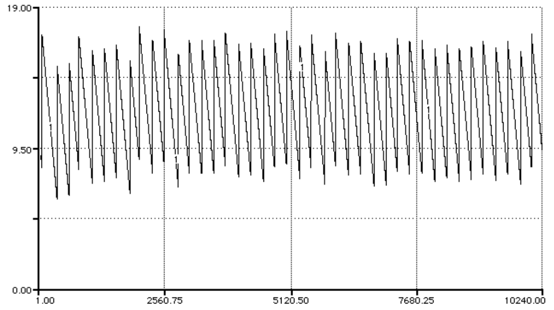
<tr><td colspan="4">

Part 4 (overt rules)</td><td colspan="4">

Part 4 (queuing)</td></tr>
<tr><td>β</td><td>SE</td><td>L. limit</td><td>U. limit</td><td>β</td><td>SE</td><td>L. limit</td><td>U. limit</td></tr>
<tr><td>-.462</td><td>.035</td><td>-.531</td><td>-.393</td><td>-.557</td><td>.022</td><td>-.560</td><td>-.515</td></tr>
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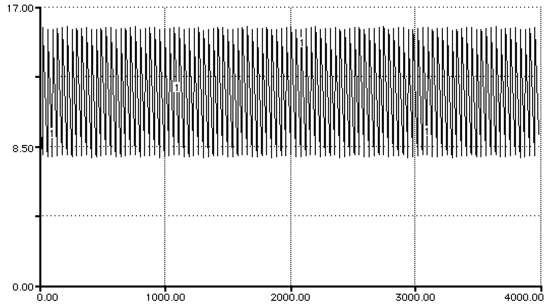
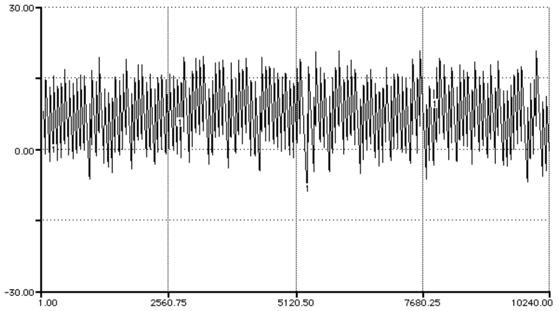
<tr><td colspan="4">

Part 5 (overt rules)</td><td colspan="4">

Part 5 (queuing)</td></tr>
<tr><td>β</td><td>SE</td><td>L. limit</td><td>U. limit</td><td>β</td><td>SE</td><td>L. limit</td><td>U. limit</td></tr>
<tr><td>.206</td><td>.034</td><td>.139</td><td>.273</td><td>-.575</td><td>.021</td><td>-.617</td><td>-.533</td></tr>
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Table 1: Examples of changes in stability with parts queuing.

This demonstrates that while the overt rules produced stable behaviour for that part in isolation, the interactive effect of queuing not only destabilizes the performance of the part but in the case of Part 5 leads to significant stockouts. The reason for this was variation in queue length shown in Figure 4.

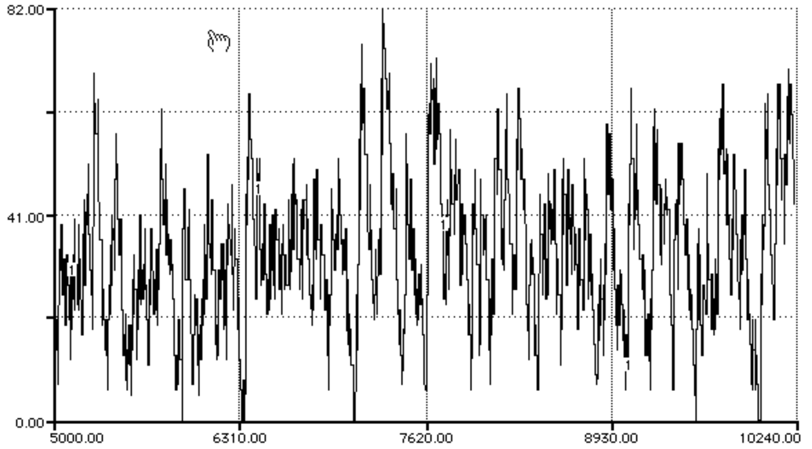


Figure 4: Queue length showing variation of 0 - 82 hrs.

The second measure used was backlog hours. In addition to measuring the stability of the individual parts, some measure of the total system performance was needed. It was clear that once the parts were in an interactive simulation where they were queuing for machine time, there were backlogs occurring. The calculation of backlog hours was :

Total backlog hours = Number of Parts in backlog * machine time per part

Table 2 shows the backlog hours for the parts that incurred backlogs. It was clear from this table that the managers would always be responding to potential linestops in the form of backlogs. These backlogs were a result of the overt rules of the system which generate the basic behaviour of the system.

Part Number	Stockout hours
Part 5	12684
Part 10	107
Total	12791

Table 2: Stock out hours for the system operating under the overt rules.

These results show that the system, based on individual re-order point and quantity calculations does not deliver the desired “no stock out” goal.

Use of managers local rule

For this simulation, the queuing simulation was taken as the benchmark because it contains the effects the interacting parts in the queue but without the imposition of any local rules. In examining the impact of the use of this local rule, it was possible to examine its impact on individual parts and on the system as a whole. The summary data in Table xxx shows that impact of the managers local rule was spread across the whole system. In all but three cases, the stability of the parts , as measured by the β values, decreased The number of interventions, namely shifting Kanbans to the front of the queue is also shown. The interventions have a systemic as well as specific impact. In each simulation, improvements in system performance were accompanied by increased instability in the performance of each bin.

	Interventions	Stability		Interventions	Stability
Part 1	_	_	Part 10	56	Down
Part 2	_	Down	Part 11	1	_
Part 3	1	Down	Part 12	84	_
Part 4	_	Down	Part 13	15	Down
Part 5	135	Up	Part 14	1	Down
Part 6	_	Down	Part 15	_	Down
Part 7	_	Down	Part 16	_	_
Part 8	25	Up	Part 17	7	Up
Part 9	3	Down	Part 18	_	_

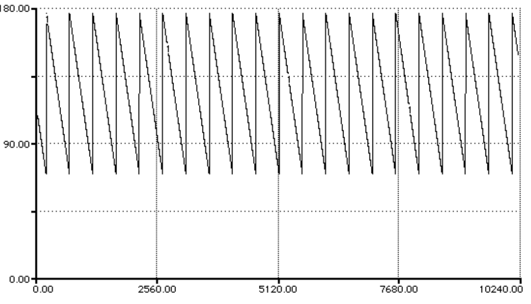
Table 3: Changes in stability for managers’ interventions.

While decreasing the stability of ten parts, the manager’s local rule improved the overall performance of the system as shown in the decrease of total stockout hours. There redundancy in the system, namely the effective buffer stock held in other bins as a result of imperfect calculations of overt rules. This has absorbed the impact of the managers interventions as they improve the performance of Part 5.

Part Number	Stockout hours (local rule)	Stockout hours (queuing)
Part 5	1485	12684
Part 8	13	–
Part 9	42	–
Part 10	423	107
Total	1963	12791

Table 4: Comparison of backlog hours for local rules and queuing

Examples of redundancy are shown in Figure 5 where the parts have effective buffers of 70 and 25 parts respectively. Such high level are a result of poor calculation ofhte overt rules becuase thay represent expensive and unnecessarily high levels.This is in contrast with other parts where the buffer was in the range of 2 - 5 parts. Nonetheless, this unintentional redundancy proved important to the operation of the local rule.



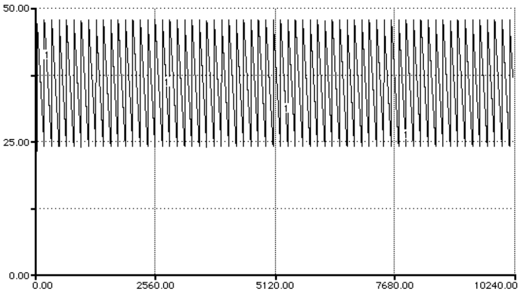
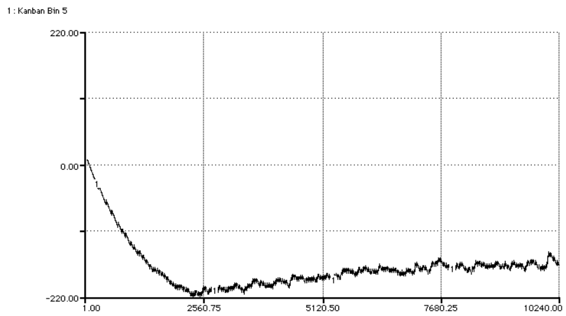


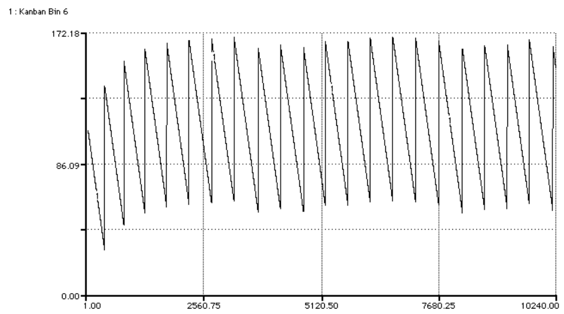
Figure 5: Bins with redundancy, which was designed in unintentionally.

Machine down time without the local rule.

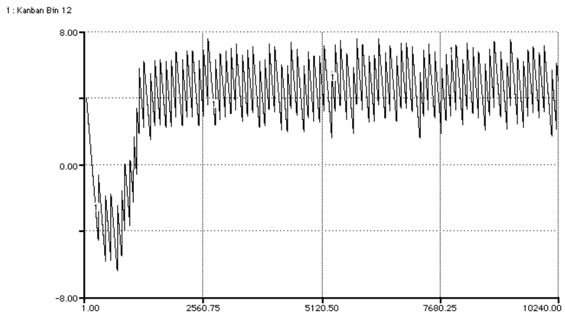
A further test of the rules was designed to examine how well the local rules dealt with a perturbation in the system. This was in the form of a 200 hour breakdown in the machine between 2000 and 2200 hours. This had the effect of producing large stockouts. Figure 6 shows examples of the impact of the machine break down on the number of parts in the bins. This simulation has no application of the local rule.



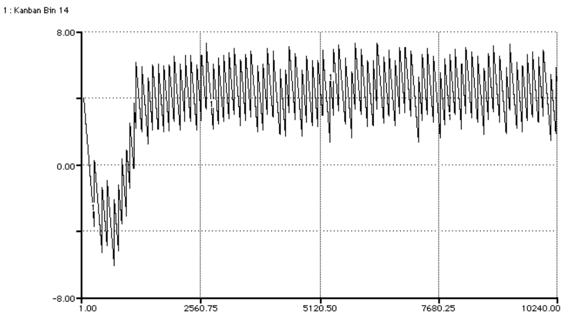
Part 5



Part 6



Part 12



Part 14

Figure 6: Impact of machine break down.

As can be seen in these examples, the system returns to a state where the stockouts were eliminated except in the case of Part 5. This is achieved through redundancy in the system which was built in, unintentionally, in the design of the overt rules which have some parts are operating well above what would be seen to be efficient Kanban operating levels. The only part that remained as a stockout was Part 5 and the graph of its performance indicated that it was gradually improving. Gupta and Gupta (1989) used simulation in analysis of Kanban systems and found such systems to be integrative in nature and goal seeking, returning to equilibrium after machine stoppages and changes to conveyance rate, production rate, levels of conveyance and production storage.

Machine down time with the local rule.

While the system showed it would self order if left alone, the manager's local rule led to large improvements in the stockout situation in comparison to doing nothing.

Part Number	Stockout hrs (Local Rule)	Stockout hrs (no local rule)	Part Number	Stockout hrs (Local Rule)	Stockout hrs (no local rule)
Part 1	960	148	Part 10	13907	47797
Part 2	4175	578	Part 11	169	65
Part 3	263	432	Part 12	567	2175
Part 4	159	–	Part 13	1316	1366
Part 5	239,194	1580802	Part 14	1014	3990
Part 6	722	–	Part 15	–	–
Part 7	118	–	Part 16	57	4
Part 8	302	–	Part 17	–	–
Part 9	4141	2658	Part 18	1386	294
			Total	268,450	1,640,309

Table 5: Comparison of backlog hours with and without the local rule.

Discussion.

From the findings on the application of the local rules, it appeared that the managers' local rule improves the overall functioning of the system measured by the number of backlog hours. Not that this was their purpose in applying the rule. Their purpose was to minimise senior management criticism over stockouts and the simulation indicated that their local rule would be effective in doing this.

The reason for the building of the simulation model was to see if the imposition of this rule would reduce senior management pressure over stockouts. The answer was clearly that the rule would be successful in doing this, as it resulted in large improvements in the number and duration of stockouts. In this case, the local rule has increased the pay-off for the managers at the local level.

At a slightly deeper level, the managers local rule had the impact of increasing the flexibility in the system through dynamic adjustment of the re-order points. At no point in the discussions with the managers was it ever mentioned that they were aware that this was what they were doing.

Evidence that the rule used by managers might be unintentionally successful was found by Watts, Hahn and Sohn (1994) who examined the effects of monitoring and dynamic re-adjustment of reorder points. They suggested a set of flexible rules for monitoring stockouts to help the manager isolate causes of system malfunctions which can be identified and isolated quickly. In particular, they suggested that order quantities and reorder points could be adjusted dynamically in response to changes in the system.

In these simulations, it was important to see the use of the managers' local rule as a subset of the overt rule on reorder points. There is significant attention given to the effect of the number of parts in Kanban systems (Fukukawa and Hong, 1993, Takahashi, 1994, Badinelli, 1992, Askin, Mitwasi and Goldberg, 1993, Wang and Wang, 1991, Abdou and Dutta, 1993 and Yanagawa, Miyazaki, and Ohta, 1994). The effect of the managers' local rule was, in effect, to vary the reorder point for the parts that went into a stockout. This in turn affects the total number of parts in the system, a crtical successfactor in Kanban systems. The difference between overt rules on re-order points (such as setting them at 8 or 16) and the managers' rule, was that the managers' rule was only applied as required. Three simulations were run to test the impact of different re-order points. The re-order points were set at 8, 16 and, in the third simulation allowed to adjust according to the managers application of the local rule. The simulation was run using a dynamic adjustment of the re-order point for just Part 5 which was the part showing greatest variation in the simulations and hence responsible for most system variation. The stockout hours are for the total system.

Reorder point	Stockout Hrs.	% Improvement
8	12,791	
16	9,202	28
Varies above 8 depending on local rule	1963	84.6

Table 6: Comparison of fixed any varying re-order points.

The situation was similar for the machine breakdown simulation where the rule returns the system to a stable equlibrium state more rapidly that fixed re-order points would. Table 7 shows that now the managers' rule clearly outperforms adjustments to the overt rules. AS can be seen in Table 7, re-order points at 8 and 16 have similar results. The local rule gives superior performance.

Reorder point	Stockout Hrs	Improvement
8	1,632,406	
16	1,620,414	.07 %
Varies above 8, depending on local rule	268,450	83.5 %

Table 7: Comparison of fixed any varying re-order points with machine breakdown.

Conclusion

The evidence of the simulations was that the manager's local rule improves the performance of the system as well as meeting the shorter term goals of reducing senior management pressure on managers on the issue of stockouts. The application of the local rule, through the unintended consquence of dynamic adjustment of re-order points, also improved the functioning of the system. The local rule also had the effect of destabilizing the system and taking advantage of unplanned redundancy in the system, while improving its performance.

The desired outcome of the rule, reduction of senior management criticism, and the unintended outcome, dynamic adjustment of re-order points, are closely interlinked. By moving cards from empty bins to the front of the queue, managers were ensuring that those bins were filled more quickly. They were also creating a flow-on problem by delaying parts for other bins. They were effectively spreading the problem more widely and creating more situations where the local rule needed to be applied. It also allowed them to take advantage of redundancy in the system. This meant relatively wide spread dynamic re-adjustment of re-order points and accessing widely dispersed redundancy, which improved the performance of the system.

It is clear that the managers local rules were effective in dealing with the managers local concerns. What is interesting is that this local rules also improved the overall performance of the system. Another local rule, used by the assembly operators, which could not be reported here, also had the effect of maximising local pay-offs for the operators but unlike the managers local rule, did not affect overall system performance. The limited evidence from Varian suggests that the effect of local rules on total system performance varies. The challenge for future research will to develop an analytic framework that classifies local rules that maximise local pay-offs and those which have wider systemic impact.

There are a number of questions that could be investigated. First, what is the connection between local rules that benefit the total system, rather than just local agents, and critical overt rules. Second, is the existence of redundancy necessary to the operation of local rules. Third, how can managers identify local rules and encourage those that have pay-offs for local agents and for the total system.

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