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A Tailored Toolkit to Enable Seamless Supply Chains

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ABSTRACT

Despite many individual well documented and high profile business process reengineering (BPR) success stories, the achievement of such enhanced performance still tends to be the exception rather than the norm. What is missing from the equation is a robust, generic, methodology which will help practitioners to plan, execute, and successfully re-engineer supply chains. The aim of this paper is to assist in this process by providing a tailored toolkit to enable a Seamless Supply Chain (SSC) based on the concept of smooth material flow and the associated information flow. This toolkit is tested in-depth via observations on 40 real-world value streams covering a range of market sectors. The applicability of each of the 12 Rules forming the Toolkit is then assessed and prioritised in relation to a range of operational factors including product marketing characteristics and product delivery processes. The consequence of our research is the segmentation of the Rules into those found to have universal applicability, and those which are especially important in specific product related scenarios. There is further partitioning into rules which are primarily of universal application, and those requiring considerable external collaboration.

KEY WORDS: re-engineering, seamless supply chains, material flow

1. INTRODUCTION

Simplified material flow has been shown to be a highly desirable feature of supply chain operations and can be achieved via innovative and thorough application of the 12 Simplicity Rules (Childerhouse and Towill 2003). Furthermore, as shown in that reference, these rules as rigorously applied during BPR Programmes produce a significant impact on 'bottom-line' performance metrics. These Rules are based upon the fundamental theoretical and practical work in this field started by Forrester (1958) and Burbidge (1961) and have been further extensively developed and honed by Towill (1999). Furthermore, if material flow is over complex then numerous symptoms become clearly visible and result in ineffective product delivery process performance. Towill (1999) goes on to identify twenty-four detailed symptoms which may be categorised into Dynamic, Physical, Organisational and Process characteristics. All may be observed either physically or via analysing numerical data and/or written communication within the chain. They are crucially important as a basis for our auditing of real-world supply chains and enable the design of structured questionnaires to elicit 'rich pictures' of particular value streams. These are found able to acquire the desired information from a wide range of sources (Childerhouse 2002). Additionally the results obtained are consistent between different analysts auditing the same value stream.

The original author, Towill (1999) explains the objective of the 12 Simplicity Rules as follows: '*… emphasis is on 'clean' i.e. unbiased and noise-free information flows; time compression of all work processes; achievement of consistent lead times; choice of smallest possible planning period; adherence to the schedule i.e. elimination of pockets of 'Just-in-Case' materials, selection by simulation of the 'best' supply chain controls; and finally, matching the simulation model to the real work process via process flow and information analyses.*' Hughes et al. (1999) similarly emphasise the need for simplicity when they argue for the need to apply a wide range of initiatives across the supply chain to drive out complexity.

This paper analyses the sample of forty value streams covering automotive, construction, food, mechanical, service and electronic market sectors. We demonstrate that the key to the desired integrated supply chain is simplified material flow and a high degree of confidence established in the twelve Simplicity Rules. Furthermore the improvements resulting from two major business process re-engineering programmes are assessed in terms of the effects of BPR on actually simplifying the material flow along the value stream (Childerhouse and Towill 2003). The context of the present paper is summarised in the pyramid model of figure 1 for enabling the Seamless Supply Chain. Level 1, Level 2 and Level 3 were previously studied in Childerhouse and Towill (2003) hence we now proceed to consider Level 4, the Learning Environment, for the present extended population of value streams. The thrust of the present paper is an assessment of the possible prioritisation of the 12 Simplicity Rules according to the operational scenario. In other words, should the resulting ‘tool box’ be segmented, and if so along what lines? There are probably a number of possible answers to these questions. In this paper we concentrate on investigating the possibility of segmentation based on the functionality/fashion-ability attributes of products flowing along the value stream.

2. ASSESSING AND ACHIEVING GOOD MATERIAL FLOW

In order to obtain ‘rich’ and consistent results across a sample of value streams the core concept utilised was the Uncertainty Circle. This was codified via Likert scales (Childerhouse and Towill, 2003) selected because it was realised that many real-world supply chains are chaotic as seen via observers within the system (Harrison 1997, Wilding 1998, Childerhouse et al. 2003). Previous applications of the Uncertainty Circle concept concluded that reducing uncertainty did indeed result in substantial improvement in bottom-line performance (Childerhouse 2002). Hence the Uncertainty Circle was used as the basis for the audit framework by assessing the uncertainty faced by any particular echelon under study.

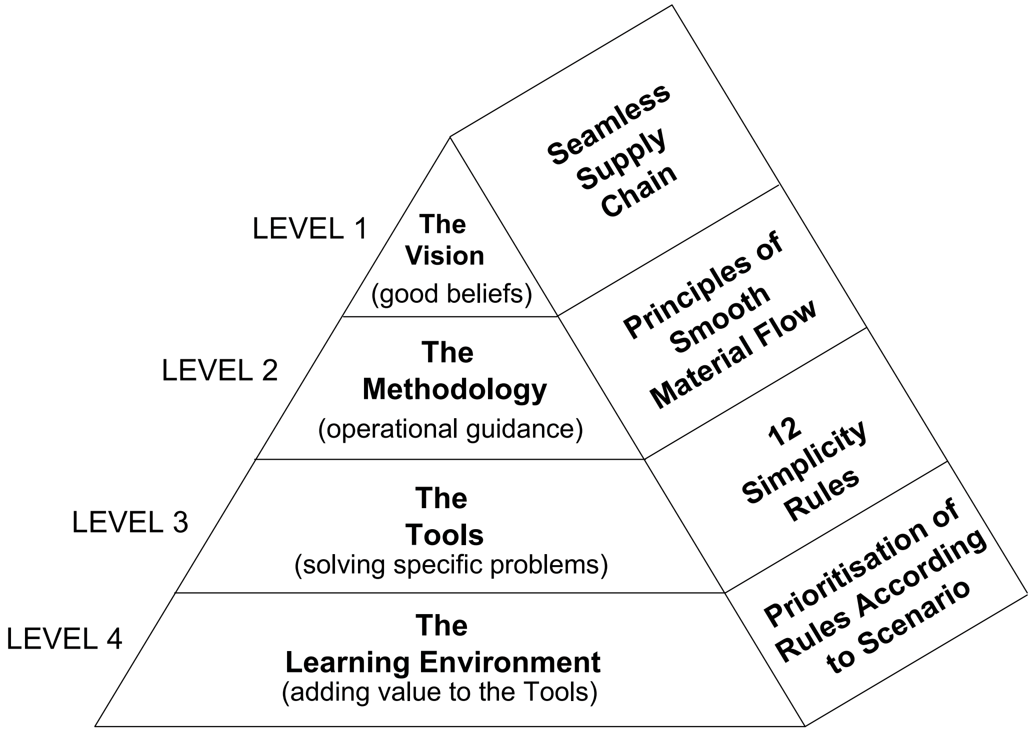

Figure 1. Pyramid Approach to Enabling the Seamless Supply Chain

(Source: Authors adapted from Werr, Stjernberg and Docherty 1997)

Our approach is based on segmenting the real-world uncertainties into the following four areas:

- supply side
- own process
- demand side
- control side

Via appropriate field-work, auditors then investigate the extent to which each uncertainty is present in the real-world echelon. They are guided by the published list of complex flow symptoms shown in table 1. Based on this evidence the analysts then rate the value stream on a 4 point Likert scale (4 = high uncertainty; 1 = low uncertainty) for each of the four areas. The resultant Euclidean Norm metric for an individual value stream calculated from these four areas can then be utilised as a single measure of supply chain integration (Childerhouse and Towill, 2003). The Uncertainty Circle concept is simple in nature with the four identifiable areas based on a control engineering approach to systems design (Parnaby and Billington 1976). An integrated value stream has minimal uncertainties in all four areas, thereby reducing the need to buffer interfaces with safety stock. The benchmark is the Stevens (1989) fully integrated supply chain, both internally and externally. It practices a high degree of interface management, hence it is used as a target Seamless Supply Chain in which all 'players' 'Think and Act as One'. To summarise, the Uncertainty Circle based audit has confirmed Level 2 of the pyramid approach of figure 1.

Having established that reducing uncertainty led to significant bottom-line performance improvements, the next step was to identify a suitable toolbox for engineering change to enable 'best practice' transfer between value streams and also across market sectors. This was achieved via the 12 Simplicity Rules advocated for smooth material flow that will be discussed in detail in the next section. We have already shown that there is a high degree of correlation between the usage of these rules and reduction of uncertainty within a particular value stream. This means that the more Simplicity Rules that are properly applied in the engineering of the value stream, the lower will be the uncertainty experienced therein. Hence Level 3 of the pyramid of figure 1 has been verified and validated. To complete this background review, we have cross-checked on the degree of adherence of the present updated sample of 40 value streams to the Simplicity Rules. The results are shown in Bar Chart format in figure 2. They are again based on Likert score assessments, using a 4 point scale (1 = rule little in evidence to 4 = rule much in evidence) averaged across the sample. As expected, some rules are more frequently encountered than others. The popularity of the 'clustering' rule is likely to be a consequence of the writings of such experienced practitioners as Burbidge and Halsall (1994), and Parnaby (1995), who focus on this particular tactic.

Class of Symptoms	**Symptoms Observed in Complex Material Flow**
Dynamic Behaviour	Systems induced behaviour observed in demand patterns System behaviour often unexpected and counter-intuitive Casual relationships often geographically separated Excessive demand amplifications as orders passed upstream Rogue orders induced by system 'Players' Poor and variable customer service levels
Physical Situation	Large and increasing number of products per pound turnover High labour content Multiple production and distribution points Large pools of inventory throughout the system Complicated material flow patterns Poor stores control
Operational Characteristics	Shop floor decisions based on batch-and-queue 'Interference' between competing value streams Casual relationships often well separated in time Failure to synchronise all orders and acquisitions Failure to compress lead times Variable performance in response to similar order patterns
Organisational Characteristics	Decision making by functional groups Excessive Quality Inspection Multiple independent information systems Overheads and indirect costs allocated across product groups, and not by activity Excessive layers of management between CEO and shop floor Bureaucratic and lengthy decision making process

Table 1. Flour Classes of Symptoms Observed in Complex Material Flow

(Source: Towill 1999)

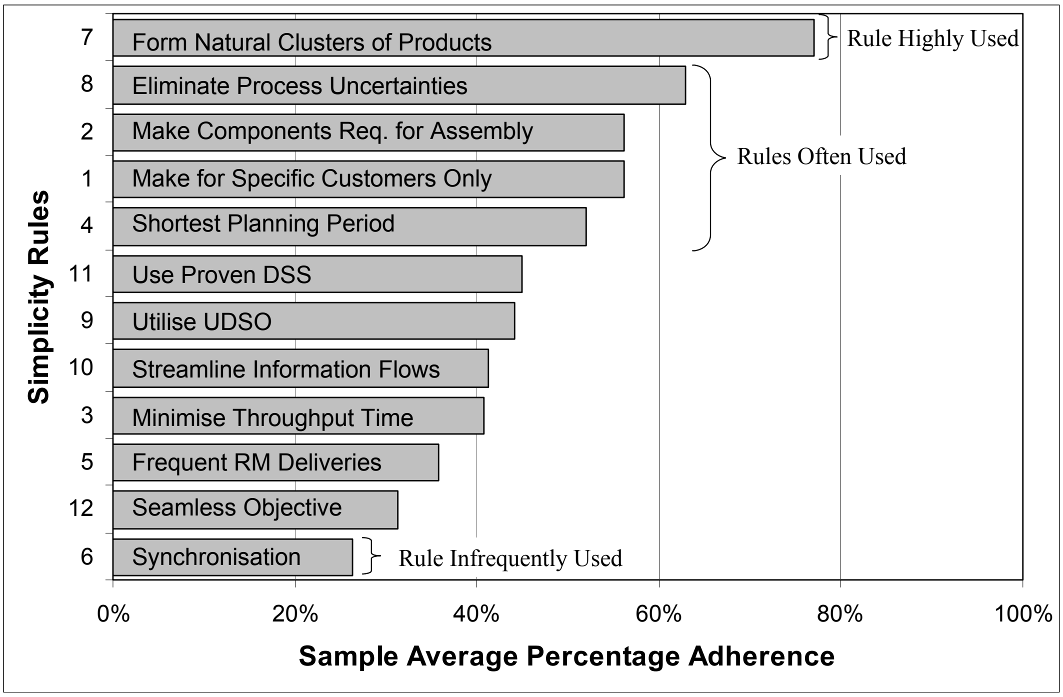

Figure 2. 40 Sample Average Percentage Adherence to Individual Simplicity Rules

(Source: Authors)

3. THE 12 RULES OF SIMPLIFIED MATERIAL FLOW

The 12 Simplicity Rules have been designed as a complete set of guidelines by Towill (1999) for practitioners to simplify their material flow, in the sense of developing the supply chain equivalent to 'Factory Physics' (Hopp and Spearman 2000). They have been produced from a detailed distillation and synthesis of existing good practice as recorded in the literature (Towill 1999). However the individual rules proposed have additionally been very much influenced by the successful Business Process Re-Engineering projects with which the authors and their associates have been involved and available in detailed Case Study format. It should be noted that it is not expected to find that each of the rules are equally applicable to every company. The emphasis placed on the individual rules are likely to be dependent on the nature of the product delivery process and market being served. This will emerge from our subsequent analysis in which their application is monitored via supply chain audits.

The following is a critical summary of each of the 12 rules that highlights why they have been included and when they are likely to be of particular importance.

Rule 1: *Only make products that can be quickly despatched and invoiced to customers*, highlights the need for companies to be pull/customer driven. This rule is of particular importance to companies operating in (say) fashion markets with unpredictable demand and hence high obsolescence risks. **Rule 2:** *Only make in one time bucket those components needed for assembly in the next*, emphasises the need to minimise work-in-progress stock levels. This is relevant to multi-stage product delivery processes that contain several processing steps separated by sub-assembly inventories. **Rule 3:** *Streamline material flow and minimise throughput time*, is of critical importance to all products. Compression of material, information and financial lead times dramatically improves the integration and performance of supply chains.

Information lead times can also be reduced via the *use of the shortest planning periods*, **Rule 4.** Furthermore, adherence to this rule will reduce the use of old and less accurate information thereby improving forecast accuracy and reducing buffer stocks. Rule 4 is of particular importance to volatile products with uncertain and highly variable demand volumes. **Rule 5:** *Only take deliveries from suppliers in small batches as and when needed for processing and assembly*, is a well recognised approach to reducing in-bound inventory levels. This rule is particularly relevant to raw materials with relatively stable demand volumes and can be further developed by using vendor managed inventory or consignment stocking policies.

Synchronisation of time buckets thought the chain, **Rule 6** is of critical importance to all supply chains. Lack of synchronisation results in buffer stocks at every location where the time buckets differ. Consequently information lead times are elongated and out-of date data is frequently used as a result of conflicting time buckets in the planning process.

Rule 7 relates to the need to avoid the conflicting objectives of serving different markets by a single supply chain strategy. Hence, by *forming natural clusters of products and designing processes appropriate to each value stream* the requirements of diverse customer requirements can be best served. The need to *eliminate all uncertainties in all processes*, **Rule 8** is universal and only by aiming for this goal will simplified material flow be truly achieved. If the uncertainties in the process are not eliminated the result is poor and variable quality levels and excessive lead times adversely impact on customer service and raw material inventory levels. **Rule 9** relates to the need for a structured approach to change. Understand, document, simply and then optimise (*UDSO*) is a well recognised method to identify and implement improvements suitable for this purpose (Watson 1994). Change without a method can often result in progression followed by recession.

Highly visible and streamlined information flows, **Rule 10** is important to the simplification of material flow for all supply chains. It is this information that co-ordinates, controls and synchronises the flow of material. **Rule 11** relates to the need to *use proven and robust decision support systems* in the management of the supply chain so scientific rigour as opposed to gut intuition guides strategy. This rule is important to all products, but is particularly relevant to those that are more volatile and unpredictable. Finally **Rule 12** is of critical importance to all types of products and related supply chains. The *operational target* *of the seamless supply chain* needs to be commonly accepted and shared by all members so to facilitate the arduous task of implementing change.

4. RESEARCH PROPOSITIONS

There are two new areas of research in this paper concerned specifically with the application of the twelve Simplicity Rules to industrial and service sector value streams. There are based on the testing of two propositions as follows:

Proposition 1 The 12 Simplicity Rules may be segmented into a (2x2) matrix to provide a meaningful framework for the focus of management effort to improve supply chain integration.

Proposition 2 Some of the 12 Simplicity Rules are more important/critical in their effect on reducing supply chain uncertainties.

The segmentation is made via matrix axes of Internal/External Rules and Universal/Product Related Rules. The assignment of Rules to segments is shown in table 2. In some cases the decision as to the matrix cell location most appropriate to a particular rule is straightforward. But in other cases there may well be overlap. For example, the use of shorter planning periods is within the internal control of an individual player at an echelon in the value stream. But there may well be opportunities to influence suppliers and persuade customers to use shorter planning periods. If the information relating thereto becomes transparent throughout the chain, then this leads to the listed universal external rule based on such operation.

Sample Usage Ranking	Simplicity Rules		Matrix Dimension		Uncertainty Reduction Ranking
	No.	Description	Spatial	Category	
1	7	Formation of Product Clusters	External	Product	8
2	8	Eliminate all Process Uncertainties	Internal	Universal	2
3	2	Minimise WIP	Internal	Product	10
4	1	Make Products for Quick Despatch	Internal	Product	9
5	4	Use Shortest Planning Period	Internal	Product	4
6	11	Use Simple Robust DSS	Internal	Product	11
7	9	Exploit UDSO	Internal	Universal	6
8	10	Information Transparency	External	Universal	5
9	3	Compress Lead Times	External	Universal	3
10	5	Take Deliveries in Small Batches	External	Product	12
11	12	Aim for SSC Operations	External	Universal	1
12	6	Synchronise "Time Buckets"	External	Universal	7

Table 2. Proposed Matrix Segmentation of 12 Simplicity Rules (Source: Authors)

The description of each of the 12 rules in the previous section explains most of the reasoning for their matrix segmentation. In particular those ranked external require the combined effort of multiple organisations across external boundaries. Whereas internal rules are those that could be applied internally firstly to obtain initial improvements, after which the effective practice thus developed should be shared and applied by other supply chain members. Those rules rated product specific are more applicable to volatile/ unpredictable products. In contrast the 6 universal rules are generic and hence are considered to be applicable in all circumstances.

The matrix segmentation is summarised in table 2. Clearly the four matrix cells are categorised by dimensions of Internal - Product; External - Product; Internal – Universal; and External – Universal respectively. Four Rules have been allocated to the first and fourth of these cells, and two Rules to the others. Note that to provide completeness ahead of the later statistical analysis in Sections 6 and 7, the Usage Rankings and Uncertainty Reduction Rankings are also shown. At this stage of the paper these rankings should be regarded as a 'rough cut' listing prior to establishing significance levels via a battery of standard tests.

5. RESEARCH METHODOLOGY

Twenty-three of the forty value stream sample have been analysed via a site-based 'Quick Scan' (QS) audit methodology. These cover a wide spectrum of European automotive system and component suppliers, together with a UK utilities organisation. During the QS audit, material and information flows are process mapped, key managers are interviewed, company archival information is evaluated and attitudinal questionnaires are completed for the interfaces of the value streams. As a result an in-depth understanding of the value stream is obtained and is then fully documented. The QS process is explained in considerable detail in Naim et al. (2002) and need not be repeated here. Suffice to say that given resources and adequate shop floor and managerial access it has proven to be a rich and time-effective method of investigation.

In the case of the remaining seventeen value streams that were not formally ‘Quick Scanned’ considerable material was available for scrutiny by the investigators. Much of this is available in the open literature (Lewis 1997, Waddington 2001, Childerhouse 2002). Structured interviews were then conducted with product champions to obtain an even deeper understanding of the product delivery and information flow processes. The product champions were selected for their overview and knowledge of the specific value stream under scrutiny. Examples of the types of managers interviewed include: European Logistics Manager, Global Purchasing Manager, Production Manager, and Managing Director. These non-Quick Scanned value streams are non-automotive and include ventilation, health care, steel processing, lighting and electronic products located within the UK plus three Antipodean dairy product value streams. For easy reference, in table 6 of Appendix A the QS audited value streams are numbered 1-23, and the remainder (non-QS) are numbered 24-40.

Appendix B provides an overview of the detailed analysis that was conducted to ensure the alignment of the QS and structured interview data collection methods. Three phases of multiple ANOVA (analyses of variance) concluded that both methods provide similar evaluations of the current status of value streams.

Once all twenty-three value streams had been ‘Quick Scanned’ three detailed questionnaires were completed by the Quick Scan team. The product champions for the additional seventeen non-automotive value streams also completed the same questionnaires. The first of the questionnaires was utilised to evaluate the level of uncertainties in the four areas of supply, demand, process and control (Childerhouse 2002). Each of the four areas is scored from one (low uncertainty) up to four (high uncertainty). The Euclidean Norm is then calculated as an overall score of uncertainty using the formula:

$$\text{Euclidean Norm} = \sqrt{\left(\text{Process Score} - 1\right)^2 + \left(\text{Supply Score} - 1\right)^2 + \left(\text{Demand Score} - 1\right)^2 + \left(\text{Control Score} - 1\right)^2} \quad \text{---- (1)}$$

The smaller the Euclidean Norm, the less is uncertainty perceived to be a problem in that particular value stream. As a corollary it is anticipated that the corresponding material flow would be much smoother.

The degree of compliance to the 12 simplicity rules was assessed for the forty value stream sample. A Likert scale from one to four was once again used in order to evaluate the extent to which these rules are applied. A score of one indicates the rule is not adhered to, whilst a score of four means it is always enforced. The total for each value stream is then calculated as a percentage of the maximum score using the formula:

$$\text{Degree of simpification} = \left(\frac{(\text{Sum of simplicity scores for the 12 rules} - 12) * 100}{\text{Maximum simplicity score} - 12} \right) \quad (2)$$

The maximum simplicity score is 4 for each of the 12 rules, and indicates the value stream is as simplified as possible and hence has an overall degree of simplification of 100%. Conversely a score of 1 for each of the 12 rules results in an overall degree of simplification of 0% when equation 2 is applied. It should be noted that the Simplicity questionnaire was applied on an organisational rather than a value stream basis. This is because a number of the questions relate to the sharing of resources and management philosophy.

The third Questionnaire is based upon table 1. Here the presence or lack of observable symptoms resulting from complex material flow is assessed via a binomial scale. In addition, a disclaimer is included for those symptoms not analysed or encountered. The resultant percentage scores are then calculated for each of the four individual areas of uncertainty together with an overall average for the value stream. The result for each case is given in detail in Appendix A.

6. STATISTICAL ANALYSIS TO INVESTIGATE PROPOSITION 1

We first consider the internal/external axis of the (2x2) matrix. The internal rules are tested by correlating the sum of internal uncertainties (process plus control) with the degree of simplification of the 6 internal rules for the sample. The correlation coefficient is -0.445 which translates to a 99% statistically significance level. Note that the negative sign of the coefficient means that the higher the adherence to these 6 internal rules, the greater is the internal uncertainty reduction.

The procedure is repeated for the external axis, but this time using the sum of the external uncertainties (demand plus supply) and the 6 proposed external simplicity rules. Statistical analysis reveals that external uncertainty correlates with these external rules at the 98% level. The correlation coefficient is -0.39, meaning that the more these rules are adhered to, the more the external uncertainty is reduced.

To examine the universal/product related axis of the (2x2) matrix it has been necessary to develop a scalar that covers the spectrum of goods from functionality products (rated 1) to fashion-ability (related 4) on the Likert scale. This demarcation follows from the seminal work by Fisher (1997) in his matching of supply chains to marketplace requirements. This scalar, again taken from Appendix A, correlates against the degree of adherence to the product specific Simplicity Rules with a coefficient of 0.39. This is statistically significant at the 98% level. The positive sign of the correlation coefficient means that those value streams with a high functionality/fashion-ability product index are more likely to show a high adherence to the product specific Simplicity Rules.

The universal Simplicity Rules are expected to be applied equally by all value streams regardless of their functionality/fashion-ability product index. In this case the correlation coefficient is 0.28 which is NOT significant at the 95% level. Hence we may conclude that there is no significant relationship between adherence to the six universal rules and the functionality/fashion-ability product index. This completes the assessment of the 40 value stream sample of Appendix A from the tailored Simplicity Rules perspective.

6.1 Summary of Evidence on Proposition 1

We have proposed the segmentation into 6 External Simplicity Rules and 6 Internal Simplicity Rules where adherence negatively correlates with external and internal uncertainty scores respectively. Furthermore there is positive correlation between usage of the 6 product Related Rules and the functionality/fashion-ability product index, but no correlation between the usage of 6 universal rules in this same index.

6.2 Conclusion

The 12 Simplicity Rules may be segmented into a (2x2) matrix based on External/Internal and Universal/Product Related cells.

7. STATISTICAL ANALYSIS OF THE SECOND HYPOTHESIS

It has already been established that adherence to the 12 Simplicity Rules significantly reduces uncertainty (Childerhouse and Towill 2003). So the next step is to investigate each rule separately to see how well they correlate with the Euclidean Norm uncertainty scores. Table

3 thereby ranks the rules according to their correlation coefficient. Furthermore the statistical significance level is also shown. Note that table 3 has been calculated using the full sample of 40 value streams listed in Appendix A. The statistical results fall into a number of clusters as follows:

Rules 12; 8; 3; and 4 are highly correlated

Rule 10 is correlated

Rules 9 and 6 are weakly correlated

Rules 7; 1; 2; 11; and 5 are not significantly correlated

It is very important to note that the three highest and six of the top eight significantly correlated rules are all graded 'universal' in table 2. Hence, the very high statistical significance of rules 12 (aim for the Seamless Supply Chain ~ 'think and act as one') and 8 (Eliminate all process uncertainties) gives operations management a clear steer on priorities to be adopted.

However it is useful to repeat the foregoing analysis but highlighting those value streams at the fashion end of the spectrum. Hence the value streams in Appendix A with high rankings (3 or 4) on the fashion-ability index were analysed using only the product related rules shown in table 2. The sample size is now 12, and although this is much smaller the results are extremely focussed. We conclude from the statistics of table 4 that the six Product Related Simplicity Rules are rated as follows:

Rules 5; 4; 2 and 1 are highly correlated

Rule 7 is weakly correlated

Rule 11 is not significantly correlated

	No.	Rule Description	Correlation Coefficient	Statistical Significance
VERY POWERFUL RULES	12	The operational target is to enable the Seamless supply chain i.e. all players “think and act as one”.	-0.51	99.9%
VERY POWERFUL RULES	8	Eliminate all uncertainties in all processes.	-0.50	99.9%
VERY POWERFUL RULES	3	Streamline material flow and minimise throughput time, i.e. compress all lead times.	-0.46	99%
VERY POWERFUL RULES	4	Use the shortest planning period, i.e. the smallest run quantity which can be managed efficiently.	-0.44	99%
	10	Streamline and make highly visible all information flows throughout the chain.	-0.40	95%
	9	Understand, document, simplify and only then optimise (UDSO) the supply chain.	-0.30	90%
	6	Synchronise “Time Buckets” throughout the supply chain.	-0.28	90%
	7	Form natural clusters of products and design processes appropriate to each value stream.	-0.25	Not Significant at 90%
	1	Only make products which can be quickly dispatched and invoiced to customers.	-0.20	Not Significant at 90%
	2	Only make in one time bucket those components needed for assembly in the next period.	-0.18	Not Significant at 90%
	11	Use only proven, simple but robust Decision Support Systems.	-0.18	Not Significant at 90%
	5	Only take deliveries from suppliers in small batches as and when needed for processing or assembly.	-0.14	Not Significant at 90%

Table 3. The 40 Value Stream Sample: Ranked Correlations between each of the 12 Simplicity Rules and the Euclidean Norm Uncertainty Scores

	No.	Rule Description	Correlation Coefficient	Statistical Significance
VERY POWERFUL RULES	5	Only take deliveries from suppliers in small batches as and when needed for processing or assembly.	-0.85	99.9%
	4	Use the shortest planning period, i.e. the smallest run quantity which can be managed efficiently.	-0.80	99.9%
	2	Only make in one time bucket those components needed for assembly in the next period.	-0.75	99%
	1	Only make products which can be quickly dispatched and invoiced to customers.	-0.69	98%
	7	Form natural clusters of products and design processes appropriate to each value stream.	-0.54	90%
	11	Use only proven, simple but robust Decision Support Systems.	-0.07	Not Significant at 90%

Table 4. The Sample of 12 Value Streams Ranked High on the Fashion-ability Axis ~ Correlations with the Six Product Related Simplicity Rules

A detailed discussion of the meaning of these results will be given in the next section. However with regard to importance/criticality of individual Simplicity Rules we may reach the following conclusion:

7.1 Summary of Evidence on Proposition 2

Using the Euclidean Norm as an uncertainty measure, there are clearly statistically significant differences between the impact made by the various Simplicity Rules. Some emerge as particularly potent. There is also statistically significant evidence to indicate that there is a preferred hierarchy in effectiveness of the product specific rules.

7.2 Conclusion

The evidence suggests that some Simplicity Rules have a greater impact on reducing value stream uncertainty. Furthermore four particular rules are highly significant in general terms, whereas four other rules appear particularly relevant in product related BPR. Rule 4 is common to both sets.

8. DISCUSSION OF RESULTS

We must emphasise that the original proposal to establish the 12 Simplicity Rules for enabling streamlined material flow are anchored to individual actions, which have been proven by industrial practice, simulation, or control theory (and combinations thereof) to improve competitive performance (Towill 1999). However at that time the Rules had been verified and validated in particular Case Study circumstances, usually by the application of one Rule at a time. Also the verification may well have been a function of the specific industry under study. Childerhouse and Towill (2003) then progressed our understanding by showing that all 12 Simplicity Rules contributed to uncertainty reduction as measured via the Uncertainty Circle principle. This verified the Rules as suitable for using at the 'toolkit' level of BPR Programmes for enabling the Seamless Supply Chain. Have we been able to shed any further light on the importance/criticality of the Rules?

To answer this question we first have to remember how change actually takes place during value stream re-engineering. Fortunately we have already established the most likely sequence of events as supply chains move along a trajectory from traditional behaviour to seamless operation. Additionally this trajectory is related to the quadrants of the Uncertainty Circle (Towill et al. 2000).

To summarise, the sequence is:

- 'get one's own house in order' first i.e. reduce uncertainties in 'our process'
- utilise this experience to reduce supply uncertainties
- exploit this solid base to work with customers to reduce demand uncertainties

In this scenario the control uncertainties may be progressively reduced as the information 'states' needed for smooth material flow are made available in lag free, noise free, and bias free format. So the contribution which can be made by application of any particular Rule may well depend on the trajectory position of the value stream at that point in time. Even if these Rules just produce 'localised' benefits at the early stages of re-engineering, they nevertheless remain important to the programme as a whole. This is partly because of the need to learn experientially how the Rules should be applied, and partly because the beneficial effect may multiply up as the re-engineering progresses along the chain. The 'Shortest Planning Period' Rules is one such example.

To explore this avenue of investigation further the statistical analysis of table 3 has been used to construct the segmentation Matrix of figure 3. This is based on the perceived gap between usage and opportunity. Inspection of this matrix shows that the product related/internal rules (1: 2: 4: and 11) are already being used widely. This is as expected, since these are the Rules which may be applied readily, since the areas of application usually lie within the management span of the 'product champion' responsible for the re-engineering programme. At the other extreme is the universal-external cell, with low usage. Yet three of these Rules are critically important to system success (12, 8, and 9), especially the first two. So this is a general area where BPR programmes need to focus, and where further research is justified. The two remaining cells throw up very specific messages. There is an apparent failure to exploit UDSO as part of BPR Programmes. This seems a potentially fatal flaw on the part of industrial engineers and systems analysts. Finally, the advantages and opportunities arising from taking more frequent delivery frequencies needs more investigation and focussed exploitation.

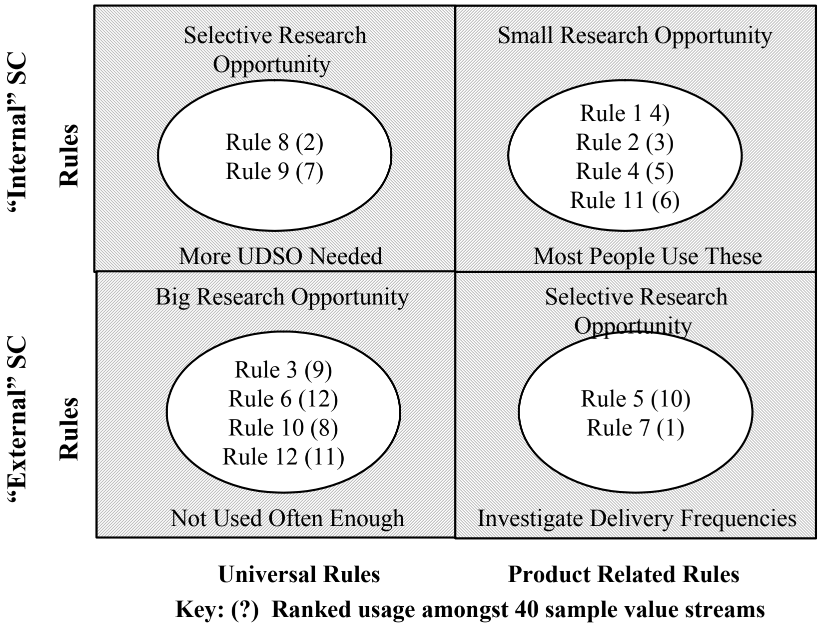

Figure 3 Simplicity rules Gap Analysis Reveals Future Research Opportunities

(Source: Authors)

9. IMPACT OF REDUCING UNCERTAINTY ON SUPPLY CHAIN RESPONSIVENESS

It is reasonable to question whether reducing value stream uncertainty has a significant beneficial impact on supply chain performance. This we have assessed via the various lead times in particular value streams. It is already well established that cycle time compression leads to substantial improvements to the 'bottom line' (Thomas 1990). A big advantage of using cycle time as a performance metric is that it is simple and unambiguous. Indeed it may be argued that part of the success of the 'Machine That Changed the World' (Womack et al. 1990) is due to their using such transparent and transferable indicators. We have been exceptionally fortunate during this research programme to be able to assess the performance of value streams both before and after extensive BPR Programmes. The results shown in table 5 are for VS 24/25 (mechanical precision products) and VS 26/27 (ventilation systems).

Supply Chain Criteria	**Performance Attribute**	**Example Supply Chains**	
		VS 24~VS 25 Mechanical Precision Products	**VS 26 ~ VS 27 Ventilation Systems**
QS Audit Scores	Change in Material Flow Integration Level	Functional to External	Internal to External
	Uncertainty Score	Down from 4.80 to 1.73	Down from 3.00 to 2.24
Complex Material Flow Symptoms	Overall % of Symptoms Present	45% Decrease down to 13%	58% Decrease down to 21%
	Dynamical	67% Decrease	17% Decrease
	Physical	20% Decrease	66% Decrease
	Operational	80% Decrease	66% Decrease
	Organisational	16% Decrease	83% Decrease
Observed Improvement in Cycle Times	Distribution Lead Time	Cut by 50%	Cut by 84%
	Manufacturing Lead Time	Cut by 83%	Cut by 50%
	Supplier Lead Time	Cut by 75%	Cut by 81%
	Total Cycle Time	Cut by 78%	Cut by 81%

Table 5. Examples of the Impact of Reducing Uncertainty on Supply Chain Responsiveness
(Source: Childerhouse 2002)

It has been possible to codify the four sources of uncertainty, and to observe the extent to which the complex flow symptoms have been reduced as a consequence of this re-engineering. The cycle times used in table 5 were made available from company databases. To provide further insight into the improvement in value stream performance distribution, manufacturing and supplier lead times are presented in addition to total cycle time. As pointed out by Braithwaite (1993), these can give vital clues as to any non-value added activities remaining to be eliminated during BPR Programmes.

The VS 24/25 BPR Programmes cover the large value stream transition from Functional to External Integration (as defined by the Stevens 1989 Change Model). The Uncertainty Score has decreased from 4.80 to 1.73 and all the complex material flow symptoms are reduced. The Dynamic and Operational Contributions are shrunk very substantially indeed. As expected the lead times are but a fraction of the initial values. There is consequential reduction in bullwhip of 50% and minimum stock turn improvements of 2 to 1 and increasing further with operating experience of the new system (McCullen and Towill, 2002).

In VS 26/27 the recorded BPR starting point was more advanced, since on the Stevens (1989) scale, the change in integration level is only from Internal to External. Hence the uncertainty score was only 3.0 to start with, and post BPR is reduced to 2.24. Nevertheless the consequential reductions in all lead times are still substantial. There is also a reported increase associated of 10% in profit margin over the BPR period (Childerhouse 2002). We have also taken this opportunity to graphically demonstrate the perceived usage of the 12 Simplicity Rules in these two BPR Programmes. Hence Figure 4 shows the increased usage in the format of spider plots. Manifestly in both BPR Programmes the application of the 12 Simplicity Rules is much greater than prior to re-engineering. Of the high impact rules, 8, 3, and 4 are now rated top usage in both cases on the Likert scale. Rule 12 has top rating on VS 25 and the penultimate rating on VS 27.

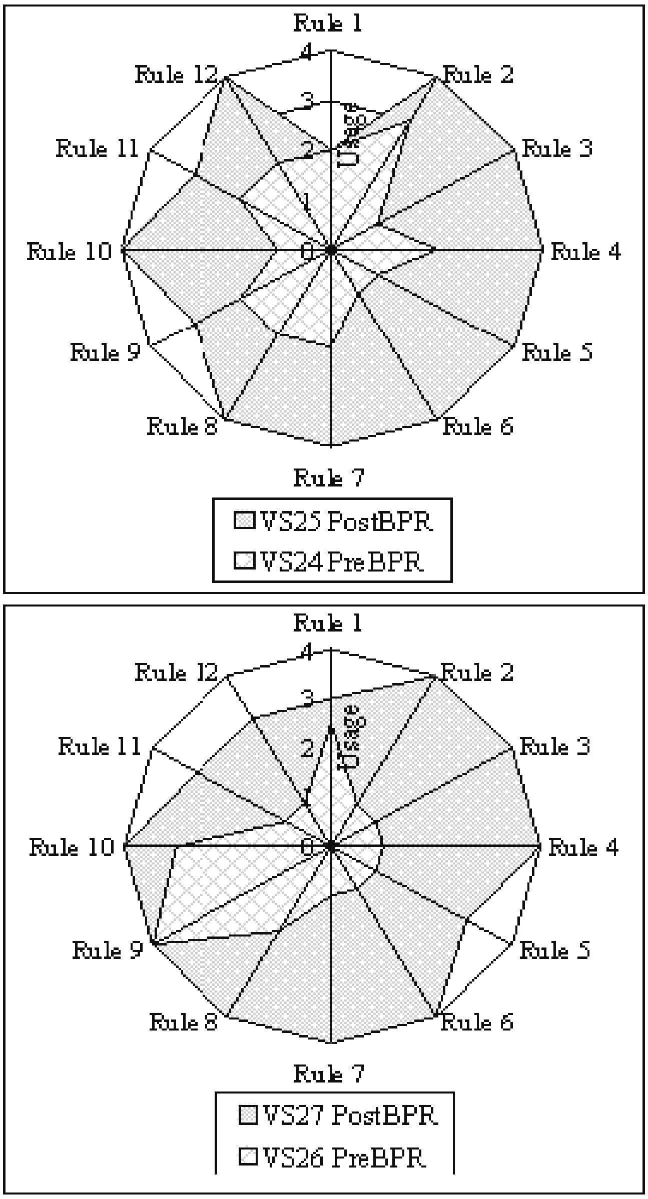

Figure 4. Spider Plots of the Perceived Application of the 12 Simplicity Rules During Two Successful BPR Programmes (Source Authors)

10. CONCLUSIONS

We have established from a sample of 40 Value Streams that the 12 Simplicity Rules, when properly applied, reduce uncertainty in material flow. The consequential bottom-line impact is considerable. For example, using the Total Cycle Time metric, reductions of up to 78% have been recorded. In one Case Study this has resulted in substantial bullwhip reduction, much higher stock turns, and higher service levels. In the second Case Study there are much higher service levels and significantly improved profit margins. Furthermore, in both cases the companies concerned have moved to a much more responsive mode of operations. This, in turn, has enabled these enterprises to re-position themselves in the marketplace.

These Case Studies substantiate the concept portrayed in figure 1 of re-engineering value streams on the basis of improved material flow. As Parnaby (1995) has remarked, what is required is *good engineering* of delivery processes as a pre-requisite for improved industrial performance. The 12 Simplicity Rules provide a good toolkit for enabling value streams to improve material flow and hence move towards the Seamless supply chain. Previous research has shown that each Rule can make a contribution to such enhancement. However, statistical analysis of the 40 value stream samples does show a ranking of the Rules based on the perceived level of uncertainty. Four Rules emerge from this investigation as particularly powerful, viz:

Rule 12: Aim for SSC Operations (External: Universal)

Rule 8: Eliminate all Process Uncertainties (Internal: Universal)

Rule 3: Compress Lead Times (External: Universal)

Rule 4: Use Shortest Planning Period (Internal: Product)

So product champions are given strong guidance on prioritisation of actions. Note that two of the top ranked Rules are External, meaning that interface management is an important issue which must be tackled before much progress can be expected. In the further statistical analysis of those companies rated *highly on the fashion-ability product index,* four Rules emerged as important in this particular scenario. These are:

Rule 5: Take Deliveries in Small Batches (External: Product)

Rule 4: Use Shortest Planning Period (|Internal: Product)

Rule 2: Minimise WIP (Internal: Product)

Rule 1: Make Products for Quick Despatch (Internal: Product)

These last three Rules have the advantage that they can be implemented internally. Their role is very important as part of the learning process which must be undergone as part of every BPR Programme. If fulfils the role of ‘getting one’s own house in order’ as the basis for partnering both upstream and downstream from a position of knowledge and experience (Towill et al. 2000). So we conclude that some of the 12 Simplicity Rules are more critical in the early stages of value stream re-engineering, but that as we approach full integration then a different cluster of Rules are the most powerful in enabling uncertainty reduction and thereby achieve smooth material flow.

11. APPENDICES

11.1 Appendix A: Simplicity Rules Applied to Forty Value Stream Sample

Table 6 contains the raw unfiltered simplicity scores for the 40 value stream sample. The first column contains the reference number for each value stream, and the second column relates to the relative fashion or functionality of the products flowing down that particular value stream. Note that the majority of the sample is mainly functional with only two of the value streams scoring four and thus indicating truly fashionable products. The third column is the overall percentage adherence to the simplicity rules; this is calculated using equation (2) of the paper proper:

$$\text{Degree of simpification} = \left(\frac{(\text{Sum of simplicity scores for the 12 rules} - 12)*100}{\text{Maximum simplicity score} - 12} \right)$$

ID	Functional/ Fashion	Degree of simplification	Simplicity Rules (4= always applied, 1= never applied)												Euclidean Norm Uncertainty
	1= Function. 4= Fashion	100%= simp. 0%= non-simp.	1	2	3	4	5	6	7	8	9	10	11	12	0= no uncert. 6= max uncert.
1	1	36%	4	1	3	2	1	1	4	3	2	1	2	1	4.80
2	1	36%	4	1	3	2	1	1	4	3	2	1	2	1	3.61
3	2	53%	3	3	3	4	1	1	4	3	2	3	2	2	3.16
4	1	53%	3	3	3	4	1	1	4	3	2	3	2	2	1.41
5	1	53%	3	3	3	4	1	1	4	3	2	3	2	2	1.41
6	2	61%	4	4	3	1	3	3	4	3	3	2	2	2	3.87
7	2	47%	3	3	1	4	1	1	4	2	2	4	2	2	4.24
8	1	56%	4	4	1	1	4	2	4	4	1	4	2	1	5.20
9	1	56%	4	4	1	1	4	2	4	4	1	4	2	1	3.00
10	1	25%	1	3	1	1	1	1	3	4	2	1	1	2	3.32
11	1	25%	1	3	1	1	1	1	3	4	2	1	1	2	2.45
12	1	28%	3	2	1	1	1	1	2	2	1	3	3	2	3.87
13	1	28%	3	2	1	1	1	1	2	2	1	3	3	2	4.24
14	1	17%	1	1	1	1	1	1	1	4	2	1	3	1	4.36
15	1	17%	1	1	1	1	1	1	1	4	2	1	3	1	3.74
16	2	33%	1	1	1	2	3	1	4	2	4	2	2	1	5.29
17	2	33%	1	1	1	2	3	1	4	2	4	2	2	1	4.47
18	1	42%	3	2	1	2	1	1	4	4	3	3	1	2	4.36
19	1	83%	3	4	4	4	4	4	4	4	2	4	3	2	3.16
20	1	33%	2	3	1	2	4	1	3	1	1	2	3	1	5.57
21	2	25%	2	1	1	3	2	1	3	2	1	1	3	1	4.47
22	3	22%	1	2	1	1	1	3	4	2	1	1	2	1	4.80
23	3	33%	1	4	2	3	1	2	4	1	2	1	2	1	4.47
24	2	25%	2	3	1	2	1	1	2	2	2	1	2	2	4.80
25	2	89%	2	4	4	4	4	4	4	4	3	4	3	4	1.73
26	2	21%	2.5	1	1	1	1	1	1	2	4	3	1	1	3.00
27	3	89%	3	4	4	4	3	4	4	4	4	4	3	3	2.24
28	3	69%	3	2	4	4	2	1	4	4	4	3	3	3	3.16
29	1	64%	1	1	4	3	2	4	4	4	4	2	4	2	3.00
30	4	69%	4	1	4	3	2	4	4	2	4	2	3	4	3.16
31	2	75%	4	4	4	4	1	4	4	4	4	1	4	1	4.58
32	3	81%	4	3	4	4	4	1	4	4	4	1	4	4	2.45
33	4	56%	2	4	2.5	4	2	1	4	3	1.5	2	3	3	3.91
34	3	75%	4	3	2	4	4	3	4	4	2	4	4	1	2.45
35	3	82%	4	4	2.5	4	4	3	4	3	3	3	3	4	2.00
36	3	60%	4	4	4	3	3	2	2	2	1.5	3	2	3	4.24
37	1	32%	2	1.5	2	1.5	2	1.5	1.5	2.5	3	1.5	2	2.5	4.03
38	2	42%	4	4	2	4	3	1	3	1	1	1	1	2	4.24
39	3	53%	4	4	3	3	2	2	3	3	2	2	1	2	3.61
40	3	22%	2	4	2	2	1	1	2	1	1	1	1	2	5.10

Table 6. Simplicity Rules Scores for Forty Value Stream Sample (Source: Authors)

The main body of the table contains the actual simplicity scores for each of the 12 rules. A score of 1 indicates that the rule was never applied, whereas a score of 4 relates to total adherence to the rule. The final column in table A.1 contains the Euclidean Norm uncertainty scores for each of the 40 value streams this is calculated from the four sources of uncertainty using the formula:

$$\text{Euclidean Norm} = \sqrt{\left(\begin{matrix}\text{Process -}\\ \text{Score}\end{matrix}1\right)^2 + \left(\begin{matrix}\text{Supply -}\\ \text{Score}\end{matrix}1\right)^2 + \left(\begin{matrix}\text{Demand -}\\ \text{Score}\end{matrix}1\right)^2 + \left(\begin{matrix}\text{Control -}\\ \text{Score}\end{matrix}1\right)^2}$$

which is equation (1) of the paper proper.

11.2. Appendix B: Cross-Check on the Consistency of Results between Different Audit Processes

The preferred method of supply chain audit is the Quick Scan approach (Naim et al. 2002). This has been shown to generate “rich pictures” of the status and performance of a cluster of trans-European value streams. However in order to enhance our understanding of an even wider range of supply chains it is essential to be able to arrive at a reasonable estimate of status from sources restricted by limitations on time or access caused by commercial pressures. Hence to extend the value stream sample audits based on structured interviews are included in our study. Obviously the same Questionnaires are used as core components for both Quick Scan and Structure Interview approaches. Furthermore, there is in addition, substantial published material available for particular value streams as noted within the paper.

To check the consistency between these different approaches a multiple ANOVA analysis has been undertaken. The results are shown in table 7 where the first four rows indicate the differences in the uncertainty scores for the QS and non-QS value streams. None of the means are significantly different from one-another. This strongly suggests that there is no inconsistency between data collection techniques. The process is repeated in the second half of the table but split into those where an in-depth knowledge has been achieved via substantial published material and those simply collected via the interview and shop floor tour. Once more no significant differences between the means are highlighted by the ANOVA so we are satisfied that there is reasonable consistency between our QS and non-QS approaches.

	QS (1-23) mean score	Non-QS (24-40) mean score	F-stat	p-value (>95% = sig.)
Process	**2.27**	**2.15**	0.13	18%
Control	**2.69**	**2.71**	0.00	2%
Supply	**2.65**	**2.12**	2.72	89%
Demand	**3.04**	**3.03**	0.00	4%
	In-depth knowledge (1-27 & 38-40) mean score	Overview knowledge (28-37) mean score	F-stat	p-value (>95% = sig.)
Process	**2.27**	**2.05**	0.37	45%
Control	**2.77**	**2.50**	0.38	54%
Supply	**2.53**	**2.10**	1.33	74%
Demand	**3.03**	**3.05**	0.00	4%

Table 7. ANOVA Analysis Comparing Mean Uncertainty Scores Between QS and Non QS Value Streams (Source: Authors)

To further cross-check for consistency between QS and non QS value stream analysis, a comparison has been undertaken between the "best" supply chain identified via each audit process. It is particularly important to obtain fair comparisons at this end of the performance spectrum since these value streams should be considered as "exemplars" demonstrating current "best practice". If these value streams are truly "exemplars" then they may be used with confidence to transfer such "best practice" both within and between market sectors. Consequently value stream numbers 4, 25, and 35 are further compared in table 8. Note that even when a Structured Interview approach was taken, that additional observations were available via "walking the process". The conclusion reached from table 8 supports our experiential view that all three value streams are good performers and exhibit much "good practice" deserving wider promulgation.

Audit Method	Best QS VS	Best non-QS with much published data available	Best non-QS with "overview" knowledge
VS ID Number	4	25	35
Euclid. Norm. Unc.	1.41	1.73	2
Description of Product	Electrical Automotive Components	Mechanical Precision Product	Insulation Systems
Degree of simplification (High is better)	53%	89%	82%
Complex material flow symptoms (Low is better)	29%	12.5%	8.3%
Comments	This was the standout Quick Scanned value stream. The Japanese transplant OEM engineered and managed the supply chain very effectively.	Very impressive published results demonstrate low bullwhip, high stock-turns, and good service levels.	The Structured Interview was supported by walking the process. It was both simple and well managed, but did not contain as many value adding steps as VS4 or VS25.

Table 8. Cross-Comparison of "Exemplars" as Identified via Three Different Audit Methods (Source: Authors)

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