

Rescheduling and Complexity for Customised Products

Final Report

SULZER



Exactly your chemistry.



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ACKNOWLEDGEMENTS

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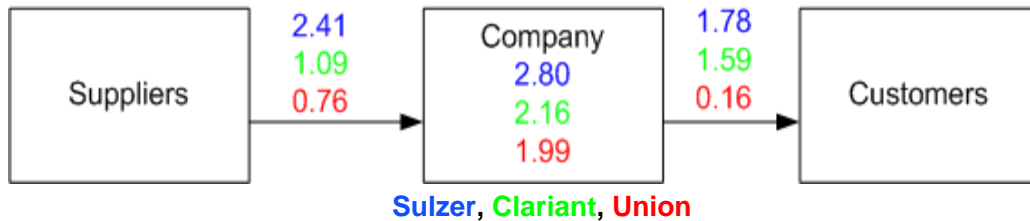
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EXECUTIVE SUMMARY

The “Rescheduling and complexity for customised products” research project was carried out for a year since June 2005 by Leeds University Business School. There were three participating manufacturing companies: Sulzer Pumps (UK) Ltd., Clariant plc UK and Union Industries Ltd. The main objective was to study the relationship between rescheduling and complexity for customised products. The key findings are given in Figure 1 below:



Key: <1 :low; 1-2: medium; >2: high

Figure 1: Supplier-Customer complexity transfers

The following recommendations were given:

Imported Complexity

- ⇒ Sulzer (high): exercise tighter control over suppliers’ performance, develop partnerships with key reliable suppliers and allow the production schedulers to have an important role in the process of purchasing materials or components.
- ⇒ Clariant (medium) and Union (low): maintain the good planning of purchasing materials by the production scheduler and further develop good relationships with reliable suppliers.

Internal Complexity

- ⇒ Sulzer (high): synchronise production: machining-assembly-test in order to avoid bottlenecks and improve forecasting of delivery dates by allowing some slack in the project schedule to cater for unforeseen problems (this recommendation also applies to Clariant).
- ⇒ Clariant (high): keep monitoring the production system; rescheduling seems to be helping towards delivering the products on time.
- ⇒ Union (medium): improve forecast of delivery dates since most of the complexity is coming from earliness.

Exported Complexity

- ⇒ Sulzer (medium): develop partnerships with customers with especial view to the penalties.
- ⇒ Clariant (medium) and Union (low): develop tolerance limits regarding rush orders and fast turnaround products (FTA), respectively.

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1 INTRODUCTION

This report records the findings of the three case studies carried out at Sulzer Pumps (UK) Ltd., Clariant plc UK and Union Industries during the “Rescheduling and Complexity for Customised Products” research project. For the characteristics of each of these companies please see Table 1. The project duration was one year since June 2005 and it involved Yorkshire-based manufacturing organisations which make customised products. This research project builds on a similar study carried out previously which focused on mass produced goods¹.

Table 1: Participating companies

Characteristic	Sulzer	Clariant	Union
Product	Specialized centrifugal pumps for the oil & gas and other industries	Innovative chemicals for the paper industry	Customised industrial doors
Size	Multinational corporation	Multinational corporation	Medium enterprise
Lead-time	9-12 months approx.	1-2 weeks approx.	4 weeks approx.
Case study	August 2005	November 2005	January 2006

The objectives of the research project were: (1) to study the relationship between rescheduling and complexity for customised products and (2) to pursue the answer to research questions including: (a) What are the typical rescheduling strategies used and how do they vary across organisations? and (b) Does rescheduling increase or decrease the level of complexity?

The following benefits to the participating companies were anticipated:

- Diagnosis and benchmarking of their rescheduling practice.
- Evaluation of the amount of complexity they are handling when rescheduling.
- Recommendations as how to manage complexity to their advantage.

There are 4 further chapters. Next, the *Background to Complexity* chapter outlines the theoretical basis of the complexity analysis followed by *Methodology*, which describes how the theory was applied, in practice, to this specific case. Thereupon the *Results* are presented and finally the *Summary of results and recommendations* concludes the report.

¹ Huaccho Huatuco, L. D. (2003). The role of rescheduling in managing manufacturing systems' complexity. DPhil thesis. Department of Engineering Science. University of Oxford. UK. pp. 237.

2 BACKGROUND TO COMPLEXITY

This research adopted the concept of entropy as a measure for complex systems, originally developed by Efstathiou and Frizelle in the “Complexity in the Supply Chain” project. Entropy is defined as the expected amount of information necessary to describe the way a system behaves over time. Complexity, in this sense, is the uncertainty generated by the variety within a system. Hence the two main characteristics of complexity are: uncertainty and variety.

The complexity analysis calculates comparative indices that highlight high complexity areas and examines their causes. The higher the index the greater the complexity displayed by the system. The complexity index is evaluated based on Equation 1, which gives the basic form for describing entropy. Here, the entropy (H) is defined as the uncertainty and variety of the system associated with a set of n events (states) for which p_i is the probability of the i^{th} event occurring. The complexity index units are given in bits per state (bps).

$$H = -\sum_{i=1}^n p_i \log_2(p_i) \quad \text{Equation 1}$$

Several practical considerations need to be taken into account when making the entropy based complexity measurements. In order to measure the complexity of a system, a series of observations are made of all the processes. Counting the variations and weighting each by the likelihood of occurrence gives rise to an index. This index represents the entropy of the system or sub-systems investigated.

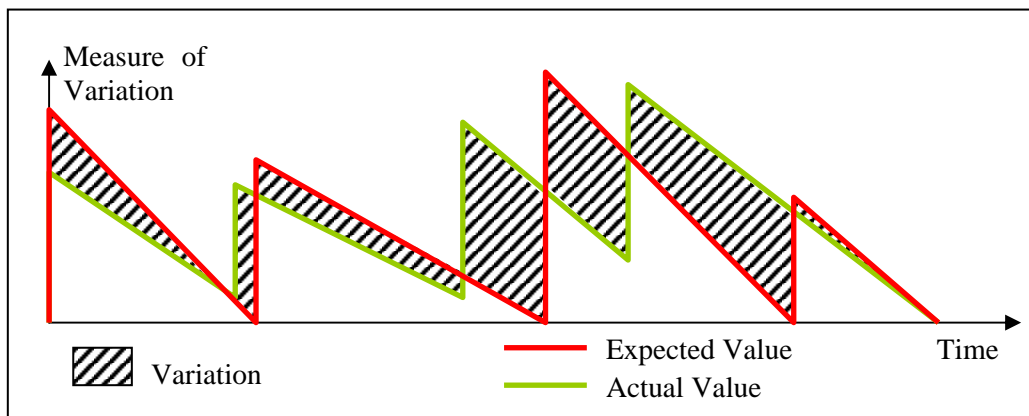


Figure 2: Measuring Variations

The level of unexpected variation within a system indicates the level of ‘out of control’ behaviour. A system that behaves totally predictably can be assumed to be completely ‘in control’. As the unpredictability of the system increases, the level of control decreases. A greater understanding of the behaviour and level of controllability of a system can be achieved through measuring the departures from what was expected to happen. This is shown in Figure 2 where the entropy is linked to the variations observed between actual and expected values. The aim of the exercise is to record these variations and to identify the causes. This method of measuring the variations is applicable to information, material flows or monetary values. The variations can be studied by employing a time, quantity or reason-based analysis, or a combination of these.

Complexity methods can be used in analysing and understanding how manufacturing organisations behave within their supply chain. The basic idea is that the delivery performance of suppliers impact on the delivery performance of the customers, with rescheduling playing a key role for managing complexity.

3 METHODOLOGY

The rescheduling and complexity for customised products project involves three industrial collaborators: Sulzer Pumps (UK) Ltd., Clariant plc UK Ltd and Union Industries. Information flow complexity within these companies can be evaluated by measuring the uncertainty and variety of the information transfers between suppliers and customers, for example. Several areas within each manufacturing organisation are to be investigated to accumulate knowledge of the entire system including an understanding of internal and external relationships, information and material flows, the scheduling process and shop floor functionality. A key feature of these case studies was the opportunity to observe the real manufacturing processes in motion. The phases of the investigation are diagrammatically represented in Figure 3.

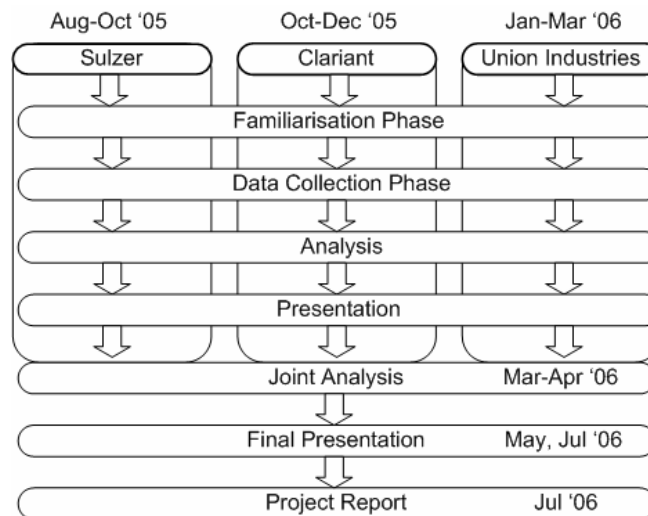


Figure 3: The Case Study Methodology

The case studies were carried out sequentially. At the end of the third case study the joint analysis took place. After this, a final presentation about the project results will be given at each participating manufacturing organisation. Finally, this project report has been prepared. Table 2 summarises the specific phases of Sulzer's rescheduling and complexity study in terms of the tasks and timetable.

Table 2: Timetable and Tasks for the Phases of the individual case studies

Phase		Familiarisation (on site)	Data Collection (on site)	Analysis (off site)	Presentation (on site)
Dates and Venues	Sulzer	24 th - 26 th Aug '05	29 th Aug - 2 nd Sept '05	3 rd - 14 th Oct '05	17 th Oct '05
	Clariant	24 th - 26 th Oct '05	27 th Oct - 11 th Nov '05	28 th Nov - 5 th Dec '05	6 th Dec '05
	Union	16 th - 17 th Jan '06	18 th - 27 th Jan 06	6 th - 13 th Mar '06	14 th Mar '06
Core Tasks		Familiarisation of people, process and plant Identification of factors that must be considered before data collection	Live data (2-3 weeks) Historical data (3-22 months) Interviews to obtain additional supporting data	Computation of complexity indices Analysis of complexity and rescheduling practice	Presentation of individual case study results

The rest of the chapter is divided into sections 3.1 to 3.4 each discussing one of the four phases, *Familiarisation, Data Collection, Data Analysis and Presentation of Results.*

3.1 Familiarisation

Prior to conducting the actual complexity measurements, between two and three days were spent within the company for familiarisation with people, information flows and processes. This involved semi-structured interviews with key personnel to understand the operations and to map out the key material and information flows – an iterative process.

3.1.1 Familiarisation with People, Process and Plant

The introduction of the research project to the participating companies was given by means of a presentation to the case study facilitator(s). Then, interviews followed including relevant people who were selected by the facilitator. To set the context each interview started with a brief of the study in terms of objectives and likely information to be needed. Interviewees were asked to explain their roles within the company and also the weekly routines in terms of information and material flows. Through this process the researcher identified the key people as well as the primary material and information flows.

In terms of plant familiarisation the researcher was given a tour of the plant site, which provided a better understanding of the manufacturing processes at each organisation.

3.1.2 Key Information Flows and Variations

The diagrammatic representation of the information flows studied is given in Figure 4, where the arrows represent the information flowing between the customer and the supplier.

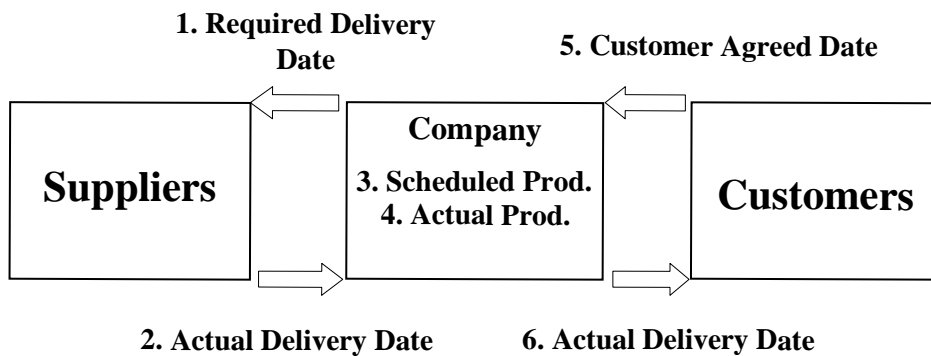


Figure 4: Information flows investigated

The variations identified and investigated in this research are given in Table 3.

Table 3: Variations identified and measured

Area	Variation
Imported Complexity: Procurement	Date received – Purchase Order delivery date
Internal Complexity: Production	Expected Production: Production Schedule Actual Production
Exported Complexity: Delivery	Actual delivery – Customer agreed date

3.1.3 Parameters Considered Prior to Data Collection

To ensure the effectiveness of data collection and the applicability of the complexity measurement method, the following parameters were determined prior to taking readings:

- ⇒ The variables to be measured.
- ⇒ The possible states of interest.
- ⇒ Frequency and duration of observations.
- ⇒ Key information flows and variations.

Fixing the parameters establishes the framework for the complexity analysis so as to ensure consistency throughout the various data collection points. Sections 3.1.3.1 to 3.1.3.3 discuss each of the parameters.

3.1.3.1 The Variables to be Measured

It is critical to effective complexity measurement that the behaviour of variety and uncertainty is understood. In the case of deliveries, this can be observed in the form of goods that do not arrive on time and in full. The variables chosen were:

- ⇒ Number of changes to the schedule.
- ⇒ Delivery dates.

Additionally, the reasons for time and quantity variations were identified in order to detect the instances of importing, exporting and absorbing complexity at the interface.

3.1.3.2 The Possible States of Interest

The results of this study focused on time-based analysis and the variables considered were the delivery dates both from the supplier to the manufacturing organisation and from the manufacturing organisation to the customer. One of the classifications of these time variations consisted of the following states of interest:

- on time or early.
- < 1 week late.
- 1-2 weeks late.
- 2-4 weeks late.
- 4-8 weeks late.
- >8 weeks late.

3.1.3.3 Frequency and Duration of Observations

The frequency of the information and material transfer was used as a guideline for the frequency of measurements. In the case of event based activities (such as deliveries) the analyses utilise all events recorded. In terms of live data, two weeks were used for setting the framework for the study. In terms of historical data, it was determined that at least 3 months of weekly data would provide sufficient data points for the analysis.

3.2 Data Collection

shows the data collection details in terms of source and period of time. It shows that between 3 and 22 months data were collected.

Table 4: Data collection details

Company	Area of assessment	Source	Period
Sulzer	Imported Complexity	Orders by supplier	Nov'04 – Aug'05
	Internal Complexity	Order book	Jun – Aug'05
	Exported Complexity	KPI1.0 2004	Mar '04 – Aug '05
Clariant	Imported Complexity	SAP Vendor OTIF	Aug – Oct '05
	Internal Complexity	Production Schedule	Jan – Oct '05
	Exported Complexity	SAP Paper OTIF	Aug – Oct '05
Union	Imported Complexity	Delivery note-MNR	Jun – Dec '05
	Internal Complexity	Production scheduler's diary- installation board collection date	Oct '05 – Jan '06
	Exported Complexity	Installation completion report- Confirmation of order: anticipated date of completion	Oct '05 – Jan '06

A sample of the data collection form used in Sulzer is given in Table 5, where positive values represent lateness, zero values represent on time and negative values represent earliness. This form provides a standard framework for the data collection process.

Table 5: Sample Data Collection Sheet

Supplier	Supplier PO No.	PO Delivery date	Date received	Date received - PO Delivery date
ABB UK	115668	05-Aug-05	05-Aug-05	0
ABB UK	115668	05-Aug-05	08-Aug-05	3
ABB UK	112835	09-Aug-05	11-Aug-05	2
AMARILLO	112628	02-May-05	10-Aug-05	100
BARIC	114167	20-Jul-05	02-Sep-05	44
BIBBY	112626	01-Aug-05	01-Aug-05	0
BURGMAN	114218	04-Aug-05	20-Jul-05	-15
BURGMAN	114360	25-Jul-05	20-Jul-05	-5
BURGMAN	114977	15-Jul-05	20-Jul-05	5
BURGMAN	113482	29-Jul-05	28-Jul-05	-1

Data collection consists of sampling information and material flows over time. In this study, information and material variations were investigated and recorded in terms of quantities and intervals over the data collection period. Thus sufficient data were gathered to ensure each state had been observed frequently enough to give a reasonable estimate of its probability. Upon completion, the collected data was analysed as discussed in section 3.3.

3.3 Data Analysis

The data analysis involved the calculation of the complexity indices for the variations mentioned in section 3.1.2 and the interpretation of the results.

The computation of the complexity indices comprises five steps:

1. Group the data into the pre-defined states (see Section 3.1.3.2).
2. Reconstruct the actual information flows.
3. Reconstruct the scheduled information flows.
4. Define the states and estimate the associated probabilities.
5. Use the probabilities to calculate the entropy, using Equation 1.

Subsequent analysis of the indices involves three more steps:

1. Compare relevant indices at different stages of the process being analysed to identify the high complexity areas. The rule of thumb used here was: < 1bps: low; 1-2: medium; >2: high.
2. Identify specific causes within each area and observe their frequency of recurrence throughout the flows, grouping them if necessary.
3. Relate these findings to the actual systems in order to identify areas for improvement.

The key findings of the individual case studies were presented to the manufacturing organisations as described in section 3.4.

3.4 Presentation of Results

The results were presented to each manufacturing organisation. Prior to this meeting, hard-copies of the presentation were distributed to the attendees to allow them to assess the confidentiality and sensitivity of the information. The attendees included key people within the organisation, people who had participated in the case study and people to whom the results would be most relevant. Fruitful discussion and feedback highlighted areas for further investigation.

Using the methodology described in this chapter, this research project produced the results discussed in chapter 4.

4 RESULTS

The results of the analysis have been classified, according to the type of complexity transfer due to rescheduling, into three main categories: Imported Complexity, Internal Complexity and Exported Complexity. Each of these categories is discussed in turn next.

4.1 Imported Complexity

The complexity indices associated with the procurement or suppliers' performance are plotted in Figure 5. In this figure, the horizontal axes show the states of earliness or lateness associated with suppliers' deliveries to the companies, whereas the vertical axes show the complexity index associated with those states. It can be seen that the average complexity associated with deliveries from suppliers to Sulzer is high (>2 bps), it is medium from suppliers to Clariant (1-2 bps) and it is low from suppliers to Union (<1 bps). All three results are within the limits of manageable complexity².

The complexity associated with the state of being 'on time or early' is value-adding complexity, which is the complexity that is needed to satisfy the end customer. Whereas the other states of lateness are regarded as non-value adding complexity. Suppliers to Sulzer are most complex in the 'on time or early' and the '>8 weeks late' states. This could be explained due to the fact that deliveries of common components are not a problem, whereas deliveries of critical component such as motors are more prone to take longer than estimated. Suppliers to Clariant and to Union show similar pattern of behaviour, with the highest contribution to complexity coming from the '<1 week late' and decreasing for the rest of the lateness states. This is because their suppliers are reasonably reliable and if they missed the requested delivery date they will deliver earlier rather than later.

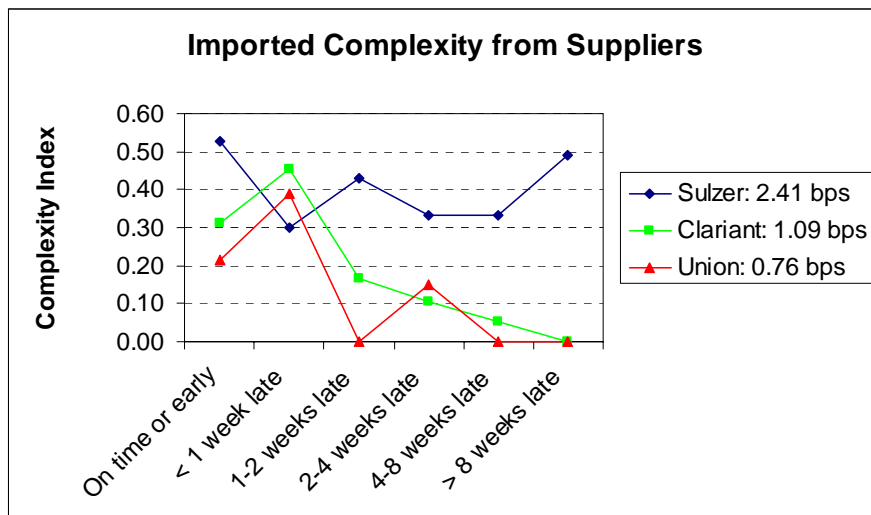


Figure 5: Imported Complexity from Suppliers

4.2 Internal Complexity

Although all three companies make customised products, they have particular characteristics that make them differ from one another, such as their production lead time. Thus the results of their internal performance are discussed separately, in the next few sections.

² Miller G A (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*. Vol. 63, pp. 81-97.

4.2.1 Sulzer

Figure 6 shows the percentage of occurrences for each of the areas which can be rescheduled in the order book. In this chart, it can be observed that the schedule adherence ('OK' state) accounts for 15 % of the total. The following processes contribute almost equally: factored, project equipment and materials (between 15%-17%). Most importantly, it can be observed that rescheduling of the order book due to the assembly area accounts for 22% of the total (Bld, Rtr, Hyd, Test and P&W). This is not surprising since the nature of the business is to make engineer-to-order pumps, which implies that there is a high level of uncertainty when making one-off products and also accounts for the variety that this sort of production implies.

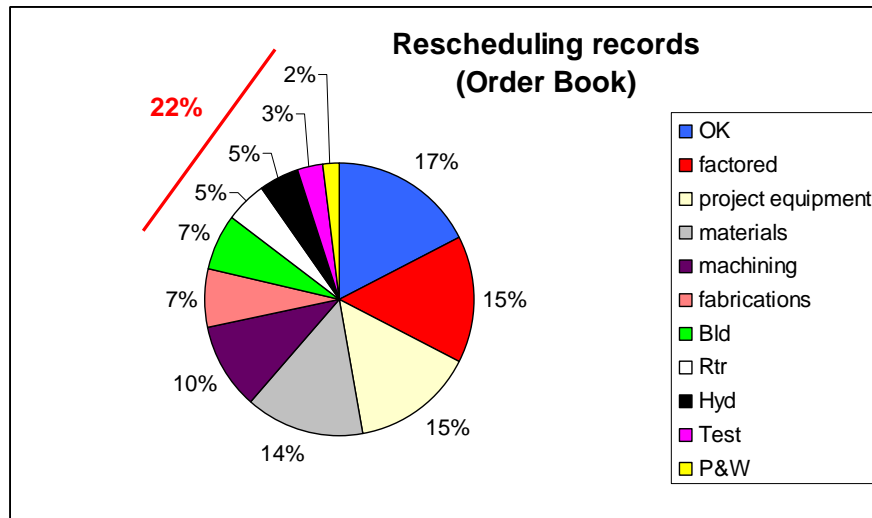


Figure 6: Order Book rescheduling by production process at Sulzer

The amount of complexity that is handled at Sulzer accounts for 2.80 bps, which is classified as high in this research. The value-adding complexity (marked in green) accounts for 15% of the total and the state that contributes the most to the non-value adding complexity (marked in red) is 'assembly'. This area consists of a series of steps, some of which are outsourced, so the performance is highly influenced by the performance of the outsourcers.

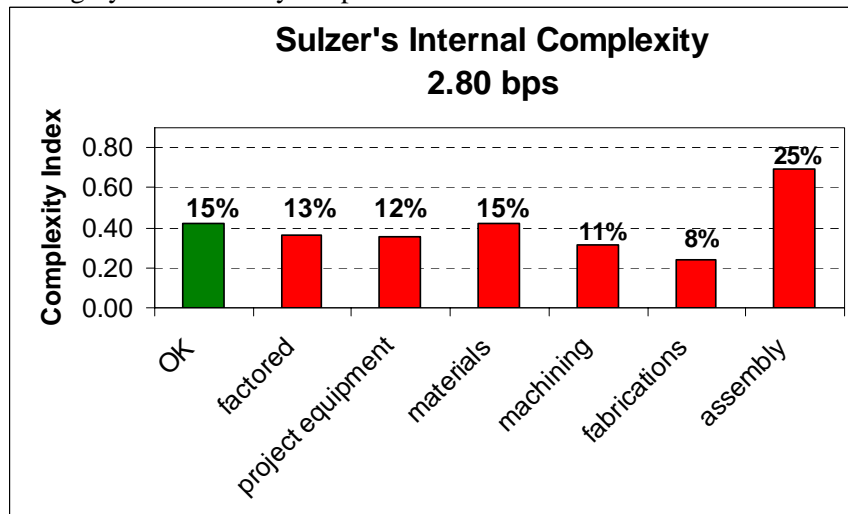


Figure 7: Internal complexity at Sulzer

4.2.2 Clariant

Figure 8 shows that production on time or according to the schedule accounts for 46% of the total. Also it can be seen that the percentages increase with lateness, this means that once Clariant has missed the production scheduled date, the innovative product is expected to be made later than earlier. This can be due to technical issues, such as the different behaviour of the chemicals/solutions in the shop floor compared with the experiments carried out previously in the laboratory.

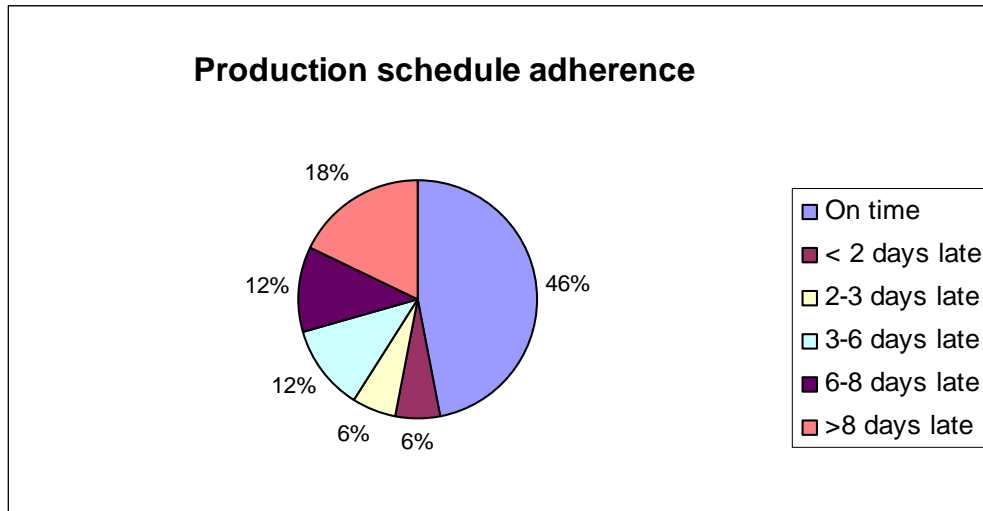


Figure 8: Actual vs. Scheduled production performance at Clariant

In Figure 9 we observe that Clariant manages a high amount of complexity and that the value-adding complexity accounts for 24% of the total. Then the non-value adding complexity contributions increase with lateness, with the biggest one coming from the '>8 days late' state. This can be attributed to technical errors during production and knock-on effects in the production schedule.

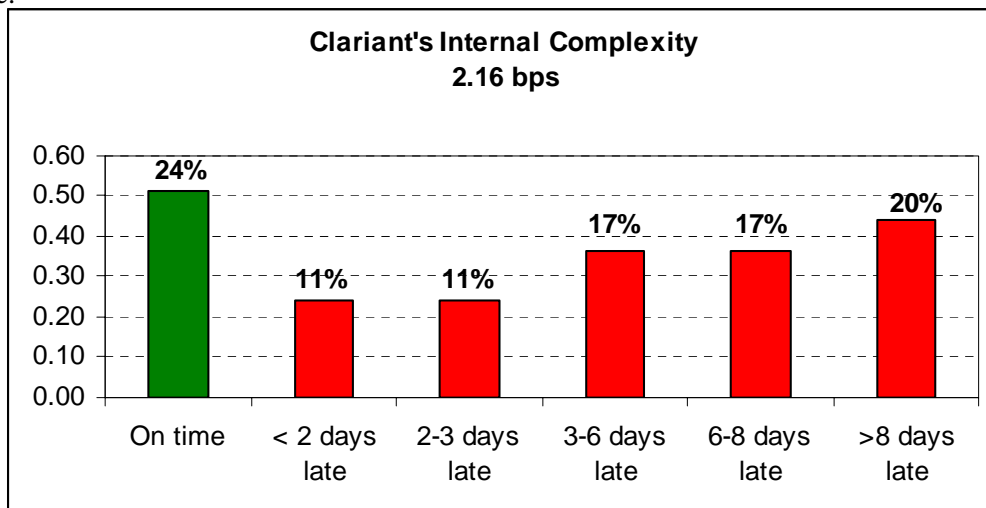


Figure 9: Internal complexity at Clariant

4.2.3 Union

According to Figure 10 Union's production is always on time or early. This is mainly due to the fact that the standard delivery time has been set to four weeks, which gives plenty of time to

account for any unforeseen circumstances that could delay production. It was also noted that Union places a strong emphasis on fixed delivery dates with the customer, so once these are agreed they are quite firm, with the customer potentially bearing the costs for any rescheduling caused by them.

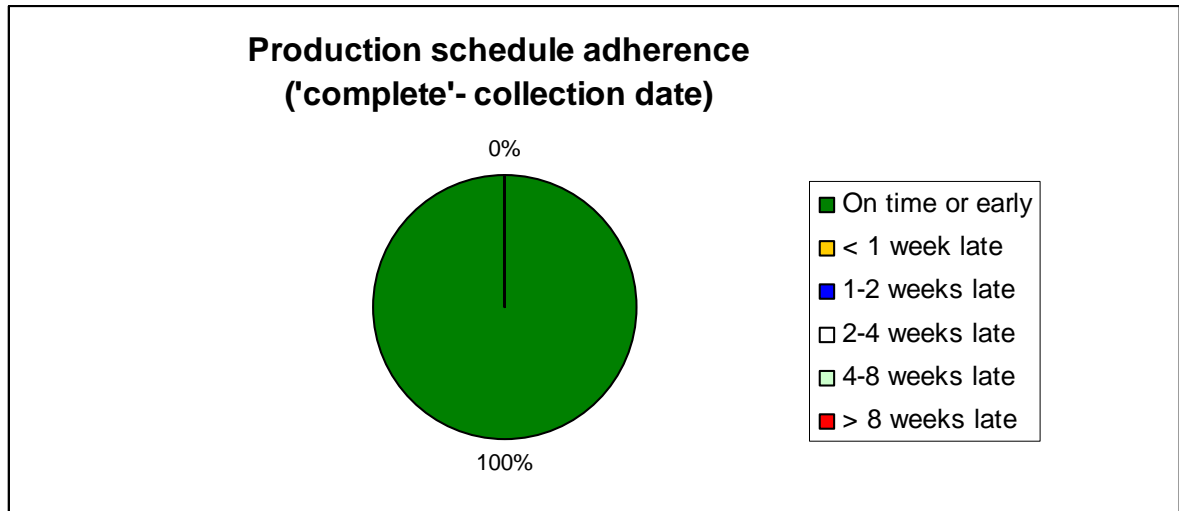


Figure 10: Actual vs. Scheduled production performance at Union

Further analysis was performed regarding the earliness of production, as seen in Figure 11. Up to 50% of the doors are finished up to a week early, another observation is that the percentage of finished doors decrease with increased earliness.

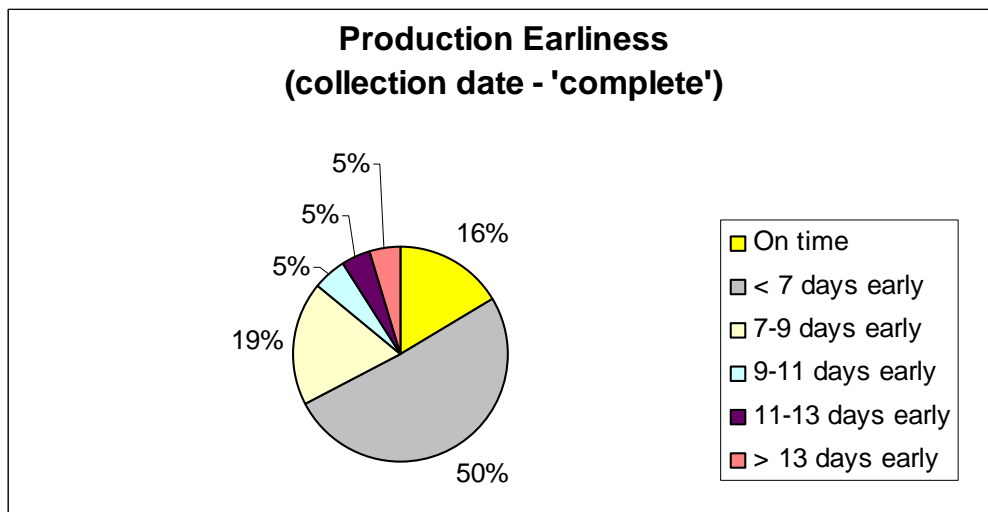


Figure 11: Production Earliness at Union

The amount of complexity handled at Union is in the medium range (1-2 bps), as seen in Figure 12. The value-adding complexity or 'on-time' delivery accounts for 21% of the total. It could be argued that finishing products early is value-adding at the moment since once the doors are completed the resulting spare capacity could be used for accommodating other orders. However, finishing products too early, such as the last three states (>9 days early) may be tying up capital that could be otherwise used, doors could become damaged or lost, and physical space may become an issue if the business were to expand. That's why those early states have been classified as non-value adding complexity.

It is worth mentioning that Union's performance is remarkable, especially considering that 74% of the requested deliveries are classified as fast turnaround (FTA).

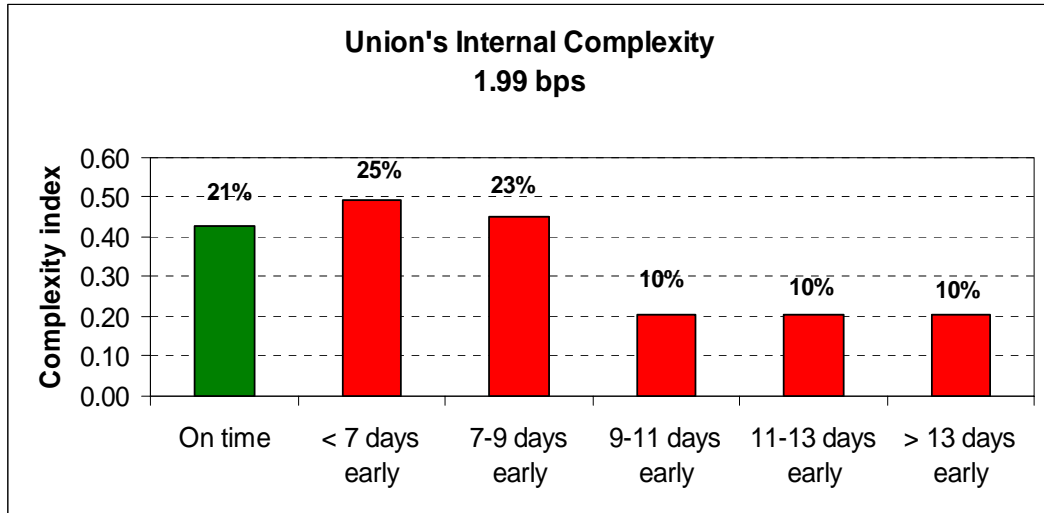


Figure 12: Internal complexity at Union

4.3 Exported Complexity

Exported Complexity refers to the complexity transfer that takes place from the companies (Sulzer, Clariant and Union) to their corresponding customers. In this context, Figure 13 shows that Sulzer and Clariant transfer a medium amount of complexity (1-2 bps) whereas Union transfers a very low amount (<1 bps). Clariant and Union show similar pattern in terms of the contributions from the states, with the highest being '<1 week late' and then decreasing complexity as the lateness increase, this means that once these companies have missed the promised delivery date they will try to deliver earlier than later. Sulzer's deliveries show a different pattern with a distinctive increase of the contributions as lateness increases. The reason for this is that having missed the deadline, efforts are made to deliver as soon as possible to avoid surpassing the penalties ceiling, but once this is surpassed, the efforts are then directed towards other projects that may be in danger of becoming late also.

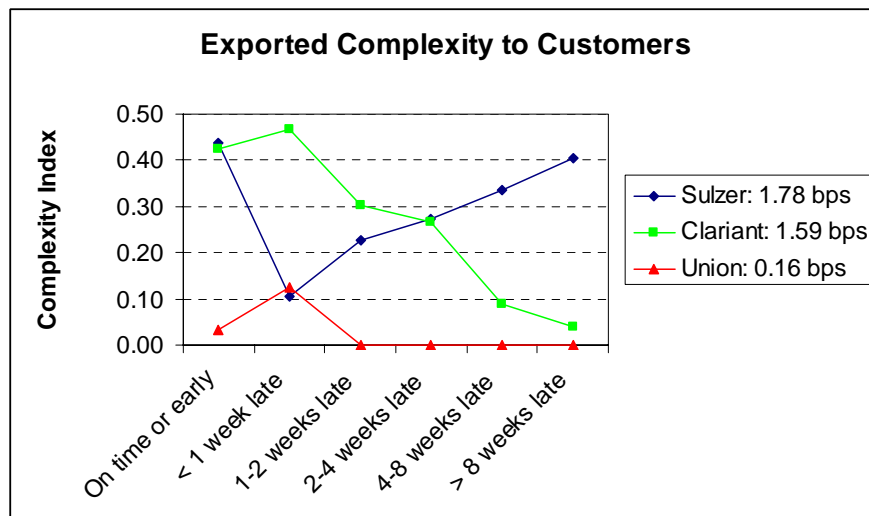


Figure 13: Exported Complexity to Customers

5 SUMMARY OF RESULTS AND RECOMMENDATIONS

5.1 Summary of results

Figure 14 summarises the results presented previously. The results seem to indicate that the higher the complexity imported from the suppliers, the higher the complexity handled internally. So, not surprisingly, good suppliers enable good internal performance. It is also observed that all three companies export less complexity to their customers than that they handle internally. It is suggested here that customers are made aware of this fact.

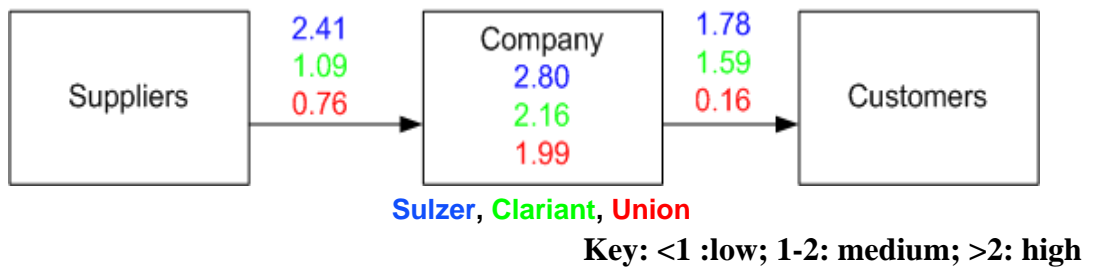


Figure 14: Supplier-Customer complexity transfers

The following good practice elements were observed at the participating companies:

- People involvement and commitment
- Frequent information exchange
- Expertise coming from experience
- Quality awareness throughout the process

Some of the issues identified at each manufacturing organisation are given in Table 6. The corresponding recommendations to tackle them are given in the next section.

Table 6: Issues identified

Sulzer	<ul style="list-style-type: none"> • Difficult to see the big picture • Not much history recording • Pressure to hit deadlines
Clariant	<ul style="list-style-type: none"> • Frequent rescheduling: rush orders • No charge to customers for rush orders • Flexibility: strength or weakness? • Not enough operators
Union	<ul style="list-style-type: none"> • No extra charge to customers for FTA deliveries • Earliness could become an issue with limited storage space

5.2 Recommendations

The following recommendations are given:

Imported Complexity

- ⇒ Sulzer (high): exercise tighter control over suppliers' performance, develop partnerships with key reliable suppliers and allow the production schedulers to have an important role in the process of purchasing materials or components.
- ⇒ Clariant (medium) and Union (low): maintain the good planning of purchasing materials by the production scheduler and further develop good relationships with reliable suppliers.

Internal Complexity

- ⇒ Sulzer (high): synchronise production: machining-assembly-test in order to avoid bottlenecks and improve forecasting of delivery dates by allowing some slack in the project schedule to cater for unforeseen problems (this recommendation also applies to Clariant).
- ⇒ Clariant (high): keep monitoring the production system; rescheduling seems to be helping towards delivering the products on time.
- ⇒ Union (medium): improve forecast of delivery dates since most of the complexity is coming from earliness.

Exported Complexity

- ⇒ Sulzer (medium): develop partnerships with customers with especial view to the penalties.
- ⇒ Clariant (medium) and Union (low): develop tolerance limits regarding rush orders and fast turnaround products (FTA), respectively.