



HAL
open science

Investigating the implications of extending synchronised sequencing in automotive supply chains: the case of suppliers in the European automotive sector

a E Coronado Mondragon, A. C. Lyons

► To cite this version:

a E Coronado Mondragon, A. C. Lyons. Investigating the implications of extending synchronised sequencing in automotive supply chains: the case of suppliers in the European automotive sector. International Journal of Production Research, 2008, 46 (11), pp.2867-2888. 10.1080/00207540601055466 . hal-00512955

HAL Id: hal-00512955

<https://hal.science/hal-00512955>

Submitted on 1 Sep 2010

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Investigating the implications of extending synchronised sequencing in automotive supply chains: the case of suppliers in the European automotive sector

| | |
|-------------------------------|--|
| Journal: | <i>International Journal of Production Research</i> |
| Manuscript ID: | TPRS-2006-IJPR-0205.R1 |
| Manuscript Type: | Original Manuscript |
| Date Submitted by the Author: | 01-Jun-2006 |
| Complete List of Authors: | Mondragon, A E Coronado; University of Liverpool,, Management School Lyons, A.; University of Livepool, Management School |
| Keywords: | ASSEMBLY, SUPPLY CHAIN MANAGEMENT, SEQUENCING |
| Keywords (user): | automotive |
| | |



1
2
3
4
5 **Investigating the implications of extending synchronised sequencing**
6 **in automotive supply chains: the case of suppliers**
7 **in the European automotive sector**
8
9

10
11
12
13
14 **Adrian E. Coronado M* and Andrew C. Lyons**

15
16 acoronad@liv.ac.uk*, a.c.lyons@liv.ac.uk,

17
18
19
20
21
22 **The University of Liverpool**
23 **Management School, Chatham Building**
24 **Chatham Street, Liverpool L69 7ZH**
25 **United Kingdom**
26

27
28 Tel: +44 (0) 151 795 3631
29 Fax: +44 (0)151 795 3666
30

31
32
33 *** CORRESPONDING AUTHOR**
34

35 **Word count: 6012**
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 **Investigating the implications of extending synchronised sequencing**
4 **in automotive supply chains: the case of suppliers**
5
6 **in the European automotive sector**
7
8
9

10
11
12 **Abstract**
13

14
15 In recent years automakers have paid considerable attention to synchronising
16 supply chain material flow. Potential benefits associated with synchronisation
17 include stability in both demand and supply patterns, inventory reduction,
18 elimination of demand amplification and better long-term planning. In major
19 European production sites, the geographic proximity of suppliers to the
20 vehicle assembly plants provided the motivation for examining the feasibility
21 of extending the synchronised sequenced delivery of components upstream in
22 the vehicle supply chain. The value stream used in the research concerned
23 the seating systems at two major European production sites. The results of
24 extending synchronised sequencing from the first to the second-tier showed a
25 reduction in demand amplification to negligible levels, achieved overall
26 synchronisation levels of 99% to 100% and considerably reduced overall
27 pipeline inventory between the vehicle assembly plant and the second-tier
28 component supplier. The findings suggest how that the geographic proximity
29 of suppliers can be used to implement multi-tier synchronised sequencing of
30 components to improve supply chain performance. Based on the results of
31 the study a series of recommendations are provided concerning the supply
32 chain implications of multi-tier synchronised sequencing.
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56

57
58 **Key words:** supply chain management, sequencing, assembly, automotive
59
60

1. Introduction

In recent years organisations in different sectors have acknowledged the importance of synchronising the flow of material in the supply chain. Indeed, synchronisation now occupies an important place in the management of the supply chain. For example, in the automotive industry the use of synchronised sequenced production, an important aspect of Just-In-Time (JIT) deliveries, can be found at the production sites of some of the largest vehicle manufacturers in the world. Synchronisation relies heavily on reliable delivery of components. According to Larsson (2002), synchronised sequential production sets extremely tight boundaries regarding delivery reliability since the entire production process is dependent upon the timely delivery of components. The researcher emphasised that the need for complete reliability comes from the fact that sequential JIT production requires suppliers to deliver unique components in the same sequence and synchronised with the assembly process of the customer.

The idea of having synchronised supply chains is influenced by the concepts such as JIT. Christensen et al. (2005) indicated that the essence of JIT is the elimination of all forms of waste in the upstream supply chain and only through the alignment of systems and processes can a network function in a synchronous fashion. Similarly, synchronisation can be viewed within a lean thinking context. Womack and Jones (1996) defined the vision of the future organisational model of manufacturing, the lean enterprise, as a group of individuals, functions, and legally separate but operationally synchronised companies.

1
2
3
4
5
6 Also, efforts to achieve synchronisation can be seen in sectors outside
7 automotive such as in Fast Moving Consumer Goods (FMCG) with existing
8 supply chain scheduling programmes such as Collaborative, Planning,
9 Forecasting and Replenishment (CPFR). Andraski (1994) reported that
10 CPFR engages the manufacturer and the retailer into exchanging
11 marketplace information in order to come up with a customer-specific plan
12 that can substantially reduce inventory.

13
14
15
16
17
18
19
20
21
22
23
24 Because of its economic impact, technology innovations and the complexity of
25 its products and supply chain, the next section of this paper discusses some
26 representative works involving the synchronisation of demand and supply in
27 the automotive industry. Then, a set of research questions are formulated
28 regarding the implications of expanding synchronisation upstream (to a
29 second-tier) and how it would be possible to measure the effects on the
30 performance of the supply chain. Data from two supply chains in the
31 automotive industry are used to illustrate the benefits that are possible to
32 achieve if synchronisation is extended to a second-tier supplier. Comments
33 and future work guidelines are provided based on the findings of the study.

50 2. Synchronised sequencing

51
52
53 The synchronisation of components represents true JIT. One piece flow as it
54 is found in sequencing of components is critical to supply chain
55 synchronisation. Doran (2002) has defined the concept of JIT within
56 synchronous manufacturing as an integrated supply chain approach to the
57
58
59
60

1
2
3 provision of goods that are defect free and which match the exact
4 requirements of the customer reflecting vehicle, rather than model, variations
5 and recognising the time critical nature of a synchronous manufacturing
6 environment.
7
8
9
10
11

12
13
14
15 Synchronisation is part of the dynamics of the supply chain. Researchers
16 have found that synchronisation improves the overall supply chain
17 performance (Coleman et al. 2004). Synchronisation facilitates inventory
18 reduction where safety stocks were necessary to cover demand and supply
19 uncertainty; also it improves the quality of forecasting and long-term planning
20 in all supply chain parties (Holweg and Bicheno 2002). Synchronisation can
21 certainly eliminate the need for forecasting operations that take place at each
22 tier. Indeed, Lee et al. (1997) demonstrated that demand distortion, such as
23 double forecasting, can be a driver for the bullwhip effect.
24
25
26
27
28
29
30
31
32
33
34
35
36

37
38
39 The results of the simulation work undertaken by Holweg and Bicheno (2002)
40 involving the case study of a UK automotive steel supply chain revealed that if
41 the demand pattern for a high-volume part with fairly stable demand was co-
42 ordinated over the supply chain, the total supply stock could be reduced by
43 more than 50%. The researchers were able to demonstrate how increased
44 batching at one tier in the system incurs inefficiency and waste in other tiers of
45 the system. In their experiments they were able to bring down the total
46 inventory in the system by up to 33% by halving batch sizes. Holweg and
47 Bicheno (2002) argued that synchronised demand and supply patterns
48 throughout the chain could be achieved by transmitting the overall demand
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 information directly along the whole supply chain. One characteristic of
4 Holweg and Bicheno (2002) is that the supply chain studied is batch-based
5 with no support of one-piece flow, as it would be the case of a true JIT supply
6 chain.
7
8
9
10

11
12
13
14
15 Another study in the automotive industry that has involved synchronisation
16 was conducted by Holweg et al. (2005). In their work the researchers
17 presented a model of the information flows within an automotive supply chain
18 from customer order, through the vehicle manufacturer, to a first-tier
19 component supplier with the objective of providing guidance for managers to
20 judge the implications of various strategies, such as comparing build-to-order
21 to current ordering policies. During a series of simulation runs, Holweg et al.
22 (2005) found that at the supplier, the greater the stability in the vehicle
23 manufacturer schedule only results in slightly reduced inventory levels and
24 production adaptation cost, which again indicates well-synchronised
25 component production yet results in problems in tying the raw material supply
26 to the demand signal. According to the researchers this effect marks a
27 common problem in the auto industry, whereby first-tier suppliers are
28 'squeezed' between vehicle manufacturer customers demanding just-in-time
29 deliveries, and unresponsive raw material producers that often operate large-
30 scale batch production systems (Holweg, 2003). Holweg et al. (2005)
31 indicated that the high inventory levels at the supplier are a result of non-
32 synchronised raw material ordering, which cannot cope with the frequent
33 rescheduling needed to adapt component production to the vehicle
34 manufacturer demand signal. Holweg et al.'s study did not include
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3
4 synchronisation between the first-tier and the second-tier, limited one-piece
5 flow and no mention of the types of components delivered.
6
7

8
9
10 The discussion on synchronisation has confirmed that in the auto industry
11 synchronised, sequenced deliveries between first-tiers and Original
12 Equipment Manufacturers (OEMs) can be found in several production sites.
13 However, synchronised sequenced deliveries of components that also include
14 a second-tier supplier are very rare. Figure 1 depicts a traditional
15 synchronised sequenced arrangement involving a first tier to OEM interface.
16
17
18
19
20
21
22
23
24
25
26

27 **'[Insert figure 1 about here]'**
28

29
30
31
32 In figure 1, synchronised sequencing of modules and components is limited to
33 the delivery of finished goods from the first-tier to the point of fit at the OEM.
34 In this scenario, the OEM transmits the requirements and the final call-off to
35 the first-tier supplier. The examination of previous research works on
36 synchronised supply provided the motivation for investigating the possibility of
37 extending synchronisation beyond the OEM – first-tier interface. Of particular
38 interest is the addition of a second-tier supplier to the existing sequenced
39 synchronised material flow domain existing between OEMs and first-tier
40 suppliers. In such scenario, the measurement of the performance of the
41 multi-tier sequencing arrangement and the analysis of the implications of one-
42 piece flow against batched deliveries are of particular interest. Specific
43 research questions include:
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

- 1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
- a) What is the impact of extending synchronised sequencing of modules upstream?
 - b) What are the implications/disadvantages of extending synchronised sequencing of modules upstream?
 - c) How can the effect of extending supply chain sequencing be measured?

3. Expanding synchronisation from one-tier to a two-tier arrangement

Figure 2 depicts the synchronisation arrangement existing between the first tier and the OEM. In this scenario, the OEM communicates production requirements to the first-tier supplier via Electronic Data Interchange (EDI). It also sends the first-tier supplier a final call-off signal so all modules can be assembled and delivered in one-piece flow. Automakers transmit the sequenced-in-line (SIL) supply a few hours before planned assembly, depending on the assembly station and the respective component (Meyr 2004). The second-tier supplier does not receive a final call-off signal from the OEM and is not in synchronisation with the OEM and the first-tier supplier. One principal characteristic of this scheme is the existing offset-time between the first and second tiers.

‘[Insert figure 2 about here]’

The launch signal depicted in figure 2 is directly linked to the way vehicles are assembled. The assembly of synchronised components is typically triggered by launching a vehicle from the painted vehicles buffer into the final assembly

1
2
3 sequence. In many modern vehicle manufacturing facilities painted bodies
4 kept in the buffer have an RFID (radio frequency identification) tag attached to
5 them. Depending on the manufacturer, in high-volume production the defined
6 time window can cover a period of between three and six hours. Some low
7 volume manufacturers have reported twelve hours. The use of fibre optic
8 links and RFID allows the OEM and suppliers to know the exact location of
9 the vehicle during the assembly process.

10
11
12
13
14
15
16
17
18
19
20
21
22 Extending synchronisation to second-tier suppliers is enhanced with the
23 consolidation of clusters of suppliers or “supplier parks” in the automotive
24 industry. In supplier parks, the geographic proximity between the OEM and
25 its suppliers is an important condition for implementing synchronised
26 sequenced deliveries of modules and components. Automotive News Europe
27 (2005) has reported the existence of 25 supplier parks in Europe. In most
28 cases, suppliers located within the confines of the supplier park serve only
29 one OEM. The geographic proximity of suppliers to the OEM can be seen as
30 a structural mechanism for integrating supply chains. For example, Tetu
31 (1998) postulated that companies have to see themselves as part of the
32 whole chain and accept the need to achieve a global optimum. Larsson’s
33 (2002) analysis of supplier parks emphasised that components (mainly high-
34 volume and colour model specific) such as seats, interior trims and bumpers
35 are supplied in sequence. In the view of the researcher one principal benefit
36 of synchronisation is that suppliers’ engagement in sequential deliveries
37 maximise reliability by the fact that the transport time from finished component
38 to assembly is no more than a few minutes.

1
2
3
4
5
6 The quality and availability of information is a key contributor to the
7
8 achievement of synchronisation. In their research work, Lyons et al. (2004a,
9
10 2004b) demonstrated how information systems can be used to improve
11
12 supply chain performance. Their results illustrated how OEM-generated
13
14 information can be used to significantly improve supply chain synchronisation
15
16 in the lower tiers.
17
18
19
20
21

22 Based on the supplier park arrangement, figure 3 depicts the proposed
23 changes to incorporate synchronised sequencing into the second-tier supplier.
24 For this to be feasible requires extending the production requirements signal
25 and the launch signal to the second-tier suppliers. Another important aspect
26 concerned the geographic proximity between the OEM, the first and second-
27 tier suppliers.
28
29
30
31
32
33
34
35
36
37
38
39

40 **'[Insert figure 3 about here]'**
41
42

43 Figure 4 depicts how synchronisation levels in the supply chain can be
44 increased by including second-tier synchronised sequencing of components.
45
46
47
48
49

50 **'[Insert figure 4 about here]'**
51
52
53
54

55 The possibility of extending sequenced deliveries upstream in the chain
56 provides a number of advantages. One of them is pushing the information
57 and materials decoupling points further upstream in the chain. Mason-Jones
58
59
60

1
2
3 and Towill (1999) argue that the further the information decoupling point is
4 moved upstream the better the improvement in the dynamic behaviour of the
5 supply chain. On the other hand, not all components are necessarily suitable
6 candidates for synchronised sequenced deliveries.
7
8
9
10
11
12

13 14 15 **4. Background to the case studies**

16
17 The two case studies presented in this research represent supply chains of
18 automotive seating systems where the seat supplier is situated on a supplier
19 park adjacent to a vehicle assembly plant. Worldwide, most vehicle
20 manufacturers have adopted sequenced deliveries for seating systems.
21 Other modules (for example, bumpers, instrument panels, powertrain
22 components) could have been chosen for this study, however in each case
23 study some seat suppliers beyond the first-tier were located in close proximity
24 to the OEM. As a module, a seating system is complex to engineer,
25 expensive and has several tiers of its own suppliers providing sub-
26 parts/components. Moreover, seating systems represent a critical part of a
27 vehicle. The background of the case studies investigated is presented in the
28 following paragraphs.
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49

50 **4.1 Supply chains' structures analysed**

51 In case A, a team of researchers worked closely with the vehicle manufacturer
52 and its suppliers for a period of six months. The headrest of the front seats
53 used in a high-volume, compact vehicle was the component/value stream
54 chosen. The production volume of the vehicle with the seats chosen was over
55 100 000 units per year and the monthly demand for the chosen type of seat
56
57
58
59
60

1
2
3 during the previous year was 8643 sets (two front and one rear seat per set).
4
5 There were five colours (cloth) offered for the type of seat in question.
6
7
8
9

10 Flexibility of operations is well developed in this supply chain. At the first-tier
11
12 level, the assembly line is shared with another type of seat that goes into
13
14 another type of vehicle. Despite this, the first tier has managed to have
15
16 uniform lead-times for all seat types and options. The justification for building
17
18 two different types of seats for different vehicles in the same seat-assembly
19
20 line is due to the OEM building two vehicle models also in the same vehicle
21
22 assembly line.
23
24
25
26
27
28

29 In case A, the chosen third-tier supplier is located eight hours away from the
30
31 supplier park. It provides foam for the front headrests. The assembly of the
32
33 foam with the previously cut and sewn headrest pockets is undertaken by the
34
35 second-tier supplier. Deliveries from the second tier are undertaken five times
36
37 a day in batches of 56 units. The second-tier supplier has a production line
38
39 exclusively dedicated to the manufacture of the headrests. The first-tier
40
41 supplier is responsible for the assembly process of the vehicle seats.
42
43 Finished vehicle seats are placed on a conveyor belt that takes them in
44
45 sequence directly to the point of fit in the assembly line. The first tier's entire
46
47 capacity is dedicated only to the OEM it serves.
48
49
50
51
52
53

54
55 A supply chain arrangement consisting of one OEM, one first and one
56
57 second-tier supplier was selected to capture the implications of multi-tier
58
59 synchronised sequencing reflected as bullwhip effect elimination and
60

1
2
3 synchronisation improvements. The components built at the second tier are
4 headrests used at the first-tier level. The first tier is the unique supplier of
5 seating systems to the OEM and the OEM builds vehicles at a rate of one
6 thousand per day.
7
8
9
10
11

12
13
14
15 In case A, the geographic proximity of the three parties involved is
16 characteristic of supplier parks. An overhead tunnel links the first-tier supplier
17 with the OEM's assembly line. Inside the overhead tunnel, a conveyor system
18 is used to transport the finished components to the point of fit at the OEM site.
19
20 The first-tier supplier owns a warehouse located five kilometres away from the
21 production unit. The second-tier supplier facility is located 20 kilometres away
22 from the first-tier warehouse. Figure 5 illustrates the supply chain
23 arrangement for case A.
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40

41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

'[Insert figure 5 about here]'

61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100

In case B, a team worked closely with the manufacturer of the seating systems during a period that covered five months. In this case, the OEM and a significant number of its suppliers are located in close geographic proximity with each other. The production volume of the vehicle with the seats chosen is over 100 000 units per year with three trim options offered for that particular type of seat. As in case A, the seating systems represented the value stream investigated and the first tier is the unique supplier of seating systems to the OEM. The front seat's headrest was the second-tier component chosen in this study (two headrests per vehicle).

1
2
3
4
5
6 High levels of flexibility in manufacturing operations characterise case B. At
7
8 the first-tier level, the same seat-assembly line used to build the seats under
9
10 study, can be used to build up to three different types of seat models.
11
12 Furthermore, the first-tier supplier has been able to standardise its operations
13
14 and assembly time duration. As proof of the flexibility developed in vehicle
15
16 assembly, the OEM is capable of building three different types of vehicles in
17
18 its two vehicle assembly lines.
19
20
21

22
23
24 The flow of material between the second tier and the first tier observed in
25
26 case B comprises deliveries in batches of 72 units. The time separating the
27
28 second tier from the first tier is 1.5 hours. The number of deliveries between
29
30 the first tier and the OEM during the day is 61. All deliveries between the first
31
32 tier and the OEM are sequenced. The time separating the first tier from the
33
34 OEM is 10 minutes. In case B the first-tier supplier is located half a mile away
35
36 from the OEM's production line. There are no overhead tunnels connecting
37
38 first-tier suppliers to the OEM. Instead, trucks are used to deliver
39
40 components. Figure 6 depicts the supply chain arrangement for case B.
41
42
43
44
45
46
47
48
49
50

51
52
53 **'[Insert figure 6 about here]'**
54
55
56
57
58
59
60

53 The flow of information and the information systems used in both case studies
54
55 are similar. Table 1 details the characteristics of the primary demand
56
57 information for each case.
58
59
60

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

‘[Insert table 1 about here]’

4.2 Information flow in case A (high-volume)

From the OEM, cumulative daily seat requirements were communicated to the supplier via EDI using the OEM's proprietary software. Each day the file showed the requirements for the next days, followed by tentative requirements for the coming weeks and months. The requirements file is the output of the OEM's proprietary system that uses as inputs actual dealer orders, the assembly plant's operating plan and sequencing rules.

Considered a well-consolidated process in the industry, the assembly of a unique seat set is triggered by launching the chosen vehicle into the final assembly sequence (usually a time window of four to five hours), at which time the actual seat requirement is sent to the first-tier supplier via an EDI- based broadcast system which is the OEM's proprietary system. The first-tier supplier uses the information from the aggregated daily seat requirements to run its own, internal material requirements planning system. The material requirements plan (MRP) is run weekly. The schedules are produced for each of the first-tier component suppliers. Schedules are sent to the suppliers via e-mail. These schedules normally contain daily requirements for the following week, as well as planned requirements for the coming weeks and months.

4.3 Information flow in case B

1
2
3 From the OEM, cumulative daily seat requirements were communicated to the
4 supplier via URL. The daily file presents requirements (firm orders) for the
5 next six days, followed by tentative requirements for the coming four weeks
6 and next six months. One of the OEM's proprietary systems generates the
7 daily requirements file based on actual dealers' orders and the plant's
8 operating plan.
9
10
11
12
13
14
15
16
17
18
19

20 Information flow in the supply chain follows a similar pattern as in case A.
21 The assembly of a unique seat set is triggered by launching the chosen
22 vehicle into the final assembly sequence (the time window in case B is only
23 three hours), at which time the actual seat requirement is sent to the first-tier
24 supplier via an EDI-based broadcast system. The first-tier supplier uses the
25 information from the aggregated daily seat requirements to run its MRP
26 system. The spreadsheets showing the production schedules are sent to
27 each of the first-tier component suppliers via e-mail. Attached schedules
28 normally contain firm daily requirements for the following week, as well as
29 planned requirements for the coming weeks and months.
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45

46 The trials illustrated in this paper are based on a frozen vehicle sequence.
47 According to Meyr (2004), the frozen sequence is the basis to derive the
48 component demand for JIT calls and sequenced-in-line supply.
49
50
51
52
53
54

55 **5. Proposed solution for second-tier sequencing: information flow** 56 **affecting stock levels and material deliveries** 57 58 59 60

1
2
3 In the two case studies analysed, the implementation of sequenced second-
4 tier deliveries demanded first and second-tier suppliers to be in close
5 proximity to the OEM. The creation of third-tier demand required the use of
6 an offset time of one day between the second and third-tier suppliers.
7
8 Ultimately, using this approach and the parts chosen for the study meant that
9 second and third-tier component demand could be determined from the final
10 vehicle demand, without the need for a complicated bill of materials parts
11 explosion. The elements considered in the proposed solution are considered
12 in table 2. Vehicle assembly operations demand, on-hand pipeline inventory
13 and deliveries sizes determine second and third-tier demand quantities. All
14 references are made to stock levels being carried with the proposed solution.
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31

32 **'[Insert table 2 about here]'**
33
34
35

36 The proposed solution uses the demand specified in the OEM production files
37 to arrive at the raw demand for each tier on a given day. The algorithm
38 compares available inventory (C_0 and D_0) with a predefined safety stock target
39 level (aa and ab) and adds or subtracts from the raw demand to return
40 available inventory to the desired level. The quantity used by the algorithm is
41 rounded to the nearest predetermined delivery batch size. Initial analysis kept
42 both target inventory level and batch sizes the same as the current system in
43 order to better appreciate the effect of implementing second-tier sequencing.
44
45 This situation showed inventory under tight control as second and third-tier
46 synchronisation improved, but inventory levels did not necessarily reduce to a
47 similar degree. With the inventory under more control, the analysis
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 spreadsheet can simulate the system under different target inventory levels.
4
5 The pseudo-code of the algorithm used is presented in figure 7.
6
7
8
9

10 **'[Insert figure 7 about here]'**
11
12
13
14

15 As previously mentioned, in the proposed trials, the demand specified in the
16 OEM production files was offset by one day, and passed on to the third-tier
17 supplier. In practice, this meant that the third-tier supplier was asked to
18 deliver the production schedule requirements one full day before vehicle
19 assembly operation's build day. This reflected a one day supply chain cycle
20 time for the seat manufacturer sequenced manufacturing and delivery. The
21 multi-tier sequencing presented in this paper only concerns the second-tier to
22 the OEM. The third tier is not included in the analysis.
23
24
25
26
27
28
29
30
31
32
33

34
35
36 In order to measure the benefits of the algorithm, a series of measures were
37 employed. The measures included bullwhip effect, synchronisation index,
38 size of pipeline inventory (in days), number of stockouts/backorders incidents
39 and the use/not of sequenced deliveries between tiers. The measure for
40 bullwhip is based on the work carried out by Fransoo and Wouters (2000).
41 Bullwhip measures the amplification between tiers by comparing the variability
42 of the demand signal from the downstream supplier (actual demand) with the
43 variability upstream. The initial condition set for synchronisation is a 100%
44 synchronisation index if the second-tier supplier makes exactly to demand but
45 offset by an appropriate lead time. Previous use of the basics of the
46 algorithm, the principles of information sharing and the use of a range of
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 indicators aggregated in the form of a scorecard can be found in Lyons et al.
4
5 (2005). Appendix A explains the measures in detail.
6
7

8
9
10 As in the theory of CPFR, sharing of information is at the core of
11 synchronisation in cases A and B. However, differences to a CPFR-based
12 approach include: suppliers serve only one OEM and therefore there is no
13 need for consolidating the sales forecasts of various customers, point of sales
14 data remains with the OEM and is not accessible by first and upstream
15 suppliers and suppliers have to have the capacity to support JIT
16 manufacturing (one piece flow).
17
18
19
20
21
22
23
24
25
26
27

28 29 **5.1 Synchronisation analysis of case A**

30
31 The value stream associated with the most popular trim option was picked for
32 this analysis. The analysis covers a total of 21 working days. The daily
33 demand registered during the period examined was equivalent to 484 units.
34 The value of the component manufactured by the second tier is €2.20 a unit.
35 Batch size of second-tier deliveries is equal to 56 units. An offset time of one
36 day existed between the second-tier and first-tier suppliers. Table 3 displays
37 the performance measures for this particular value stream.
38
39
40
41
42
43
44
45
46
47
48
49
50

51 **‘[Insert table 3 about here]’**
52
53
54

55 The high bullwhip index of 7.87 identified in table 3 means that the variance of
56 the demand registered at the upstream tier (shown as deliveries) is higher
57 than that registered at the point of origin. Figure 8 illustrates the behaviour of
58
59
60

1
2
3 the supply chain through the plotted values of OEM demand and raw material
4
5 at the first and second-tier deliveries.
6
7
8
9

10 **'[Insert figure 8 about here]'**
11
12

13
14
15 The next task to reduce the bullwhip effect consisted of using demand
16
17 visibility through a frozen schedule which comprised firm requirements for the
18
19 next six days. Those firm requirements specified in the frozen schedule were
20
21 offset to create the second-tier demand. Firm requirements, on-hand
22
23 inventory and delivery batch sizes determined second-tier demand quantities.
24
25 The results of the analysis of suppliers' tiers for case A are shown in table 4.
26
27 Resulting pipeline inventory days equal to zero are shaded in grey. Given the
28
29 eight-hour distance separating the third tier from the second tier, a raw
30
31 material inventory of one day was kept at the second tier.
32
33
34
35
36
37
38

39 **'[Insert table 4 about here]'**
40
41
42

43
44 The values shown in table 4 reveal a substantial reduction in the bullwhip
45
46 effect. That means that the proposed solution has been able to reduce the
47
48 variance of the demand registered at the upstream tier (shown as deliveries)
49
50 and more in tune with the requirements specified in the frozen schedule.
51
52 Figure 9 displays the plotted values of the proposed solution. The output of
53
54 the trials is shown in appendix B.
55
56
57
58
59

60 **'[Insert figure 9 about here]'**

5.2 The impact of implementing second-tier sequencing in case A

Because of the improvements achieved with synchronisation between the OEM and the first tier (shown in table 4 and figure 9), it is expected that further benefits to the supply chain would be possible if sequenced deliveries were extended to the second-tier supplier. To test the hypothesis proposed changes consisted of eliminating the offset time of one day between the second and first tiers and changing second-tier supplier batch size deliveries to one unit. The results of modelling the implementation of second-tier sequenced deliveries are shown in table 5. Resulting pipeline inventory days equal to zero are shaded in grey.

‘[Insert table 5 about here]’

The values shown in table 5 make clear that with the introduction of synchronised sequenced second-tier suppliers it is possible to register a bullwhip measure of only 1.02. The value registered for bullwhip represents a minimum amplification of the demand signal all the way up to the second-tier, a variance of the demand registered at the second-tier (shown as deliveries) almost equal to that registered at the point of origin. Given the eight-hour distance separating the third tier from the second tier, a raw material inventory of one day was kept at the second tier.

In figure 10, the values plotted clearly depict deliveries from the second-tier supplier following the pattern of OEM’s demand. The synchronisation level

1
2
3 attained is equal to 99%. The original level was equal to 89.44%. Figure 10
4
5 also shows the low levels of inventory associated with this particular solution.
6
7
8 The output of the trials is shown in appendix B.
9

10
11
12
13 **‘[Insert figure 10 about here]’**
14

15 16 17 **5.3 Reductions in inventory costs in case A**

18
19 The proposed solutions can have a significant impact in the reduction of
20
21 inventory at the first-tier supplier and finished goods at the second-tier
22
23 supplier. The results of the proposed solutions applied to an existing supplier
24
25 park arrangement are shown in table 6.
26
27

28
29
30
31
32 **‘[Insert table 6 about here]’**
33

34
35
36 Table 6 shows an almost total reduction of daily average inventory value in
37
38 the second-tier sequenced solution. With second-tier sequencing, pipeline
39
40 inventory between the OEM and second-tier raw material is equal to one day.
41
42 The original value was 5.17 days.
43
44

45 46 47 48 **5.4 Synchronisation analysis of case B**

49
50 The value stream of the component associated with the supply chain in case
51
52 B has a daily demand of 42 units. The analysis for this value stream covers a
53
54 total of 44 working days. The batch size of the second-tier supplier deliveries
55
56 is equal to 72 units. Table 7 shows the performance of the current supply
57
58 chain. The bullwhip effect measure of 2.16 represents an opportunity to
59
60

1
2
3 reduce the variance of the demand registered at the second tier (shown as
4
5 deliveries).
6
7
8
9

10 **‘[Insert table 7 about here]’**
11
12
13

14
15 Other values shown in table 7 include an inventory pipeline of 5.67 days
16
17 comprising the OEM, the first and second tiers. Synchronisation shows a total
18
19 of 63.65%. The plotted values of the OEM demand, raw materials at the first
20
21 tier and second tier deliveries are shown in figure 11.
22
23
24
25
26

27 **‘[Insert figure 11 about here]’**
28
29
30

31
32 As in case study A, the next task to reduce the bullwhip effect in case study B
33
34 consisted of using demand visibility through a frozen schedule which
35
36 comprised firm requirements for six days. Firm requirements, on-hand
37
38 inventory and delivery batch sizes determined second-tier demand quantities.
39
40 Second-tier demand is offset by one day. The results of the analysis of
41
42 suppliers’ tiers for case study B are shown in table 8. Resulting pipeline
43
44 inventory days equal to zero are shaded in grey. The output for this case
45
46 study is shown in appendix B.
47
48
49
50
51
52

53 **‘[Insert table 8 about here]’**
54
55
56
57
58
59
60

1
2
3 The use of demand visibility can enable the reduction of bullwhip effect and
4 pipeline inventory. Figure 12 shows the plotted values for the improvements
5 registered in table 8.
6
7
8
9

10
11
12
13 **‘[Insert figure 12 about here]’**
14

15
16
17 Based on the results achieved, bullwhip effect has been reduced from 2.16 to
18 1.88 and pipeline inventory between the first tier and second tiers has been
19 reduced from 5.67 days to 4.33 days. Synchronisation has reached 75.35%.
20
21
22
23
24

25 26 27 **5.5 The impact of implementing second-tier sequencing in case B** 28

29 As in case study A, further benefits are possible to achieve if a sequenced-
30 deliveries policy is designed to include the second-tier supplier. Proposed
31 changes consist of eliminating the offset time of one day between the second
32 and first tiers and changing second-tier supplier batch size deliveries to one
33 unit. The results of modelling the implementation of second-tier sequenced
34 deliveries are shown in table 9. Resulting pipeline inventory days equal to
35 zero are shaded in grey. The output of the algorithm for case B is shown in
36 appendix B.
37
38
39
40
41
42
43
44
45
46
47
48
49
50

51 **‘[Insert table 9 about here]’**
52

53
54
55 The values shown in table 9 make clear that with the introduction of
56 sequenced second-tier suppliers it is possible to register a perfect bullwhip
57 measure of 1.00. The value registered for bullwhip means that there is no
58
59
60

1
2
3 amplification of the demand signal all the way up to the second tier, a
4
5 variance of the demand registered at the second tier (shown as deliveries)
6
7
8 equal to that registered at the point of origin.
9

10
11
12 In figure 13, the values plotted clearly depict deliveries from the second-tier
13
14 supplier following the pattern of OEM's demand. Synchronisation between
15
16 the second tier and the OEM has reached 100%. Figure 13 also shows the
17
18 low levels of inventory associated with this solution.
19
20
21

22
23
24
25 **'[Insert figure 13 about here]'**
26
27

28
29 As previously shown in case study A, in case study B the proposed solutions
30
31 also have a significant impact on the reduction of inventory at the first-tier
32
33 supplier and finished goods at the second-tier supplier. Table 10 shows the
34
35 results achieved in terms of inventory savings. From a total of 3.67 days, it
36
37 was possible to reduce inventory levels to almost zero days.
38
39
40

41
42
43
44 **'[Insert table 10 about here]'**
45
46
47

48 **6. Conclusions**

49
50 Using actual demand data from OEMs in the automotive industry, the present
51
52 work has shown the significant benefits associated with extending
53
54 synchronised sequencing of components (in this case deliveries) upstream in
55
56 the supply chain to achieve high levels of synchronisation. Previous works in
57
58 the field have addressed the concept of synchronised sequencing mainly from
59
60

1
2
3 an OEM to first-tier supplier perspective and without paying attention to
4 considerations such as geographic proximity, time windows for deliveries and
5 present offset times.
6
7
8
9

10
11
12 Lessons learned from the study revealed that trust is another aspect involved
13 with building-up/improving synchronisation. Organisations (suppliers and
14 customers) are willing to share information more freely if they have built a
15 genuine, mutually supportive partnership. Also, it became clear that multi-tier
16 sequencing along the supply chain depends on being flexible throughout the
17 entire process, from machining of components, to paint shop and assembly
18 line. Flexibility depends on reducing process set-up times and being
19 organisationally responsive.
20
21
22
23
24
25
26
27
28
29
30
31
32

33
34 One important aspect of these findings and at the same time a limitation is
35 that the results may only apply to industries with multi-tier supply chain
36 structures. Machinery and aerospace manufacturing are appropriate
37 examples of industries with multi-tier supply chains that may benefit from
38 extending sequencing upstream of first-tier suppliers. The findings of the
39 study may be of limited value to industries with shallow supply chains such as
40 food, chemicals and pharmaceuticals.
41
42
43
44
45
46
47
48
49
50
51
52

53 Another limitation of this study is that it does not include guidelines to modify
54 the way current automakers generate their production schedules. However,
55 this study has demonstrated how building an efficient second-tier
56
57
58
59
60

1
2
3 synchronised sequencing system requires the use of a reliable vehicle
4 manufacturing plan.
5
6
7
8
9

10 The scope of this study is different to the other works discussed in the first
11 sections of the paper. The main differences to Holweg and Bicheno's (2002)
12 and Holweg et al.'s (2005) works are in terms of the possibility of supporting
13 one-piece flow and extending synchronisation to the second-tier supplier. The
14 findings of this work can be seen as complementary to the studies cited
15 above.
16
17
18
19
20
21
22
23
24

25
26
27 The research revealed that substantial benefits are possible to achieve if
28 synchronisation is expanded beyond the OEM – first-tier level. If it happens
29 that a second-tier supplier is located within the confines of a supplier park or
30 more realistically situated within the frozen time window of the OEM schedule,
31 it will be worth considering the expansion of synchronisation to cover that
32 second-tier supplier. However, the second-tier supplier must have production
33 facilities dedicated to support the JIT operations of the first-tier supplier it
34 serves and that may prevent it from serving other customers outside the
35 supplier park. Compensation to a supplier involved in synchronisations can
36 be in terms of volumes and length of contract.
37
38
39
40
41
42
43
44
45
46
47
48
49
50

51
52
53 At a time manufacturing organisations are facing growing competition and
54 more demanding customers, synchronisation through sequencing presents an
55 innovative solution to achieve high levels of responsiveness and efficiency.
56
57
58 Moreover, the organisation's commitment to lean policies and the geographic
59
60

1
2
3 proximity of suppliers, such as those found in supplier parks, will favour the
4
5 implementation of synchronised sequencing between the OEM, the first tiers
6
7 and beyond. Also flexibility of manufacturing operations is a critical
8
9 component to support the successful run of sequenced deliveries of
10
11 components in the supply chain. Even if geographic proximity is in place,
12
13 efforts to implement sequenced deliveries can be futile if flexibility of
14
15 operations is not present. Future research initiatives should concentrate on
16
17 investigating the requirements for extending the frozen fence in schedules so
18
19 more suppliers upstream of the first tier can participate in supply chain
20
21 synchronisation even if they are not in close proximity to the OEM and a first-
22
23 tier supplier.
24
25
26
27
28
29
30

31
32 The results show that the same benefits of synchronisation experienced
33
34 between an OEM and a first-tier supplier are extendable upstream in the
35
36 chain. Indeed, a supply chain that includes second-tier synchronised
37
38 sequencing can substantially enhance performance in terms of bullwhip
39
40 reduction, overall synchronisation levels and reduced supply chain inventories
41
42 and cycle times.
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Appendix A. Bullwhip effect and synchronisation

The bullwhip effect measure is shown in equation 1 and is based on the work carried out by Fransoo and Wouters (2000).

$$\text{Bullwhip - measure} = \frac{\frac{\sigma_{upstream}}{\mu}}{\frac{\sigma_{downstream}}{\mu}} \quad (1)$$

Where: σ = Standard deviation of demand pattern,

μ = Mean of demand pattern

upstream = demand shown at 1st, 2nd or 3rd tier supplier

downstream = demand at point of fit of component

A bullwhip index < 1 means that the variance of the demand registered at the upstream tier is lower than that registered at the point of origin. Situations where a bullwhip index < 1 might occur include daily deliveries of goods from lower tiers in the supply chain. A bullwhip index equal to 1 means a perfect supply chain. Therefore, C_{out} and C_{in} are exactly the same.

The initial condition set for synchronisation says that a 100% synchronisation index might occur in a supply chain if both 2nd and 3rd tier suppliers make/build exactly to actual demand, but off-set by appropriate supply chain lead times. The maximum value for the synchronisation index is 100, however it is possible to register negative values. The synchronisation index is directly dependent on the sum of absolute errors. A synchronisation index is negative

1
2
3 if the total sum of absolute errors divided by the number of days comprising
4 the period of study is bigger than the mean demand for the period examined
5
6 (Mean Absolute Deviation $(MAD)_{\text{offset}} > \mu$). A synchronisation index is closer
7
8 to 100 if the total sum of absolute errors divided by the number of days
9
10 comprising the period of study is significantly smaller than the mean demand
11
12 for the period examined $(MAD_{\text{offset}} < \mu)$.
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Appendix B

CASE A

Composite file requirements list

| | D-1 | D-2 | D-3 | D-4 | D-5 | D-6 | D-7 | D-8 | D-9 | D-10 | D-11 | D-12 | D-13 | D-14 | D-15 | D-16 | D-17 | D-18 | D-19 | D-20 | D-21 |
|--------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|
| Requirements | 454 | 452 | 510 | 488 | 512 | 240 | 298 | 334 | 340 | 288 | 416 | 416 | 412 | 418 | 418 | 470 | 528 | 522 | 528 | 560 | 318 |

Final call-off file requirements list

| | D-1 | D-2 | D-3 | D-4 | D-5 | D-6 | D-7 | D-8 | D-9 | D-10 | D-11 | D-12 | D-13 | D-14 | D-15 | D-16 | D-17 | D-18 | D-19 | D-20 | D-21 |
|--------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|
| Requirements | 504 | 534 | 578 | 572 | 574 | 244 | 298 | 348 | 366 | 318 | 416 | 510 | 612 | 700 | 418 | 470 | 780 | 522 | 534 | 554 | 318 |

Non-sequenced second-tier deliveries

| | D-1 | D-2 | D-3 | D-4 | D-5 | D-6 | D-7 | D-8 | D-9 | D-10 | D-11 | D-12 | D-13 | D-14 | D-15 | D-16 | D-17 | D-18 | D-19 | D-20 | D-21 |
|------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|
| Deliveries 2 nd t | 784 | 504 | 560 | 560 | 280 | 616 | 280 | 336 | 280 | 448 | 448 | 504 | 616 | 280 | 784 | 728 | 224 | 784 | 560 | 280 | |
| Deliveries 3 rd t | 960 | 780 | 510 | 230 | 610 | 330 | 630 | 240 | 430 | 370 | 550 | 540 | 220 | 670 | 590 | 530 | 740 | 240 | 550 | 240 | |
| 1 st t RM stock | 380 | 350 | 332 | 320 | 26 | 398 | 380 | 368 | 282 | 412 | 444 | 438 | 442 | 22 | 388 | 646 | 90 | 352 | 378 | 104 | |
| 2 nd t RM stock | 276 | 552 | 502 | 172 | 502 | 216 | 566 | 470 | 620 | 542 | 644 | 680 | 284 | 674 | 480 | 282 | 798 | 254 | 244 | 204 | |

Sequenced second-tier deliveries

| | D-1 | D-2 | D-3 | D-4 | D-5 | D-6 | D-7 | D-8 | D-9 | D-10 | D-11 | D-12 | D-13 | D-14 | D-15 | D-16 | D-17 | D-18 | D-19 | D-20 | D-21 |
|------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|
| Deliveries 2 nd t | 405 | 534 | 578 | 572 | 574 | 244 | 298 | 348 | 366 | 318 | 416 | 510 | 612 | 700 | 418 | 470 | 780 | 522 | 534 | 554 | |
| Deliveries 3 rd t | 900 | 500 | 500 | 600 | 200 | 600 | 300 | 400 | 300 | 400 | 400 | 500 | 600 | 400 | 700 | 800 | 200 | 800 | 500 | 300 | |
| 1 st t RM stock | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | |
| 2 nd t RM stock | 595 | 561 | 483 | 511 | 137 | 493 | 495 | 547 | 481 | 563 | 547 | 537 | 525 | 225 | 507 | 837 | 257 | 535 | 501 | 247 | |

CASE B

Composite file requirements list = Final call-off file requirements list

| | D-1 | D-2 | D-3 | D-4 | D-5 | D-6 | D-7 | D-8 | D-9 | D-10 | D-11 | D-12 | D-13 | D-14 | D-15 | D-16 | D-17 | D-18 | D-19 | D-20 | D-21 | D-22 |
|--------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Requirements | 58 | 46 | 70 | 66 | 54 | 0 | 56 | 54 | 50 | 68 | 0 | 46 | 54 | 40 | 60 | 46 | 0 | 38 | 30 | 38 | 38 | 42 |
| | D-23 | D-24 | D-25 | D-26 | D-27 | D-28 | D-29 | D-30 | D-31 | D-32 | D-33 | D-34 | D-35 | D-36 | D-37 | D-38 | D-39 | D-40 | D-41 | D-42 | D-43 | D-44 |
| Requirements | 0 | 42 | 36 | 36 | 34 | 48 | 0 | 38 | 56 | 36 | 54 | 34 | 50 | 48 | 54 | 46 | 52 | 46 | 54 | 42 | 50 | 36 |

Non-sequenced second-tier deliveries

| | D-1 | D-2 | D-3 | D-4 | D-5 | D-6 | D-7 | D-8 | D-9 | D-10 | D-11 | D-12 | D-13 | D-14 | D-15 | D-16 | D-17 | D-18 | D-19 | D-20 | D-21 | D-22 |
|------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Deliveries 2 nd t | 0 | 36 | 72 | 72 | 36 | 36 | 108 | 0 | 36 | 72 | 0 | 108 | 0 | 36 | 72 | 36 | 0 | 72 | 0 | 36 | 36 | 36 |
| Deliveries 3 rd t | 100 | 100 | 50 | 50 | 0 | 100 | 50 | 100 | 0 | 0 | 100 | 0 | 100 | 50 | 0 | 50 | 50 | 0 | 50 | 0 | 50 | 0 |
| 1 st t RM stock | 33 | 59 | 61 | 31 | 13 | 121 | 65 | 47 | 69 | 1 | 109 | 63 | 45 | 77 | 53 | 7 | 79 | 41 | 47 | 45 | 43 | 1 |
| 2 nd t RM stock | 106 | 84 | 62 | 26 | 90 | 32 | 132 | 96 | 24 | 124 | 16 | 116 | 130 | 58 | 72 | 122 | 50 | 100 | 64 | 78 | 42 | 142 |

| | D-23 | D-24 | D-25 | D-26 | D-27 | D-28 | D-29 | D-30 | D-31 | D-32 | D-33 | D-34 | D-35 | D-36 | D-37 | D-38 | D-39 | D-40 | D-41 | D-42 | D-43 | D-44 |
|------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Deliveries 2 nd t | 0 | 108 | 0 | 36 | 0 | 72 | 0 | 72 | 0 | 36 | 72 | 0 | 72 | 36 | 72 | 36 | 72 | 36 | 36 | 36 | 72 | 36 |
| Deliveries 3 rd t | 100 | 0 | 100 | 0 | 50 | 0 | 50 | 0 | 50 | 50 | 0 | 100 | 0 | 50 | 50 | 50 | 50 | 100 | 0 | 50 | 0 | 50 |
| 1 st t RM stock | 109 | 67 | 67 | 31 | 69 | 21 | 93 | 55 | 35 | 71 | 17 | 55 | 41 | 65 | 47 | 73 | 57 | 47 | 29 | 59 | 45 | |
| 2 nd t RM stock | 34 | 134 | 98 | 148 | 76 | 126 | 54 | 104 | 118 | 46 | 146 | 74 | 88 | 66 | 80 | 58 | 122 | 86 | 100 | 28 | 42 | |

Sequenced second-tier deliveries

| | D-1 | D-2 | D-3 | D-4 | D-5 | D-6 | D-7 | D-8 | D-9 | D-10 | D-11 | D-12 | D-13 | D-14 | D-15 | D-16 | D-17 | D-18 | D-19 | D-20 | D-21 | D-22 |
|------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Deliveries 2 nd t | 58 | 46 | 70 | 66 | 54 | 0 | 56 | 54 | 50 | 68 | 0 | 46 | 54 | 40 | 60 | 46 | 0 | 38 | 30 | 38 | 38 | 42 |
| Deliveries 3 rd t | 50 | 100 | 0 | 100 | 0 | 100 | 0 | 50 | 50 | 0 | 100 | 50 | 0 | 100 | 0 | 0 | 100 | 0 | 50 | 0 | 50 | 0 |
| 1 st t RM stock | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 nd t RM stock | 76 | 130 | 60 | 94 | 40 | 140 | 84 | 80 | 80 | 12 | 112 | 116 | 62 | 122 | 62 | 16 | 116 | 78 | 98 | 60 | 72 | 30 |

| | D-23 | D-24 | D-25 | D-26 | D-27 | D-28 | D-29 | D-30 | D-31 | D-32 | D-33 | D-34 | D-35 | D-36 | D-37 | D-38 | D-39 | D-40 | D-41 | D-42 | D-43 | D-44 |
|------------------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Deliveries 2 nd t | 0 | 42 | 36 | 36 | 34 | 48 | 0 | 38 | 56 | 36 | 54 | 34 | 50 | 48 | 54 | 46 | 52 | 46 | 54 | 42 | 50 | 36 |
| Deliveries 3 rd t | 100 | 0 | 50 | 0 | 50 | 0 | 100 | 0 | 0 | 100 | 0 | 100 | 0 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 0 |
| 1 st t RM stock | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2 nd t RM stock | 130 | 88 | 102 | 66 | 82 | 34 | 134 | 96 | 40 | 104 | 50 | 116 | 66 | 68 | 64 | 68 | 66 | 70 | 66 | 74 | 74 | 38 |

References

Andraski, J.C., 1994. Foundations for successful continuous replenishment programs'. *International Journal of Logistics Management*, Vol. 5, No. 1, pp. 1-8.

Automotive News 2005. Guide to Purchasing 2005. European Supplier Parks, 21, pp. 22

Christensen W.J., Germain R. and Birou L., Build-to-order and just-in-time as predictors of applied supply chain knowledge and market performance. *Journal of Operations Management*, 2005, **23**, 470–481

Coleman J., Lyons A. and Kehoe D., The glass pipeline: increasing supply chain synchronisation through information transparency", *International Journal of Technology Management*, 2004, **28** (2), 172-190.

Doran D., Manufacturing for synchronous supply: A case study of Ikeda Hoover Ltd. *Integrated Manufacturing Systems*, 2002, **13** (1), 18-24.

Fransoo, J., and Wouters, M., Measuring the bullwhip effect in the supply chain. *Supply chain management: An international journal*, 2000, **5** (2), 78-89.

Holweg M. and Bicheno J., Supply chain simulation: a tool for education, enhancement and endeavour. *International Journal of Production Economics*, 2002, **78**, 163-175.

[Holweg, M., 2003. The three-day car challenge—investigating the inhibitors of responsive order fulfilment in new vehicle supply systems. *International Journal of Logistics: Research and Applications* 6 \(3\), 165–183.](#)

Holweg M., Disney S.M., Hines P. and Naim M. 2005. Towards responsive vehicle supply: a simulation-based investigation into automotive scheduling systems. *Journal of Operations Management*, **23**, 507–530

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Howard M. and Holweg M., Investigating the intangible: lessons learnt from research into automotive inter-organisational IT systems. *International Journal of Automotive Technology and Management*, 2004, **4** (4), 354-373

Larsson A., The Development and Regional Significance of the Automotive Industry: Supplier Parks in Western Europe. *International Journal of Urban and Regional Research*, 2002, **26** (4), 767-784.

Lee H.L., Padmanabhan V. and Whang S., Information distortion in a supply chain: The bullwhip effect, *Management Science*, 1997, **43** (4), 546-558.

Lyons, A., Coleman, J., Kehoe, D. and Coronado, A., Performance observation and analysis of an information re-engineered supply chain: a case study of an automotive firm. *Industrial Management and Data Systems*, 2004a, **104** (8), 658-666

Lyons, A. Coronado A., Kehoe, D. and Coleman J., Improving the synchronisation of supply chains: an automotive case study. *International Journal of Automotive Technology and Management*, 2004b, **4** (4), 354-373

Lyons, A., Coronado A., Bremang A., Kehoe D.F. and Coleman J., Prototyping an information system's requirements architecture for customer-driven, supply-chain operations. *International Journal of Production Research*, 2005, **43** (20), 4289-4319.

Mason-Jones, R. and Towill, D.R., Using the information de-coupling point to improve supply chain performance, *International Journal of Logistics Management*, 1999, **10** (2), 13-26.

Meyr H., Supply chain planning in the German automotive industry. *OR Spectrum*, 2004, **26**, 447 – 470.

1
2
3 Stevenson M., Hendry L., Kingsman B., A review of production planning and
4 control: the applicability of key concepts to the make-to-order industry.
5 *International Journal of Production Research*, 2005, **43** (5): 869-898
6
7
8
9

10 Tetu L., Supply chain planning & synchronisation, APICS. The Performance
11 Advantage, 1998, **8** (6)
12
13
14

15 Womack J P and Jones D T, Lean Thinking. Banish Waste and Create wealth
16 in your corporation. 1996, Simon & Schuster, New York.
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Tables

| Supply chain | Information characteristics | Fixed period |
|--------------|--|--|
| Case A | Primary demand shows 1 st tier's daily requirements for the next 10 days plus monthly forecasts | Non-stable. Keeps changing until the final call-off day |
| Case B | Primary demand shows 1 st tier's daily requirements for the next 12 days plus monthly forecasts | Quantities specified in the primary demand are fixed from 6 days prior to the final call-off day |

Table 1. Primary demand information characteristics

| | |
|---------|---|
| n : | period examined (days) |
| R_n : | already available fixed daily OEM raw demand |
| aa : | predefined first-tier raw material inventory level |
| ab : | predefined second-tier raw material inventory level |
| ba : | second-tier batch size deliveries (units) |
| bb : | third-tier batch size deliveries (units) |
| C_0 : | initial first-tier raw material inventory |
| D_0 : | initial second tier raw material inventory |
| S_n : | second-tier raw material deliveries |
| T_n : | third-tier raw material deliveries |

Table 2. Elements of the second-tier sequencing solution

| | 2 nd tier | 1 st tier | Overall at OEM level |
|---------------------------|--------------------------------|-----------------------------|----------------------|
| Deliveries downstream | non-sequenced | sequenced | – |
| Bullwhip | – | – | 7.47 |
| Synchronisation % | 79.89% | 99% | 89.44% |
| Pipeline Inventory (days) | RM: 1.53 days FG: 1.60 days | RM: 2.04 days FG: 0 days | 5.17 days |
| Stockouts/Backorders | 0/0 | 0/0 | – |

Table 3. Bullwhip and other measures for case study A

| | 2 nd tier | 1 st tier | Overall at OEM level |
|---------------------------|--------------------------------|-----------------------------|----------------------|
| Deliveries downstream | non-sequenced | sequenced | – |
| Bullwhip | – | – | 1.40 |
| Synchronisation % | 72.25% | 99% | 85.62% |
| Pipeline Inventory (days) | RM: 0.93 days FG: 0.94 days | RM: 0.68 days FG: 0 days | 2.54 days |
| Stockouts/Backorders | 0/0 | 0/0 | – |

Table 4. Bullwhip and other measures improvements for case study A

| | 2 nd tier | 1 st tier | Overall at OEM level |
|---------------------------|-----------------------------|--------------------------|----------------------|
| Deliveries downstream | sequenced | sequenced | – |
| Bullwhip | – | – | 1.02 |
| Synchronisation % | 98.98% | 99% | 98.99% |
| Pipeline Inventory (days) | RM: 0.99 days FG: 0 days | RM: 0 days FG: 0 days | 0.99 days |
| Stockouts/Backorders | 0/0 | 0/0 | – |

Table 5. Case study A: bullwhip implications of 2nd tier sequenced deliveries

Tables

Daily demand: 484 units
Component Value: €2.20

| | current | second tier non sequenced solution | second tier sequenced solution |
|--|-----------|------------------------------------|--------------------------------|
| Average Daily Inventory 1 st tier RM and 2 nd tier FG (days) | 2.64 | 1.62 | 0.002 |
| Inventory Value | €3,883.13 | €1,724.98 | €2.20 |

Table 6. Inventory savings comparison for case A

| | 2 nd tier | 1 st tier | Overall at OEM level |
|----------------------------------|--|-------------------------------------|----------------------|
| Deliveries downstream | non-sequenced | sequenced | – |
| Bullwhip | – | – | 2.16 |
| Synchronisation % | 27.30% | 100% | 63.65% |
| Pipeline Inventory (days) | RM: 2.00 days FG: 1.50 days | RM: 2.17 days FG: 0 days | 5.67 days |
| Stockouts/Backorders | 0/0 | 0/0 | – |

Table 7. Bullwhip and other measures for case study B

| | 2 nd tier | 1 st tier | Overall at OEM level |
|----------------------------------|--|-------------------------------------|----------------------|
| Deliveries downstream | non-sequenced | sequenced | – |
| Bullwhip | – | – | 1.88 |
| Synchronisation % | 50.70% | 100% | 75.35% |
| Pipeline Inventory (days) | RM: 1.95 days FG: 1.15 days | RM: 1.23 days FG: 0 days | 4.33 days |
| Stockouts/Backorders | 0/0 | 0/0 | – |

Table 8. Bullwhip and other measures improvements for case B

| | 2 nd tier | 1 st tier | Overall at OEM level |
|----------------------------------|-------------------------------------|-------------------------------------|----------------------|
| Deliveries downstream | sequenced | sequenced | – |
| Bullwhip | – | – | 1.00 |
| Synchronisation % | 100% | 100% | 100% |
| Pipeline Inventory (days) | RM: 1.86 days FG: 0 days | RM: 0.02 days FG: 0 days | 1.88 days |
| Stockouts/Backorders | 0/0 | 0/0 | – |

Table 9. Case study A: bullwhip implications of 2nd tier sequenced deliveries

Daily demand: 42 units
Component Value: £5.69

| | current | second tier non sequenced solution | second tier sequenced solution |
|--|---------|------------------------------------|--------------------------------|
| Average Daily Inventory 1 st tier RM and 2 nd tier FG (days) | 3.67 | 2.38 | 0 |
| Inventory Value | £876.00 | £568.10 | £0.00 |

Table 10. Inventory savings comparison for case B

Figures

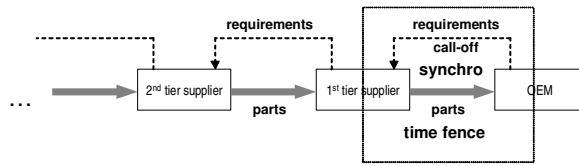


Figure 1. A traditional one-tier synchronisation arrangement

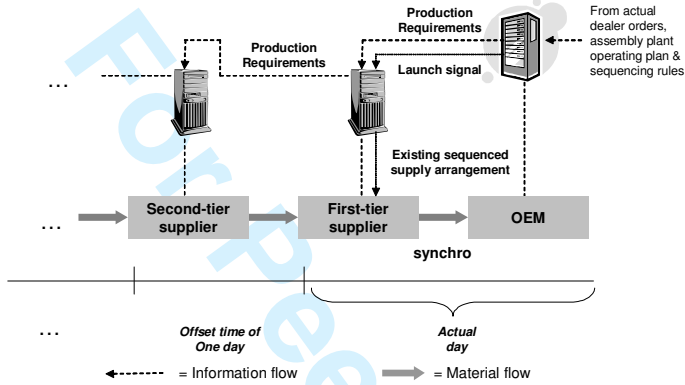


Figure 2. First-tier synchronisation arrangement

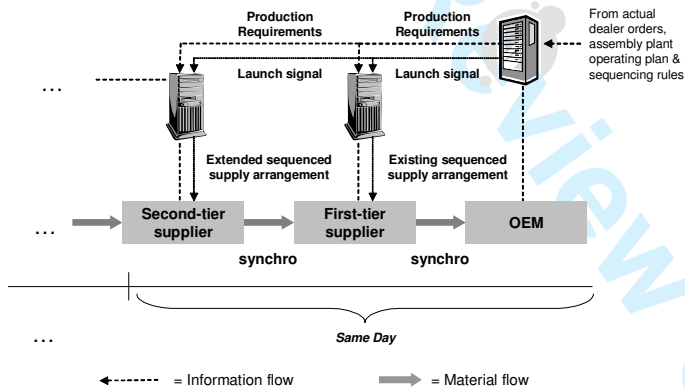


Figure 3. Extending synchronisation to the second-tier

Figures

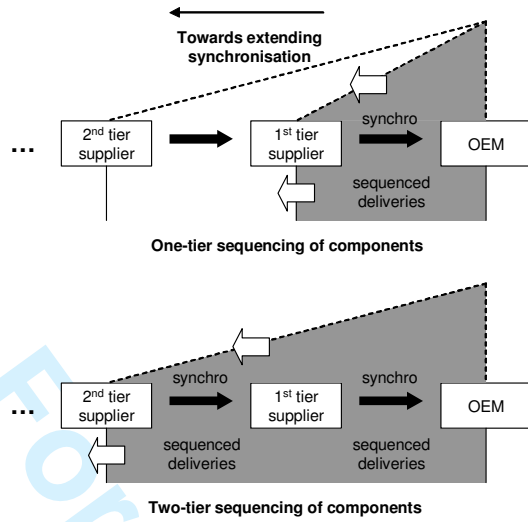


Figure 4. Comparing one-tier versus two-tier sequenced synchronisation

Deleted: Extending synchronisation to a second-tier

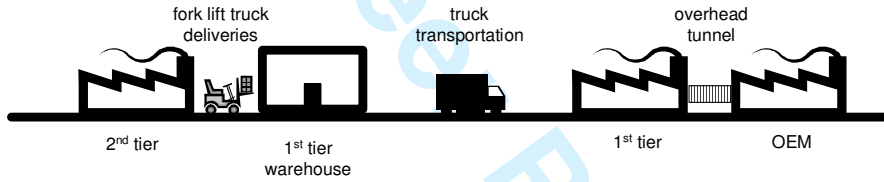


Figure 5. Case study A supply chain arrangement

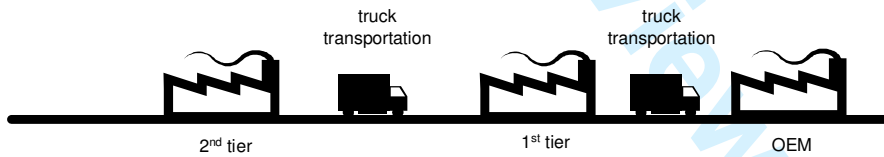


Figure 6. Case study B supply chain arrangement

Figures

```

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

```

****/ second-tier material deliveries /****
For i =1 to n step 1
{
 if $aa + R_i - C_{i-1} < 0$
 $S_i = 0$
 else
 $S_i = \text{round up}(aa + R_i - C_{i-1}, ba)$
 $C_i = C_{i-1} + S_i - R_i$
}

****/ third-tier material deliveries /****
For j = 1 to n step 1 //one day offset time between 3rd and 2nd tiers/****
{
 if $ab + R_{j+1} - D_j < 0$
 $T_j = 0$
 else
 $T_j = \text{round up}(ab + R_{j+1} - D_j, bb)$ ****/one day offset time between 3rd and 2nd tiers/****
 $D_j = D_j + T_j - R_{j+1}$
}

Figure 7. Algorithm employed for second-tier sequenced deliveries

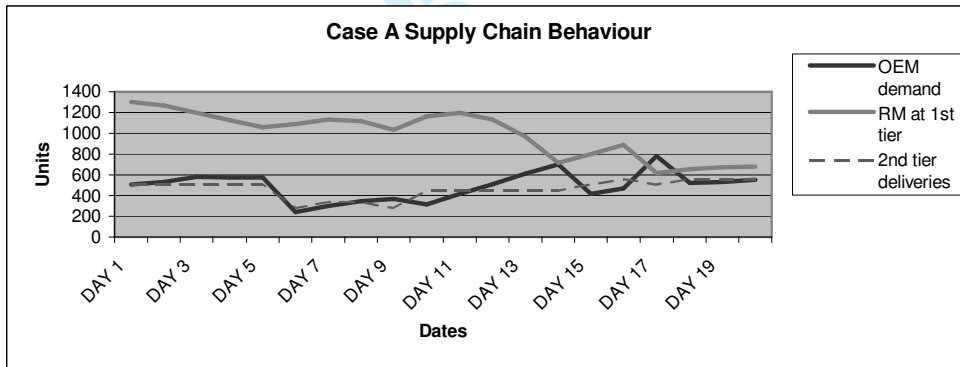


Figure 8. Case study A supply chain details

Figures

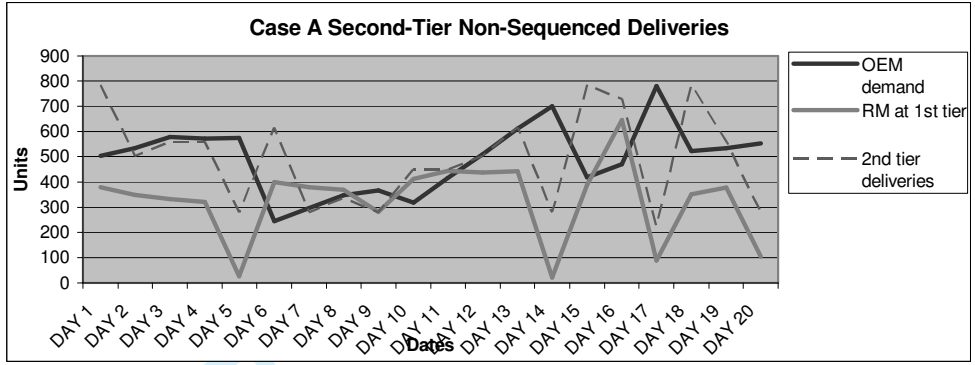


Figure 9. Plotted values of improvements to case A

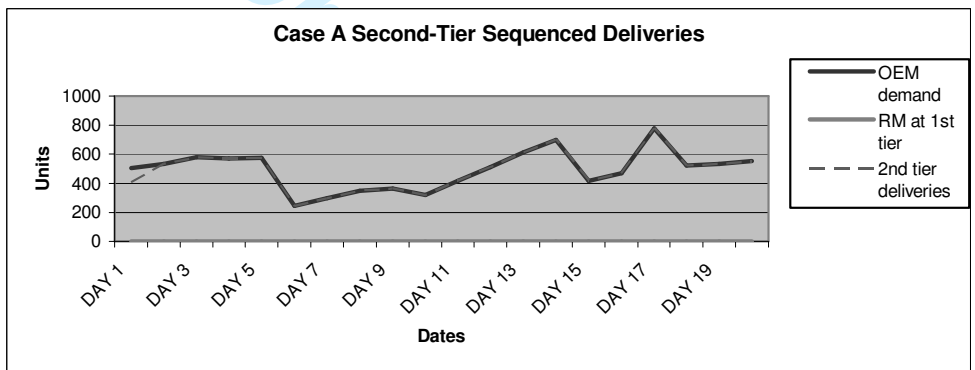


Figure 10. Case study A plotted values of bullwhip implications

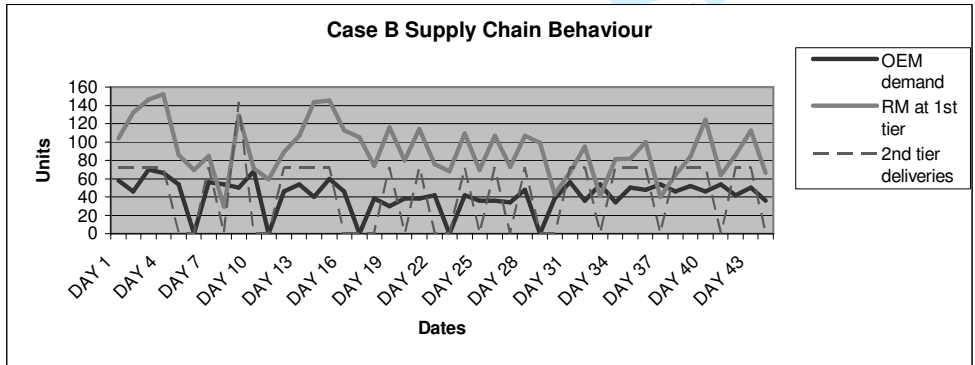


Figure 11. Case study B supply chain details

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Figures

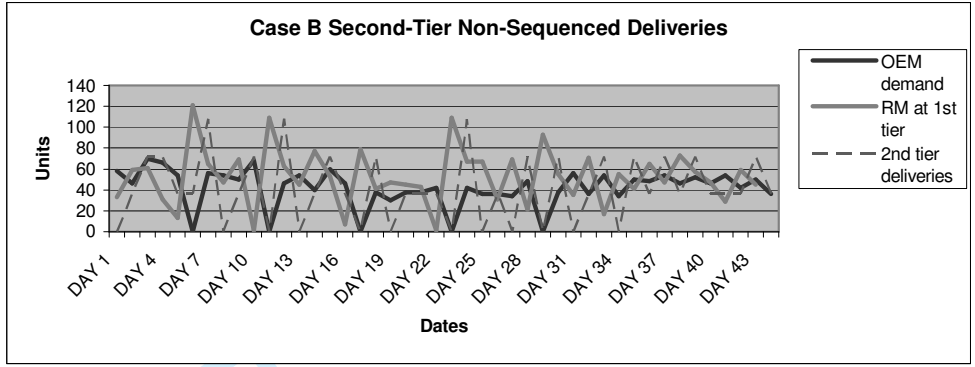


Figure 12. Plotted values of improvements to case study B

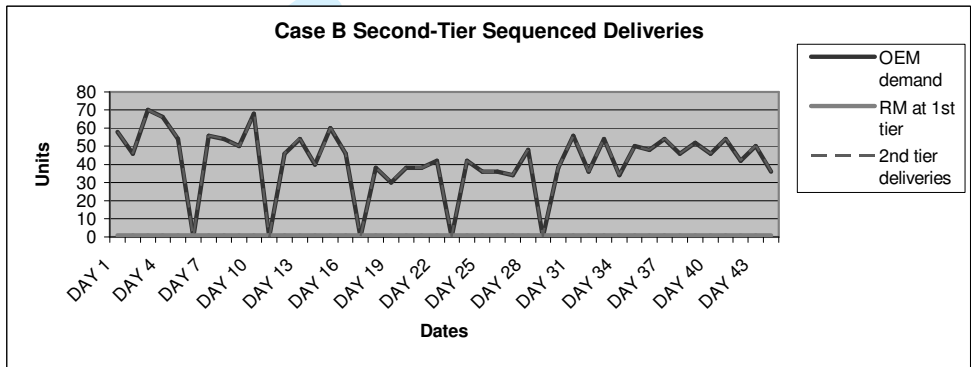


Figure 13. Case study B plotted values of bullwhip implications