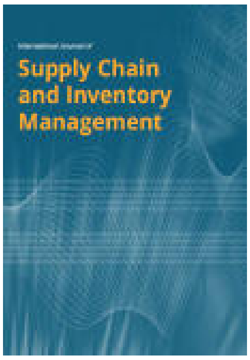
INDERSCIENCE PUBLISHERS
Linking academia, business and industry through research



International Journal of Supply Chain and Inventory Management

ISSN online: 2054-1007 - ISSN print: 2054-099X
https://www.inderscience.com/ijscim

Modelling and performance measurement of supply streams

Ahmed Deif, Amr Nounou

DOI: 10.1504/IJSCIM.2023.10056179

Article History:

Received:	15 April 2021
Last revised:	16 April 2021
Accepted:	15 February 2023
Published online:	19 June 2023

Modelling and performance measurement of supply streams

Ahmed Deif*

Industrial Technology and Packaging,
OCOB,
California Polytechnic State University,
1 Grand Ave, San Luis Obispo, CA 93407, USA
Email: adeif@calpoly.edu
*Corresponding author

Amr Nounou

Faculty of Engineering,
German International University,
Cairo Governorate 4824201, Egypt
and
College of Engineering and Technology,
American University of the Middle East,
250 St, Kuwait
Email: amr.nounou@hotmail.com

Abstract: Managing supply chain networks are generally complex due to the structure (static) complexity as well as behaviour (dynamic) complexity. This complexity is even increased through the wide range of performance metrics used to integrate the supply chain. This paper proposes a new approach to manage supply chain delivery using a flow analysis perspective along with a performance improvement protocol while capturing the entire supply chain. Adopting lean thinking that focus on flow streamlining, a supply chain flow dashboard (SCFD) management tool was developed. The tool balances between simplicity and usefulness and is augmented with a management protocol that suggests the actions needed. Two cases form different supply chain industries were used to demonstrate the applicability of the proposed approach. The proposed approach offers managers and practitioners a frontline primary tool that can simply manage the delivery performance and allow for next level and deeper supply chain performance assessment opportunities.

Keywords: supply chains; delivery; lean supply chain; performance evaluation; supply chain flow dashboard; SCFD.

Reference to this paper should be made as follows: Deif, A. and Nounou, A. (2023) 'Modelling and performance measurement of supply streams', *Int. J. Supply Chain and Inventory Management*, Vol. 4, No. 2, pp.175–193.

Biographical notes: Ahmed Deif is an Associate Professor of Operations and Supply Chain Management at the Department of Industrial Technology and Packaging at California Polytechnic State University. Before joining Cal Poly, he was an Assistant Professor at multiple universities (University of Regina, Canada, University of Windsor, Canada, and Nile University, Egypt). His

current research interests are in innovation and sustainability of supply chain management, lean and green manufacturing/service systems, and dynamic analysis of manufacturing systems. He has a diverse portfolio in his industrial experience ranging from the automotive industry to steel industry to electronic industry and final assembly industry at various engineering and consultancy capacities.

Amr Nounou earned his Dr.-Ing. in Mechanical Engineering as well as MSc in Textile and Clothing Engineering (at the Faculty of Mechanical Engineering) from TU Dresden and BSc in Mechanical Engineering from The American University in Cairo. In addition to his academic experience, he has more than ten years of experience in the industry in the fields of production management, product development, project management, strategic planning and change management. His research interests are in the areas of lean management, quality improvement, thermal ergonomics, facilities planning and strategic management.

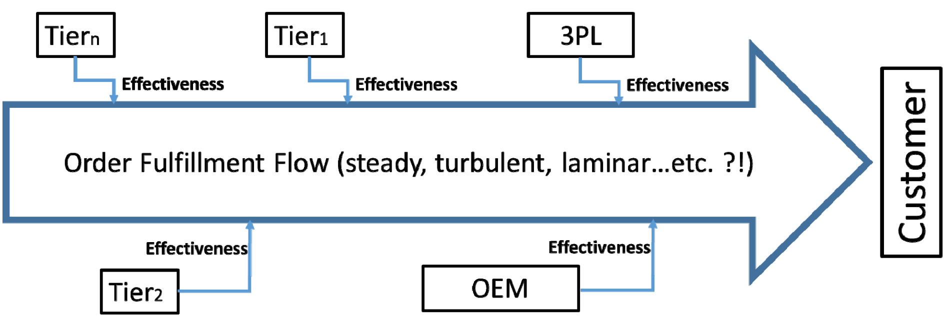
1 Background

Supply chains networks are structurally (static) complex systems to manage due to the high degree of sub-systems or echelons coupling as well as the information required to integrate and synchronise these echelons. The division of these echelons into upstream, midstream and downstream adds another layer of behaviour (dynamic) complexity due to traditional local optimisation approaches implemented separately in each of these sub-systems. Furthermore, the wide range of performance metrics used to integrate the supply chain contributes to the complexity of the management process. In an attempt to avoid complexity of the supply chain performance management systems, companies might select to be viewing only a part of the supply chain (Maestrini et al., 2017). Decoupling the complex inter-system relationships among the supply chain echelons and focusing on limited yet inclusive metrics can also reduce both structural and behavioural complexity of the management process.

As supply chains bear a wide range of performance perspectives, typically evaluation of supply chains involves multiple objectives and accordingly a list of performance indicators. Maestrini et al. (2017) regarded supply chain performance management systems as a set of metrics and provided a review on the topic classifying the scope of metrics used in the literature as internal (within the business entity) and external (among the business entities). In addition to quantitative performance indicators, frequently administrative qualitative ones are also included adding to the extensiveness of the evaluation process. Stevenson (2009) has grouped supply chain performance indicators under; suppliers, inventory, operations, order fulfilment, customers and financial. As Afonso and do Rosário Cabrita (2015) used the balanced scorecard in evaluating the performance of supply chains, the evaluation indicators/parameters were categorised as Financial, Customer, Internal Business and Innovation & Learning. Mohib and Ahmed (2020) provided that for a more effective supply chain risk evaluation, the quantitative tracking of supply volumes over the supply chain should be used instead of just following a binary evaluation of being a full quantity or not. Maestrini et al. (2017) broke down the types of metrics used in supply chain performance management systems into; financial, non-financial, qualitative and quantitative. At the core of this research is to identify from a lean perspective the performance evaluation of supply chain, and whether it is to be financial (e.g., profit maximisation), typical lean production focused (e.g., lead time reduction), multiple perspective supply chain performance or other.

Learning from the Lean manufacturing paradigm can be helpful in this regard. Stevenson (2009) highlighted that the ultimate objective of lean is to provide a free from interruptions smooth flow of supply fitting the demand from customers. Hou et al. (2017) reviewed the historical development of distribution systems, logistics and supply chains, considered them as strategies based on flow and viewed their future development as being within the context of flow. Nounou (2018) in evaluating the system performance, utilised the system harmony focusing on flow attributes (stability and laminarity), realisation of the takt times and utilisation of the resources. Supply chain management complexity (both dynamic and static) can also be reduced with this flow approach. This paper proposes a new approach to manage the entire supply chain performance from a delivery flow perspective that simplify the static complexity by modeling the different echelons as sub-streams merging into a main flowing stream (that delivers to the customers downstream). The behavioural complexity from this new perspective is reduced by offering inclusive yet simple metrics that capture both the steadiness and uniformity of this delivery flowing stream of the supply chain. Figure 1 depicts the new proposed approach.

Figure 1 Schematic conceptualisation of the supply chain flow (see online version for colours)



Previous Lean approaches into supply chain management focused primarily on waste reduction within the processes along the supply chain increasing its effectiveness (Afonso and do Rosário Cabrita, 2015). Tortorella et al. (2017) focused on identifying the practices of lean supply chain management and their effect on the supply chain performance. Extending the operational value stream mapping to capture the overall supply chain value stream (Jones and Womack, 2011) is a typical example of multiple attempts to extend various lean performance evaluation tools to the supply chain domain. Another example includes the work of Berger et al. (2018) who studied lean inventory management strategies in a lean supply chain management context involving four different pull scenarios and used delivery service time and lead time in evaluating the results. The same mapping approach had driven Afonso and do Rosário Cabrita (2015) to present a lean supply chain performance evaluation using a lean balanced scorecard approach. More examples of using lean systems' tools in the supply chain context include Cudney and Elrod (2011), Lamming (1996), Machado Guimarães and Crespo de Carvalho (2013) and Manzouri et al. (2014).

With the success of the lean thinking mapping to supply chain management, some researchers discussed existing challenges. For example, Bortolotti et al. (2016) pointed out that the literature does not sufficiently explain the connections between supply chain features and lean implementation and studied the extension of lean practices along a supply network and the interrelationships between the aspects of both. They specifically stated that the higher the distance between the owner of lean knowledge in the supply network and the receiving echelon increases the challenge of extending the lean practices. Tortorella et al. (2017) also showed that there is a general perception that lean supply chain management improves the combination of followed methods, however extending the lean principles along the supply chain represents a challenge.

This work aims at reducing the complexity of the supply chain evaluation problem through learning from the lean thinking paradigm while acknowledging the challenges existing in direct mapping. This attempt will be realised through focusing on managing the delivery flow in the supply chain. While doing this, the proposed approach will also be extended to capture the performance along the entire supply chain in terms of the production planning and control systems applied by each supplier/echelon. In specific, it will be structured to include the order fulfilment approaches and the inventory management policies of these echelons. In Grassi et al. (2020) and discussions in Stevenson (2009) inventory management policies were associated with order fulfilment approaches. Maestrini et al. (2017) highlighted that the internal and external supply chain performance management systems need to be consistent and aligned and that future research is expected to tackle this subject.

1.1 Research contribution

This paper contributes to the discussion on the supply chain evaluation and its complexity by offering an integrated approach that will consider the full span of the supply chain and enable integration with the lean principles through focusing on the concept of flow. The proposed approach will focus on the delivery flow in the supply chain as a measure for the performance along with providing a performance improvement procedure along the whole chain. Accordingly, this new approach is hereby aimed with the following main principles;

- modelling of the supply stream delivery flow
- enabling performance evaluation extended over the full span of the supply chain
- providing a frame of improvement course of actions

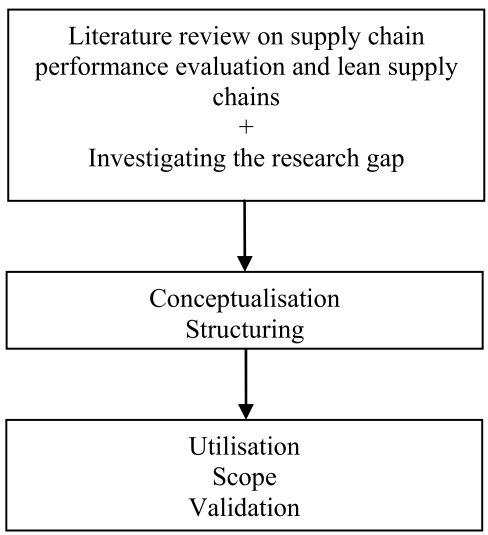
1.2 Paper outline

Section 1 of the paper includes the introduction and the identification of the research contribution. The methodology is then illustrated in Section 2. Section 3 provides a conceptualisation leading to the structuring of the developed tool and improvement protocol which are presented in Section 4. Section 5 presents two case studies demonstrating the application of the tool. In Section 6 the discussion and future scope of the work are presented. A summary of the work is provided in Section 7.

2 Methodology

The research methodology depicted in Figure 2 is based on the previously outlined motivation to develop a tool reducing the complexity of modelling and evaluating the performance of supply chains focusing on the delivery flow as a lean approach. The approach will adopt and adapt from the tools and discussions in Nounou (2018). The work started by a literature review concerning performance evaluation in supply chain management with focus on lean supply chains. Meanwhile, investigating the research gap provided the orientation of the work and characterised the approach aimed as an outcome. Then a conceptualisation highlighting the main considerations was conducted as a preparation based on which the structuring of the tool was achieved. The tool was employed in two case studies from two different application areas illustrating its utilisation and relating to practical implications.

Figure 2 Research methodology



3 Conceptualisation

The approach aimed in this paper in evaluating the supply chain performance is targeted to be adopting a flow viewpoint. The flow in the provided context will represent the subject of the delivery performance evaluation in terms of quality and quantity. To improve the delivery in the main flow, it will be necessary to coordinate and adjust the flow from the sub-streams which is a core role of supply chain management. The resulting flow of the supply chain is to be viewed as the mainstream.

Responsiveness to customers is one of the final goals of an entire supply chain (Ortega-Jimenez et al., 2020). Soltan and Mostafa (2015) pointed out that market responsiveness involves both capturing of the market request as well as the reaction accordingly. Ortega-Jimenez et al. (2020) investigated the interactions within the context of strategic reconfigurable system resulting in higher plant responsiveness while focusing on the intervention impact of supply chain management. Responsiveness is to represent an important parameter in the connection between the suppliers sub-streams and the mainstream in the flow perspective of this work. To operationalise responsiveness, supply chain practitioners usually turn their attention to the order fulfilment system.

Make-to-stock (MTS), assemble-to-order (ATO), make-to-order (MTO) and engineer-to-order (ETO) are the typically applied order fulfilment approaches and usually based on the increased degree of customisation in the sequence provided. The customer expectations in the E-business context involves fast ordering and delivery which might exceed the organisation order fulfilment capability. Furthermore, demand variability in this context represents an additional order fulfilment challenge (Stevenson, 2009).

Grassi et al. (2020) illustrated that in the sequence of MTS, ATO and MTO an increased required market response time is featured being considerably less than cycle time in the case of MTS and greater than the cycle time in the case of MTO. They provided that short response time motivates keeping stocks and applying a production planning relying on forecasting, with just in time (JIT) being more applicable at increased required market response time and material requirement planning (MRP) is being effective at even higher required market response time and higher customisation. They pointed out that the customer anticipations in an Industry 4.0 context, involves both fast product delivery as well as high customisation.

Table 1 describes the response of the suppliers under different order fulfilment approaches and inventory management policies and identifies the response activities/logistics involved in each approach. Table 1 provides the typical logistics of; ordering, receiving, storeroom, processing, warehouse and shipping identifying them as sub-streams logistics while identifying delivery as main stream logistics.

Table 1 Typical order response logistics

		Typical order response logistics							
		Sub-streams logistics							*Mainstream logistics*
Order fulfilment approach	*Inventory management policy*	*Ordering*	*Receiving*	*Storeroom*	*Processing manufacturing*	*Processing assembly*	*Warehouse*	*Shipping*	*Delivery*
ETO	Procurement	Start							
MTO	MRP				Start				
ATO	JIT					Start			
MTS	Forecasting							Start	

Table 2 Supply chain stages and related performance aspects

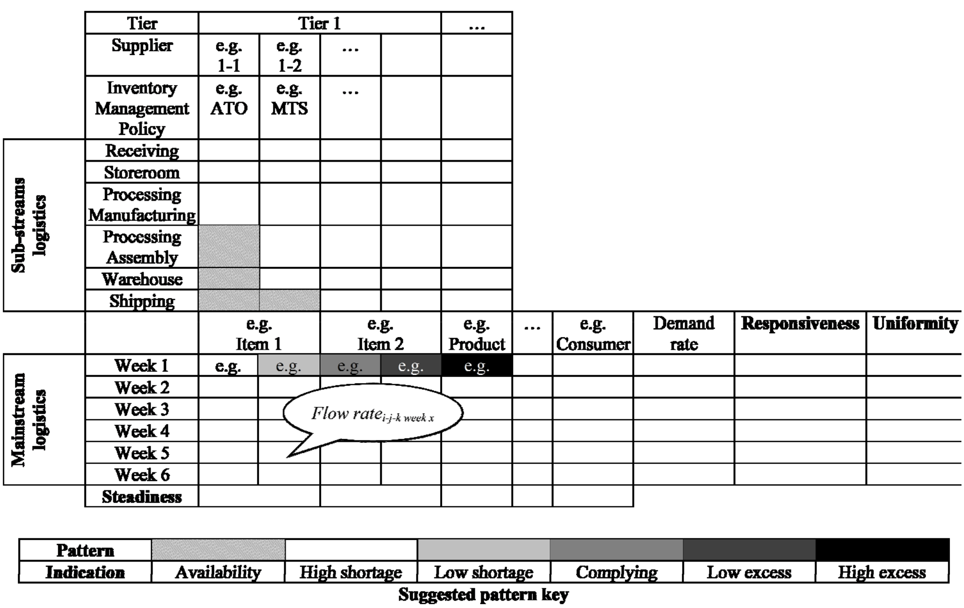
Stage in the supply chain	*Performance related aspect/s*
Sub-streams logistics (suppliers internal)	Order fulfilment approaches and the inventory management policies
Mainstream logistics (external among suppliers)	Flow quality and quantity

According to the above discussion, the proposed approach will target to capture the two stages of flow logistics in a supply chain; the sub-streams logistics (the order fulfilment) and the mainstream logistics in its attempt to manage delivery flow and its responsiveness. The two stages and the related performance aspects are presented in Table 2. This formulation is to lead to the structuring of the proposed tool in the next section.

4 Structuring the SCFD tool

The proposed tool structure is to include an upper section representing the sub-streams logistics and a lower section representing the mainstream logistics. As discussed earlier, responsiveness can be used as a delivery flow performance measure relating to the quantity in the context of its match with the expectation. Adapting from the Spatial Value Stream Map and discussions in Nounou (2015, 2018) including the flow rate as well as the flow uniformity and steadiness, the proposed supply chain flow dashboard (SCFD) is constructed and presented in Figure 3. The SCFD includes an upper section to provide information about the suppliers (sub-streams logistics) and a lower section to provide information about the delivery flow along the supply chain (mainstream logistics) as well as a visual and quantitative evaluation of the responsiveness, uniformity and steadiness of that flow. The uniformity and steadiness are aimed here to reflect the quality of the flow.

Figure 3 Supply chain flow dashboard



In the upper section, the cells representing the sub-streams activities/logistics can be hatched and/or include characteristic quantities (if available) reflecting the availability of items at each stage. In the lower section, the uniformity and steadiness will represent flow quality attributes where the uniformity relates to the consistency of flow rate of the different items (levelling) at a specific time interval along the supply chain stream and steadiness relates to the consistency of the flow rate of a specific item along intervals of time.

Adapted from Nounou (2018), the flow steadiness and uniformity will be evaluated as follows:

- The flow of an item is the flow of the total of this item provided by all suppliers. The steadiness of this flow (item steadiness) is equal to the number of time intervals transitions where the delivery flow rate maintains its magnitude within a designated threshold as a +/– percentage (steady time intervals transitions) divided by the total number of time intervals transitions as a percentage. The item steadiness is calculated as follows:

$$\text{Item steadiness} = \frac{\text{number of steady time intervals transitions}}{\text{total numberof time intervals transitions}}, \% \qquad (1)$$

  Additionally, flow steadiness can be evaluated for a single supplier for the purpose of supplier evaluation for example.

- The flow uniformity will be evaluated at each time interval and considered as uniform delivery if the flow rate maintains its magnitude within an designated threshold as a +/– percentage for all items flow rates otherwise, the flow at this time interval is considered as not uniform. Accordingly, the percentage difference between the highest and lowest item flow rates at this time interval will be calculated and compared to the threshold. This percentage difference will be calculated as follows:

$$\begin{aligned}&\text{Percentage difference between the highest and}\\ &\text{lowest item flow rates at timeinterval x} = \qquad (2)\\ &\frac{(\text{highest item Flow rate}_{\text{time x}} - \text{lowest item Flow rate}_{\text{time x}})}{\text{lowestitem Flow rate}_{\text{time x}}}, \%\end{aligned}$$

- The overall steadiness can be calculated as an average among all supply stages and the overall uniformity as the number of time intervals with uniform flow divided by the total number of time intervals and both represented as percentages. They are calculated as follows:

$$\text{Overall steadiness} = \frac{\text{sum of the item steadiness}}{\text{total number of items}}, \% \qquad (3)$$

$$\text{Overall uniformity} = \frac{\text{number of uniform time units}}{\text{total number of time units}}, \% \qquad (4)$$

Responsiveness in the developed SCFD will be evaluated for the supply stream at each time interval through dividing the delivery flow rate to customers by the customers' desired demand rate and expressing it also as a percentage as follows:

$$\text{Responsivenesstime x} = \frac{\text{Flow rate time x}}{\text{Demand rate time x}}, \% \qquad (5)$$

The discrepancy in responsiveness is going to result in either congestions or oppositely insufficient supply that can induce operational disturbances and result in associated cost change. To enhance visual management, the cells in the SCFD representing the flow rate are provided with patterns reflecting the compliance with (or the deviation from) the required flow rate.

In addition to the upper and lower sections of the proposed SCFD, an improvement protocol is suggested to augment the SCFD. The protocol simply requires supply chain managers to set a specific steadiness, uniformity and/or responsiveness target levels and in case of performance discrepancy, the protocol directs these managers to areas of improvements depending on the type, location and magnitude of that discrepancy. It is important to note that the suggested protocol is generic rather than specific to ensure in addition to usefulness, the applicability to wide range of supply chain industries. The algorithm of the improvement protocol is outlined as follows:

If: Responsiveness ≠100% (or designated threshold)

Then: Explore supply stream inefficiency source (which echelon has Responsiveness discrepancy)

Then: Take/suggest sub-stream order fulfilment corrective action (e.g., adjust inventory, capacity scaling, internal process improvement, multiple supplier policy…etc.)

Else: Alternative sourcing or demand management

If: Uniformity ≠ 100% (or designated threshold)

Then: Explore supply stream discrepancy source(s)

Then: Take/suggest sub-stream order fulfilment corrective action similar to the responsiveness issue, eliminate flow barriers, explore logistics losses and/or improve integration/coordination among echelons

Else: Alternative sourcing or explore supplier alliance and/or vertical integration options

If: Steadiness ≠ 100% (or designated threshold)

Then: Explore stream delivery disruption source(s)

Then: Take/suggest order fulfilment corrective action similar to the responsiveness issue

Else: Alternative sourcing or modify inventory policies (order quantity, weeks of supply and safety stock)

5 Application of the proposed SCFD

This section attempts to demonstrate the proposed supply chain delivery flow modeling approach in a case-context and examines to what extent the empirical findings correspond to the conceptual framework of SCFD discussed earlier. Literature points to the importance of multi-case in case study research, particularly for validating concepts (see for e.g., Eisenhardt, 1989; Yin, 1989). For that purpose, a manufacturing supply chain as well as an agriculture supply chain are both used to illustrate the validity and applicability of the proposed SCFD modelling approach.

Supply chain for PC manufacturing case study

The first case study captures a PC Assembly company that is adopting a sub-stream (internal) policy of assemble to order (ATO) supply chain approach to fulfil customer orders. The PC assembly line involves simple assembly of the main components (motherboard with mounted processor, power supply, CD/DVD in addition to other peripherals) into the case and then after testing, the PC is packed with other cables and materials. ABC Company received an order from a government agency to deliver PCs for schools as part of a national program. The contract was for 1,000 PC/month (demand rate). Each PC required the following main components quantities (based on the BOM) and the number of their suppliers that are shown in Table 3.

Table 3 PC BOM and number of suppliers in the considered ABC case

Component	*Quantity*	*No. of suppliers*
Power supply	1	2
Motherboard	1	1
CD/DVD	1	1
Case	1	2
Packaging	1	1

Table 4 tracks the supply delivery of the different components to ABC over a period of 6 months as well as the production rate of PCs realised by the company using the lower section of the proposed SCFD. The MRP engineer designated deliveries with responsiveness discrepancy of +/–10% or more of the required volume as bad performing supplier delivery while those with discrepancy less than 10% as average delivery performance (only those with 0% discrepancy are rated as good delivery performance). The thresholds used for uniformity and steadiness determination were relaxed to 15% acknowledging the complexity of electronics supply chain.

Table 4 highlights some of the supply chain delivery responsiveness issues especially due to non-optimal uniformity flow performance while relatively minor issues regarding steadiness are noticed. The second power supply supplier scored 80% in steadiness performance (as an individual supplier) but the whole supply of the power supply as an item achieved a steadiness of 100%. The same happened with the case supply. On the other hand, the uniformity of the supply chain performance was hurt due to suppliers' delivery performance in early months. In these months, the difference between the case supply and at least one of other items was beyond the 15% acceptable uniformity level. It is also interesting to note that the responsiveness metric was impacted by the flow stability performance. The company failed to deliver the full required volume on time in four instances while experiencing extra inventory in the last month (which will be used to clear the backlogged PCs in previous months). The SCFD with extra columns for showing the detailed calculations is provided in the Appendix.

Table 4 SCFD mainstream logistics application to the considered ABC case

		Power Supply		*Case*		*Motherboard*	*Packaging*	*CD/DVD*	*PCs*	*Demand rate*	*Responsiveness*	*Uniformity*
		Supplier P-1	*Supplier P-2*	*Supplier C-1*	*Supplier C-2*							
	Target quantity	*500*	*500*	*500*	*500*	*1,000*	*1,000*	*1,000*	*1,000*			
Mainstream logistics	Month 1	500	500	600	600	980	1,000	990	970	1,000	97%	Not uniform
	Month 2	500	500	600	600	980	1,000	990	980	1,000	98%	Not uniform
	Month 3	450	500	550	600	980	1,000	995	960	1,000	96%	Not uniform
	Month 4	490	500	570	500	1,000	1,000	997	1,000	1,000	100%	Uniform
	Month 5	470	600	580	500	1,000	1,000	1,000	990	1,000	99%	Uniform
	Month 6	500	600	600	500	1,000	1,000	1,000	1,010	1,000	101%	Uniform
	Steadiness	100%	80%	100%	80%	100%	100%	100%	100%			Overall uniformity = 3 / 6 = 50%
		100%		100%		100%	100%	100%	100%			
		Overall steadiness = average among all items = 100%										

Pattern	< 90%	≥ 90%, < 100%	100%	> 100%, ≤ 110%	> 110%
Indication	High shortage	Low shortage	Complying	Low excess	High excess

Following the improvement protocol suggested in SCFD, the company needs to pay attention to many of their suppliers' order fulfilment policies. For example, they can work with some of them to improve their yield and/or scale up their capacity (like in the case of the first power supplier). The company can also improve steadiness by adjusting some of their current purchasing practices including reducing their order quantities from some of the oversupplying supplier (like the supplier 2 of the PC cases) or redistributing the order quantities among suppliers (more from supplier 2 and less from supplier 1 of power supply). It is also clear that to improve uniformity of the delivery flow, some effort needs to be put (e.g., planning and technology usage) to better integrate the delivery levelling (time and quantity) among suppliers on a monthly basis.

It is worth noting here, that monitoring responsiveness rate on the SCFD will help avoiding a situation where maintaining a steady and uniform delivery flow occurs at the expense of low capacity utilisation (consistent on time small deliveries by suppliers)

Supply chain for strawberry processing case study

The second case study captures a typical strawberry supply chain adopted from Mohib and Ahmed (2020). The first stage in this supply chain is the farming (or growing) stage with yield variation due to factors like weather, pests, workers availability and harvest cycle uncertainties. The second stage is processing (postharvest) with capacity uncertainties that are function in labor and machinery availability. The following stage is distribution with supply risks associated to typical cold chain problems like pallet damage, transportation delays and temperature control. The final stage is typically at the retailer with expected final volume fluctuations due to factors like handling and quality control. The considered supply chain is shown in Figure 4.

Figure 4 Strawberry supply chain stages (see online version for colours)

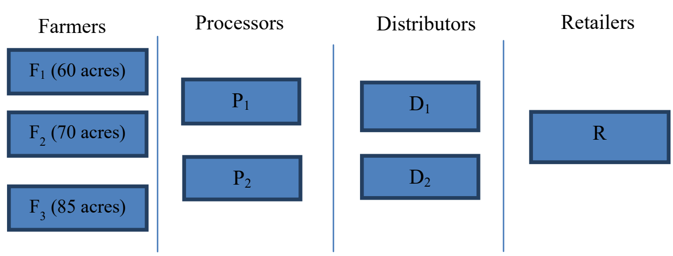


Table 5 tracks the supply delivery of the different stages of the strawberry supply chain in Central California for a specific giant retailer who orders 5 million pounds per season over a period of 10 seasons using the lower section of the proposed SCFD. The retailer designated deliveries with responsiveness discrepancy exceeding +/– 15% of the required volume as bad performing supplier delivery while those between 5–15% discrepancies as average delivery performance (only those between 0–5% discrepancies are rated as good delivery performance). As for the uniformity and steadiness threshold, it was also set at 15% acknowledging the general high lose rate in agriculture supply chains as well as their short life sensitivity.

Table 5 SCFD mainstream logistics application to the considered strawberry supply chain

		Farming (in million lb) avg. yield/acre is: 25,000 Ib/season 3 farms considered			*Processing (in million lb) 2 processors*		*Distribution (in million lb) 2 agents*		*Retail (in million lb) received*	*Demand rate (in million lb) 5M/Ib*	*Responsiveness*	*Uniformity*
		Farm 1	*Farm 2*	*Farm 3*	*Processor 1*	*Processor 2*	*Agent 1*	*Agent 2*				
	Target quantity	*1.4*	*1.5*	*2.1*	*2.5*	*2.5*	*2*	*3*	*5*			
Mainstream logistics	Season 1	1.5	1.7	2.2	2.2	3			5	5	100%	Uniform
	Season 2	1.5	1.7	2.2	2.2	3			5	5	100%	Uniform
	Season 3	1.5	1.8	2.2	2.2	3	2.1	2.9	5	5	100%	Uniform
	Season 4	1.5	1.7	2.2	2.2	3	2.1	2.9	5	5	100%	Uniform
	Season 5	1.2	1.7	2.2	2.2	2.5	2.1	2.4	4.5	5	90%	Uniform
	Season 6	1.2	1.4	2.2	2.2	2.5	2.2	2.5	4.5	5	90%	Uniform
	Season 7	1.6	1.7	2.2	2.5	2.5	2.3	2.45	4.75	5	95%	Not uniform
	Season 8	1.5	1.7	2.2	2.5	2.5	2.3	2.45	4.75	5	95%	Uniform
	Season 9	1.5	1.7	2.2	2.5	2.5	2.2	2.3	4.5	5	90%	Not uniform
	Season 10	1.5	1.7	2.2	2.5	2.5	2.2	2.3	4.5	5	90%	Not uniform
	Steadiness	78%	78%	100%	100%	89%	100%	89%	100%			Overall uniformity = 7 / 10 = 70%
			100%		100%		100%					
		Overall steadiness = average among all items = 100%										

Pattern	< 85%	≥ 85%, < 95%	≥ 95%, ≤ 105%	> 105%, ≤ 115%	> 115%
Indication	High shortage	Low shortage	Complying	Low excess	High excess

Source: Adopted from Mohib and Ahmed (2020)

The delivery flow analysis from Table 5 shows that the strawberry delivery responsiveness had a performance that ranged between good and average in most cases. It is also shown that the supply chain suffers from uniformity issues mainly due to the downstream distribution stage. Looking at the steadiness of the delivery flow, the supply chain is performing well within the designated 15% threshold. The SCFD with extra columns for showing the detailed calculations is provided in the Appendix.

These SCFD scores will guide the supply chain management for example at the retailer stage while using the proposed delivery flow improvement protocol to come up with clear improvement policies. To fix the delivery distribution steadiness issues, more effort need to be directed towards downstream logistics. This is very true due to the limited shelf life of strawberry as well as the challenges of the cold chain requirements for this type of fruits. The low uniformity scores for some seasons suggest that policies are needed to cope with the seasonal impact. Risk analysis is required to mitigate these scenarios were seasonal disruption affects delivery uniformity. The supply chain managers can also investigate reducing the 15% threshold to improve waste efficiency. In addition, uniformity can be improved through alternative sourcing as well as some demand management practices.

The above case studies demonstrated the applicability of the proposed SCFD. The case analysis point to the ease and usefulness of this flow approach to manage delivery in different types of supply chains. Furthermore, monitoring the suggested delivery flow indicators would help supply chain practitioners to look in the right direction to ensure that suppliers are delivering in full and on time in a seamless levelled pattern. It was also shown that SCFD can be applied for different time scales as in the first case study a weekly time scale was used while in the second case study a seasonal time scale was used. It is noted that the sub-streams logistics (upper part) of the tool was not used in the two case studies as it requires deeper knowledge of each of the suppliers' internal dynamics. It is however important to mention that it can be used in a simplified way as in Figure 3 as a guide for the applied inventory or other sub-streams order fulfilment management policies.

6 Discussion and future scope

The developed SCFD approach aims at decreasing the complexity of supply chain's delivery management using a lean thinking approach. In attempting to do so, it adopts a flow perspective to capture and manage deliveries along the whole supply chain streams. As lean managers strive to streamline the flow through ensuring value stream levelling using Heijunka tool, supply chain managers will strive to stabilise the delivery flow among suppliers using SCFD tool. The stability in this context refers to the delivery flow's steadiness and uniformity capturing both spatial and temporal dimensions of that flow.

The impact of lean thinking adoption on the proposed approach is also seen in the close similarity between the SCFD and some elements of TOC (theory of constraints). As the underpinning objective of TOC is to capture the constraints that slow down the flow in a system and then manage that constraint to improve efficiency, the improvement protocol of the SCFD follows the same route and determines where the flow stability issues are and accordingly offers directions to manage these issues. Both approaches are grounded on the belief that every complex system, including supply chain delivery system, consists of multiple linked flows, one of which acts as a constraint upon the entire system. The best managing approach then is to capture that limiting flow and resolve (streamline) it.

The management use of the SCFD can be both direct and indirect. Examples of direct usage include supporting the operation of the supply chain through monitoring the static (structural) and dynamic (behavioural) delivery performance and improving it. Another direct usage would be in supplier evaluation and how to improve supplier flow's integration to the main supply chain stream. Indirect usages will involve some insights during the design phase of future (or improved) supply network through considering quality of the flow as an integral factor of the design process. This can include examining different settings for the three SCFD metrics' thresholds (responsiveness, steadiness and uniformity). These settings examination can be function in industry benchmarking, suppliers' relationship or combination of other managerial parameters. In addition, the SCFD can play a role in the planning activity in a prognostic way (studying future scenarios) or in diagnostic way (involving current or historical delivery data). Possible SCFD utilisation is summarised in Table 6.

Table 6 Possible utilisation of the SCFD

	Utilisation time scope		
	Past (historic)	*Present (current)*	*Future (in advance)*
Designing a Supply Chain (SC)		X	X
Evaluating the (static and dynamic) performance of a SC	X	X	
Improving the performance of the SC		X	X
Supplier evaluation	X	X	
Supplier performance improvement		X	X

A critical element to complete the SCFD discussion relates to cost. Although cost was not within the focus of the proposed dashboard, some cost elements of the delivery flow can be captured through a suggested relevant metric named as Responsiveness Deficiency. This cost metric captures the discrepancy between the required delivery flow level and the actual one and then relates it to either the holding cost of the resulted inventory (if the deficiency is positive – overflow) or the backlog cost (if the deficiency is negative – underflow). The suggested cost metric is outlined in equations (6) and (7) and would be applied to each echelon to determine the impact of delivery deficiency on each echelon's cost as well as the overall flow cost. As in all supply chain cost analysis, it is challenging to figure out the exact holding and backlog costs at each echelon which is highly dependent on the type of the product and industry.

$$\text{Responsiveness deficiency}_{\text{i}-\text{j time x}} = \text{Flow rate}_{\text{i}-\text{j time x}} - \text{Required flow rate}_{\text{i}-\text{j time x}}, \% \tag{6}$$

$$\begin{aligned} &\text{Responsiveness deficiency cost}_{\text{i}-\text{j time x}} = \\ &(\text{Flow rate}_{\text{i}-\text{j time x}} - \text{Required flow rate}_{\text{i}-\text{j time x}}) \\ &\times \text{Lost opportunitycost or Holding cost, } \% \end{aligned} \tag{7}$$

It is important also to acknowledge the limitation of the proposed SCFD tool. By the intentional design of the tool and aiming at simplicity, it has a specific focus on the delivery flow as the main management perspective for supply chain. Practitioners who would disagree on that and have higher emphasise on other supply chain dimensions, would see this as an inclusion limitation. Limitation also includes the need for detailed supplier order fulfilment data to utilise the upper section of the SCFD, and such data in many cases are not available especially as the distance between upstream and downstream gets larger.

Future work can address some of these limitations and will explore how to include other flow related metrics that can address different supply delivery aspects without compromising on the simplicity and applicability objectives. Furthermore, there is a need to have more case applications to investigate how the SCFD would play out in different industries. A sensitivity analysis to decide on the optimal threshold settings for the metrics on the SCFD can open further insights for the management impact of the new approach.

7 Summary

The paper proposed a new approach to manage the entire supply chain delivery using a flow analysis perspective along with an intervention protocol. Adopting lean thinking that focus on flow streamlining, a SCFD management tool was developed. The tool balances between simplicity and usefulness through offering a visual dashboard that captures delivery flow's steadiness (i.e.. consistency) and uniformity (levelling). Furthermore, the dashboard accounts for responsiveness level in terms of matching the required demand to ensure high service level performance. Finally, the tool is augmented with a management protocol that utilises the data on the dashboard to suggest corrective sub-streams order fulfilment policies and actions that will streamline the mainstream delivery flow at high responsiveness level.

The SCFD was applied to data from two case studies in the manufacturing and the agriculture supply chain industries. Results demonstrated the applicability of the tool and its ability to guide managers to improve the supply chain delivery flow. Further discussion about the tool usability and limitations was also presented.

The proposed approach is an attempt to add to the growing field of supply chain performance's literature. The main contribution of the developed tool is to challenge the current complexity resulting from the wide inclusion of multiple metrics through offering a flow perspective that can manage the supply chain responsiveness (on time and in full). This by no means suggests that the proposed SCFD is to replace the current supply chain performance metrics and tools, but rather offer managers and practitioners a frontline primary tool that can simply manage the delivery performance and open the door (and complement) for next level and deeper supply chain performance assessment.

References

Afonso, H. and do Rosário Cabrita, M. (2015) 'Developing a lean supply chain performance framework in a SME: a perspective based on the balanced scorecard', *Procedia Engineering*, Vol. 131, pp.270–279, doi: 10.1016/j.proeng.2015.12.389.

Berger, S.L.T., Tortorella, G.L. and Frazzon, E.M. (2018) 'Simulation-based analysis of inventory strategies in lean supply chains', *IFAC-Papers OnLine*, Vol. 51, No. 11, pp.1453–1458, doi: 10.1016/j.ifacol.2018.08.310.

Bortolotti, T., Romano, P., Martínez-Jurado, P.J. and Moyano-Fuentes, J. (2016) 'Towards a theory for lean implementation in supply networks', *International Journal of Production Economics*, Vol. 175, pp.182–196.

Cudney, E. and Elrod, C. (2011) 'A comparative analysis of integrating lean concepts into supply chain management in manufacturing and service industries', *International Journal of Lean Six Sigma*, Vol. 2, No. 1, pp.5–22.

Eisenhardt, K.M. (1989) 'Building theories from case study research', *Acad. Management Review*, Vol. 14, No. 4, pp.532–550.

Grassi, A., Guizzi, G., Santillo, L.C. and Vespoli, S. (2020) 'A semi-heterarchical production control architecture for Industry 4.0-based manufacturing systems', *Manufacturing Letters*, Vol. 24, pp.43–46, doi: 10.1016/j.mfglet.2020.03.007.

Hou, H., Chaudhry, S., Chen, Y. and Hu, M. (2017) 'Physical distribution, logistics, supply chain management, and the material flow theory: a historical perspective', *Information Technology and Management*, Vol. 18, No. 2, pp.107–117, doi: 10.1007/s10799-015-0229-1.

Jones, D. and Womack, J. (2019) *Seeing the Whole Value Stream*, The Lean Enterprise Institute, Inc., MA, USA, ISBN-13: 978-1-934109-32-8.

Lamming, R. (1996) 'Squaring lean supply with supply chain management', *International Journal of Operations & Production Management*, Vol. 16, No. 2, pp.183–196.

Machado Guimarães, C. and Crespo de Carvalho, J. (2013) 'Strategic outsourcing: a lean tool of healthcare supply chain management', *Strategic Outsourcing: An International Journal*, Vol. 6, No. 2, pp.138–166.

Maestrini, V., Luzzini, D., Maccarrone, P. and Caniato, F. (2017) 'Supply chain performance measurement systems: a systematic review and research agenda', *International Journal of Production Economics*, Vol. 183, pp.299–315, doi: 10.1016/j.ijpe.2016.11.005.

Manzouri, M., Ab-Rahman, M.N., Zain, C.R.C.M. and Jamsari, E.A. (2014) 'Increasing production and eliminating waste through lean tools and techniques for halal food companies', *Sustainability*, Vol. 6, No. 12, pp.9179–9204.

Mohib, A.M.N. and Deif, A.M. (2020) 'Supply chain multi-state risk assessment using universal generating function', *Production Planning & Control*, doi:10.1080/09537287.2019.1680891.

Nounou, A. (2015) 'Development of a spatial value stream map (SVSM)', Paper presented at the *IIE Engineering Lean and Six Sigma Conference 2015*, Atlanta, GA, USA, 30 September to 2 October.

Nounou, A. (2018) 'Developing a lean-based holistic framework for studying industrial systems', *Production Planning & Control*, doi: 10.1080/09537287.2018.1517422.

Ortega-Jimenez, C.H., Garrido-Vega, P. and Torres, C.A.C. (2020) 'Achieving plant responsiveness from reconfigurable technology: intervening role of SCM', *International Journal of Production Economics*, Vol. 219, pp.195–203, doi: 10.1016/j.ijpe.2019.06.001.

Soltan, H. and Mostafa, S. (2015) 'Lean and agile performance framework for manufacturing enterprises', *Procedia Manufacturing*, Vol. 2, pp.476–484, doi: 10.1016/j.promfg.2015.07.082.

Stevenson, W.J. (2009) *Operations Management*, 10th ed., McGraw-Hill/Irwin, New York.

Tortorella, G.L., Miorando, R. and Marodin, G. (2017) 'Lean supply chain management: empirical research on practices, contexts and performance', *International Journal of Production Economics*, Vol. 193, pp.98–112.

Yin, R.K. (1989) *Case Study Research – Design and Methods*, 2nd ed., illustrated, revised; SAGE Publications Inc., Thousand Oaks, CA, USA, ISBN 9780803934702.

Appendix

Table A1 Calculations for the ABC case

		Power supply						*Case*						*Motherboard*		*Packaging*		*CD/DVD*		*PCs*							
		Supplier P-1		*Supplier P-2*		*Total*		*Supplier C-1*		*Supplier C-2*		*Total*		*Total*		*Total*		*Total*		*Total*		*D*	*Responsiveness*	*Highest total*	*Lowest total*	*Ratio (highest / lowest)*	*Uniformity*
		Q (target = 500)	*r*	*Q (target = 500)*	*r*	*Q (target = 1,000)*	*r*	*Q (target = 500)*	*r*	*Q (target = 500)*	*r*	*Q (target = 1,000)*	*r*	*Q (target = 1,000)*	*r*	*Q (target = 1,000)*	*r*	*Q (target = 1,000)*	*r*	*Q (target = 1,000)*	*r*						
Mainstream logistics	Month 1	500		500		1,000		600		600		1,200		980		1,000		990		970		1,000	97%	1,200	970	*1.24*	Not uniform
	Month 2	500	1.00	500	1.00	1,000	1.00	600	1.00	600	1.00	1,200	1.00	980	1.00	1,000	1.00	990	1.00	980	1.01	1,000	98%	1,200	980	*1.22*	Not uniform
	Month 3	450	0.90	500	1.00	950	0.95	550	0.92	600	1.00	1,150	0.96	980	1.00	1,000	1.00	995	1.01	960	0.98	1,000	96%	1,150	950	*1.21*	Not uniform
	Month 4	490	1.09	500	1.00	990	1.04	570	1.04	500	*0.83*	1,070	0.93	1,000	1.02	1,000	1.00	997	1.00	1,000	1.04	1,000	100%	1,070	990	1.08	Uniform
	Month 5	470	0.96	600	*1.20*	1,070	1.08	580	1.02	500	1.00	1,080	1.01	1,000	1.00	1,000	1.00	1,000	1.00	990	0.99	1,000	99%	1,080	990	1.09	Uniform
	Month 6	500	1.06	600	1.00	1,100	1.03	600	1.03	500	1.00	1,100	1.02	1,000	1.00	1,000	1.00	1,000	1.00	1,010	1.02	1,000	101%	1,100	1,000	1.10	Uniform
	Steadiness	100%		80%		100%		100%		80%		100%		100%		100%		100%		100%							Overall uniformity = 3 / 6 = 50%

Overall steadiness = average among all items = 100%

Pattern	< 90%	≥ 90%, < 100%	100%	> 100%, ≤ 110%	> 110%
Indication	High shortage	Low shortage	Complying	Low excess	High excess

Note: Q: quantity, r: ratio (month i+1 / month i), D: demand

Table A2 Calculations for the strawberry supply chain case

	Farming (in million lb) avg. yield/acre is: 25,000 lb/season 3 farms considered								*Processing (in million lb) 2 processors*						*Distribution (in million lb) 2 agents*						*Retail (in million lb) received*		*D*	*Responsiveness*	*Highest*	*Lowest*	*Ratio*	*Uniformity*
	Farm 1		*Farm 2*		*Farm 3*		*Total*		*Processor 1*		*Processor 2*		*Total*		*Agent 1*		*Agent 2*		*Total*		*Total*							
	Q (target = 1.4)	*r*	*Q (target = 1.5)*	*r*	*Q (target = 2.1)*	*r*	*Q (target = 5)*	*r*	*Q (target = 2.5)*	*r*	*Q (target = 2.5)*	*r*	*Q (target = 5)*	*r*	*Q (target = 2)*	*r*	*Q (target = 3)*	*r*	*Q (target = 5)*	*r*	*Q (target = 5)*	*r*						
Mainstream logistics Season 1	1.5		1.7		2.2		5.4		2.2		3		5.2		2.1		2.9		5		5		5	100%	5.4	5	1.08	Uniform
Season 2	1.5	1.00	1.7	1.00	2.2	1.00	5.4	1.00	2.2	1.00	3	1.00	5.2	1.00	2.1	1.00	2.9	1.00	5	1.00	5	1.00	5	100%	5.4	5	1.08	Uniform
Season 3	1.5	1.00	1.8	1.06	2.2	1.00	5.5	1.02	2.2	1.00	3	1.00	5.2	1.00	2.1	1.00	2.9	1.00	5	1.00	5	1.00	5	100%	5.5	5	1.10	Uniform
Season 4	1.5	1.00	1.7	0.94	2.2	1.00	5.4	0.98	2.2	1.00	3	1.00	5.2	1.00	2.1	1.00	2.9	1.00	5	1.00	5	1.00	5	100%	5.4	5	1.08	Uniform
Season 5	1.2	*0.80*	1.7	1.00	2.2	1.00	5.1	0.94	2.2	1.00	2.5	*0.83*	4.7	0.90	2.1	1.00	2.4	*0.83*	4.5	0.90	4.5	0.90	5	90%	5.1	4.5	1.13	Uniform
Season 6	1.2	1.00	1.4	*0.82*	2.2	1.00	4.8	0.94	2.2	1.00	2.5	1.00	4.7	1.00	2.2	1.05	2.5	1.04	4.7	1.04	4.5	1.00	5	90%	4.8	4.5	1.07	Uniform
Season 7	1.6	*1.33*	1.7	*1.21*	2.2	1.00	5.5	1.15	2.5	1.14	2.5	1.00	5	1.06	2.3	1.05	2.45	0.98	4.75	1.01	4.75	1.06	5	95%	5.5	4.75	*1.16*	Not uniform
Season 8	1.5	0.94	1.7	1.00	2.2	1.00	5.4	0.98	2.5	1.00	2.5	1.00	5	1.00	2.3	1.00	2.45	1.00	4.75	1.00	4.75	1.00	5	95%	5.4	4.75	1.14	Uniform
Season 9	1.5	1.00	1.7	1.00	2.2	1.00	5.4	1.00	2.5	1.00	2.5	1.00	5	1.00	2.2	0.96	2.3	0.94	4.5	0.95	4.5	0.95	5	90%	5.4	4.5	*1.20*	Not uniform
Season 10	1.5	1.00	1.7	1.00	2.2	1.00	5.4	1.00	2.5	1.00	2.5	1.00	5	1.00	2.2	1.00	2.3	1.00	4.5	1.00	4.5	1.00	5	90%	5.4	4.5	*1.20*	Not uniform
Steadiness	78%		78%		100%		100%		100%		89%		100%		100%		89%		100%		100%							Overall uniformity = 7 / 10 = 70%

Overall steadiness = average among all items = 100%

Pattern	< 85%	≥ 85%, < 95%	≥ 95%, ≤ 105%	> 105%, ≤ 115%	> 115%
Indication	High shortage	Low shortage	Complying	Low excess	High excess

Notes: Q: Quantity, r: Ratio (Season i+1 / Season i), D: Demand rate (in million lb) 5M/lb

Source: Adopted from Mohib and Ahmed (2020)