

Please cite as (this is a post-print version):

Moazzam, M., Akhtar, P., Garnevska, E., and Marr, N (accepted 16th August 2018). Measuring agri-food supply chain performance and risk through a new analytical framework: a case study of New Zealand dairy, *Production, Planning and Control*.

Measuring agri-food supply chain performance and risk through a new analytical framework: a case study of New Zealand dairy

ABSTRACT

Many researchers and practitioners have long recognized the significance of measuring performance. Although general guidelines for measuring business performance are widely available, not appropriate measurement frameworks have been developed for measuring agri-food supply chain performance. Particularly, food quality and risk-related indicators have not been well integrated in existing performance measurement systems. Our research therefore addresses this knowledge gap by first providing an in-depth review on extant performance measurement systems and frameworks. It then develops an analytical framework by extending the Supply Chain Operations Reference (SCOR) model, which has been extensively implemented across non-food industries. The analytical framework is further validated by utilising a case study of 50 farmers and 10 dairy companies, operating in the New Zealand dairy industry.

Our pilot testing and subsequent findings show that the individual metrics interlocked with the analytical framework are in-line with the key industrial practices adapted by the New Zealand dairy industry. In addition, the framework is flexible and scalable to evaluate and benchmark other agri-food supply chains — ranging from fresh products such as fruits and vegetables to processed foods such as canned fruits. The findings further show that the detailed information required for measuring the level-3 SCOR metrics is not easily available in the industry, as researchers need to access specific company records that may be confidential. Consequently, this study provides how agri-food supply chain managers can employ our new analytical framework in-conjunction with the SCOR model for a deeper understanding of the complicated performance measurement indicators applied in their agri-food production systems and relevant supply chains.

KEYWORDS

Performance measurement frameworks; measuring agri-food supply chain performance and risk; literature review; case study of New Zealand dairy; SCOR model

1. Introduction

Measuring supply chain performance has gained remarkable attention recently (e.g. Luning, Marcelis, and Jongen 2002, Aramyan et al. 2007, Widyaningrum and Masruroh 2012, PMA 2016, Govindan, Mangla, and Luthra 2017). There are many reasons for this attention such as benchmarking against supply chain competitors, dynamics of contemporary supply chains, increasing competition, international quality standard requirements, demanding customers, and fast-changing information technology. Importantly, performance measurement systems are more challenging for agri-food supply chains because they are unique and different from general supply chains due to their distinguishing characteristics such as perishability, short shelf life, production seasonality, variability in quality and quantity, long production throughput time, and specialized transportation requirements (Van der Vorst 2000). Additionally, some agri-food supply chains carry highly perishable commodities such as milk, fresh fruits, and vegetables (Aramyan et al. 2007), which build a very challenging environment for agri-food supply chain managers to maintain the quality and other performance standards. Risk arising from many other factors such as contamination from production processes can be challenging to tackle. Defective and risky products are recalled because of health concerns. Such recalls are costly and damage firms' reputation and service quality (Maruchek et al. 2011). For example, Danone (a French company) cancelled its contract with Fonterra Co-operative Group (the largest dairy in New Zealand, holding more than 96% of the total dairy shares in the country) due the risk of contaminated milk they supplied. Danone consequently claimed NZ\$ 492.9 million compensation against Fonterra. Also, Fonterra recalled its products from France and other international markets. The contamination was caused by a rusty production pipe at its Waikato factory in New Zealand but this operational risks has significantly damaged Fonterra's reputation and service quality as well as risking the reputation of its global supply chain network partners, such as Danone (Tanquintic-Misa 2014).

The performance measurement systems and its indicators (e.g., risk) in agri-food supply chains is therefore complex due to their specific characteristics (Van der Vorst 2000, Van der Spiegel 2004, Aramyan et al. 2006). Crucially, performance measurement systems developed for general supply chains are not suitable for agri-food supply chains, as measurement indicators such as food contamination risks, health risks, and many other seasonal factors are different than the ones used in general supply chains. While we acknowledge that many researchers (Neely, Gregory, and Platts 1995, Beamon 1999, Gunasekaran, Patel, and

McGaughey 2004, Van der Spiegel 2004, Varma and Deshmukh 2009) have investigated against performance measurement criteria (financial and non-financial performance indicators, holistic to entire supply chain, food quality, risk assessment, and environmental sustainability), the performance measurement frameworks (e.g. Supply Chain Council 2010) do not integrate all above mentioned criteria simultaneously and food quality has not been addressed explicitly. Some researchers have succinctly examined risk factors in food supply chains (e.g., Prakash et al. 2017). However, the research gap of intersecting the key risk and quality factors with leading performance models (e.g., SCOR Model) is still limited (Hadiguna and Tjahjono 2017).

In line with this knowledge gap, the contributions of this paper are threefold. Firstly, it conducts an in-depth literature review against the measurement criteria and compares them with the key measurement frameworks, including the risk and quality related literature. Secondly, based on the review and the SCORE model's characteristics, this research develops a comprehensive analytical framework for measuring agri-food supply chain performance. Finally, our framework is validated by applying data collected from 50 farmers and 10 companies operating in the New Zealand dairy industry – the world leading dairy export industry.

Following the introduction, the second section identifies five criteria from the literature on performance measurement in agri-food supply chain management that are helpful in choosing the right set of performance indicators epitomizing the unique characteristics of a supply chain. Section three reviews existing performance measurement systems and frameworks in the context of these five criteria. This leads us to section four that concludes our literature review, explicitly highlights the knowledge gap and introduces an analytical framework for agri-food supply chains. To validate the framework, a case study is presented in section five and the final section concludes this research paper.

2. Performance indicators

The literature on supply chain performance measurement systems is too large and multi-dimensional to develop a clear understanding from all aspects. Ahi and Searcy (2015) reviewed 445 journal articles and reported 2555 performance indicators found in the literature of green and sustainable supply chain management. Given the large number of performance indicators in practice, there is always a possibility that researchers confuse the objectives of evaluations while choosing the right set of performance indicators. In selection of appropriate set of performance indicators, a number of researchers have used a set of criteria to evaluate

existing performance measurement frameworks (Gunasekaran, Patel, and Tirtiroglu 2001, Beamon 1999, Neely, Gregory, and Platts 1995, Varma and Deshmukh 2009, Van der Spiegel et al. 2004, Prakash et al. 2017). For example, Van der Spiegel, et al. (2004) developed a criteria-based approach for the selection of appropriate measurement frameworks for food quality systems. They evaluate performance measurement frameworks against six quality dimensions, namely product quality, availability, costs, flexibility, reliability, and service. The study further uses five criteria namely: financial and non-financial indicators; holistic to entire supply chains; food quality focus; risk assessments; and environmental sustainability in order to evaluate existing performance measurement frameworks and choose the appropriate ones for agri-food supply chains. These criteria are briefly discussed as following. The next section first reviews these generic performance criteria. It then focuses on the key performance measurement frameworks and models. By combining the various indicators and models, it finally proposes an analytical framework for agri-food supply chains.

2.1 Financial and non-financial indicators

The most popular criterion used by the researchers in the past to select a balanced set of KPIs between financial and non-financial indicators. Numerous researchers (e.g. Beamon 1999, Holmberg 2000, De Toni and Tonchia 2001, Van Aken and Coleman 2002, Chan 2003, Gunasekaran, Patel, and McGaughey 2004, Van der Vorst 2006, Vanteddu, Chinnam, and Yang 2006, Aramyan et al. 2007) emphasize to maintain the balance between financial and non-financial indicators for performance measurement systems. For instance, Beamon (1999) claimed that traditional supply chain performance measurement systems heavily focus on financial measures as a primary (if not sole) criterion. Gunasekaran et al. (2001) further emphasized that supply chains relying purely on financial or operational aspects, depriving themselves of the benefits that would accrue from adapting a balanced approach. To support, Van der Vorst (2006) suggests that a balanced set of food supply chain indicators must be considered, which include total value added activities, return on investment, chain business processes, lead time, responsiveness, inventory levels, delivery reliability, product quality, process efficiency, degree of utilization, human wellbeing, and future perseverance.

2.2 Holistic to entire supply chain

The second criterion advocates the use of cross-industry performance indicators, spanning the entire supply chain. A holistic approach aligns the performance of individual firms with other partners in a supply chain. As agri-food supply chains consist of cross-industry processes

involving different players, it needs to keep the whole system united by including all supply chain partners. In such multi-echelon food chains, individual firms strive to achieve their own goals that might be conflicting with overall supply chain goals. Thus, the use of a single firm performance indicator results in local optimization that is not aligned with the whole chain. Researchers (e.g. Beamon 1999, Lambert and Pohlen 2001, Chan and Qi 2003, Chan 2003, Van der Vorst 2006, Vanteddu, Chinnam, and Yang 2006) have emphasized the need for a performance measurement system of holistic nature that control the entire supply chain rather than a single firm.

2.3 Food quality focus

Food quality is another criterion, which is an inherent part of agri-food supply chains and must be evaluated at sufficient level of detail. Food quality is a unique characteristic of agri-food supply chains, which distinguishes them from general supply chains. Van der Spiegel, et al. (2004, pp. 505) defined quality as a function “to comply with the expectations of the user or consumer, while the production process is optimally organized, utilized, and controlled”. A number of researchers (e.g. Van der Spiegel et al. 2004, Luning, Marcelis, and Jongen 2002, Aramyan et al. 2006) suggested that a performance measurement system designed for agri-food supply chains must incorporate performance indicators of food quality. Luning et al. (2002) classified food quality into intrinsic and extrinsic quality attributes shown in Table 1.

Insert table 1 near here

Although quality assurance systems such as good manufacturing practices (GMP), Hazard Analysis at Critical Control Points (HACCP, also part of risk assessment), International Organization for Standardization (ISO), and British Retail Consortium (BRC) are helpful for manufacturers in managing business processes but none of them guarantees product quality and safety for customers, thereby creating risk and quality issues (Van der Spiegel et al. 2004). In order to maximise customer value, agri-food product quality must be ensured at each stage along the entire agri-food supply chain. Therefore, the measurement tools must incorporate appropriate performance indicators related to food quality that can also cover risk factors, as Fonterra’s example mentioned in the introduction – linking risk and product quality.

2.4 Risk assessments

Risk assessment is another criterion being an integral part of all the supply chains. Due to the increasing trend of collaboration at global level-extended supply chain networks are

becoming more and more exposed to uncertainty, consequently emphasizing the risk factors to be addressed. Wang, Tiwari, and Chen (2017) classified the sources of uncertainty into three categories: supply, process, and demand. Supply uncertainty stems from the variability of supply, such as the faults or delays in delivery, whereas demand uncertainty is caused by volatile demand. Process uncertainty, however, is a result of unreliable production process, causing risk and safety issues. Inherently, all supply chains are prone to a various types of risk. A comprehensive typology of risk at supply chain level given by McCormack et al. (2008) is shown in Figure 1.

Insert figure 1 near here

A number of other researchers have also highlighted the escalating importance of supply chain risk assessments. For examples, Tummala and Schoenherr (2011) introduced a supply chain risk management process (SCRMP) to help SC managers to identify, assess, evaluate, and control risk in supply chain performance. Similarly, in an attempt to measure risk in agri-food supply chains, Leat and Revoredo-Giha (2013) organized performance indicators related to risk into individual stages as well as supply chain levels. Moreover, Zubair and Mufti (2015) identified eighteen risk perspectives in dairy product supply chains and developed a risk matrix to prioritize the risk perspectives.

Risk management in supply chain context has been under researched. There is a substantial amount of literature on performance measurement frameworks focusing solely on risk management in supply chain (Wagner and Bode 2008, Tummala and Schoenherr 2011, Leat and Revoredo-Giha 2013, Zubair and Mufti 2015, Wang, Tiwaria, and Chen 2017, Prakash et al. 2017). These frameworks usually aim at developing approaches for identification, assessment, analysis, and the treatment of vulnerable areas in a supply chain (Wang, Tiwari, and Chen 2017). However, performance measurement systems with risk assessment as part of an overall analytical frameworks are limited (Hadiguna and Tjahjono 2017). When assessing supply chain risk, the researchers record causes, probability, and consequences for each event that may have a detrimental impact on return on investment. There is a continuous debate on the selection of performance indicators that are comprehensive enough to span over the hierarchical levels of management as well as holistic enough to stretch across the inter-firm process of a supply chain.

2.5 Environmental sustainability

To measure the environmental sustainability of a supply chain is yet another criterion of recent importance (Akhtar et al. 2017). The recent literature is rich of performance indicators on sustainability in agri-food supply chains. For example, Rota et al. (2012) provided a theoretical framework of life cycle analysis for measuring collaboration and sustainability at various stages of an agri-food supply chain. Manzini and Accorsi (2013) proposed a conceptual framework to integrate supply chain designs and management for simultaneously controlling quality, safety, sustainability, and logistics efficiency of food products and processes. Van der Vorst et al. (2013) and Akhtar et al. (2015) used triple bottom line framework to assess the sustainability of global food supply chains. Bourlakis, et al, (2014) integrated performance indicators related to efficiency, flexibility, responsiveness, and product quality to develop an integrated performance measurement system for measuring SC sustainability in the Greek dairy sector. They believed that the large dairy manufacturers in Greece are true champions of sustainability and their guidelines can be used for further developments in agri-food measurement systems.

The above-mentioned five criteria epitomize performance measurement in agri-food supply chains. The subsequent section provides review of performance measurement frameworks in line with these criteria.

3. Review on performance measurement systems and frameworks

As discussed above the performance indicators and measurement frameworks found in the literature on supply chain management are too many to develop a clear understanding and select an appropriate one. Performance measurement frameworks can be broadly categorised into solitary or hybrid. The solitary frameworks include the original piece of work such as Activity Based Costing (ABC), the Balanced Scorecard (BSC), and the Supply Chain Operations Reference (SCOR) Model, among others. Hybrid frameworks, on the other hand, are developed by integrating (partially or wholly) two or more solitary frameworks into a new framework, thereby overcoming the weaknesses of solitary framework. The examples of such developments include hybrid frameworks developed by Bullinger et al. (2002), Pohlen (2003), Aramyan et al. (2006), Reiner and Hofmann (2006), Yao and Liu (2006), Bhagwat and Sharma, (2007b), Thakkar et al. (2009), and Widyaningrum and Masruroh, (2012). However, a common problem with the use of these frameworks is the weak synchronization between metrics from two different contexts. Both solitary and hybrid frameworks are going to be presented and reviewed later in this section.

Although the literature on general supply chain performance measurement systems has reached its maturity, the frameworks developed to evaluate agri-food supply chains are limited (Hadiguna and Tjahjono 2017, Prakash et al. 2017). In order to find an analytical framework for agri- food supply chains, commonly used performance measurement systems are reviewed against the aforementioned performance criteria. Performance measurement frameworks are first reviewed under classification given by Ramaa et al. (2009). Ramaa et al. (2009) categorised supply chain performance measurement systems into function-based measurement systems (FBMS), dimension-based measurement systems (DBMS), the supply chain balanced scorecard (SCBS), hierarchical-based measurement systems (HBMS), interface based measurement systems (IBMS), perspective-based measurement systems (PBMS), and the supply chain operations reference model (SCOR), which are discussed in the following sections.

3.1 Function-based measurement system

Christopher (1995) introduces a framework called activity based costing to evaluate the performance of individual functions. The framework is useful to consolidate the cost drivers of manufacturing functions. This model heavily relies on financial indicators and evaluates each function in isolation, which leads towards functional optimization at the cost of entire chain performance (Lapide 2000). In other words, the model is only suitable when functional performance is needed to be optimized (Ramaa, Rangaswamy, and Subramanya 2009).

3.2 Dimension- based measurement system

Many researchers (e.g. Neely, Gregory, and Platts 1995, Beamon 1999, Van der Vorst, Beulens, and van Beek 2000, Aramyan et al. 2006, Aramyan et al. 2007, Joshi et al. 2012, Akhtar et al. 2015) view supply chain performance measurement as a combination of dimensions; agility, quantitative, qualitative, quality, cost, flexibility, responsiveness, financial, non-financial, time, and innovativeness. For example, Aramyan et al. (2006) introduced a conceptual framework for measuring the performance of agri-food supply chains. They critically reviewed Activity Based Costing (ABC), the Balanced Scorecard (BSC), Economic Value Added (EVA), Multi-Criteria Analysis (MCA), Life-Cycle Analysis (LCA), Data Envelopment Analysis (DEA), the Supply Chain Operations Reference (SCOR) Model, and organized performance indicators especially adapted from the SCOR model and BSC (efficiency, flexibility, responsiveness, and quality), as shown in Figure 2.

Insert figure 2 near here

Aramyan et al. (2007, 2009) validated this model by applying empirical data from the tomato supply chain headquartered in Netherlands. The framework mainly focused on food quality in agri-food supply chains, although environmental sustainability was implicitly measured as part of the process quality.

To identify key performance attributes (KPA) and key decision factors (KDF) in evaluating cold chains and implementing continuous improvement, Joshi et al. (2012) introduced a framework comprising of performance measures grouped as cost, quality, safety, traceability, service aspects, return on assets, innovativeness, and relationships. This framework is helpful to facilitate decision makers in quantifying performance indices and to understand complex relationships among relevant cold chain attributes. It comprises of a comprehensive set of performance indicators, following a balanced and holistic approach. Moreover, it adequately focuses food quality in cold chains but does not consider risk assessments and environmental sustainability. Widyaningrum and Masruroh (2012) also introduced a hybrid framework to evaluate the sea fishery supply chain in terms of efficiency, flexibility, responsiveness, food quality, facility, and government involvements. This framework is based on the SCOR model and the study conducted by Aramyan et al. (2007), which adheres to food quality and environmental sustainability in agri-food chains but does not address the risk assessments that are important parts of agri-food supply chains. This leaves a significant gap in measuring agri-food chain performance.

3.3 Supply chain balanced scorecard

Kaplan and Norton (1992) introduced the Balanced Scorecard (BSC) as a decision making tool for managers. As depicted in Figure 3, it maintains a balance between financial and non-financial performance measures and aligns them with organizational strategy (Kaplan and Norton 1996, Lapidé 2000, Varma and Deshmukh 2009). However, it does not provide adequate assistance for the process of designing a performance measurement system and competitive benchmarking (Neely, Gregory, and Platts 1995, Varma and Deshmukh 2009). Moreover, the BSC does not provide a holistic view spanning entire supply chains, rather it captures the performance of individual firms (Gilmour 1999, Lapidé 2000, Lambert and Pohlen 2001, Aramyan et al. 2006), again a clear knowledge gap to address.

Insert figure 3 near here

Researchers have succinctly tried to link the balanced scorecard to supply chain performance measurement systems. For example, Brewer and Speh (2000) developed a

supply chain performance measurement framework based on Balanced Scorecard. They integrated appropriate inter-functional and inter-firm level performance measures related to SCM goals, customer benefits, financial benefits, and SCM development. Bhagwat and Sharma (2007b) also conducted a review of SCM performance metrics and distributed them into four balanced scorecard perspectives. Moreover, Varma and Deshmaukh (2009) identified and tried overcoming three major shortcomings of the balanced scorecard in measuring supply chain performance. However, the shortcomings are a) the balanced scorecard does not define the relative importance of metrics, b) it does not allow benchmarking with competitors, and c) it does not allow dissimilar metrics to be combined. Bigliardi and Bottani (2010) further included food quality-related performance measures to a BSC based-framework developed by Bhagwat and Sharma (2007b) to evaluate agri-food supply chains. To some extent, Bigliardi and Bottani (2010) provided further directions to integrate different performance measurement aspects.

3.4 Hierarchical-based measurement systems

A hierarchical-based measurement system (HBMS) comprises of performance measures related to various levels of organizational hierarchies such as strategic, tactical, and operational. Numerous researchers have developed HBMSs to evaluate supply chains (Rangone 1996, Van der Vorst 2000, Gunasekaran, Patel, and Tirtiroglu 2001, Gunasekaran, Patel, and McGaughey 2004). For example, Li and O'Brian (1999) developed a model to measure and improve efficiency and effectiveness at different supply chain levels under four criteria; profit, lead time performance, delivery promptness, and waste elimination. At chain levels, assumptions associated with the criteria are set for each SC stage, so that the SC performance can meet the customer service targets and the best SCM strategy is selected. At operations levels, manufacturing and logistics activities are optimised under given targets. This model is balanced and holistic in nature. Consequently, it helps in evaluating and integrating decision making to assess potential partners in supply chains.

Gunasekaran et al. (2001) also introduced a framework for measuring supply chain performance at strategic, tactical, and operational levels. In addition to three hierarchical levels, performance indicators are classified into financial and non-financial indicators. Table 2 describes supply chain metrics framework given by Gunasekaran et al. (2004).

Insert table 2 near here

Bhagwat and Sharma (2007a) viewed that the framework given by Gunasekaran et al. (2001) is helpful in selecting appropriate metrics and costing methods at different levels in an organization. Additionally, Gunasekaran et al. (2004) extended the HBMS developed by Gunasekaran et al. (2001) to link these performance metrics to four SCOR processes: plan, source, make, and deliver that mainly constitute a supply chain.

In order to develop a performance measurement system for meat supply chain in Iran, Fattahi et al. (2013) considered six criteria related to the unique characteristics of agri-food supply chains. These are: financial, quality, safety, customer service, efficiency, flexibility, and chain coordination. The framework has been structured around the balanced scorecard and uses Delphi techniques to allocate selected performance indicators at strategic and tactical levels, thus making it of hierarchical nature. Although the majority of HBMSs are balanced, holistic, and focus on food quality, they do not consider risk assessments and environmental sustainability.

3.5 Interface-based measurement systems

Lambert and Pohlen (2001) developed a framework to align the performance of each link within the supply chain. This link-by-link approach looks at the supply chain as a series of different interfaces and aims to optimise the performance at individual links as well as the supply chain as a whole. The framework given by Lambert and Pohlen (2001) has been appreciated by the researchers for a variety of reasons. For example, Pohlen (2003) highlighted that the performance of individual functions or interfaces can be used to demonstrate supply chain collaboration outcomes. Gaiardelli et al. (2007) also admired Lambert and Pohlen's framework for its usefulness in managing relationships with suppliers and customers at each link in the supply chain.

3.6 Perspective-based measurement systems

A substantial number of researchers measure supply chain performance from one or more perspectives (Gerbens-Leenes, Moll, and Uiterkamp 2003, Otto and Kotzab 2003, Li et al. 2005, Yakovleva 2007, Leat and Revoredo-Giha 2013, Van der Vorst, Peeters, and Bloemhof 2013, Wiengarten and Longoni 2015, Zubair and Mufti 2015). For example, Otto and Kotzab (2003) developed a framework to measure supply chain performance from six possible perspectives; system dynamics, operations research, logistics, marketing, organizational, and strategy. According to Hofmann (2006), this framework can be employed to identify standard problems, their possible solutions, and most importantly to optimize the trade-off of measures

among the perspectives based upon the perceived dominance of perspectives in a supply chain. Whereas, Papakiriakopolous and Pramatarı (2010) argued that the existence of different perspectives makes it difficult to identify the significance of different areas of performance measurement systems.

Gerbens-Leenes, Moll and Uiterkamp (2003) introduced a framework for measuring environmental sustainability across the multi-echelon food supply chain. Li et al. (2005) developed a measurement instrument for studying supply chain management practices from six possible perspectives including strategic supplier partnership, customer relationship, information sharing, information quality, internal lean practices, and postponement. Yakovleva (2007) also proposed a set of sustainability indicators to measure the effects of the multi-echelon food supply chain and tested the model using empirical data collected from British chicken and potato supply chains. Moreover, Van der Vorst et al. (2013) presented a framework for food supply chain logistics including drivers, strategies, performance indicators, metrics, and improvement opportunities. They evaluated 17 Dutch food & drinks companies and logistic service providers using this framework. Leat and Revoredo-Giha (2013) examined ASDA's Pork-Link supply chain and identified key risks and challenges involved in developing a resilient agri-food supply system. They particularly focused primary product supply and how risk management and collaboration amongst stakeholders can increase supply chain resilience - reducing risk aspects.

Additionally, Zubair and Mufti (2015) identified eighteen risk perspectives in Pakistani dairy supply chain and developed a risk matrix based on probability and impact scores in order to prioritize these risk perspectives. Wiengarten and Longoni (2015) also investigated 90 Indian manufacturing companies to assess the impact of supply chain integration on operational, environmental, and social sustainability. They found that a coordinated outward integration has a positive impact on several operational and sustainability performance dimensions, whereas a collaborated outward integration provided significantly higher benefits, mainly on the flexibility and sustainability performance dimensions compared to other collaborated integration strategies.

Although above discussed frameworks are holistic but they are not balanced in nature, as by definition, they aim at evaluating generic perspectives of supply chain performance.

3.7 Supply chain operations reference model (SCOR)

The supply chain operations reference (SCOR) model is a standard process-based measurement system developed by Supply Chain Council (Stewart 1997). The model is

structured around five supply chain processes namely Plan, Source, Make, Deliver, and Return with four levels of the process detail. The performance indicators are organized under five attributes; reliability, responsiveness, agility, cost, and asset. Overall, SCOR model is more comprehensive as compared to other frameworks due to its extensive lists of well documented 589 metrics organised at the levels of process details. Its performance attributes maintain balance between financial and non-financial metrics. Five cross-industry processes exemplify the holistic nature of the SCOR model. It is noteworthy that the SCOR metrics are diagnostic in nature; Level-1 metrics are strategic and diagnostic for overall performance of a supply chain, whereas level-2 metrics are diagnostic for level-1 metrics and level-3 metrics are diagnostic for level-2 metrics.

The model, after release of its first version in 1996, has undergone several updates in attempting to improve the previous versions. For example, the performance measures related to risk assessments and environmental sustainability are only present in its 10th or later versions. However, it assumes but does not sufficiently addresses food quality, which is an important component of agri-food supply chains (Aramyan et al. 2006). Simatupang and Sridharan also (2004) believe that the SCOR model is the most suitable for performance measuring and benchmarking in supply chains due to its comprehensiveness and standard processing and metric definitions, which enable companies to evaluate and improve performance at individual as well as entire supply chain levels.

Many other researchers have also used the SCOR model to quantify supply chain performance at cross-industry process levels (Stewart 1997, Huang, Sheoran, and Keskar 2005, Hwang, Lin, and Lyu 2008, Irfan et al. 2008, Millet, Schmitt, and Botta-Genoulaz 2009, Liu 2009, Li, Su, and Chen 2011, Jamehshooran, Shaharoun, and Haron 2015). Irfan et al. (2008) discussed SCOR-based supply chain management systems developed by Pakistan Tobacco Company to optimise its cross-country management processes. They believe that their system is scalable to any enterprise's unique process configurations. Liu (2009) used SCOR model to examine the effect of implementing ISO/TS-16949 on supply chain performance of Taiwanese companies. Li, Su and Chen (2011) tested and validated the SCOR model by evaluating the integration of quality assurance in five supply chain processes, each of which having positive impacts on both customer-facing SC quality performance and internal-facing firm-level performance. Jamehshooran, Shaharoun, and Haron (2015) also found positive effects of implementing the SCOR model on supply chain performance in Iranian companies.

The SCOR model is a popular tool for designing and simulating of supply chain processes. Persson et al. (2012) combined the SCOR model and discrete-event simulation to design supply chain processes. They reported that comprehensive and well-documented SCOR metrics enable faster model building for ERP-systems. Earlier, Millet, Schmitt, and Botta-Genoulaz (2009) critically analysed and reviewed SCOR Version 7 according to its contribution to the alignment of business processes and information systems. They developed an alignment reference model based on SCORE Version 7 that supports a more efficient ‘multi-view’ methodology of business process mapping, especially for ERP-implementation projects.

4. Theoretical conclusions, knowledge gap and our analytical framework for agri-food supply chains

As can be observed from Table 3, none of performance measurement systems integrate all five criteria simultaneously, which is the research gap this study attempts to bridge. This section proposes a SCOR model based analytical framework and discusses its five performance attributes in detail. Table 3 summarises the review of frequently used performance measurement systems. By comparing the early discussed literature (i.e. section 2) and the Ramaa et al. (2009)’s categorization, we concluded that a framework satisfying all the five performance criteria should qualify for a performance measurement system in agri-food supply chains, particularly risk and quality factors in agri-food supply chains need more attention.

Insert table 3 near here

The choice of right measurement tools very much depends upon the type of products and the nature of problems that a researcher is going to address. The previous section reveals that the literature on supply chain performance measurement systems lacks specific frameworks fulfilling performance criteria for agri-food supply chains. This research gap needs to be bridged by developing a framework comprising of performance measures that epitomise agri-food supply chains. Although the literature review highlights that the SCOR model (version 10.0 and later) qualifies some important aspects of agri-food supply chains, it does not explicitly address food quality and its risk (Aramyan et al. 2006). For this reason, the model needs to be modified by incorporating relevant food quality metrics and risk aspects (Prakash et al. 2017). Considering the literature (Key examples, Luning, Marcelis, and Jongen 2002, Aramyan et al. 2007, Widyaningrum and Masruroh 2012) and the SCOR model attributes, we proposed an analytical framework that integrates food quality/risk and bridges the potential

research gap. Figure 4 presents a schematic diagram of the proposed framework. This diagram is interconnected with the metrics listed in Table 4. Also, Food quality and risk aspects mentioned in Figure 4 corresponds with the highlighted metrics in Table 4 (i.e. underneath level-3 metric and connecting to the level 1 metric, reliability).

Insert figure 4 near here

The SCOR model provides a balanced set of KPIs between customer-focused attributes (reliability, responsiveness, and agility) and internal-focused attributes (cost and asset). Table 4 presents selected attributes and relevant SCOR metrics for the proposed analytical framework for agri-food supply chains. *Reliability* represents to the ability to perform tasks as expected (perfect conditions of the orders fulfilled). As such, SCOR metrics related to *Quality* and environmental sustainability come under this category. To address food quality in agri-food supply chains, six metrics are added at level-3 under the reliability attribute. *These metrics focus at food safety and health, shelf life (freshness), and sensory properties (taste, odour, colour, appearance, texture, and sound), convenience (ease of use), and product reliability (compliance to product composition and nutritional information), and process quality (presence of quality assurance systems).* Environmental sustainability is an overall measure of environmental compliance, waste processing, and ISO-14000 certification of suppliers.

Insert table 4 near here

Responsiveness refers to the speed at which tasks are performed, whereas *Agility* describes the ability to respond to external influences and the ability to change. The SCOR model measures agility in terms of flexibility, adaptability, and *value at risk - which needs more research work to fulfil the specific aspects for agri-food supply chains. The SCOR risk management is about identification, assessment, and mitigation of potential disruptions - whereby its strategic level KPI is value at risk (VAR) that is further disintegrated at tactical levels of Plan, Source, Make, Deliver, and Return. Thus, our framework significantly contributes in both food quality and risk aspects – contributed to the knowledge gap.* The cost attribute in the SCOR model describes the costs of operating processes: labour costs, material costs, and transportation costs. The asset attribute refers to the efficiency and effectiveness of asset utilization measured in terms of cash-to-cash cycle time, return on fixed assets, and return on working capital.

5. Case study for validation: the New Zealand dairy industry

5.1 Industry background

To validate our proposed analytical framework, the New Zealand dairy industry was selected because of the following reasons. First, not enough research has been conducted in this industry (Akhtar et al. 2015). Second, this industry plays important role not only locally but also globally. For instance, New Zealand is the 8th largest milk producing country with global share of 4.4% (USDA 2015). Its dairy industry is predominantly an export business with only less than 5% of production consumed domestically whereas the remaining 95% is exported, which accounts for 40% share of the total global dairy trade (Fonterra 2015). The indicators presented in Table 5 reinforce that New Zealand's share of global dairy trade outweighs its share of production. Moreover, with 23.3% share of the total exports, the dairy industry is the largest contributor to New Zealand's GDP (Statistics New Zealand 2015).

Insert table 5 near here

Additionally, the New Zealand dairy industry is a unique example of vertically integrated value chains. Cooperative form of ownership structure is predominant, whereby farmers control about 92% of the dairy industry in the form of three cooperatives namely Fonterra, Westland, and Tatua (Coriolis 2014). New Zealand dairy farmers are comparatively low cost producers with no subsidies from the government. Table 6 shows a comparison of the key indicators of the dairy farms in top dairy product-exporting countries. Truly operating at economies of large scale, New Zealand dairy farms have largest herd sizes as compared to others.

Insert table 6 near here

The dairy cooperatives in coordination with other organizations such as Dairy NZ and Federated Farmers provide various services to support dairy farmers. These services include: annual farm dairy and environmental assessment; milk quality support; milk temperature management; mastitis support; animal health and welfare; effluent management; nitrogen management and water waste management. These services are designed to address environmental and food safety requirements that assist dairy farmers in meeting regulatory requirements. Figure 5 presents a flow diagram of the dairy value chain (Commerce Commission New Zealand 2013).

Insert figure 5 near here

In this case study, dairy farmers and dairy companies were selected as key operators in the dairy supply chain of New Zealand. Dairy farming, milk collection and primary processing, secondary processing, and exports are all predominantly cooperative enterprises represented by dairy farmers and dairy companies. The dairy supply chain is vertically integrated right from the farm input provision through to retailing and/or exporting.

5.2 Method and samples

Cross-sectional data from 50 dairy farms and 10 dairy companies was collected through an internet survey. The geographical location of respondent dairy farms is given in Table 7. The survey was conducted using services provided by Qualtrics (www.qualtrics.com).

Insert table 7 near here

Before the main data collection, semi-structured interviews with 3 dairy farmers and 2 dairy companies’ directors were conducted to pilot test the items/questions. The purpose was to see whether individual questions are in line with their operations or not. Moreover, the purpose was to analyse whether or not the dairy supply chain partners, namely dairy farmers and dairy companies, keep adequate information as part of their routine record keeping in order for us to be able to compute SCOR metrics and the measure used in our framework? It was learnt during the pilot testing that information required to compute level-1 and level-2 metrics was readily available from the dairy farmers and companies. However, information required to compute level-3 metrics was not readily available, without accessing the companies’ confidential records, which is a limitation for this research.

The SCOR metrics (as shown in table 4) related to attributes of reliability, responsiveness, cost, and asset management require objective information, however, the “agility” attribute that mainly evaluates the impact of risk and supply chain disruptions is based on subjective judgements. There are four strategic level KPIs that represent agility amongst them “upside supply chain flexibility” and “value at risk” are used the most. The upside supply chain flexibility metric represents the ability (in minimum number of days required) of their business entity to fulfil an unusual increase in demand on sustainable basis. This unusual increase in demand is mainly caused by supply chain disruptions, natural disasters, and discrete events that are linked with risk management, highlighting the important of our framework and its applications for the formers (see Figure 4). However, value at risk (VAR) metrics is very complicated to compute and requires information from five level-2 KPIs, namely VAR-Plan, VAR-Source, VAR-Make, VAR-Deliver, and VAR-Return. The typical

enabled-processes used to retrieve information from their enterprise systems for value at risk KPIs is given in Figure 6. To have access to information in such details, we first needed to implement the SCOR-based performance management system. It was also learnt during the pilot testing of the framework that it was neither necessary nor feasible for the dairy farmers to maintain record of such details, which further contributed to the knowledge gap. The dairy framers reported that no major risk specific KPIs were currently being used for decision making at their farms, however, they use financial indicators such as changes in return on investment, return on equity, operating profit, milk prices, and debt to asset percentage as indirect tools for risk assessments. They were optimistic that using strategic value at risk metrics from our framework would be helpful for them in forward planning of their business operations.

Insert Figure 6 near here

To ensure the validity of the information used to compute the SCOR metrics, the respondents were asked to consult their records of at least five years and provide subjective values for agility related metrics. To compute “Value at Risk” metrics, the respondents were asked to give a subjective judgement in percentage of time their business underperformed their set targets. They were asked to provide a future value at 95% confidence level, a usually used statistical confidence level. Their response was based on their previous performance and experiences in terms of dealing with supply chain disruptions and a subjective judgement about the future prospects. Moreover, it includes the number of time monetary impacts of the individual events. The dairy companies, on the other hand, reported of using a wide range of sophisticated risk assessment and mitigation tools including value at risk, integrated in our framework.

Following the pilot testing, the analytical model and questionnaires were calibrated in line with current practices of supply chain partners; dairy farmers and dairy companies in this case. The selection of KPIs at strategic, tactical, and operational level was made in accordance with availability of information and record keeping practices of the respondents. For this case study, we selected supply chain reliability related KPIs to operational level (up to level-3), supply chain responsiveness, cost, and asset related KPIs to tactical level (up to level-2), and agility related KPIs to strategic level (up to level-1), as shown in table 4.

5.3 Findings and validation

The SCOR metrics of research participants (New Zealand dairy farmers and dairy companies) are given in Table 8. Based on the results of pilot testing and feedback from the respondents SCOR metrics at strategic (level-1), tactical (level-2) and operational (level-3) levels were selected in accordance with readily available information from the respondents. One major assumption of SCOR framework is to retrieve information from enable process (as shown in figure 6), which is only possible after implementation of SCOR model as performance management system. Notwithstanding questionnaires designed required information from financials and routine recodes of any business organization.

Perfect order fulfilment represents the percentage of orders meeting delivery performance with complete and accurate documentation and no delivery damages. In order to calculate perfect order fulfilment for dairy farmers and dairy companies, three level-2 and twelve level-3 metrics were selected. Perfect order fulfilment of respondent dairy farmers was higher (99.9%) than respondent dairy companies (96.2%) mainly due to the non-applicability of various metrics on dairy farmers, which again contributed to finding applications in the dairy sector. Moreover, the dairy companies (private as well as farmer-owned cooperatives) reported to conduct regular quality assurance audits of dairy farm premises in addition to the standard operating procedures (SOPs) for milk quality testing. The milk quality testing included all quality attributes such as sensory properties, *Bactoscan*, temperature, and somatic cell count. Also, the regional councils perform yearly environmental audits for the dairy farms. For low quality or hazardous milk, the dairy companies penalize dairy farmers to a certain extent, ranging from demerit points to the value of whole affected milk or loss to the company. The application of these indicators contributes to the importance of frameworks and its links with the SCOR model.

Insert table 8 near here

The order fulfilment cycle time represents the average actual cycle time consistently achieved to fulfil customer orders. For each individual order, this cycle time starts from the order receipt and ends with customer the acceptance of orders. It consists of a ‘gross’ component and a ‘net’ component named order fulfilment process time, according to the following formula:

Order Fulfilment Cycle Time = Order Fulfilment Process Time + Order Fulfilment Dwell Time.

Due to the presence of certain dwell (non-value added) time between two consecutive milking of dairy cows, the order fulfilment cycle time for NZ dairy farmers was the same as their make cycle time. Among the respondent dairy farmers, 86% used to milk dairy animals twice a day, whereas remaining 14% practise once a day milking. The major reason to adapt once a day milking was a higher decrease in logistics cost than milk production, and the balancing between environmental risk and higher productivity. The mean value of order fulfilment cycle time of respondent dairy farmers was 33.7 hours, which helps to reduce environmental risks due to additional productivity.

On the other hand, order fulfilment cycle time of dairy companies represented source, make, deliver, and cycle times. The source cycle time of dairy companies depends on geographic distance between the point of milk production and processing plants, and the number of milk collections per day. The respondents were also asked for average time from the dairy farms to processing plants. The milk collection frequency of dairy companies is dependent on dairy seasons and milk volume produced at each dairy farm. During the peak season, milk was collected 'twice a day' from large dairy farms and 'once a day' from small dairy farms, whereas during the off-peak season 'once a day' from large dairy farms and once in two days from small dairy farms. The source cycle time for 'once a day' milk collection was reported as 24 hours and for 'once in two days' milk collection 48 hours - again trying to reduce the logistics runs contributing to environmental aspects. Such schedules also help them to improve milk quality and reduce health-related risk that could be caused by the poor quality of milk.

The agility attribute describes the ability to respond to external influences and the ability to change. To measure supply chain agility, two level-1 metrics (upside supply chain flexibility and value at risk) and relevant level-3 metrics were selected. The upside supply chain flexibility refers to the ability to fulfil unusual increase in demand on sustainable basis. As dairy companies in New Zealand are required by the law to collect all the milk produced by its member farmers, therefore this metric was not applicable to the New Zealand dairy content, the specific finding again contributing to the knowledge gap. However, dairy companies were quite flexible to any increase in demand of dairy products. The respondents reported that an unusual increase in demand is unrealistic in our dairy sector. Also, the respondents reported that they do respond to any changes in demand for dairy products if required. The upside supply chain flexibility of dairy companies for an unusual increase in demand was 4.5 days.

Value at risk represents the monetary impact of probable risk events. The respondent dairy farmers were asked whether their dairy farms' income was negatively affected by risk factors, 20% reported "no". Those 80% who answered "yes" were asked questions about the number of events they underperformed against set targets. The mean value of the respondent dairy farmers at risk was 13.22%, and the dairy farmers reported two major types of risk affecting their income from dairy. *These are market risk and physical risk. The market risk includes compliance cost in the form of regulations imposed by government and dairy companies, milk price variability, feed price variability, share price variability, exchange rate variability, and higher interest rates.*

The physical risks include drought, floods, animal diseases and employee diseases such as eczema. Among the physical risks, summer drought was the biggest risk factor reported by almost all of the dairy farmers as it affected grass production, resulting low productivity per animal or higher supplement feed costs. The risk management strategies reported by the selected dairy farmers include: early culling; good feed management so yield per animal does not go down; maintaining buffer stock of imported/brought-in supplement feed such as palm kernel; feed maize silage; fertilize and irrigate during drought; stick to operational plan/regularity in feeding cows; split calving to reduce exposure to weather conditions; and efficient farm management especially during calving and mating seasons.

On the other hand, the mean value at risk of respondent dairy companies was 23.6%. The respondents mentioned that their business performance is being affected by various risk factors *including fluctuations in milk supply (mainly due to weather and seasonality), foreign exchange risk, interest rate risk, credit risk, liquidity risk, capital risk, and dairy product price risk.*

The cost attribute describes the cost of operating the processes. It includes labour costs, material costs, and transportation costs. The SCOR level-1 metrics include supply chain management (SCM) costs and cost of goods sold (COGS). The SCM cost refers to the sum of costs to plan, source, make, deliver, return, and mitigate risk. The COGS represents operating expenses such as direct labour, direct , and indirect production related costs. It is noteworthy here that there is a redundant overlap in 'cost to make' and cost of goods sold. Production related costs account for cost of goods sold. In the case of dairy farmers in New Zealand, SCM costs represent administrative expenses, consultation costs, transportation costs, risk mitigation costs, and other overhead costs (such as cooperative membership fees and compliance costs). The mean values of SCM costs as percentage of supply chain revenue of respondent dairy farmers and dairy companies were 14.6% and 16.5% respectively, whereas

the mean values of COGS as the percentage of supply chain revenue of the dairy farmers and dairy companies were 70.94% and 72.7% respectively. The total cost as percentage of supply chain revenue of New Zealand dairy farmers was 85.46%, which is less than Argentina (85.7%), Australia (92.8%), Canada (115%), and the USA (98%) (Hemme 2015). This clearly demonstrates that how effectively the industry is using the indicators highlighted the performance measurement frameworks.

Return on fixed assets ratio measures the operating profit an organization receives on its invested capital in supply chain fixed assets used in Plan, Source, Make, Deliver, and Return. The dairy farmers and dairy companies had return on fixed assets ratio of 3% and 11% respectively. The major reason for low return on fixed assets ratio is huge capital investment in pasture-based production systems. On the other hand, return on working capital ratio assesses revenue generation from investment in working capital. The mean values of return on working capital of dairy farmers and dairy companies were 40% and 36% respectively.

Above results exemplify successful application of the proposed analytical framework in the New Zealand dairy industry. The strategic level SCOR metrics also show that the key players operating in the milk industry are performing better compared to certain other countries.

6. Conclusion

6.1 Contributions

The performance measurement systems used in agri-food supply chains are complex due to their unique features. Consequently, such systems and their indicators have received considerable attention from researchers and practitioners. However, there are significant gaps in measurement systems/frameworks and their suitability for agri-food supply chains. Particularly, extant measurement systems/frameworks do not explicitly emphasise food quality and risk aspects. This study therefore has especially contributed to these aspects by comprehensively reviewing different performance measurement systems, frameworks and their indicators: 1) financial and non-financial, 2) holistic to entire supply chains, 3) food quality focused, 4) risk assessments and resilience focused, 5) environmental sustainability, 6) function-based measurement system, 7) dimension-based measurement systems, 8) supply chain balanced scorecard, 9) hierarchical-based measurement systems, 10) interface-based measurement systems, 11) perspective-based measurement systems, and 12) supply chain operations reference model. Research shows that more than 2500 performance indicators are rooted in such performance measurement systems and frameworks. Despite such a large

number of measurement systems, frameworks, and their respective indicators, agri-food practitioners have been facing challenges to apply them in terms of controlling food quality, risk and other aspects. Succinctly, our contribution was three-fold: First, we extensively review measurement systems and frameworks, particularly from agri-food industries. This has not been done before, as far as we are aware after this in-depth review. One can easily get confused that why we need another framework after all those already exist. The extensive review fortunately helped to answer this by identifying the specific knowledge gap on food quality and risk measures, which are explicitly integrated in our framework. Second, this study develops the framework that is particularly applicable to enhance food quality and to control risk aspects in agri-food supply chains and productions, though we also tested other relevant indicators as discussed in the case study. Thirdly, we empirically demonstrated that the application of this framework has been utilized in the New Zealand dairy industry, which is one of the world largest sources of dairy exports.

6.2 Implications and limitations

The proposed analytical framework is flexible and scalable to evaluate and benchmark agri-food supply chains, ranging from fresh products such as dairy, fruit, and vegetables to processed foods such as canned fruits – showing the generalisation of findings. This framework is more comprehensive as compared to those commonly found in the literature (see the literature review section for details), as it requires information beyond financial measures available in balance sheets. Importantly, it integrates the prerequisite quality and risk aspects of dairy products. Alternatively, it is equally suitable for micro enterprises even not keeping formal record of their business transactions such as smallholder farmers in developing countries. However, in such cases, reliability of the data is questionable. For one-to-one benchmarking, the SCOR metrics are selected up to level-3, which are selected based specific requirements. In most cases, such detailed information is not readily available. However, for benchmarking, the SCOR metrics up-to-level 2 suffice and the required information is readily available. Our framework is scalable up to level-3 metrics and can be utilised to evaluate and benchmark other agri-food supply chains. Future research may extent its application in other food production systems and relevant supply chains.

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TABLES

Table 1 Quality attributes of food.

Intrinsic Quality Attributes	Extrinsic Quality Attributes
Food safety and health	Production system
Shelf life and sensory properties	Product handling and transportation
Convenience and product reliability	Environmental aspects

Source: Luning et al. (2002)

Table 2 Supply chain metrics framework.

Process	Strategic	Tactical	Operational
Plan	Level of customer perceived value of product, Variances against budget, Order lead time, Information processing cost, Net profit versus productivity ratio, Total cycle time, Total cash flow time, Product development cycle time	Customer query time, Product development cycle time, Accuracy of forecasting techniques, Planning process cycle time, Order entry methods, Human resource productivity	Order entry methods, Human resource productivity
Source		Supplier delivery performance, supplier lead time against industry norm, supplier pricing against market, Efficiency of purchase order cycle time, Efficiency of cash flow method, Supplier booking in procedures	Efficiency of purchase order cycle time, Supplier pricing against market
Make	Range of products and services	Percentage of defects, Cost per operation hour, Capacity utilization, Utilization of economic order quantity	Percentage of Defects, Cost per operation hour, Human resource productivity index
Deliver	Flexibility of service system to meet customer needs, Effectiveness of enterprise distribution planning schedule	Flexibility of service system to meet customer needs, Effectiveness of enterprise distribution planning schedule, Effectiveness of delivery invoice methods, Percentage of finished goods in transit, Delivery reliability performance	Quality of delivered goods, On time delivery of goods, Effectiveness of delivery invoice methods, Number of faultless delivery notes invoiced, Percentage of urgent deliveries, Information richness in carrying out delivery, Delivery reliability performance

Source: Adopted from Gunasekaran et al. (2004)

Table 3 Supply chain performance measurement systems and risk.

Performance Measurement Systems	Balanced	Holistic	Food Quality	Risk Assessment	Environmental Sustainability
A. Function based measurement system					
Christopher (1995)	×	×	×	×	×
B. Dimension based measurement systems					
Van der Vorst et al. (2000)	×	√	√	×	×
Aramyan et al. (2007)	√	√	√	×	√*
Joshi et al. (2012)	√	√	√	×	×
Widyaningrum and Masruroh (2012)	√	√	√	×	√
C. Supply chain balanced scorecard					
Bhagwat and Sharma (2007b)	√	√	√*	×	×
Varma and Deshmukh (2009)	√	√	√*	√	×
Bigliardi and Bottani (2010)	√	√	√	×	×
D. Hierarchical based measurement systems					
Rangone (1996)	√	×	√*	×	√
Li and O'Brien (1999)	√	√	×	×	×
Chan and Qi (2003a)	√	√	√*	×	×
Gunasekaran et al. (2004)	√	√	√*	×	×
Bhagwat and Sharma (2007a)	√	√	√*	×	×
Li et al. (2007)	×	√	×	×	×
Fattahi et al. (2013)	√	√	√	×	√
E. Interface based measurement system					
Lambert and Pohlen (2001)	×	√	×	×	×
F. Perspective based measurement systems					
Otto and Kotzab (2003)	×	√	×	×	×
Gerbens-Leenes et al. (2003)	×	√	×	×	√
Li et al (2005)	×	√	×	×	×
Yakovleva (2007)	×	√	√	×	√
Papakiriakopoulos and Pramataris (2010)	√	√	×	×	×
Van der Vorst et al. (2013)	×	√	×	×	√
Leat and Revoredo-Giha (2013)	×	√	√	√	×
Zubair and Mufti (2015)	×	√	×	√	×
Wiengarten and Longoni (2015)	×	√	√	×	√
G. Supply chain operations reference (SCOR) model					
Irfan et al. (2008)	√	√	√*	×	×
Liu (2009)	√	√	√*	×	×
Millet et al. (2009)	√	√	√*	×	×
Li et al. (2011)	√	√	√*	×	√

The symbols used are: × for “No”, √ for “Yes”, and √* for “Yes, but not sufficient”.

Table 4 Tabular representation of analytical framework for agri-food supply chains.

Attribute	Level-1 Metric	Level-2 Metric	Level-3 Metric
Reliability	RL1.1 perfect order fulfilment	RL2.1 percent orders delivered in full	RL3.33 delivery item accuracy RL3.35 delivery quantity accuracy
		RL2.2 delivery performance to customer commit date	RL3.31 customer commit date achievement time customer received RL3.34 delivery location accuracy
		RL2.4 perfect condition	RL3.14 percent orders meeting environmental performance RL3.24 percentage supplies received with product quality compliance RL3.60 percentage orders fulfilled free of health hazards RL3.61 percentage orders fulfilled with expiry date compliance RL3.62 percentage orders fulfilled with sensory properties compliance RL3.63 percentage orders fulfilled with convenience compliance RL3.64 percentage orders fulfilled with product composition compliance RL3.65 presence of quality assurance system
Responsiveness	RS1.1 order fulfilment cycle time	RS2.1 source cycle time RS2.2 make cycle time RS2.3 deliver cycle time RS2.4 delivery retail cycle time	
Agility	AG1.1 upside SC flexibility		
	AG1.4 value at risk (VAR)	AG.2.15 VAR (Plan) AG.2.16 VAR (Source) AG.2.17 VAR (Make) AG.2.18 VAR (Deliver) AG.2.19 VAR (Return)	
Costs	CO1.1 SCM cost	CO2.1 cost to plan CO2.2 cost to source CO2.3 cost to make CO2.4 cost to deliver CO2.5 cost to return CO2.7 cost to mitigate	
	CO1.2 cost of goods sold		CO3.140 direct labour cost CO3.141 direct material cost CO3.155 indirect cost related to production
Assets	AM1.2 return on fixed assets	AM2.5 fixed assets	
	AM1.3 return on working capital	AM2.9 working capital	

Metrics RL3.24, RL3.60, RL3.61, RL3.62, RL3.63, RL3.64 and RL3.65 represent food quality and are non-SCOR metrics.

Table 5 Global share of top dairy exporters in 2014.

Major Dairy Exporters	Cheese		Butter		Non-Fat Dry Milk		Whole Milk Powder	
	Share of Global Prod. (%)	Share of Global Exports (%)	Share of Global Prod. (%)	Share of Global Exports (%)	Share of Global Prod. (%)	Share of Global Exports (%)	Share of Global Prod. (%)	Share of Global Exports (%)
Argentina	3.08	3.47	0.59	1.60	-	1.17	5.14	6.73
Australia	1.75	9.20	1.23	5.15	4.68	8.73	-	3.79
EU-28	52.27	43.94	23.61	16.49	35.39	34.40	14.62	18.18
New Zealand	1.73	16.94	6.09	64.15	9.02	20.39	29.64	66.50
USA	28.40	22.49	8.84	8.48	23.90	29.07	0.95	0.84

Source: Adapted from (USDA 2015)

Table 6 Key indicators of international dairy farm comparison 2014.

Major Dairy Exporters	Farm Size	*Cost of Production	Milk Price	Milk Yield
	<i>No. of cows/farm</i>	<i>US\$/100 kg milk ECM</i>	<i>US\$/100 kg milk ECM</i>	<i>1000 kgME/cow/year</i>
Argentina	157	33	38.5	6.0
Australia	268	39	42	6.0
Canada	80	84	73	8.6
EU-28	160	n.a.	49	6.8
New Zealand	410	46	48.5	5.1
USA	181	54	55	9.6

* Cost of milk production represents cash costs and opportunity cost only.

Source: Adopted from (Hemme 2015)

Table 7 Geographical location of respondent dairy farms in New Zealand.

Region	Frequency	Percent
Bay of Plenty	6	12.0
Canterbury	3	6.0
Hawkes Bay	2	4.0
Manawatu	15	30.0
Marlborough	2	4.0
Northland	1	2.0
Southland	1	2.0
Taranaki	4	8.0
Waikato	13	26.0
Wellington	3	6.0
Total	50	100

Table 8 Performance metrics for New Zealand dairy supply chain.

Performance Metrics	Dairy Farmers		Dairy Companies	
	Mean	SD	Mean	SD
RL1.1 perfect order fulfilment (%)	99.9	.40	96.2	1.65
RL2.1 percent orders delivered in full (%)	NA	-	98.6	0.80
RL2.2 delivery performance to customer commit date (%)	NA	-	98.9	0.58
RL2.4 perfect condition (%)	99.9	.40	98.7	0.89
RS1.1 order fulfilment cycle time (hours)	33.7	8.70	24.0	20.91
RS2.1 source cycle time (hours)	-	-	8.8	6.25
RS2.2 make cycle time (hours)	33.7	8.70		
Fresh milk			2.3	0.58
Milk powders			12.0	-
Butters and fats			10.0	-
Cheese			14.2	12.30
Others (yoghurt etc.)			16.8	15.52
RS2.3 deliver cycle time (hours)	NA	-		
Ambient dairy			11.2	22.69
Chilled dairy			14.4	14.39
AG1.1 upside supply chain flexibility (days)	NA	-	4.5	3.84
AG1.4 overall value at risk (%)	13.2	14.35	23.6	12.47
CO1.1 supply chain management cost (as % of SC revenue)	14.6	5.02	16.5	8.15
CO1.2 cost of goods sold (as % of SC revenue)	70.9	10.54	72.7	16.37
AM1.2 return on fixed assets (Ratio)	.03	.03	0.11	0.05
AM1.3 return on working capital (Ratio)	.40	.38	0.36	0.28

FIGURES



Figure 1: Typology of Supply Chain Risk

Source: (McCormack et al., 2008)

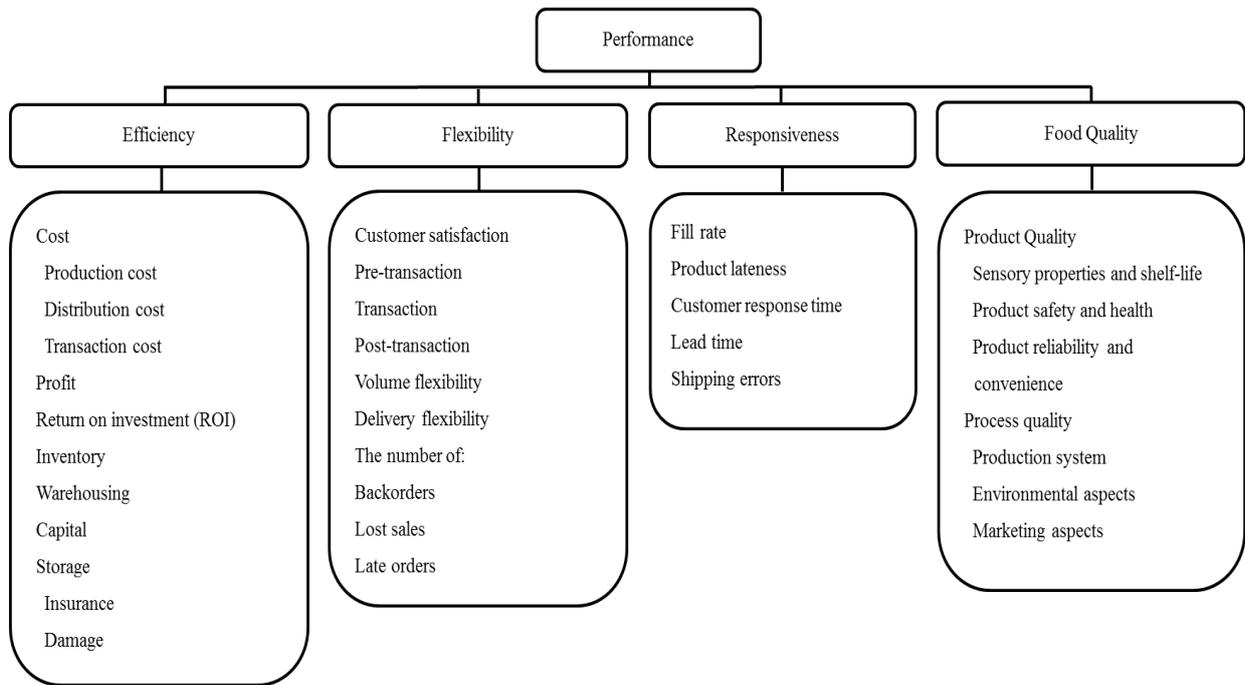


Figure 2 Conceptual Framework for agri-food supply chain performance.

Source: (Aramyan et al., 2006)

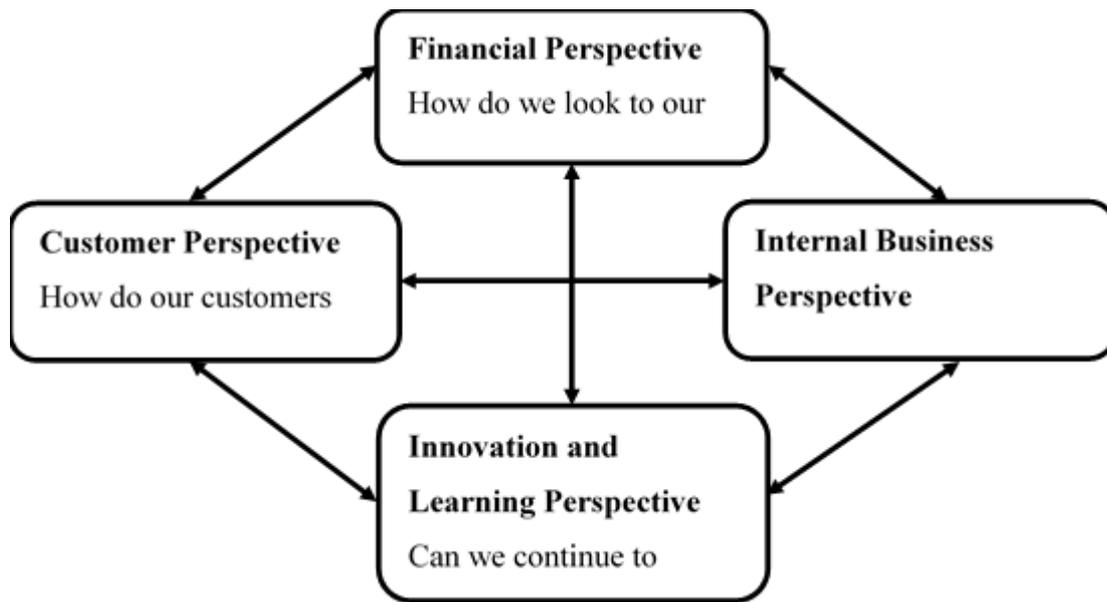


Figure 3 Balanced scorecard.

Source: (Kaplan and Norton, 1992)

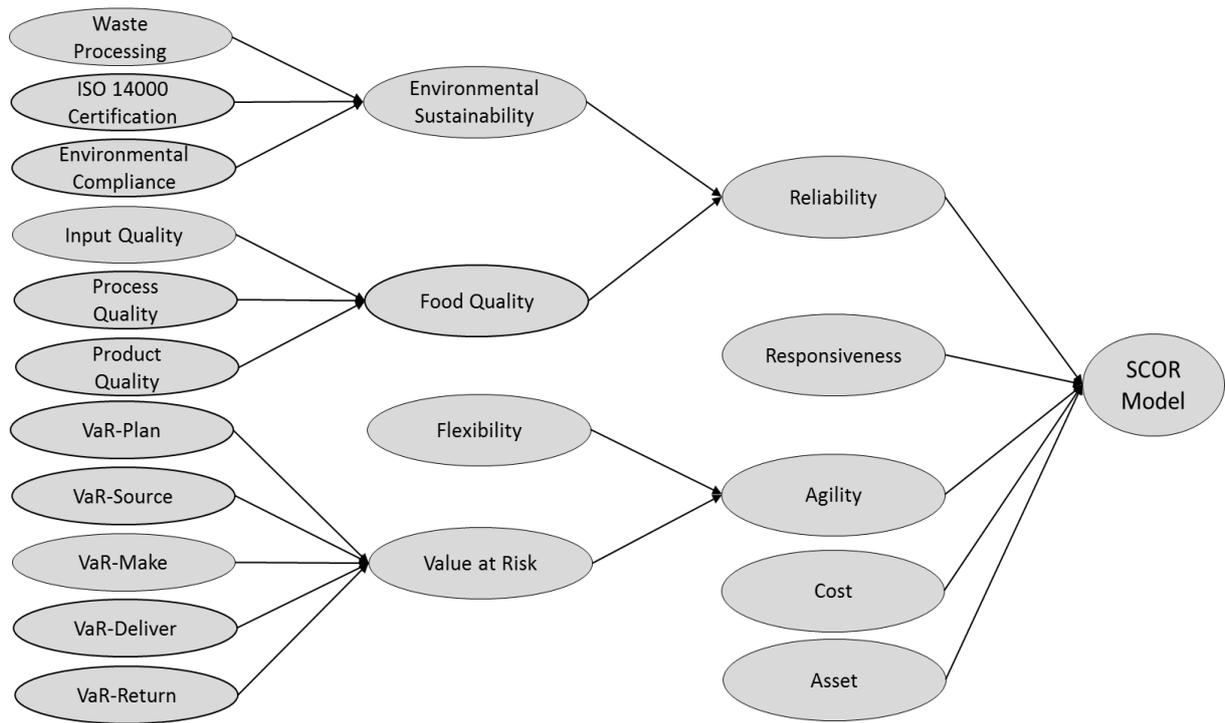


Figure 4 Pictorial representation of analytical framework for agri-food supply chain performance and risk

Source: Authors

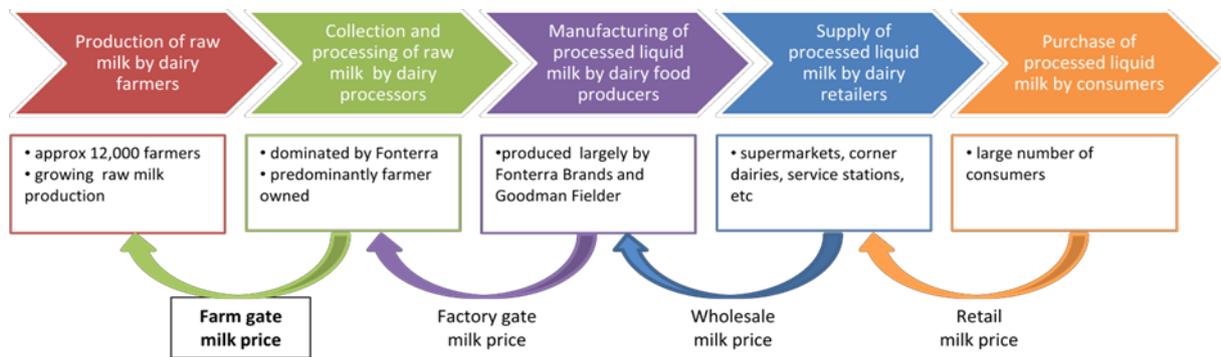


Figure 5 New Zealand dairy value chain.

Source: (Commerce Commission New Zealand, 2013)

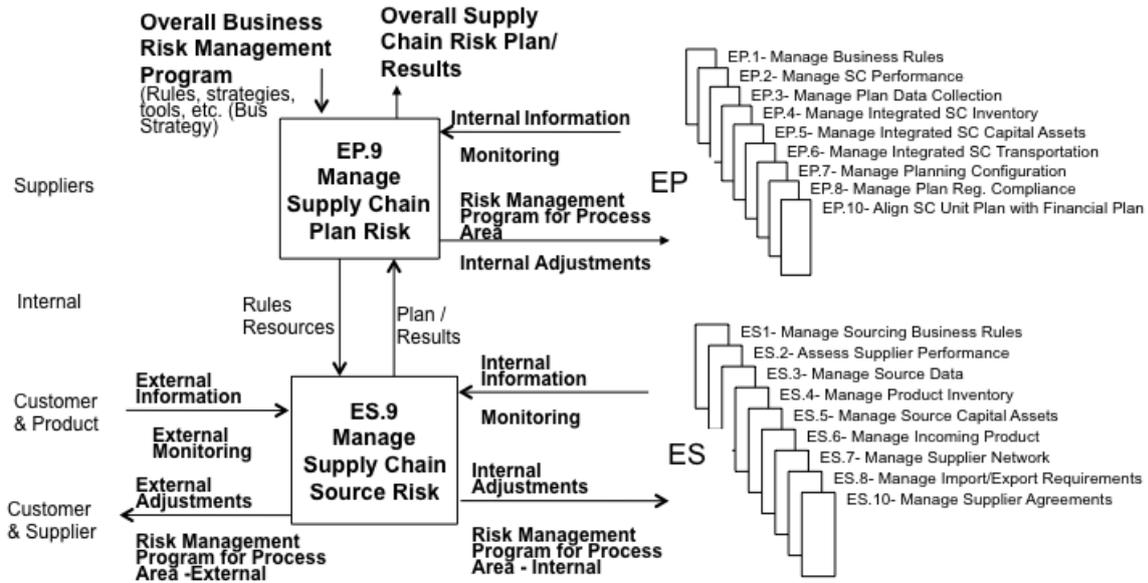


Figure 6 SCOR Supply Chain Risk Management – Typical Enable process

Source: (Supply Chain Council, 2012)

Authors

	<p>Dr Muhammad Moazzam is currently an Assistant Professor and Program Head of Logistics and Supply Chain Management (SCM) at National University of Sciences and Technology (NUST) Business School, Pakistan since September 2016. Muhammad has several years of teaching, research and industry experience. In addition to current job, he has worked as lecturer in agribusiness at Massey University New Zealand, outbound logistics team member at Ezibuy International Distribution Centre at Palmerston North New Zealand and lecturer in agribusiness at University of Agriculture Faisalabad Pakistan. Muhammad’s education includes PhD degree in logistics and SCM from Massey University New Zealand, MBA in marketing and agribusiness and BSc (honours) in agricultural economics from University of Agriculture Faisalabad, Pakistan. His research interests include agri-food supply chain management, SC optimization, global SCs and benchmarking. He has presented his work at a number of international conferences and authored several journal articles.</p>
	<p>Dr Pervaiz Akhtar is Professor of Management Systems at Hull University Business School (UK). He holds external/visiting professorships in Big Data and Analytics/Management Science, IESEG (France) and Abasyn University (Pakistan). He is also the Member of the Academic Executive Council and has served as Director for multiple programmes. Capitalising on over 15 years of academic and industrial experiences from leading public, private, and non-profit-making organizations, his expertise encompasses a vast range of specialised domains from Business Analytics, Data Science, Information Systems, Innovative Research Methods/Techniques, Logistics, Transportation and Operations Management to Supply Chain Planning and Control. His research has appeared in top ranked journals. He is a corresponding author and can be reached at pervaiz_khan972@hotmail.com or pervaiz.akhtar@hull.ac.uk or p.akhtar@ieseg.fr</p>
	<p>Dr Elena Garnevska is a Senior Lecturer in Agribusiness Management at Massey University, New Zealand. Her research interests focus on agribusiness, supply/value chains, environmental sustainability, agricultural cooperatives, and food marketing strategies.</p>
	<p>Dr Norman Marr returned to New Zealand after 12 years as Professor of Marketing at the University of Huddersfield in the United Kingdom. Prior to this he spent four years at Otago University and five years at Massey University teaching and researching in their Marketing Departments. He gained his MSc (Transport) and his PhD (Marketing and Logistics) from Cranfield School of Management and held senior positions in distribution and logistics management with a number of international organisations. As a result of his involvement in research activities over the last 20+</p>

	<p>years, he has been a regular contributor to international journals in the area of customer service, logistics and marketing, with over 100 articles and conference papers. He has successfully supervised twenty PhD students and over 100 Masters students from a variety of countries including New Zealand, Saudi Arabia, Syria, Jordan and the United Kingdom.</p>
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