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Multi-indicator supply chain management framework for food convergent innovation in the dairy business

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ABSTRACT

A comprehensive integrated framework of indicators currently used in lean, agile, sustainable and resilient supply chain paradigms is developed under the umbrella of convergent innovation (CI) and applied to the management of the supply chain of a dairy company, including procurement, processing and distribution of their products to customers. CI is a meta-framework that opens new frontiers for commercial innovation, supply chains and market systems by making the convergence of economic, social and environmental outcomes the target of business and actor decisions throughout society to build supply and demand for commercially viable outcomes. This framework provides a company with a multi-indicator supply chain management tool designed to accommodate the supply chain paradigms of being lean, agile, sustainable and resilient, as well as providing milk-based essential nutrition within a process called convergent innovation. The proposed analytical framework can serve as a decision support tool to systematically evaluate and improve the dairy supply chain from plant production to retailers. In jurisdictions without a quota system for milk production at the farm level, the system constructed in this paper could be expanded to handle farm production and shipment to dairy processing plants.

1. Introduction

During the global coronavirus pandemic, the agri-food sector is facing new challenges, from supply chain disruption with its consequences on food systems, to meeting high market demand, to protecting its workforce, all while avoiding transportation network disturbances and absenteeism and maintaining a high level of food safety and consumer confidence [137]. The supply chain of the agri-food sector requires convergence of innovation. Convergent innovation (CI) is a meta-framework that opens new frontiers for commercial innovation, supply chains and market systems by making the convergence of economic, social and environmental outcomes the target of business decisions and those of actors throughout society that can build supply and demand for such outcomes [1,2,3,4,5]. Rooted in a combination of behavioural, social and complexity sciences, CI views individuals themselves as central actors whose decision making and behaviour shape and are shaped by contexts defined by the ways organizations and systems are designed and operate. This brings a person-centric approach to commercial and social organizations as well as to the systems within which these are embedded, at all three levels (individual, organizational and system), of economy and society. The present study focuses on business organizations in the agri-food sector and their supply chain, taking dairy as the focal sector.

The dairy supply chain is a complex [6] and interconnected dynamic system [7] that covers many stakeholders and activities of milk production, handling, storage, processing, packaging, transport, distribution, wholesale and retail sales and so forth [8]. It is a direct network of business processes with precedence relationships [9] that aims to achieve specific business objectives such as greater competitiveness, better customer service and higher profitability, while at the same time keeping the supply chain system functional [10].

In Fig. 1, a generalized picture of the Canadian dairy supply chain portrays the complexity and some dynamic characteristics of the dairy supply chain management system. In general, milk from a dairy farm is shipped to a dairy plant, and then from the dairy plant processed dairy products are transported to the company's distribution centre. From the company's distribution centre, dairy products are sent to a customer's

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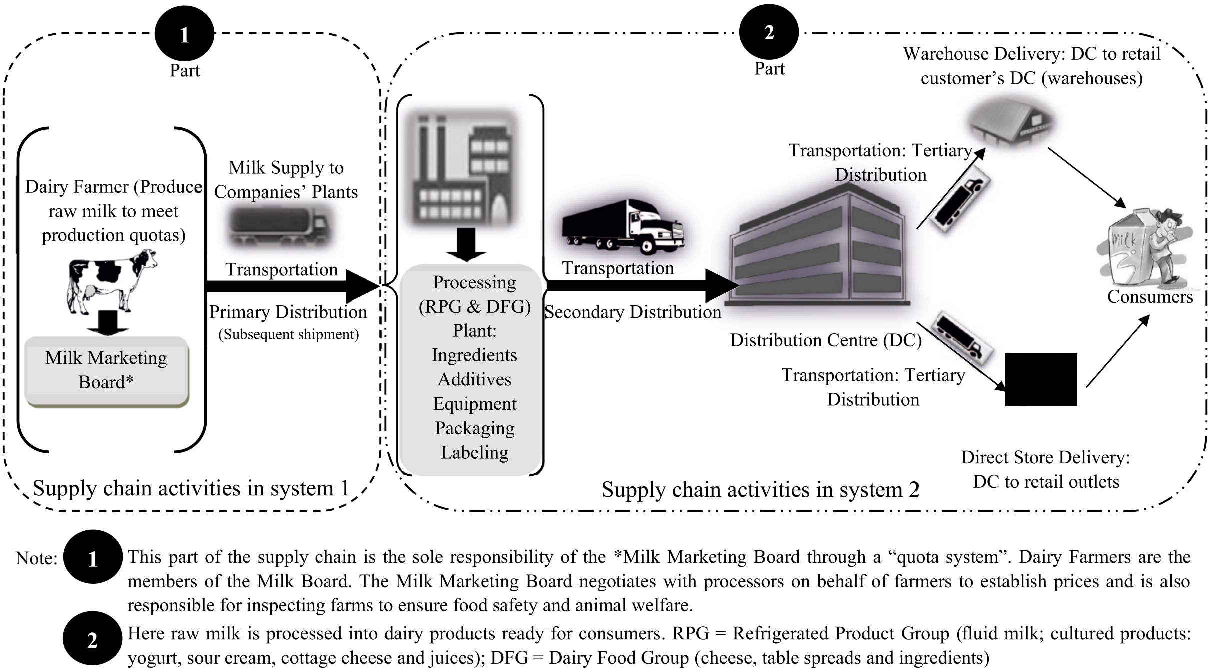

Fig. 1. Generalized illustration of the complexity and dynamics of a dairy supply chain. Source: Author's interpretation.
Note: This part of the supply chain is the sole responsibility of the *Milk Marketing Board through a "quota system". Dairy Farmers are the members of the Milk Board. The Milk Marketing Board negotiates with processors on behalf of farmers to establish prices and is also responsible for inspecting farms to ensure food safety and animal welfare.
Here raw milk is processed into dairy products ready for consumers. RPG = Refrigerated Product Group (fluid milk; cultured products: yogurt, sour cream, cottage cheese and juices); DFG = Dairy Food Group (cheese, table spreads and ingredients)

warehouse or to a retail store. In Canada, the supply of milk from dairy farms to a company's processing plant is not part of the company's dairy supply chain management, since this part of the supply chain is managed by a "quota system" whereby a dairy farmer under the Milk Marketing Board holds a permit to market milk to the company's processing plant [11]. The Board is responsible for transporting milk to the processing plant. While milk production at the farm and subsequent shipment to the company's processing plant (Part 1 in Fig. 1) are not included in the supply chain management of dairy companies in Canada, milk supply chain systems in other countries may include both systems depicted in Fig. 1.

Various interconnected activities such as integrated planning, implementation, coordination and control of all business processes and activities are necessary [7] to efficiently supply dairy products from processing plants to consumers. To have an efficacious supply chain management system, the dairy business is striving to be lean to create value by eliminating any type of waste and to be agile by taking steps to ensure responsiveness, competency, flexibility, and quickness. While being lean [12,13] and agile [14,15] is essential for the efficient management of the dairy supply chain, other paradigms like being sustainable [16,17] and resilient [18] to face any type of disruption in the supply chain are also very important. In the present world context, it is necessary to keep this complex and dynamic supply chain/logistic system functional in order to ensure long-term sustainability [19,20,21]. Apart from these management concerns, the dairy supply chain is crucial for supplying milk-based essential nutrition [22] to consumers. A unique description of the lean, agile, sustainable, resilient and nutrition (LASRN) paradigms for dairy supply chain management is presented in Section 2.2.

To understand the proper functioning of the supply chain system from the perspective of the various paradigms, appropriate key performance indicators (KPIs) [23] related to these paradigms must be monitored and evaluated. An essential step for the effective management of the dairy supply chain system is integrating and analyzing KPIs employed with the LASRN paradigms via the utilization of multiple criteria decision analysis (MCDA) techniques. MCDA can help make subjective decisions in an objective way by directly taking into account many different kinds of indicators or criteria, some of which may be in conflict with each other, such as cost and environmental indicators [24]. MCDA techniques allow one to better understand a complex problem and thereby make more informed decisions [25]. Combining the KPIs of the LASRN paradigms [26] within the MCDA framework in supply chain management operationalizes a procedure for permitting the convergence of innovation (CI) [27] to take place in real-life decision making. This innovation is also required for long-term nutrition security [28] through the supply chain and keeps companies competitive in this era of climate change, globalization and technological advances.

In this context, a Multi-Indicator Supply Chain Management framework is proposed which captures the concept of CI in decision-making for supply chain management by considering the aspects of the LASRN paradigms in a holistic manner within an MCDA structure. To understand the core aspects and difficulties of this framework, the concepts of CI, LASRN paradigms, KPIs and MCDA are described in the next section. In Section 3, the methodology-related issues in the Multi-Indicator Supply Chain Management Framework are presented, followed by a discussion of the output of the framework and conclusions in Sections 4 and 5, respectively.

2. Overview of the key aspects of multi-indicator supply chain management framework

Sustainable supply chain refers to the management of material, information and capital flows as well as cooperation among operators along the supply chain while taking into account the economic, environmental and social dimensions of sustainability [29]. Sustainable supply chain management (SSCM) represents the voluntary integration of sustainability with the key inter organizational business systems to create a coordinated supply chain aimed at achieving short-term and long-term profitability, competitiveness and resilience [30,31,32]. Given its holistic nature and the diversity of its key drivers, SSCM requires a multi-indicator approach which enables one to evaluate the impact of alternative strategies aimed at improving particular aspects, while at the same time monitoring the impact on the whole system performance.

A substantial amount of literature is available on lean, agile, sustainable, resilient paradigms [33] as well as on MCDA [34]. However, the convergence of innovation (CI) and nutrition paradigm of the dairy supply chain are relatively new concepts in the literature. In this section, a brief discussion of the different aspects of the multi-indicator supply chain management framework is explained in order to assist in understanding the above ideas.

2.1. Convergence innovation

As introduced earlier, Convergence Innovation (CI) [27] is a solution-oriented approach to addressing the complex challenges that constrain both the profitability of businesses and society's ability to face issues lying at the nexus of agriculture, industry and health systems. CI creates platforms to support decision-making and action by individuals and actors throughout society to increase production, innovation, and consumption of food derived from strategically relevant agricultural commodities having high CI potential. In the context of food, the Food Convergent Innovation (FCI) approach supports agri-food businesses and organizations in their ecosystems to accelerate targeted food innovations with lasting commercial success as well as environmental and societal enhancements. FCI achieves its aim by combining theory- and data-driven science and technologies to capitalize on powerful computational models, and to utilize human and social capital to bridge disciplines and sectors. Milk is a food with high CI potential for fostering affordable health for people and the planet, as well as creating prosperity for dairy businesses while helping to contain ever-increasing health care costs [27].

From a supply chain management perspective, integrating lean, agile, sustainable, resilient and nutrition perspectives into supply chain management has huge CI value. However, accommodating conflict and convergence between these requirements in dairy supply chain management is particularly challenging because of the diversity of its products in terms of complexity of supply chain management, perishability and shelf-life concerns for dairy products, and tough competition among dairy businesses. Thus, CI amplifies the benefits of modernity and attenuates its problems, while integrating both traditional and modern elements.

Fig. 2 displays the general CI process with respect to the dairy business when reading from left to right (Part 1 to Part 3). The various components in this Fig. are explained in this section in general and in more detail in Section 3. Notice in Part 1 of Fig. 2 that the four divisions given as A, B, C and D link to the right side of Fig. 1 labelled as the circled number 2. More specifically, supply chain planning (A) in Fig. 2 refers to the processing plant in Fig. 1; transportation management (B) to the arrows with trucks drawn above them; warehouse management/distribution centres (C) to the drawn distribution centre; and customer service/order to cash (D) to the warehouse and direct store deliveries.

2.2. Lean, agile, sustainable, resilient and nutrition (LASRN) paradigms

As can be seen on the Part 1 in Fig. 2, the four divisions of the supply change management perform various duties. For example, supply chain planning is responsible for forecasting that leads to a sales plan, production plan, inventory plan, and financial plan and so forth. Transportation management is accountable for safe and secure transportation of the product orders using route and network optimization. The warehouse management/distribution centres division receives and stores finished goods; maintains accurate inventory; picks, prepares and loads orders for shipping; ensures safety for the workers and so forth. The customer service/order to cash division is involved with recording warehouse orders and customer services. All four of the divisions in Part 1 of Fig. 2, through their assigned duties generate various data which can be categorized according to operational, logistic, environmental, social and economic database. As can be seen each of these databases in Part 1 in Fig. 2 can be further subdivided as O_1 to O_o, L_1 to L_l, ENV_1 to ENV_{env}, SC_1 to SC_{sc} and EC_1 to EC_{ec} for operational, logistic, environmental, social and economic databases, respectively. The overall database can be used to calibrate key performance indicators according to the LASRN paradigms described in this section and depicted as Part 2 in Fig. 2.

2.2.1. Lean

The lean paradigm reflects the supply chain's ability to enhance value through waste elimination [35] and continuous improvement in the supply chain management system [36] in order to achieve competitive cost and market advantage [37,38,39]. While "leanness may be an element of agility in certain circumstances, by itself it will not enable the organization to meet the precise needs of the customer more rapidly" [40, p. 206].

2.2.2. Agile

The agile paradigm is associated with the ability to respond quickly and effectively to shifts in consumer demand and market conditions [41]. Agility represents "the ability of an organization to respond rapidly to changes in demand, both in terms of volume and variety" [42, p. 38]. It helps to create responsive supply chains and depends on flexible manufacturing systems of the company [42].

2.2.3. Sustainable

Like other industrial supply chains, sustainability is an important issue [43,44,45] for the dairy supply chain since "the need for sustainable practices in the food supply chain is becoming acute" [46, p. 102]. The sustainable paradigm examines environmental demand in terms of energy and water requirements, carbon emission, waste generation and disposal, as well as social aspects related to human equity, such as working conditions, health and safety management [47,48].

2.2.4. Resilient

Resilience refers to the capacity of the supply chain to cope with unexpected disturbances [49] from regular price and financial market volatility [50], demand, supply, logistic, external and informational risk [51]. In the resilient paradigm, risk and uncertainty are important issues for the performance of the supply chain [35,52].

2.2.5. Nutrition

The nutrition paradigm is related to the nutrition sensitivity of supply chains as well as to the nutritional quality of supplied food products. Food supply chains are largely responsible for providing essential nutrients on which public health depends. The nutrition aspects of dairy supply chains are crucial issues in the present world as nutrition and health outcomes [53] are associated with the food supply chains of food systems. Dairy supply chains ensure furnishing milk related essential nutrition to people through procuring milk primarily from commercial farms, then manufacturing it and selling it through modern supermarket outlets [54]. Therefore, dairy supply chains can be used to ensure "adequate, but not excessive, amounts of energy and of a high-quality, varied diet with sufficient micronutrients" through proper innovation, investment and policy transformation [54].

2.3. Key performance indicators (KPIs)

The operational, logistic, environmental, social, and economic databases as portrayed in Part 1 of Fig. 2 are the basis to generate KPIs as well as their actual and reference values in Part 2 of Fig. 2. A Key Performance Indicator is an aggregate metric that is tied to a strategic

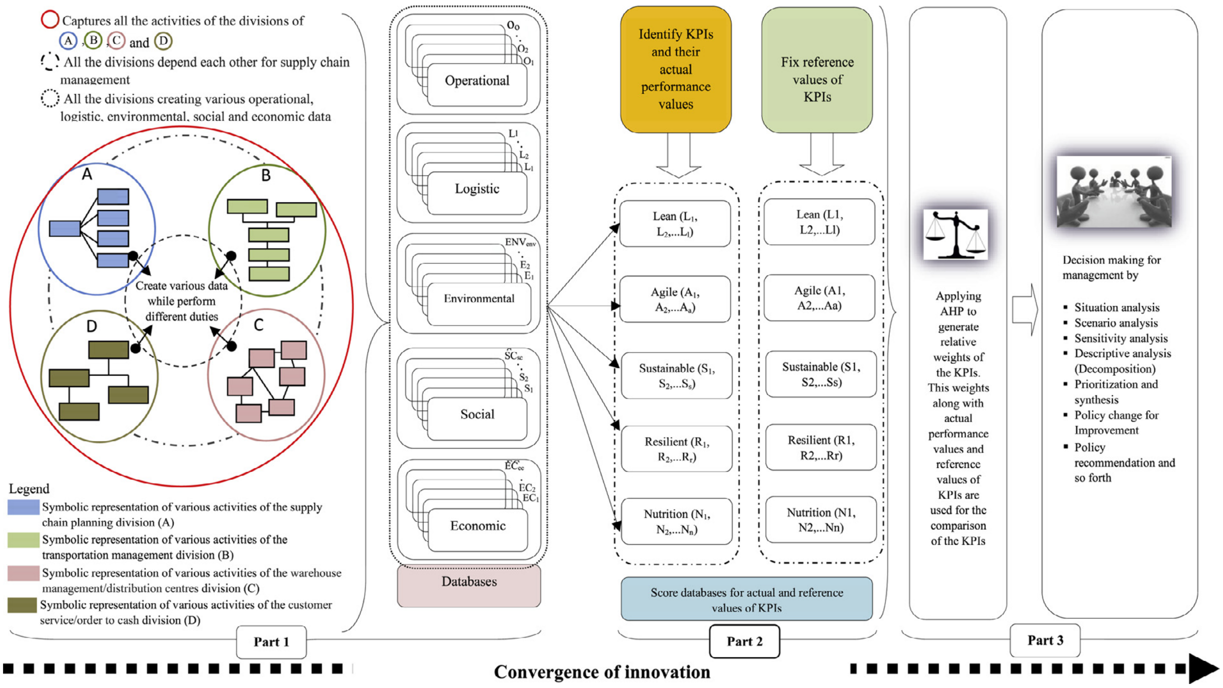

Fig. 2. A schematic diagram of the proposed framework. Note: Dairy supply chain management can be regarded as an open system, meaning inputs for supply chain management come from four different divisions (Part 1): supply chain planning (A); transportation management (B); warehouse management/distribution centres (C); and customer service/order to cash (D). The four divisions perform various duties within their jurisdiction and also when interchanging information with each other as part of the duties to deliver actionable information for goods or services for efficient management of supply chain. Each division has its own duties which are connected to other divisions. The four divisions generate different information that can be grouped as different databases and sub-databases: operational (O_1 to O_o sub-database), logistic (L_1 to L_l sub-database), environmental (ENV_1 to ENV_{env} sub-database), social (SC_1 to SC_{sc} sub-database) and economic (EC_1 to EC_{ec} sub-database). Data from these databases can be grouped by key performance indicators (KPIs) under lean, agile, sustainable, resilient and nutrition paradigms as shown in Part 2. Reference values of the KPIs of LASRN are specified by experts (stakeholders of the supply chain management that includes owners of the company; top management; middle managers; all the employs below middle managers and the customers) and the actual values of the KPIs of LASRN are generated from LASRN databases by applying various techniques. As shown in Part 3, after obtaining the actual values and reference values of the KPIs, an AHP analysis can be carried out to understand the status of the actual values of the KPIs in comparison to the reference values of the KPIs.

objective and has at least one defined time-bound target value (number, range, limit, percentage, trend, variation), whereas a metric is measure or a combination of measures for quantitatively assessing, controlling or improving a process, product or team. KPIs help to "evaluate, control, budget, motivate, promote, celebrate, learn, and improve" [55, p. 586] supply chain management and "paint a clear picture of strategy, focus on what matters/requires attention, monitor progress towards the desired state through measurement, performance and risk assessment and decision making" [56, p.1] in supply chain management. A KPI is different than a metric. It is reasonably easy to develop a list of performance indicators but identifying KPIs is difficult as only the 10 most representative indicators are preferred as KPIs for an organization [23]. Nevertheless, identifying the most representative KPIs is also important because "if too many indicators are considered, data collection and data processing become difficult to handle at a reasonable cost, redundancies might appear, and the message expressed by the indicator set becomes difficult to understand" [57, p. 230]. For decision makers and supply chain management specialists, KPIs are a high priority in research and policy agendas since they help strategic decision making in an environment where there are dynamic problems with many decision layers such as milk production, milk processing in plant, dairy manufacturing, capacity/supply/demand allocation, transportation, cost, waste management, parameter uncertainty and so forth [58]. Key performance indicators (KPIs) reflect and derive from organizational goals.

2.4. Multi-criteria decision analysis (MCDA)

MCDA has widespread application in modeling and understanding management policies and strategies. MCDA comes with many methods such as "Analytical Hierarchical Process (AHP), Analytic Network Process (ANP), Multi-Attribute Utility Theory (MAUT), Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH), Preference Ranking Organization METHod for Enrichment Evaluation (PROMETHEE), Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) and ELimination Et Choix Traduisant la REalité (ELECTRE)" [59, p. 442].

The Analytical Hierarchal Process (AHP) of MCDA is used to generate the relative importance of the KPIs as shown in Part 3 of Fig. 2. MCDA provides a structured and transparent framework that can break down complex problems, facilitate discussion and produce a systematic and visual presentation of the perspectives of diverse stakeholders [60,61,62].

MCDA can be a suitable framework for developing an integrated management model since it is regarded as a suitable set of methods for multi-criteria-based management due to its flexibility and the possibility it offers to facilitate decision-making in the face of conflicting choices and criteria as well as its potential to open up dialogue between stakeholders, analysts and decision makers [63,64,65,66,67,68,69]. MCDA has the capacity to combine multidirectional data in order to develop LASRN scenarios based on actual and reference values of the indicators and stakeholders' opinion and prioritizes the performance of the different management scenarios by incorporating the inputs of stakeholders in the form of weighting [70].

In this study, Saaty's [71] Analytical Hierarchical Process, one of the most widely used MCDA methods [59], is proposed as the MCDA structure (as shown in Part 3 of Fig. 2) to generate weightings of the KPIs. Previously, AHP has been used for addressing supply chain-related issues such as plant layout, new product screening, vendor selection,

Table 1
Probable list of the indicators of lean, agile, sustainable, resilient and nutrition paradigms to analyse the supply chain management under the proposed framework.

Paradigms	KPIs*	Indicators to develop KPIs	Number of indicators
Lean (L)	Waste Management Performance (WMP)	Waste from inappropriate processing [85]	6
		Unnecessary inventory [86]	
		Over production [87]	
		Waiting time waste [88]	
		Transport waste [89]	
		Rate of product defects [90, 91, 92, 93, 94, 95]	
	Inventory Performance (IP)	Fill rate [96]	3
		Inventory carrying cost [97, 98]	
		Frequent product inspection [99, 100]	
Agile (A)	Supply-Chain Network Performance (SCNP)	Forecast accuracy [101, 102]	4
		Order fill lead time [103, 104]	
		Delivery reliability [105]	
		Delivery performance [106]	
	Customer Care Services Performance (CCSP)	Attention to customer complaints [107]	4
		Relationship with customers [108]	
		Improved customer service [109]	
		Total consumer complaints [110, 111]	
	Financial Performance (FP)	Supply chain cost [102]	3
		Transportation cost [102]	
		Distribution cost [102]	
	Supply Chain Flexibility (SCF)	Upside supply chain flexibility [112]	3
		Upside supply chain adaptability [112]	
		Downside supply chain adaptability [112]	
Sustainable (S)	Human Equity (HE)	Working hours [113]	4
		Working conditions transparency [113]	
		Health and safety management [113, 114]	
		Injury rate [115]	
	Environment (ENV)	CO_2 emission [113, 114, 115]	5
		Water Consumption [114, 116]	
		Energy Consumption [115]	
		Waste generation [114, 116]	
		Green packaging [113]	
Resilient (R)	Delivery Performance (DP)	Delivery failure [91, 93, 117]	3
		Damage in transit [91, 93, 117]	
		Transportation disruption [91, 93, 117]	
	Operations Performance (OP)	Defective product [91, 92, 93, 94, 95]	2
		Production interruption [91, 92, 93, 94, 95]	
	Information Systems Efficiency (ISE)	Information quality [91, 117, 118]	4
		Information security [91, 117, 118]	
		Information sharing systems implementation [91, 117, 118]	
		Transaction complexity [91, 117, 118]	
Nutrition (N)**	Essential Nutrient (EN)**	Protein supply**	4
		Supply of other elements of nutrition**	
		Nutritional quality of ingredients**	
		Organic/Vegetable ingredients (such as protein) in number of products**	
	Nutrition Features (NF)**	Standardized labelling of nutrition**	2
		Percentage of people covered by dairy products **	

Note:
* KPIs represent composite indicators.
** Proposed by the authors. In Fig. 2, KPIs under lean (for example L_1 to L_l), agile, sustainable, resilient and nutrition paradigm represent the KPIs mentioned in this table. The indicators that are listed in the third column are essential for supply chain management. It is assumed that the indicators are causally linked, meaning performance of one indicator may influence another. However, based on the aim and objectives of the supply chain management under study, list of indicators can be appropriately changed.

manufacturing performance [45,72] and managing risks [73]. Within the current research, AHP is utilized to determine relative importance, or weight, by employing pairwise comparisons among the KPIs for a given paradigm as listed in Table 1. The scales range from 1 to 9, for which definitions and explanations used for comparing pairs of KPIs are explained in Table 2. These pairwise comparisons are stored in a matrix for which the normalized principal Eigen vectors constitute the weights.

2.5. Informed decision making

As indicated on the far-right side in Part 2 of Fig. 2, management ultimately wishes to make informed decisions using the results determined following the process up to this point. In other words, all of the steps going from left to right (Part 1 to 3 in Fig. 2) within the CI process feed into the final decisions that are made.

3. Methodologies embedded in the framework

This paper relies on secondary information drawn from journal articles, books, and reports related to supply chain management and MCDA. All the concepts and indicators in this paper result from a narrative review of the scientific literature. The authors' association with one of the leading dairy industries in Canada and previous work experience also helped to elaborate some information and justify the secondary information.

The methodological structure of the multi-indicator supply chain management framework for food convergent innovation [27] in the dairy business is illustrated in Fig. 2. This framework is based on ref-

Table 2
Scales used to make pair wise comparisons of the KPIs for a given paradigm.

Intensity of importance on an absolute scale	Definition	Explanation
1	Equally important	Two KPIs contribute equally to the management
3	Reasonably more important	Experience and judgment of the supply chain people reasonably favour one KPI over another
5	Strongly more important	Experience and judgment f the supply chain personnel strongly favour one KPI over another
7	Very strongly more important	When supply chain people think a KPI is strongly favoured and has demonstrated the dominance over another KPI
9	Completely more important	When supply chain personnel think any KPI is completely favourable over another KPI
2, 4, 6, 8	Intermediate value between two adjacent judgments	When compromise is needed between KPIs

Source: Based on [119, 120].

erence and actual values of KPIs and the Analytical Hierarchical Process (AHP) method of MCDA. The dairy supply chain can be regarded as an open system [74] in which various activities are performed under four divisions (Part 1 of Fig. 2). These divisions can be regarded as systems of systems [75] of the entire supply chain. Systems of systems approaches seek to respect the different value systems of multiple participants, to harness complexity through effective integration, and to engage the world of uncertainty and unpredictability with an adaptive response [75].

Systems of systems understanding is required to understand the factors of these four divisions for efficient management of the supply chain. Multidimensional indicators are needed to measure the efficiency of the supply chain. As an open system, jurisdictions or boundaries of duties of those four divisions (systems of systems) as well as scales of different duties related to those divisions are very important for identifying indicators. Indicators help to develop different KPIs, which are needed to track the performance of the supply chain. The reference values of the KPIs help to understand the performance of the supply chain by comparison with the actual performance of KPIs. AHP can be used to analyse the actual and reference values of KPIs.

System boundaries and scale issues of the duties of the four divisions, guidelines to identify indicators for KPIs and indicators lit; principles and frameworks for generating KPIs and reference values of KPIs; AHP method for analyzing actual and reference values of KPIs; and presenting results of the framework are described below.

3.1. Principles and frameworks for generating KPIs and reference values of KPIs

The selection of KPIs as shown in Part 2 of Fig. 2 must be based on thorough knowledge of supply chain management. When selecting KPIs, it is important to keep in mind that they should have broad impact [76] in managing the supply chain. Certain principles such as a clearly defined strategic framework, goals and objectives of the supply chain are important to develop KPIs [77]. The developed KPIs must capture the activities of the supply chain, reflect the outcomes of the activities of the supply chain, like indicators also be based on SMART (specific, measurable, achievable, realistic and timely) rules and be fully understood by stakeholders [77]. Two types of framework can be considered for developing KPIs: a system-based framework which can provide systemic KPIs of the systems as a whole and a content-based framework that provides KPIs for each division or individual part [57] of the supply chain. Both systems-based KPIs and content-based KPIs are useful, but which one is more useful depends on the nature of the management. If possible, developing KPIs through both system- and content-based frameworks is suggested. In the proposed framework, KPIs are suggested based on a system of systems approach considering that the four divisions of the supply chain management of a company are part of the systems of systems of the supply chain as shown in Fig. 2. This approach addresses multiple functions of the divisions and reflects the complexity of the supply chain. It also allows us to identify a set of KPIs that provide representative pictures of the LASRN aspects of the supply chain.

Identifying reference values of the KPIs is very important from the perspective of the proposed multi-indicator supply chain design and management framework. The reference values of the KPIs will allow MCDA to be applied to analyze the efficiency of the supply chain and assist in scenario development for decision making. Reference values can be determined using normative and relative considerations. Normative reference values are defined based on science or policy, whereas relative reference values are based on indicator values for similar systems or a reference/ideal system [78]. The relative reference values can also be established by surveying the key personnel of the supply chain or through a literature review. Here, the reference values will be determined based on the objectives of the supply chain of the company and will reflect the goals the company wants to reach in terms of achieving high scores on the KPIs. The company can monitor its position in the performance of its KPIs through comparison with the reference values of KPIs. Reference values of KPIs are the important consideration for this framework.

3.2. System boundaries and scale issues

As mentioned before a supply chain, for example, is managed by different divisions of a company, such as supply chain planning; transportation management; warehouse management/distribution centres; and customer service/order to cash (Part 1 of Fig. 2). Each division is responsible for different activities to make the supply chain efficient. Each division (system of systems) has its own role, resources and rules as well as indicators or bars to monitor the performance of the system. These roles, resources and rules of each division can be regarded as system boundaries. However, these roles, resources and rules vary from company to company and can only be identified by studying or analyzing the documents related to the supply chain model of each company, strategic management of the supply chain, supply chain objectives, indicators, key informants (resource personnel) and stakeholders. This analysis is very important to understand the system boundaries and scale issues in the supply chain.

Identifying the system boundaries [79] of different divisions is necessary to develop a multi-indicator-based framework. The system boundary of each division identifies the roles and activities of the division. These roles and activities of the different divisions help to understand different criteria that are essential to manage the supply chain. For example, forecasting is one of the responsibilities of the supply chain planning division upon which production in the plant depends. Based upon these responsibilities, the supply chain planning division has different KPIs. These KPIs are crucial for multi-indicator-based decision making; otherwise, a lot of duplicate indicators will be created that will create a problem for decision making. Defining system boundaries is also important for information sharing and informed decision making [80] because it specifies the responsibilities of the divisions and helps to maintain integrated databases that are critical for further analyzing and monitoring the performance of each division.

In a dairy supply chain, each division involves many activities carried out by internal as well as external actors and moves materials and information throughout the four divisions (See Part 1 in Fig. 2). Therefore, it is essential to define the scale of these activities as well as the material and information that are flowing across divisions. For example, if finished production is considered part of the supply chain planning division, production at the plant is influenced by various elements of the supply chain at different scales at the farm, regional and national levels. In this proposed framework, the activities of the four divisions are defined as a system boundary for the company, and the actors and information and the operational and logistic services within the boundaries of these divisions are considered the scale issues for the management of the supply chain.

3.3. Guidelines to identify the indicators for KPIs and indicators list

In this framework, the identification of the appropriate indicators is very important for developing KPIs, as depicted in Part 2 of Fig. 2. Appropriate indicators capture the essence of the concepts of LASRN paradigms and are crucial for strategic decision making to satisfy the goals of supply chain management. In the identification of the indicators for this framework, the core concepts of the LASRN paradigms are considered as a heuristic model [81] to conceive and guide the selection of the appropriate indicators that represent the operational, logistic, environmental, social and economic dimensions, as shown in Part 1 of Fig. 2. In the literature, there are many indicators related to LASRN paradigms. However, based on the LASRN paradigms, subjective judgment following SMART (specific, measurable, achievable, realistic, time-bound and trackable) principles [82], a list of indicators is identified and grouped under lean, agile, sustainable, resilient and nutrition paradigms, as shown in Table 1. The definitions, justification, measuring techniques, units and sources of data to develop the indicators that are listed in Table 1 are presented in Table A1-1 in Appendix 1.

Various indicators related to the LASRN information of the supply chain can be collated from the different activities of the four divisions. Inventory information, various secondary documents, annual reports and other databases can constitute the sources of this information. Indicator values can be generated by applying various techniques such as inventory analysis, organizational analysis, life cycle assessment, efficiency analysis, carbon footprint, cost-benefit analysis, and multivariate analysis.

These indicators are important for effective management of the supply chain. They are also used to develop KPIs under LASRN paradigms. By aggregating the indicators of LASRN paradigms, 13 KPIs related to the functions of supply chain management are proposed for this framework as listed in Table 1. It should be pointed out that different aggregation rules can be used to develop KPIs, such as additive aggregation (arithmetic mean), geometric aggregation (multiplication), and multi-criteria analysis [83]. In this paper, geometric aggregation, which is the product of normalized weighted indicators, is used to avoid concerns related to interaction and compensability.

Under the Lean paradigm, the waste management performance (WMP) and inventory performance (IP) KPIs are constructed by combining 6 and 3 lean indicators, respectively. The supply-chain network performance (SCNP), customer care services performance (CCSP), financial performance (FP) and supply chain flexibility (SCF) KPIs of the agile paradigm are built by combining 4, 4, 3 and 3 agile indicators, respectively. The human equity (HE) and environment (ENV) KPIs of the sustainable paradigm are constructed by combining 4 and 5 sustainable indicators respectively. The Resilient paradigm contains delivery performance (DP), operations performance (OP) and information systems efficiency (ISE) that are combination of the 3, 2 and 3 resilient indicators, respectively. The nutrition paradigm has essential nutrient (EN) and nutrition features (NF) KPIs built by combining 4 and 2 nutrition indicators, respectively. Indicators related to the nutrition paradigm in Table 1 are suggested by the authors.

Developing KPIs by combining multiple indicators can be subject to criticism if an appropriate set of indicators is developed. In this situation, there is no need for composite indicators [84]. However, the proposed KPIs furnish a useful summary of the different aspects of LASRN paradigms and therefore provide supply chain managers with a basis for effective management. These KPIs also capture the complexity and multidimensional aspects of the paradigms and thereby allow managers to understand better the situation.

In Table 4 in Section 4.0, the aggregated values of KPIs are determined using the geometric mean of the hypothetical values provided in Table 4 of the indicators mentioned in Table 1. From Table 4, it can be seen, for example, that waste management performance (WMP) represented by L_i in Part 2 of Fig. 2 is determined by combining the six indicators from WMP in Table 1.

3.4. Analytical hierarchical process (AHP)

Fig. 3 shows the hierarchical structure of the LASRN framework connecting the overall LASRN objective with the five paradigms and KPIs for each paradigm. As just mentioned, within each paradigm, AHP is used to calculate the weights of the associated KPIs.

As an example of how to calculate weights using AHP, consider the case of the lean paradigm which consists of two KPIs written in the second column of Table 1 opposite lean as Waste Management Performance (WMP) and Inventory Performance (IP). This same information is displayed on the left in Fig. 3. Using the notation given in Part 2 in Fig. 2, the letters L_1 and L_2 are used to represent the KPIs consisting of WMP and IP, respectively, within the lean paradigm. To assess the intensity of importance of L_1 over L_2, the notation used is

$$I_L(L_1, L_2) = l_{12},\ if\ L_1 \text{ is compared to } L_2$$

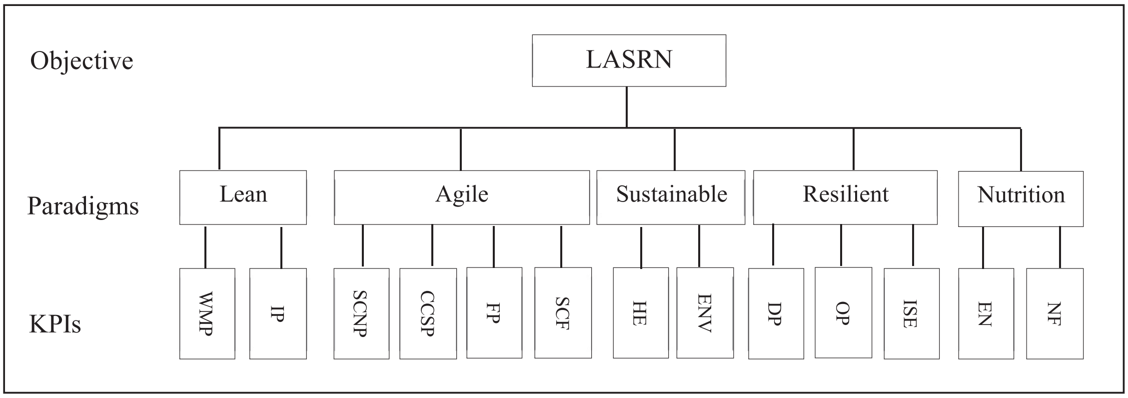

Fig. 3. Hierarchical structure of the framework for generating relative importance of the KPIs by using AHP. Note: The first step in the AHP process is to develop a hierarchy (graphical representation) of the LASRN framework (objective) in terms of management for the supply chain in terms of the paradigms and KPIs.

If, for instance, the relative importance of L_2 over L_1 were "reasonably more important", then the number 3 is selected as indicated in Table 2. Because the above relationship is comparing L_1 to L_2, the number assigned to l_{12} is the reciprocal of 3, which is 1/3. Under the assumption that diagonal entries in a matrix L to store all of the pairwise comparisons is unity, the matrix for the two lean KPIs is as shown below, along with the steps to determine the normalized principal Eigen vector following the algorithm provided by [121].

$$L = \begin{array}{c|cc} & L_1 & L_2 \\ \hline L_1 & 1 & 1/3 \\ L_2 & 3 & 1 \end{array} \xrightarrow{\text{Sum each column of the matrix}} L = \begin{array}{c|cc} & L_1 & L_2 \\ \hline L_1 & 1 & 1/3 \\ L_2 & 3 & 1 \\ \text{Sum} & 4 & 4/3 \end{array} \xrightarrow{\text{Normalized relative values for entries in a column are calculated by dividing each element by the sum of its column}}$$

$$L^n = \begin{array}{c|cc} & L_1 & L_2 \\ \hline L_1 & 1/4 & 1/4 \\ L_2 & 3/4 & 3/4 \\ \text{Sum} & 1 & 1 \end{array} \xrightarrow{\text{Normalized principal Eigen vector is obtained by averaging across the rows}} W_L = \frac{1}{2}\begin{bmatrix} 1/4 & 1/4 \\ 3/4 & 3/4 \end{bmatrix} = \begin{bmatrix} 0.25 \\ 0.75 \end{bmatrix} = \begin{bmatrix} W_{l_1} \\ W_{l_2} \end{bmatrix}$$

Following the above procedure for each of the other paradigms given in Table 1 and Fig. 3, weights can be obtained for the KPIs for the paradigm under consideration. For a specific paradigm, the KPI weights are the same for both the actual performance values and reference values, shown on the left and right, respectively, within Part 2 of Fig. 2. After determining the relative importance of the KPIs separately for each paradigm by using AHP, the total scores of the KPIs for the actual and reference values are generated. For the case of the actual performance values of the KPIs for a particular paradigm such as L, the total score is calculated using:

$$TS_{av} = \sum_{i=1}^{l} W_{L_i} L_i$$

where TS_{av} is the total score of the weighted actual value for L_i KPI of paradigm L and W_{L_i} is the weight for L_i. With respect to the fixed reference values of the KPIs, the total score is calculated as:

$$TS_{rv} = \sum_{i=1}^{l} W_{L_i} Li$$

where TS_{rv} is the total score of the weighted reference values for *Li* KPI of paradigm L, and W_{L_i} is the weight for *Li*. After utilizing the above formulae to calculate the total scores of the actual and reference KPIs, the findings can be presented graphically as shown below:

If $TS_{av} > TS_{rv}$ then

If $TS_{av} < TS_{rv}$ then

If $TS_{av} = TS_{rv}$ then

3.5. Presenting the findings

The results based on the multi-indicator supply chain management framework can be presented in the form of a color-coded dashboard comparing the total scores of the weighted actual and weighted reference values of KPIs as shown in Fig. 4. This dashboard allows the comparison and monitoring of the performance of the KPIs in terms of reference values. The decision maker can analyze the dashboard to make decisions (as shown in Part 3 of Fig. 2) regarding which KPIs could be improved. In this framework, the total score of the weighted reference value for any KPI of any paradigm is the ideal score that supply chain management wants to obtain. Anything below the total score of the weighted reference value of any KPI (marked by a blue ellipse having a downward arrow) means that the particular KPI is not performing well [122]. This observation can help the decision maker to take action to improve the process for that particular KPI. If the total score of the weighted reference and the actual value are the same, the decision maker may decide not to change the process to improve the KPI. If the total score of the weighted actual value of any KPI is higher than the total score of the weighted reference value of that KPI, this means that the process for that KPI is working well.

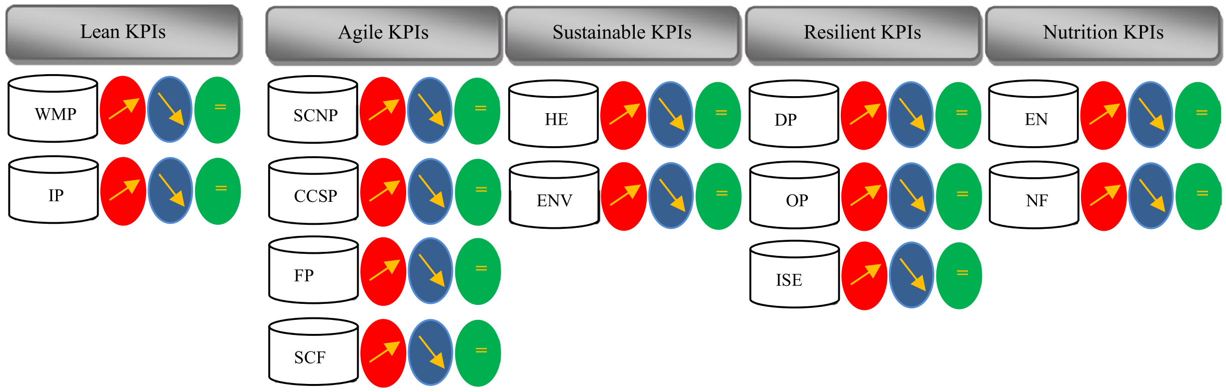

Fig. 4. Dashboard of actual performance of KPIs with respect to reference values of KPIs. Note: A red colored ellipse containing an upward facing arrow means that the actual value of KPI is above the reference value; a blue colored ellipse having a downward facing arrow indicates that the actual value of KPI is below the reference value; a green colored ellipse with an equal sign points out that the actual value of KPI is equal to the reference value. Companies prefer to have a higher or equal KPI score. A higher score reflects better performance of the supply chain.

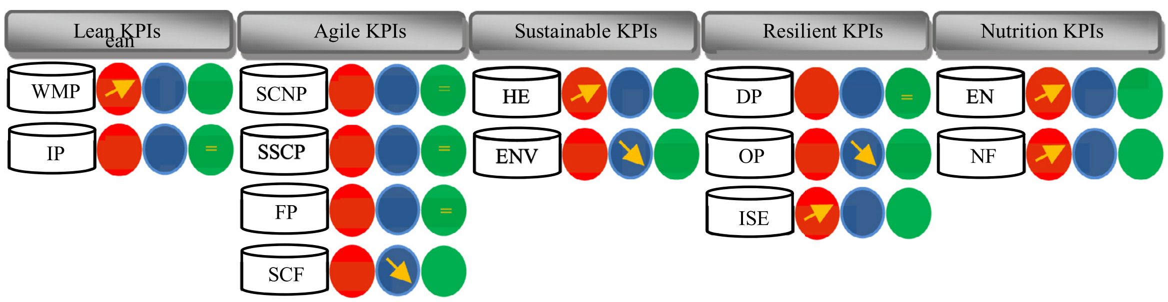

Fig. 5. Presentation of the findings

4. A Hypothetical case study using the proposed framework

Fig. 5 graphically presents the results of the application of the proposed framework to a hypothetical setting of supply chain management. The actual and reference scores of the indicators are listed in Table 3. Following the proposed aggregation techniques within the framework, the actual and reference values of the KPIs are calculated and shown in Table 4. The relative importance of the KPIs by using AHP is presented in Table 5. The overall scores of the KPIs are given in Table 6. The dashboard in Fig. 5 represents the overall findings using the proposed framework. This hypothetical case study demonstrates that the framework is capable of portraying the present situation and opportunities for improving the performance of the supply chain. For example, according to this case study, the actual performance of WMP in the lean paradigm is above the reference value. This means the supply chain is doing very well in managing WMP and management does not need to take any action to improve it. IP of the lean paradigm is also equal to the expectation, so management may take action to improve it or keep it as usual and concentrate on other paradigms where its performance is low. In the agile paradigm, the performance of supply chain management is equal to the expectation in the SCNP, SSCP and FP KPIs but below expectation in SCF. For this paradigm, management can keep the process the same for SCNP, CCSP and FP and allocate resources to improve SCF. In the sustainable paradigm, HE is above the expectation but ENV is below the standard performance. Management can therefore take steps to improve ENV. For the resilient paradigm, DP is meeting expectations, OP is below, and ISE is above. For the nutrition paradigm, NE and NF are above expectation.

In summary, the dashboard indicates the performance of the supply chain management for different KPIs, and how management can act accordingly to improve the KPIs. This case study shows that the process of analysing and presenting the KPIs of supply chain management by using this framework is highly interactive and makes it easy to identify the areas where the management has the opportunity to improve the overall performance and efficiency of the supply chain.

5. Discussion of the framework and concluding remarks

The proposed framework offers a sensible procedure to clearly show where improvements can be made to enhance the performance of supply chains within the dairy industry. The potential users of the framework could be mainly: (i) the single operator if the supply chain is vertically integrated; (ii) all the operators in a horizontal supply chain configuration. It is clear that in the second case one operator, generally the most economically dominant, should lead the others to the framework adoption allowing its spreading through the whole supply chain. The evaluations of KPIs for five key paradigms permits one to pinpoint where improvements could be carried out by referring to the graphical findings summarized in the Dashboard as displayed in Figs. 4 and 5 for the general situation and the particular case study, respectively.

The design of this Multi-Indicator Supply Chain Management Framework contains a range of distinct attractive features. For example, the overall idea of Food Convergence Innovation possesses five key paradigms which reflect the most important aspects of supply chain management in the dairy sector, including for the first time the nutrition paradigm beyond the most established lean, agile, sustainable and resilient ones. Furthermore, to evaluate each paradigm, informative KPIs are proposed by the authors for assessing the effectiveness of the supply chain system. The latter can thus be realistically assessed according to crucial paradigms and associated KPIs which directly reflect highly desirable properties of this kind of supply chain ecosystem. By systematically implementing the framework presented herein, and obtaining quantitative measurements of the KPIs, allows the elimination

Table 3
Actual and reference values of the indicators.

Paradigms	KPIs	Indicator to develop KPIs	Actual values of the Indicators	Reference values of the Indicators	Differences		
					BRV	URV	ERV
Lean (L)	WMP	Waste from inappropriate processing	80	90	10		
		Unnecessary inventory	85	95	10		
		Over production	90	95	5		
		Waiting time waste	97	98	1		
		Transport waste	95	95			0
		Rate of product defects	100	100			0
	IP	Fill rate	100	100			0
		Inventory carrying cost	87	85		2	
		Frequent product inspection	100	100			0
Agile (A)	SCNP	Forecast accuracy	100	100			0
		Order fill lead time	100	100			0
		Delivery reliability	100	100			0
		Delivery performance	100	100			0
	CCSP	Attention to customer complaints	100	100			0
		Relationship with customers	100	100			0
		Improved customer service	100	100			0
		Total consumer complaints	100	100			0
	FP	Supply chain cost	80	85	5		
		Transportation cost	85	85			0
		Distribution cost	89	85		4	
	SCF	Upside supply chain flexibility	90	90			0
		Upside supply chain adaptability	95	90		5	
		Downside supply chain adaptability	90	90			0
Sustainable (S)	HE	Working hours	100	100			0
		Working conditions transparency	95	100	5		
		Health and safety management	95	100	5		
		Injury rate	100	100			0
	ENV	CO_2 emission	75	75			0
		Water Consumption	83	85	2		
		Energy Consumption	85	85			0
		Waste generation	90	90			0
		Green packaging	95	95			0
Resilient (R)	DP	Delivery failure	100	100			0
		Damage in transit	100	100			0
		Transportation disruption	94	95	1		
	OP	Defective product	99	100	1		
		Equipment obsolescence	87	85		2	
		Production interruption	100	100			0
		Production or technological change	85	85			0
	ISE	Information quality	100	100			0
		Information security	96	100	4		
		Information sharing systems implementation	97	100	3		
Nutrition (N)	EN	Protein supply	95	95			0
		Supply of other elements of nutrition	85	85			0
		Nutritional quality of ingredients	83	85	2		
		Organic/Vegetable ingredients (such as protein) in number of products	75	75			0
	NF	Standardized labelling of nutrition	100	100			0
		Percentage of people covered by dairy products	52	55	3		

Note: BRV = Bellow reference value; URV = Upper to reference value; ERV = Equal to reference value

Table 4
Actual and reference values of the KPIs generated from the indicator values in Table 3.

Paradigms	KPIs	Actual values of the KPIs	Reference values of the KPIs	Differences		
				BRV	URV	ERV
Lean (L)	WMP	91	95	5		
	IP	95	95			0
Agile (A)	SCNP	100	100			0
	CCSP	100	100			0
	FP	85	85			0
	SCF	92	90		2	
Green (G)	HE	97	100	3		
	ENV	85	86	1		
Resilient (R)	DP	98	98			0
	OP	93	92		1	
	ISE	98	100	2		
Nutrition (N)	EN	84	85	1		
	NF	72	74	2		

Table 5
Relative importance of the KPIs by using AHP.

Paradigms	KPIs	Assigned scale value	Importance	Weight of KPIs
Lean	WMP	1	Reasonably less important	0.25
(L)	IP	3	Reasonably more important	0.75
Agile	SCNP	5	Strongly more important	0.15
(A)	CCSP	7	Very strongly more important	0.27
	FP	9	Completely more important	0.36
	SCF	5	Strongly more important	0.22
Sustainable	HE	6	Intermediate value between two adjacent judgments	0.50
(S)	ENV	6	Intermediate value between two adjacent judgments	0.50
Resilient	DP	7	Very strongly more important	0.30
(R)	OP	9	Completely more important	0.40
	ISE	5	Strongly more important	0.30
Nutrition	EN	4	Intermediate value between two adjacent judgments	0.50
(N)	NF	4	Intermediate value between two adjacent judgments	0.50

Table 6
Overall scores of the KPIs after multiplying relative important and KPIs values.

Paradigms	KPIs	Actual values of the KPIs	Reference values of the KPIs
Lean	WMP	22.75	23.75
(L)	IP	71.25	71.25
Total score		94	95
Agile	SCNP	15	15
(A)	CCSP	27	27
	FP	30.6	30.6
	SCF	20.24	19.8
Total score		98.24	98.24
Sustainable	HE	48.5	50
(S)	ENV	42.5	43
Total score		91	93
Resilient	DP	29.4	29.4
(R)	OP	37.2	36.8
	ISE	29.4	30
Total score		96	96.2
Nutrition	EN	42	42.5
(N)	NF	36	37
Total score		78	79.5

of subjective judgements in decision-making and optimize the overall functioning [123] of the supply chain ecosystem.

Only a few other researchers have made use of some of the ideas reflected in this paper in their work. For example, Agarwal [41] utilized ANP (Analytical Network Process) to model the indicators for the paradigms consisting of lean, agile and leagile (a combination of lean and agile) regarding decision making in supply chain management. Cabral [124] proposed a decision-making model for supply chain management based on the paradigms of lean, agile, resilient and green (LARG). Azevedo [125] studied the influence of the paradigms of agile and resilient on supply chain performance. Carvalho and Cruz-Machado [126] investigated the integration of the lean, agile, resilient and green paradigms in their studies of the contradictions and synergies arising in supply chain management performance. Espadinha et al [50] modeled the lean, agile, green and resilient (LAGR) paradigms for addressing interoperability in supply chain management and argued that their model is suitable for some industries. Apart from the LAGR paradigms-based framework, in the literature many other structures have been proposed to manage supply chains. Examples include the six-sigma framework [127,128]; hierarchical framework [129,130]; supply-chain operations reference framework (SCOR) [131, 132]; financial matrices-based framework [133,134]; and non-financial matrices-based framework [135].

In the present world context, dairy supply chain management has an obligation to provide the best information possible related to the nutrition and green paradigms to ensure that product statements are credible and defensible. In this respect, the proposed framework put forward in this paper is very crucial as it is capable of incorporating the nutrition paradigm into dairy supply chain management. This is very important as the dairy supply chain provides basic human nutrition and operates within a rich diversity of food products and markets. Accordingly, considering the nutrition paradigm as a part of the modeling process is essential from a public health perspective. Addressing nutrition along with green paradigms in product packaging will certainly add value to the products.

Dairy companies are being forced to adjust and improve their supply chain management in order to strengthen their brand image. Companies need innovative supply chain management to succeed and gain competitive advantage in the business. They also want to ensure customer satisfaction through the value of the milk supply chain by providing appropriate dairy products in terms of both quantity and quality. LASRN-based supply chain management can be a turning point for them to gain a competitive advantage. The proposed framework offers a process that will help supply chain managers adopt best practices [136]. In addition, utilizing LASRN management paradigms will certainly help achieve sustainability.

A better decision support system and guidelines will ensure the profitable and efficient use of resources as well as the sustainability of the supply chain. This framework can assist food manufacturing firms in designing and implementing LASRN-based management to optimize competitiveness within a responsible environment. This enlightened management approach contributes to enhancing both the health of people and the planet within an overall process called Convergent Innovation [27].

The novel framework designed in this study was motivated by the need to improve the performance of the dairy supply chain management of a major company located in Canada. This enterprise, as well as other dairy companies, can use their own data with this methodology to determine where enhancements can be made to their dairy supply chains. For illustrative purposes in this study, the authors used representative, but hypothetical data, to demonstrate how the Convergence Innovation approach can be utilized, since the actual data are confidential. Moreover, the approach can be appropriately expanded or revised to handle special situations in dairy supply change management.

Declaration of Competing Interest

The authors declare no conflict of interest.

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Ethics statement

The research proposal for this paper was approved by the Research Ethics Board Office of McGill University, Canada.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.sftr.2021.100045.

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