Quantitative models for supply chain management within dairy industry: a review and discussion

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Abstract: The topic of supply chain management in dairy industry has received a great deal of attention in recent years due to its structural characteristics, such as long sequence dependent setup times, large changeover costs, numerous flavoured and coloured product types with the complicated changeover rules, limited shelf life restricting the storage duration and delivery conditions for each perishable raw material, intermediate and final product. This paper is intended to provide a critical review on quantitative supply chain models within the dairy industry. A number of problem variants are investigated in terms of: 1) solution approaches; 2) problem and model characteristics; 3) decision levels. Through the analysis of the review, a framework is developed for the existing literature to reveal major trends, explore research opportunities, and give several directions for future research. [Received 8 December 2012; Revised 12 August 2013; Revised 2 January 2014; Accepted 3 February 2014]

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1 Introduction

Supply chain management (SCM) has become one of the most important strategies for achieving competitive advantage in different industries. During the last three decades, SCM is a common approach with wide range of applications to take an integrated look at closely related procurement, production, storage and distribution processes. Nowadays, more effective planning and control of these processes in supply chains begin to be directed towards food SCM.

The most important fresh food segments are dairy products. Dairy industry is a significant component of many economies, and is a major industry in the most developed and developing economies of the world. Dairy product is the collective name for products milk, cream, yoghurt, kefir, buttermilk, butter, cheese, ice-cream, condensed milk and milk powder. In the literature, these products and manufacturing processes are explained in detail from the primary production of the milk to the following phases by Bylund (1995). The individual products are made through a complex, multi-step process. A typical production process consists of a number of stages such as, receiving materials, mixing and blending according to recipe, processing and packaging. Out of a limited number of raw materials (e.g. raw milk) still a moderate number of intermediate products (e.g. full-fat milk, diet milk, aroma milk) are produced within the processing step. High product complexity typically occurs at the packaging level due to different tastes and customer individual packaging forms (Lütke Entrup, 2005).

The dairy industry is characterised by unique features that differentiate it from the other industries. The specific characteristics of dairy industry are summarised such as high number of products and variants, divergent product structure, complicated setup operations with sequence dependent times having different changeover rules, capital intensive processing equipment, shared resources, identical machines, hygienic factors, multi-stage production process, necessity for lot traceability due to quality and environmental issues, special needs for handling, transportation and storage technologies, and shelf life restriction for raw materials, intermediate products, and end products which has directly influence on wastage, inventory levels and out of stock rates and product preference of the customer (Nakhla, 1995; Lütke Entrup, 2005; Amorim et al., 2011a).

Due to the mentioned factors, production planners face a complex task in which a number of constraints have to be met. Deciding which and how much white mass to produce in each tank given the available connections to the filling and packaging lines is a challenging task. The synchronisation of production stages is difficult due to the difference between processing and packaging rates and the limitations on intermediate storage. Furthermore, the technical constraints such as cleaning and traceability requirements interfere with the timing and assignment decisions. To these production challenges must be added those for high demand variability. Moreover, in the dairy industry, the challenges associated with demand variability are compounded by the short shelf life of the finished products and relatively long production lead times. These all together make the planning and scheduling of the processing system a challenging task (Kilic, 2011). Besides, transportation is a significant component of total cost for a company where the movement of raw materials or products is required. Major components of the transportation costs include the labour cost of the drivers, the cost of fuel and the cost of the vehicles. These costs are especially important where perishable products are being transported and specialised handling is required (Butler et al., 2005). It is important nowadays that dairy products must be delivered within allowable delivery times or time-windows.

In this research, based on the characteristics, we review the most relevant and recent literature on the supply chain problems within the dairy industry. The aim is to provide a detailed literature review of previous research on quantitative models addressing a variety of problem types and solution approaches to be subject of production planning, distribution planning and scheduling problems. The research presents a literature review consisting of past reviews and surveys besides the current research articles. Due to the diversity of available publications, the search has to be directed by setting appropriate limits. As for the methodology, we review the peer-reviewed articles published in the English language, proceeding papers, PhD dissertations commonly cited in the literature. Furthermore, we review past reviews and review articles to obtain some related research in addition to corresponding literature.

In this review, we confine ourselves to the production planning and scheduling, distribution planning, and vehicle routing problems (VRPs) within dairy SCM. Inventory models with deteriorating or perishable products have also received considerable attention in the literature. For a complete review on perishable inventory models, the reader is referred to Nahmias (1982), Raafat (1991), Goyal and Giri (2001), Karaesmen et al. (2011) and Bakker et al. (2012). Inventory management is a topic beyond the scope of this review.

Since dairy industry is an important part of the food sector, interested readers are referred to following review articles on food, and the agricultural supply chain: Ahumada and Villalobos (2009) reviewing models for the agricultural food business; Akkerman et al. (2010) addressing research done in the field of food distribution where different characteristics are identified as key issues such as quality, safety and sustainability; Tarantilis and Kiranoudis (2005) and Grunow and Van der Vorst (2010) providing an editorial perspective on food production and SCM; Pahl et al. (2007) focusing on deterioration constraints of production planning, lot sizing and inventory; Amorim et al. (2011b) reviewing the production distribution planning problems tackling with perishability explicitly; Soysal et al. (2012) reviewing the quantitative models for sustainable food logistics management; Shukla and Jharkharia (2013) providing a state of the art on agri-fresh product SCM.

Dairy industry that is a sub-segment of the food industry shares similar fundamental properties. However, there are several differentiating characteristics: the production is semi-continuous/continuous make and pack process operating with shared resources and parallel packaging machines; the setup operations are more complicated with sequence dependent time; there are different changeover rules for not only the products but also the product groups; more critical hygienic factors should be taken into account; a variety of intermediate and final products is produced by a single raw material (e.g. milk). Moreover, dairy shows the highest criticality with regard to very restricted and limited shelf life reflecting not only physical state but also representing whether it is in a saleable condition or not. The main objective of this paper is to review existing operations research literature on SCM problems in the dairy industry and to identify the areas where further research is needed. The fundamental motivation for this review comes from the practical significance of the supply chain planning problems in the dairy industry. In the last decade, the literature is replete with publications related to the applications of operations research methodologies to SCM problems within the dairy industry. However, a unified body of literature that deals SCM problems in the dairy industry does not exist yet. To the best of our knowledge, there is no previous review study particularly focusing on SCM problems in the dairy industry. The main contribution of this review study is to fill the perceived gap by providing a comprehensive overview of the current literature on the applications of SCM in the dairy industry.

We have scrutinised the previous reviews, in order to determine the classification criteria. To our knowledge, although there is no review offering assessments especially on dairy supply chain problems, the literature on the food SCM includes many surveys. Various classification schemes are available to categorise the SCM research. Ahumada and Villalobos (2009) classify the reviewed perishable and non-perishable agricultural foods into modelling approaches under the consideration of different planning levels. Akkerman et al. (2010) concentrate on the food distribution by focusing on quality, safety and sustainability. Pahl et al. (2007) present a categorisation on perishability, deterioration and classify the articles in terms of material flow along the supply network. Amorim et al. (2011b) categorise production and distribution planning problems by gathering the lot sizing, scheduling, vehicle routing articles into one group. Of all the previously published review literature, the classification scheme used by Amorim et al. (2011b) is the closest one to what we present.

Figure 1 presents the factors used to dissect and organise this review. The classification scheme followed presents problem areas along with the solution methodology developed. From the perspective of the problem scope, we divide the paper into three main problem types such as production planning and scheduling, vehicle routing and distribution planning, integrated production and distribution planning. In a second level of the classification, we make a further categorisation using the particularities of the solution approaches used. The reviewed research is classified by problem types based on solution approaches. The papers are listed as summary tables in the every subsection of the review with the fundamental subdivisions such as perishability, product types, supply chain processes, fictitious data or case study, product stages, solution approach, decision levels, objective function, shelf life, capacity and time constraints, labour and working time restrictions, production overtimes, setups. The supply chain planning matrix developed by Meyr et al. (2002) classifies the planning tasks into two dimensions planning horizon and supply chain processes. The framework presented by Meyr et al. (2002), as seen in Figure 2, is used to display the supply chain processes focused on. These processes are highlighted in the figure.

Figure 1 Classification scheme

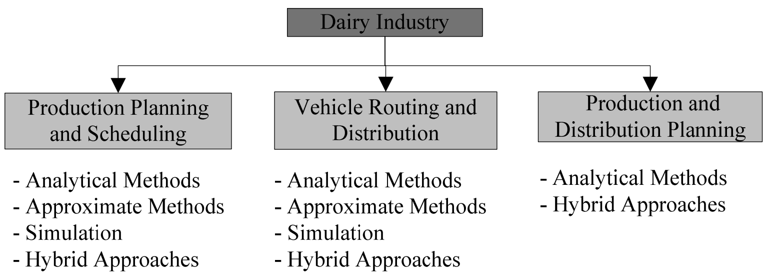
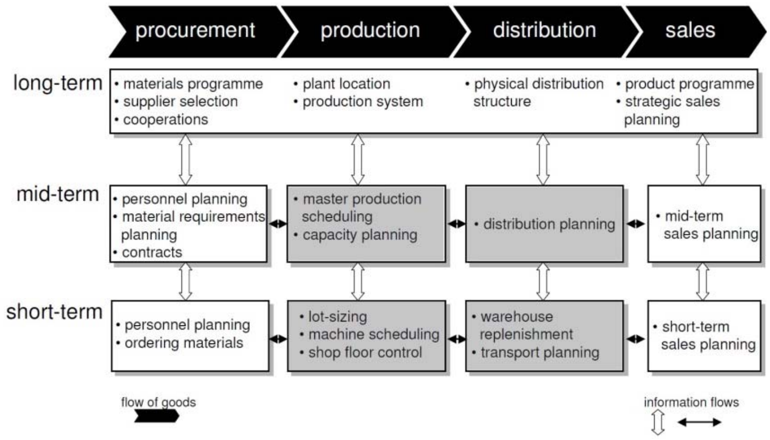


Figure 2 Supply chain planning matrix



Source: Meyr et al. (2002)

The remainder of this article is organised as follows. In Section 2, literature review on quantitative models in the dairy industry is presented with the subsections corresponding with the variety of problem types and solution approaches. In Section 3, the paper ends with conclusions, and possible directions for the future research.

2 Quantitative models in dairy industry

In this section, we review quantitative models in the supply chain literature within the dairy industry. The three subsections corresponding to the various problems types arising from the dairy industry are presented with respect to the solution approaches. The covered problem types are: production planning and scheduling; vehicle routing and distribution planning; integrated production and distribution planning problems. The reviewed works are ordered chronologically. They have been classified according to the solution approach proposed.

2.1 Production planning and scheduling

Production planning and scheduling is crucial for achieving competitive advantage in different industries (Grunder et al., 2013; Hsu et al., 2009). As well, the dairy industry contains various complex optimisation problems. Several production planning problems arise from the different processing stages. The individual products are made through a complex, multi-step process. Extra care must be taken to ensure high standards of sanitisations, control of allergens, batch traceability, and product freshness. Due to divergence of the product structure, pressure on product freshness, respecting lot sizing policies, demand variability, synchronising material consumption among the production stages, the task of planners becomes more complex in the dairy industry. The production environment has several industry-specific characteristics involving traceability requirements, limited production resources, time- and sequence-dependent cleaning of production units. The characteristics together lead to challenging of scheduling problems which require efficient and flexible modelling approaches (Kilic, 2011). In the remainder of this section, we classify the production planning and scheduling research in the dairy industry based on the solution methodologies used. These classifications are analytical methods, approximate methods, simulation and hybrid approaches.

2.1.1 Analytical methods

Pioneering research is done by Sullivan and Secrets (1985), Rutten (1993) and Jakeman (1994) in the field of production planning within the dairy industry. Sullivan and Secrets (1985) design a small optimisation-based decision support system (DSS) for production planning and inventory forecasting of dairy industry and they implement it to a real world application. The designed milk flow analysis program is prepared as an interactive and user-friendly primal linear programming (LP) model. Rutten (1993) considers the operational level planning problem in a process industry producing milk replacer. The considered problem is handled with a hierarchical approach decomposing the large problem into two sub-problems, which can be solved using an LP approach. The objective is to minimise the total costs of raw materials. They develop a DSS operating in an acceptable solution time. Jakeman (1994) discusses a knowledge-based production management system using modelling techniques, handling industry specific issues of food production and providing expert information to assist operators and production management to make decisions in complex production operating environments. The proposed system is applied to practical applications of ice cream and yoghurt production. A case study is presented on yoghurt production process by taking into account various important specific restrictions. The knowledge-based production management system yields interesting results in improving efficiency and understanding plant operations. This is the first fundamental research considering the incubation process incorporated into the filling and packaging.

Until recently, the use of optimisation-based techniques for the production planning problem in the dairy industry has received little attention in the operations research literature. Lütke Entrup et al. (2004a, 2004b) consider shelf life issues for integrated production planning and scheduling problem in an industrial case of stirred type of yoghurt within the dairy industry. The focus is particularly on the filling and packaging stages of the production process. The mixed integer linear programming (MILP) models are based on the principle of block planning and combination of a discrete and a continuous time representation. The objective function is maximisation of the contribution margin considering revenues and variable costs. Both of the papers take into account a shelf life dependent pricing component, sequence independent setups and cleaning time. While Lütke Entrup et al. (2004b) consider the planning periods based on the production day, Lütke Entrup et al. (2004a) present a position-based planning model. As an extension of the both research, Lütke Entrup et al. (2005) develop several block programming MILP models for the same industrial case of yoghurt production. These are standard models with day bounds, setup conservation allowing the overnight production and position-based splitting the planning horizon up into consecutive enumerated positions. The models aim at the maximisation of the contribution margin taking into account shelf life integrated price component. However, the MILP models focus on flavouring and packaging stages. Thus, operations involving the processing and storage of products are neglected. The improvement of the position-based model, integration of the fermentation process into the planning procedure and incorporation of uncertainty are presented as the future directions of the research.

Bongers and Bakker (2006) introduce a multi-stage scheduling model derived from a medium size ice cream manufacturer. The model handles a simplified process consisting of only one pasteurisation and packaging process. The solutions of the model are achieved using a commercial scheduling software. Later, Subbiah and Engell (2009, 2010) study on the same case which is considered by Bongers and Bakker (2006). While Subbiah and Engell (2009) demonstrate an application of the timed automata (TA)-based approach to the problem of scheduling batch processes with resources subject to sequence dependent changeovers, Subbiah and Engell (2010) describe the application of the TA-based approach to model and solve batch scheduling problems, which are subject to sequence dependent changeovers and limited discrete resources with the objective of makespan minimisation.

Doganis and Sarimveis (2007) propose an MILP model for production scheduling in yoghurt industry. The model considers the sequencing limitations, sequence dependent changeover times and costs in addition to standard constraints encountered in the production scheduling such as material balances, inventory limitations, machinery capacity, labour shifts and manpower restrictions. The objective of the proposed MILP model is only minimisation of all major sources of variable costs such as setup, inventory and labour costs. However, the model is limited to the single production line. Doganis and Sarimveis (2008a) extend their previous research by presenting a customised MILP model to optimise yoghurt packaging lines consisting of multiple parallel machines where actions have to be synchronised across all machines due to common feeding line. The proposed model decides the produced quantities of each product at each machine, the starting and finishing time for the production of each item in each machine, the total machine utilisations including changeover times, the inventory levels at the end of the day with the given data of the demand during the scheduling horizon. The model incorporates sequence dependent setup costs and times, the cleaning task at the end of the day, multiple intermediate due dates, job mixing and splitting, product specific machine speed, and minimum lot sizes. The performance of the proposed model is illustrated through its application to the yoghurt production plant of a leading dairy product manufacturing company. Doganis and Sarimveis (2008b) address a new MILP model that combines the advantages of the models presented by Doganis and Sarimveis (2007, 2008a). They integrate the production constraints, management directives with the proposed model. The shelf life restriction is not only considered in the constraints to keep stable the remaining shelf life on the production process, but also in the objective function in which there is a penalisation to control the freshness on delivery. The number and sizes of lots are not limited and the total production time is limited by the available machine time. The objective of the MILP model is a minimisation function involving setup, storage, machine utilisation, overtime labour costs and a term for marketability loss.

Environmental considerations are taken into account by a number of researchers in the dairy industry. Stefanis et al. (1997) consider environmental conditions in the optimal design and scheduling of batch/semi-continuous processes and present examples from the cheese production process. They use life cycle analysis (LCA)-based methodology within general multi-objective formulation consisting of process economics and environmental impact. The process of interest is investigated to evaluate environmental impact with a set of metrics such as air, water pollution, global warming. Vaklieva-Bancheva and Kirilova

(2010) focus on both the environmental consideration and the choice of the production recipes for the products within the scheduling framework. They propose a mathematical formulation to solve the multi-objective optimisation problems for a special class of schedules. These papers contribute to the literature in terms of the consideration of environmental issues as well as design and scheduling within the dairy industry.

Wang et al. (2010) take into consider the determination of buffer capacity in dairy filling and packaging lines. They use the transient analysis method to analyse the performance of the filling and packing system using Bernoulli two-machine model. They also perform sensitivity analysis on larger buffer capacity, higher filling station throughput, and initial inventory buildup. The performance parameters of the system are production rate, work in process during transients, necessary extra time of filling station, operating, blockage and starvation times of filling and packaging stations.

Jang and Klein (2011) consider business-to-customer and business-to-business aspects of an agricultural supply chain model motivated by the needs of a local dairy farm. They present an optimisation model using mathematical modelling techniques. They study on the strategic planning issue by forming cooperative agreements, deciding the size of cooperative, and defining the production quantities. The research differentiates from the literature by dealing with business-to-customer and business-to-business aspects on strategic level decisions of dairy industry.

Guan and Philpott (2011) develop a multi-stage stochastic programming model taking into account uncertainty and a linear price-demand curve to solve the production planning problem in the dairy industry. In addition, they analyse sales policy by a multi-stage stochastic quadratic model using a decomposition algorithm. This is the only work that takes into account uncertainty and dynamic policies in dairy SCM.

Kopanos et al. (2010a, 2010b) study on the lot sizing and scheduling problem in a multi-product yoghurt production line of a real life plant. A mixed discrete/continuous time MILP model is proposed. The problem under question is mainly focused on the packaging stage, whereas timing and capacity constraints are imposed with respect to the pasteurisation, homogenisation and fermentation stage. Sequence dependent setup times and costs are explicitly taken into account and optimised by the proposed framework. However, the scheduling problem they consider only involves the packaging stage. Kopanos et al. (2011a) present a MILP framework for the resource constrained production planning problem in a semi-continuous food process, similar to the dairy industry. Quantitative as well as qualitative optimisation goals are included in the proposed model. Renewable resource limitations are appropriately taken into account. All of the above mentioned works are related to the single stage production systems in the dairy industry. Kopanos et al. (2011b) present a novel MILP formulation and solution strategy to address the challenging production scheduling problems in the multi-product, multi-stage dairy industry. The main features of the proposed approach rely on the integrated production stages, and the inclusion of strong valid integer cuts favouring shorter computational times. In a paper by Kopanos et al. (2012b), the MILP model developed by Kopanos et al. (2011b) is further enhanced by introducing new sets of tightening constraints in order to improve computational efficiency in industrial size scheduling problems in food industry. Both of the papers consider production scheduling problem in a real world multi-stage food processing industry with the limited shelf life of intermediate mixes in the aging stage.

Amorim et al. (2013a, 2014) investigate the production planning problem with a different point of view from the existent literature. While Amorim et al. (2013a) assess the suitability of financial risk measures for mitigating crucial risks in the production planning of perishable goods, Amorim et al. (2014) consider the influence of customer purchasing behaviour on the production planning of perishable goods. The paper presented by Amorim et al. (2013a) goes beyond the literature considering risk management within dairy supply chain. They explore the trade-off between expected profits and risk under perishable nature of goods by developing risk-averse production planning model. The model is developed as a two-stage stochastic programming model. In this model, they asses the sustainability of financial risk measures and consider uncertainty in the demand level, decay rates and customer purchasing behaviour. They present deterministic and stochastic mathematical models accounting consumer purchasing behaviour. The impact of customer purchasing behaviour is investigated by the influence of the age dependent demand, and the effect of faithfully representing product quality risk in the model. Investigation of demand uncertainty under risk management perspective is highlighted as a promising area. Apart from these, Amorim et al. (2013b) focus on lot sizing and scheduling decisions of the production process consisting of multi-product and multi-parallel lines with complex setup structure. They analyse the performance of existent and well identified formulations in the literature for small bucket and big bucket capacitated lot sizing and scheduling problems.

Recently, Kilic et al. (2013) and Banaszewska et al. (2013) take into account blending and intermediate production stages besides the final production stage. Kilic et al. (2013) consider a capacitated intermediate product selection and blending problem which is a two-stage production system. They focus on a baker industry example but the model is applicable with small modifications to the dairy industry. They introduce a MILP model and give scenario-based analysis. Banaszewska et al. (2013) present a comprehensive dairy valorisation model for mid-term allocation of raw milk to end products and production planning. They present a MILP model that allocates raw milk to the most profitable dairy products by taking into account recipes, composition variations, dairy production interdependencies, seasonality, demand, supply, capacities, and transportation flows. They also analyse the effect of seasonality for milk valorisation.

2.1.2 Approximate methods

Nakhla (1995) expresses the increasing need for flexibility due to rising logistical demands as the result of the change in the market conditions for food processing companies. The problem arises from a yoghurt production process being a specific dairy product industry. A rule-based scheduling approach is introduced for packaging lines.

Vaklieva et al. (2005) consider a multi-objective optimisation problem analysing the trade-off between plant profit and environmental impacts in curds manufacturing process of a dairy industry. They use a genetic algorithm (GA) technique as a solution approach to find the conditions leading to the best compromise between both objectives taking into account the effect of the amount and composition of processed milk, processing unit's assignment and number of processed batches. The paper presents a salient research contribution by considering the amount and composition of processed milk and inherent losses in addition to production constraints.

Marinelli et al. (2007) present a real capacitated lot sizing and scheduling problem with parallel machines and shared buffers in a packaging company producing yoghurt. The discrete mathematical planning model aims at minimising the setup, storage and processing costs. As a solution methodology, they propose a two-stage heuristic based on the decomposition of the problem into lot sizing on tanks and scheduling on lines. In order to obtain the lower bounds, the proposed model formulation is relaxed in five ways, while the upper bound value is calculated with the two-stage optimisation heuristic consisting of a nested local search framework. In the computational efforts, the data is generated with the two different scenarios for the dedicated and general purpose lines. The proposed two-stage heuristic is very effective and produces near optimal solutions within very short computational times. However, it is assumed that the production rate is fixed by a single bottleneck stage, setup time, and setup cost are sequence independent.

Banerjee et al. (2008) consider the planning and scheduling of milk food processing process. They propose a hybrid meta-heuristic approach based on a multi-objective Bee Colony algorithm combined with the constructive rough set heuristics. They also present a case study on process scheduling of a milk production centre.

Gellert et al. (2011) consider an integrated sequencing and scheduling problem of filling lines in the dairy industry. The fundamental focus is to sequencing and scheduling of dairy industry production process under consideration of cleaning and sterilising issues. They introduce an application of the general sequencing and scheduling framework. They utilise a GA for the sequencing by incorporating a problem specific algorithm for the fixed sequence scheduling. They also propose the suboptimal greedy and optimal shortest path algorithms. The aim is to find a production plan consisting of a processing order or sequence, and a feasible schedule, which minimises the makespan. This research differentiates itself from the literature in the sense that it focuses on the scheduling under consideration of cleaning and sterilising issues.

In a recent study, Van Elzakker et al. (2012) present a new MILP scheduling model and algorithm for the scheduling in the fast moving consumer goods industry. A problem specific formulation is used since the efficiency of the model is crucial to be able to address larger cases. They focus on the ice cream production process of parallel mixing and parallel packing lines. The objective is the minimisation of the makespan. An algorithm is proposed to tackle with the periodic cleaning characteristic of the production process. The proposed model is evaluated based on the ice cream scheduling case study presented by Bongers and Bakker (2006).

2.1.3 Simulation

Kuriyan et al. (1987) present a preliminary research using simulation to solve the scheduling problem in the dairy industry. In this research, production schedules are generated by using efficient sub-optimal algorithms and the performance of the algorithms are evaluated by using simulation package. The use of a simulation approach is a research direction which has a gap on the production planning and scheduling application area in the dairy industry.

2.1.4 Hybrid approaches

Claassen and Van Beek (1993) develop and implement a pilot DSS to solve a planning and scheduling problem for the packaging line which is the most bottleneck process of the cheese production of a large dairy company. They handle the problem for both tactical and operational control levels. On the operational control level, the sequence of packaging lines is identified with the sequence dependent setup times by an asymmetric travelling salesman heuristic solution approach and the sequence of jobs is determined by logical rules. On the tactical level, an MILP model is introduced to determine the feasible and daily master production schedule.

The research papers stated below contribute to the literature using a seminal solution approach to incorporate environmental considerations in the scheduling problems. Berlin et al. (2007) present a method to calculate the sequence of yoghurt products to minimise milk waste of yoghurt production. The goal of the research is to find a practical method to calculate a sequence of a great number of cultured products. Furthermore, they design a method which describes an interdisciplinary approach incorporating a heuristic sequencing approach fundamentally based on the production rules, constraints with the LCA methodology. They take into account the environmental impact and economic aspects simultaneously, by combining environmental systems analysis and production scheduling. As an extension of previous research, Berlin and Sonesson (2008) present an application of the proposed method to minimise the waste caused by a sequence for a given set of products and to calculate the environmental impact of a waste in the dairy industry. The environmental impact of the proposed sequences is calculated with a detailed scheduling model and LCA method.

Adonyi et al. (2009) consider the short-term flow shop scheduling problem in the dairy industry. They propose two distinct approaches aiming at makespan minimisation. First, they introduce an s-graph representation and apply the branch and bound technique. Second, they introduce integer programming (IP) formulation and apply the basic GA as a solution technique.

Amorim et al. (2011a) present multi-objective mixed integer programming (MIP) models using block planning approach to solve a lot sizing and scheduling problems considering perishability issues on packaging process of yoghurt production having a fixed shelf life. The setup considerations are handled as sequence dependent for the major setups and sequence independent for the minor setups. The model is analysed for two distinct scenarios depending on make-to-order and hybrid make-to-order/make-to-stock production systems. The proposed MILP model is hybridised with a non-dominated sorting GA. It differs from the literature by introducing a multi-objective MIP model to solve lot sizing and scheduling problems.

2.1.5 Research directions

To summarise the reviewed literature on production planning and scheduling within the dairy industry, the preliminary research on production planning and scheduling problem presents analytical methods applications and DSSs (Sullivan and Secrets, 1985; Rutten, 1993; Jakeman, 1994). Scheduling problems are initiative research areas (Bongers and Bakker, 2006; Subbiah and Engell, 2009, 2010). They extensively presented as the mathematical modelling applications (Doganis and Sarimveis, 2007, 2008a, 2008b; Kopanos et al., 2011a, 2011c, 2012a; Van Elzakker et al., 2012). As well, the integrated production planning and scheduling problems are taken into account with the mathematical modelling applications (Kopanos et al. 2010a, 2010b, 2011b; Lütke Entrup et al., 2004a, 2004b, 2005). A systematic methodology is used to incorporate environmental considerations in the optimal scheduling and design of batch processes (Stefanis et al., 1997; Vaklieva-Bancheva and Kirilova, 2010). Buffer capacity determination with transient analyses, strategic planning with optimisation models and production planning with stochastic programming are other miscellaneous applications (Guan and Philpott, 2011; Jang and Klein, 2011; Wang et al., 2010). The contribution by Guan and Philpott (2011) is the first example that considers stochastic parameters within dairy SCM. Recently, Amorim et al. (2013a, 2014) present research directions considering stochastic parameters by means of two distinct perspectives (e.g. consumer purchasing behaviour and risk management).

Although, the perishability and shelf life issues, capacity and time constraints, working time and overtime restrictions, changeover considerations are not explicitly taken into account by pioneering research papers, these problem characteristics have gained attention in recent research. Perishability, consideration of shelf life, sequence dependent setup time, and environmental aspects appear to be the most promising aspects that support the realistic representations.

Approximate methods such as heuristic and metaheuristic methods support the solution efforts by requiring less running times. Whereas research papers using these methods are capable of representing the specific characteristics of dairy industry, capacity and time constraints with working time and overtime restrictions, sequence dependent setup and cleaning times and perishability and shelf life issues are rarely taken into account (Banerjee et al., 2008; Gellert et al., 2011; Marinelli et al., 2007; Nakhla, 1995; Vaklieva et al., 2005).

Kuriyan et al. (1987) is the only paper that applies simulation methodology for the production scheduling in the dairy industry. Simulation applications allow production scheduling to be modelled more realistically.

Some of the preliminary research papers combine heuristics, and exact optimisation methods by a DSS (Claassen and Van Beek, 1993). The environmental issues within the production planning are considered with the TSP optimisation heuristics and LCA methodology (Berlin et al., 2007; Berlin and Sonesson, 2008). Integrated production planning and scheduling problem is commonly taken into account by mathematical modelling integrated with heuristic and metaheuristic methods (Adonyi et al., 2009; Amorim et al., 2011a). Research papers using hybrid approaches rarely consider some of the specific characteristics of dairy industry. These characteristics are stressed in a recent article by Amorim et al. (2011a) within the hybrid approach.

Table 1 summarises the reviewed literature of production planning and scheduling within the dairy industry. The papers are listed in the order presented in the review. For each research, the table illustrates the different characteristics in a systematic manner. Abbreviations are also explained in the nomenclature.

Table 1 Summary of production planning and scheduling research

Reviewed literature	*Perishability*	*Product types*	*Supply chain processes*	*Fictitious data/case study*	*Product stages*	*Production stages*	*Solution approach*	*Decision levels*	*Objective*	*Shelf life*	*Capacity and time constraints*	*Labour, working time, overtimes*	*Setups*
Analytical methods													
Sullivan and Secrest (1985)	-	D	PRD	CS	RM-FP	O	LP and DSS	O	S	-	C	-	-
Rutten (1993)	-	D	PRD	CS	RM-IP-FP	O-P	LP and DSS	O	S	-	C	O	-
Jakeman (1994)	-	I-Y	PRD	CS	IP-FP	I-P	OT	O	S	-	-	-	-
Bongers and Bakker (2006)	P	I	PRD	CS	FP	O-P	OT	O	S	SL	CT	-	
Subbiah and Engell (2009)	P	I	PRD	CS	FP	O-P	OT	O	S	SL	CT	-	SD
Subbiah and Engell (2010)	P	I	PRD	CS	FP	O-P	OT	O	S	SL	CT	-	SD
Kopanos et al. (2011a)	P	I	PRD	CS	FP	O-P[MP]	MILP	O	S	SL[IC]	CT	-	P-SD
Kopanos et al. (2011c)	P	I	PRD	CS	FP	O-P[MP]	MILP	O	S	SL[IC]	CT	-	P-SD
Kopanos et al. (2012b)	P	I	PRD	CS	FP	O-P[MP]	MILP	O	S	SL[IC]	CT	-	P-SD
Van Elzakker et al. (2012)	P	I	PRD-STR	CS	IP-FP	O-P[MP]	MILP	O	S	-	CT	-	P-SD
Lütke Entrup et al. (2004a)	P	Y[ST]	PRD	CS	FP	F-P[MP]	MILP	O	S	SL[IO]	CT	O	SI
Lütke Entrup et al. (2004b)	P	Y[ST]	PRD	CS	FP	F-P[MP]	MILP	O	S	SL[IO]	CT	O	SI
Lütke Entrup et al. (2005)	P	Y[ST]	PRD	CS	FP	F-P[MP]	MILP	O	S	SL[IO]	CT	O	SI
Doganis and Sarimveis (2007)	-	Y	PRD-STR	CS	FP	P[SP]	MILP	O	S	-	T	-	SD
Doganis and Sarimveis (2008a)	-	Y	PRD-STR	CS	FP	P[MP]	MILP	O	S	-	T	-	SD
Doganis and Sarimveis (2008b)	P	Y	PRD-STR	CS	FP	P[MP]	MILP	O	S	SL[IO]	T	-	SD

Notes: **Perishability*; P – perishability

**Product types*; C – cheese, D – dairy and milk, I – ice cream, Y – yoghurt [SE-set or ST-stirred], O – others

**Supply chain processes*; PRC – procurement, PRD – production, STR – storage, DST – distribution

**Fictitious data or case study*; HY – hypothetical application, CS – case study

**Product stages*; RM – raw materials, IP – intermediate products, FP – final products

**Production stages*; F – fermentation, I – incubation, P – filling and packaging [SP-single packaging line or MP-multiple and/or parallel packaging line], O – other production processes

**Solution approach*; DSS – decision support system, MIP – mixed integer programming, MILP – mixed integer linear programming, MINLP – mixed integer nonlinear programming, LP – linear programming, IP – integer programming, NLP – nonlinear programming, SP – stochastic programming, HE – heuristic, MH – metaheuristic, FZ – fuzzy, HD – hybrid approaches, HI – hierarchical solution approaches, SM – simulation, AN – analytical methods, LCA – life cycle analysis, TA – timed automata, GA – genetic algorithm, OT – other

**Objective*; S – single objective, M – multi objective

**Shelf life*; SL – shelf life [IO-in objective function or IC-in constraints]

**Capacity and time constraints*; C – capacity, T – time, CT – capacity and time

**Labour, working time and overtimes*; L – labour, W – working time, O – overtime

**Setups*; G – product group (family) setups, P – product setups, SD – sequence-dependent, SI – sequence-independent.

Table 1 Summary of production planning and scheduling research (continued)

Reviewed literature	*Perishability*	*Product types*	*Supply chain processes*	*Fictitious data/case study*	*Product stages*	*Production stages*	*Solution approach*	*Decision levels*	*Objective*	*Shelf life*	*Capacity and time constraints*	*Labour, working time, overtimes*	*Setups*
Analytical methods													
Kopanos et al. (2010a)	-	Y	PRD-STR	CS	FP	F-P[MP]	MILP	O	S	-	CT	-	G-SD
Kopanos et al. (2010b)	-	Y	PRD-STR	CS	FP	F-P[MP]	MILP	O	S	-	CT	-	G-SD
Kopanos et al. (2011b)	-	Y[SE&ST]	PRD	CS	FP	P[MP]	MILP	O	S	-	CT	-	G-SD and P-SI
Wang et al. (2010)	-	D	PRD	CS	IP-FP	P	OT	O	M	-	-	-	-
Guan and Philpott (2011)	P	D	PRD-STR-DST	CS	FP	O	SP	O	S	-	C	-	-
Stefanis et al. (1997)	-	C	PRD	CS	RM-IP-FP	O	LCA	O	M	-	CT	-	-
Vaklieva-Bancheva and Kirilova (2010)	-	C	PRD	CS	RM-FP	O	OT	O	M	-	T	-	-
Jang and Klein (2011)	-	D	PRD	CS	FP	-	OT	S	S	-	-	-	-
Amorim et al. (2013a)	P	O-D-Y	PRD-STR	CS	FP	P[MP]	SP	O-T	S	SL[IC]	CT	-	SI
Amorim et al. (2013b)	P	O-D-Y	PRD-STR	CS	FP	P[MP]	SP	O-T	S	SL[IC]	CT	-	G-SI and P-SI
Amorim et al. (2013c)	-	O-D-Y	PRD-STR	HY	FP	P[MP]	MILP	O	S	-	CT	-	G-SD and P-SI
Kilic et al. (2013)	-	O-D	PRD-STR	CS	IP-FP	O	MILP	O	S	-	CT	-	SI
Banaszewska et al. (2013)	-	D	PRD	CS	RM-FP	O	MILP	O	S	-	C	-	-

Notes: **Perishability*; P – perishability
**Product types*; C – cheese, D – dairy and milk, I – ice cream, Y – yoghurt [SE-set or ST-stirred], O – others
**Supply chain processes*; PRC – procurement, PRD – production, STR – storage, DST – distribution
**Fictitious data or case study*; HY – hypothetical application, CS – case study
**Product stages*; RM – raw materials, IP – intermediate products, FP – final products
**Production stages*; F – fermentation, I – incubation, P – filling and packaging [SP-single packaging line or MP-multiple and/or parallel packaging line], O – other production processes
**Solution approach*; DSS – decision support system, MIP – mixed integer programming, MILP – mixed integer linear programming, MINLP – mixed integer nonlinear programming, LP – linear programming, IP – integer programming, NLP – nonlinear programming, SP – stochastic programming, HE – heuristic, MH – metaheuristic, FZ – fuzzy, HD – hybrid approaches, HI – hierarchical solution approaches, SM – simulation, AN – analytical methods, LCA – life cycle analysis, TA – timed automata, GA – genetic algorithm, OT – other
**Objective*; S – single objective, M – multi objective
**Shelf life*; SL – shelf life [IO-in objective function or IC-in constraints]
**Capacity and time constraints*; C – capacity, T – time, CT – capacity and time
**Labour, working time and overtimes*; L – labour, W – working time, O – overtime
**Setups*; G – product group (family) setups, P – product setups, SD – sequence-dependent, SI – sequence-independent.

Table 1 Summary of production planning and scheduling research (continued)

Reviewed literature	*Perishability*	*Product types*	*Supply chain processes*	*Fictitious data/case study*	*Product stages*	*Production stages*	*Solution approach*	*Decision levels*	*Objective*	*Shelf life*	*Capacity and time constraints*	*Labour, working time, overtimes*	*Setups*
Approximate methods													
Nakhla (1995)	-	D-Y	PRD	HY	FP	P	HE	O	S	-	-	-	-
Vaklaiva et al. (2005)	-	C	PRD	CS	RM-IP-FP	O	GA	O-T	M	-	-	-	-
Banerjee et al. (2008)	P	D	PRD	CS	FP	O	HE	O	M	-	T	-	-
Marinelli et al. (2007)	-	Y	PRD-STR	CS	FP	P[MP]	MILP-HE	O	S	-	C	-	SI
Gellert et al. (2011)	-	D	PRD	HY	FP	P[SP]	MH	O	S	-	C	-	P-SD
Simulation													
Kuriyan et al. (1987)	-	D-Y	PRD	CS	IP-FP	O-P	SM & HE	O	S	-	-	-	-
Hybrid approaches													
Claassen and Van Beek (1993)	-	C	PRD	CS	FP	P[MP]	HD[MILP-HE] and DSS	O-T	S	-	-	L-O	SD
Adonyi et al. (2009)	-	D-C	PRD	CS	FP	O	HD[IP-HE] and OT	O	S	-	-	-	-
Amorim et al. (2011a)	P	Y	PRD	CS	FP	P[MP]	HD[MILP-MH]	O	M	SL[IO]	T	-	G-SDand P-SI
Berlin et al. (2007)	-	Y	PRD	CS	FP	P	HD[LCA-HE]	O-S	S	-	-	-	-
Berlin and Sonesson (2008)	-	D-Y	PRD	CS	FP	P	HD[LCA-HE]	O-S	S	-	-	-	-

Notes: **Perishability*; P – perishability
**Product types*; C – cheese, D – dairy and milk, I – ice cream, Y – yoghurt [SE-set or ST-stirred], O – others
**Supply chain processes*; PRC – procurement, PRD – production, STR – storage, DST – distribution
**Fictitious data or case study*; HY – hypothetical application, CS – case study
**Product stages*; RM – raw materials, IP – intermediate products, FP – final products
**Production stages*; F – fermentation, I – incubation, P – filling and packaging [SP-single packaging line or MP-multiple and/or parallel packaging line], O – other production processes
**Solution approach*; DSS – decision support system, MIP – mixed integer programming, MILP – mixed integer linear programming, MINLP – mixed integer nonlinear programming, LP – linear programming, IP – integer programming, NLP – nonlinear programming, SP – stochastic programming, HE – heuristic, MH – metaheuristic, FZ – fuzzy, HD – hybrid approaches, HI – hierarchical solution approaches, SM – simulation, AN – analytical methods, LCA – life cycle analysis, TA – timed automata, GA – genetic algorithm, OT – other
**Objective*; S – single objective, M – multi objective
**Shelf life*; SL – shelf life [IO-in objective function or IC-in constraints]
**Capacity and time constraints*; C – capacity, T – time, CT – capacity and time
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2.2 Vehicle routing and distribution planning

The dairy industry is an important part of the food sector, and the attention has been shifted towards faster replenishment and improved logistical performance in addition to the production costs in this industry. The dairy industry is a large-scale industry due to numerous farms, collection centres, manufacturing facilities, distribution centres and markets. The dairy products are sensitive to environmental conditions and can be affected by rapid changes of environmental conditions. Logistic activities are especially important where dairy products are being transported and specialised handling is required. Furthermore, they show continuous quality changes throughout the supply chain, all the way until final consumption. Hence, in the dairy industry, quality, health, and safety require central consideration and more effort for the routing and distribution planning (Akkerman et al., 2010).

Several authors have previously addressed VRPs arising in the dairy industry. In the remainder of this section, we classify the vehicle routing and distribution research in the dairy industry based on the solution methodologies used. These classifications are analytical methods, approximate methods, simulation, and hybrid approaches.

2.2.1 Analytical methods

Milk collection issues and DSS development are challenging logistics problems that have long been of interest to researchers using analytical methods (Butler et al., 1997, 2005; Claassen and Hendriks, 2007). Butler et al. (1997) consider a symmetric travelling salesman problem applied to milk collection problem in the dairy industry. A number of possible IP formulations are presented and valid cutting plane inequalities are combined with branch and bound method to identify optimal integer solutions. Wide variety of DSS applications appears in the literature. Butler et al. (2005) introduce a DSS based on previous technique to plan milk collection operations and to schedule the routes. They also discuss automatic data capture devices and database management systems to provide effective management. Both of the papers contribute to the literature by providing optimisation techniques and introducing efficient DSS for milk collection in the dairy supply chain. Claassen and Hendriks (2007) develop a MILP model to solve a milk collection problem. They propose a DSS generating milk collection plans associated with daily milk collection routes combined with the midterm planned milk demand.

The paper presented by Nicholson et al. (2011) focus on the effects of localisation on supply chain costs which are complex to analyse in multi-product, multi-process dairy supply chain. They develop an optimisation model to minimise total supply chain costs, including assembly, processing, interplant transportation and final product distribution. The research contributes to the literature by presenting a strategic level transhipment model.

2.2.2 Approximate methods

The limitations of mathematical techniques have forced the use of heuristics in finding feasible solutions for large-scale VRP problems in the dairy industry. Chung and Norback (1991) present the VRP of foods including dairy and frozen goods. They introduce a heuristic approach consisting of clustering, insertion procedures for the allocation of drivers and vehicles. Sankaran and Ubgade (1994) consider a routing problem in the dairy industry. They introduce an operational level DSS by using a novel heuristic approach for the minimisation of the transportation cost. Adenso-Diaz et al. (1998) consider the dairy routing problem as a version of the travelling salesman problem with the time windows. They propose a hierarchical approach and a local search heuristic as the solution methodologies. They also design and implement a DSS to organise the delivery network for a dairy industry.

As pioneering research in the literature, Tarantilis and Kiranoudis (2001, 2007) analyse the distribution of fresh milk. They formulated the problem as a heterogeneous fixed fleet VRP. Tarantilis and Kiranoudis (2001) developed a threshold-accepting-based algorithm for a heterogeneous fixed-fleet VRP applied to a fresh milk industry with the goal of minimising the total transportation time. Tarantilis and Kiranoudis (2007) propose a metaheuristic methodology for solving a practical variant of the well-known VRP. Using a two-phase construction heuristic, the proposed metaheuristic approach enhances its flexibility to easily adopt various operational constraints. Via this approach, two real-life distribution problems faced by a dairy and a construction company are tackled and formulated as a VRP. Both of the papers have salient contributions to the literature as the pioneering vehicle routing applications in the dairy industry.

In the literature, GA is used as a common alternative solution approach (Lin and Chen, 2003; Xu et al., 2011). Lin and Chen (2003) present a dynamic allocation problem with uncertain supply for the perishable commodity supply chain to develop an analytical model and an optimal control mechanism for the allocation of orders. The objective of the problem is to maximise the total net profit, which involves total sales, costs, and penalties, of the perishable commodity supply chain subject to the dynamic variations in supply capabilities and demand uncertainties. The model determines the optimal orders placed to suppliers, and the amount of perishable commodities allocated to retailers. A two-stage extended GA is developed to control the dynamic orders and allocation quantities of suppliers and retailers. Simulation experiments are conducted to evaluate the performance of GA under various sizes of problem domains and different status of supply uncertainties. The perishability and uncertainty considerations within a dynamic assignment problem are the main contributions to the dairy industry literature. Xu et al. (2011) develop a multi-objective programming model with random fuzzy coefficients for solving the logistics distribution centre location problem. Chance-constrained programming is used to represent the uncertainty in the model. The spanning tree-based GA is proposed to solve the problem.

Lahrichi et al. (2012) and Dayarian et al. (2013a, 2013b) present real life applications of milk collection and distribution in the dairy industry. Although the problems addressed similar characteristics, they handle the problem with different perspectives and propose different solution approaches. Lahrichi et al. (2012) consider dairy transportation problem taking into account supply, demand and transportation details. The problem has different characteristics such as delivery destination at the end of the routes, different capacities for the vehicles, different number of vehicles at each depot, multiple depots and periods at the same time. They introduce a mathematical model, and propose a heuristic solution approach which is a generalised version of tabu search algorithm. Dayarian et al. (2013a) present a deterministic multi-attribute VRP. They introduce a branch and price methodology adapted to the special structure of the problem. Main contributions are introduction of VRP problem within an extra level of difficulty associated with the assignment of routes to plants, development of branch and price algorithm including structural exploration that improve the computational efficiency, and presentation of extensive analysis to illustrate algorithm efficiency and investigate the characteristics of the problem. Dayarian et al. (2013b) consider multi-period VRP. They introduce dynamic programming-based label correcting algorithm. The problem is a VRP problem in which suppliers of producers vary on a seasonal basis and inspired from a dairy industry. The solution is based on branch and price algorithm, strong branching rule to find integer solutions.

More recently, Li and Wang (2013) consider a VRP for dairy cold chain with random demands and time window. They introduce a mathematical model with chance constrained programming and penalty function. A scanning insert algorithm is proposed to solve the model. While the scanning stage classifies the costumers accordance with capacity of the vehicle and time window restrictions, insertion stage adjust the vehicle route to find the final optimal distribution.

2.2.3 Simulation

There are very few research papers addressing VRP problem by using simulation approach in the literature. The available literature focuses fundamentally on milk distribution issues (Manzini et al., 2005; Quinlan et al., 2012). Manzini et al. (2005) provide a supply chain optimisation model for the milk distribution by presenting an industrial case. They introduce a simulation model to handle shipping and distribution process. They study on two important strategic aspects as make-to-order and make-to-stock production policy by simulation. Quinlan et al. (2012) consider milk transport problem under different seasonality assumptions. They propose a simulation model to estimate milk transport costs and carbon emissions from milk transport associated with alternative milk supply patterns.

2.2.4 Hybrid approaches

Most of the early works on hybrid approaches has used DSS and heuristic algorithms. Basnet et al. (1996, 1997, 1999) introduce a DSS for milk tanker routing as a particular version VRP within New Zealand dairy industry. Basnet et al. (1996) give a general description of the milk collection scenario, DSS and graphical interfaces. While Basnet et al. (1997) introduce a typical allocation problem and heuristic solution approaches, Basnet et al. (1999) present an exact algorithm incorporating a MILP problem with additional nonlinear constraints.

Most of the papers on hybrid applications have been devoted the use of MIP and simulation applications with the heuristic approaches. Foulds and Wilson (1997) have proposed two heuristics algorithms for an interesting variation of the generalised allocation problem arising in the New Zealand dairy industry. The research differs from the literature by considering the problem as a variant of generalised allocation problem. It is a pioneering research presenting hybrid approach combining MILP model and heuristics to tackle with milk collection and transportation problem in the dairy industry. Dooley et al. (2005) consider a milk transport simulation model to estimate transport costs by taking into account milk segregation. It is also used to evaluate alternative transport management strategies in the dairy industry. They use GA as a solution mechanism to search for the least cost solution for the collection of milk from farms. Another application is provided by Bottani and Rizzi (2006). They introduce a solution methodology based on a fuzzy multi-attribute decision making approach for selection and ranking problem of the most suitable third part logistic service provider. The proposed fuzzy TOPSIS methodology is tested by a real case application of a firm operating in the dairy industry. The research differentiates form the literature with a quantitative methodology based on a structured framework for the selection of the most appropriate third part logistic service provider.

2.2.5 Research directions

To summarise the reviewed literature on vehicle routing and distribution within the dairy industry, due to complexity on modelling and solution of problems representing dairy industry characteristics, there is limited research using analytical methods. Most of the research papers focus on procurement stage. The models are represented as a variant of travelling salesman problem, DSS using analytical methods, transhipment models for dairy supply chains (Butler et al., 1997, 2005; Claassen and Hendriks, 2007; Nicholson et al., 2011).

In the literature, analytical methods are commonly supported by heuristic and metaheuristic methods. In the preliminary research of approximate methods, the research papers present vehicle routing and DSS development examples (Chung and Norback, 1991; Sankaran and Ubgade, 1994; Adenso-Diaz et al., 1998). Most of the VRPs in the dairy industry are solved using metaheuristic solution approaches (Tarantilis and Kiranoudis, 2001, 2007). The dynamic allocation problem and the distribution centre location problem with fuzzy application are other research areas in the approximate methods literature (Lin and Chen, 2003; Xu et al., 2011). The development of efficient solution approaches to tackle the special structure of the milk collection and distribution problems are recent issues in the literature (Lahrichi et al., 2012; Dayarian et al., 2013a, 2013b).

There are limited simulation applications on milk distribution problems (Manzini et al., 2005; Quinlan et al., 2012). The simulation applications are still the promising research direction in the literature.

Most of the papers study on mathematical models integrated with the heuristic approaches (Basnet et al., 1996, 1997, 1999; Foulds and Wilson, 1997). In addition, the milk transportation problems have been solved using metaheuristic algorithms (Dooley et al., 2005). There also exist hybrid approximate methods dealing with multi-criteria decision making problems (Bottani and Rizzi, 2006). The hybrid methodologies need to be considered recently in the literature, because of their more flexible frameworks. Table 2 summarises the reviewed literature of vehicle routing and distribution within the dairy industry. The papers are listed in the order presented in the review. For each research, the table illustrates the different characteristics in a systematic manner. Abbreviations are also explained in the nomenclature.

Table 2 Summary of vehicle routing and distribution research

Reviewed literature	*Perishability*	*Product types*	*Supply chain processes*	*Fictitious data/case study*	*Product stages*	*Production stages*	*Solution approach*	*Decision levels*	*Objective*	*Shelf Life*	*Capacity and time constraints*	*Labour, working time, overtimes*	*Setups*
Analytical methods													
Butler et al. (1997)	-	D	PRC	CS	RM	-	IP and DSS	O	S	-	-	-	-
Butler et al. (2005)	-	D	PRC	CS	RM	-	OT and DSS	O	S	-	CT	-	-
Claassen and Hendriks (2007)	-	D	PRC	HY	RM	-	MILP and DSS	O	S	-	-	-	-
Nicholson et al. (2011)	-	D	DST	CS	IP-FP	-	OT	S	S	-	-	-	-
Li and Wang (2013)	-	D	DST	HY	FP	-	MILP	O	S	-	CT	-	-
Approximate methods													
Chung and Norback (1991)	-	D	DST	CS	FP	-	HE	O	S	-	-	O	-
Sankaran and Ubgade (1994)	-	D	DST	CS	RM	-	HE & DSS	O	S	-	CT	-	-
Adenso-Diaz et al. (1998)	-	D	DST	CS	FP	-	HE	O	S	-	-	-	-
Tarantilis and Kiranoudis (2001)	P	D	DST	CS	FP	-	MH	O	S	-	-	-	-
Tarantilis and Kiranoudis (2007)	P	D	DST	CS	FP	-	MH	O	S	-	-	-	-
Lin and Chen (2003)	P	D	STR-DST	HY	FP	-	LP-MH-SM	T	S	-	-	-	-
Xu et al. (2011)	-	I	DST	CS	FP	-	MILP-FZ-MH	T	M	-	C	-	-

Notes: **Perishability*; P – perishability
**Product types*; C – cheese, D – dairy and milk, I – ice cream, Y – yoghurt [SE-set or ST-stirred], O – others
**Supply chain processes*; PRC – procurement, PRD – production, STR – storage, DST – distribution
**Fictitious data or case study*; HY – hypothetical application, CS – case study
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**Labour, working time and overtimes*; L – labour, W – working time, O – overtime
**Setups*; G – product group (family) setups, P – product setups, SD – sequence-dependent, SI – sequence-independent.

Table 2 Summary of vehicle routing and distribution research (continued)

Reviewed literature	*Perishability*	*Product types*	*Supply chain processes*	*Fictitious data/case study*	*Product stages*	*Production stages*	*Solution approach*	*Decision levels*	*Objective*	*Shelf Life*	*Capacity and time constraints*	*Labour, working time, overtimes*	*Setups*
						Approximate methods							
Lahrichi et al. (2012)	-	D	PRC-DST	CS	RM		MILP-MH	O-S	S	-	CT	-	-
Dayarian et al. (2013a)	-	D	PRC-DST	CS	RM	-	MILP-HE	T-S	S	-	CT	-	-
Dayarian et al. (2013b)	-	D	PRC-DST	CS	RM	-	MILP-HE	T	S	-	CT	-	-
						Simulation							
Manzini et al. (2005)	P	D-C-Y	DST	CS	RM-FP	-	SM	O-T-S	S	SL[IC]	-	-	-
Quinlan et al. (2012)	-	D	DST	CS	RM	-	SM	O	S	-	CT	-	-
						Hybrid approaches							
Basnet et al. (1996)	-	D	DST	CS	FP	-	HD[OT-HE-IP] and DSS	O-S	S	-	C	-	-
Basnet et al. (1997)	-	D	DST	CS	FP	-		O-S	S	-	C	-	-
Basnet et al. (1999)	-	D	DST	CS	FP	-		O-S	S	-	C	-	-
Foulds and Wilson (1997)	-	D	PRC	CS	RM	-	HD[MILP-HE]	O	S	-	-	-	-
Dooley et al. (2005)	-	D	PRC-STR	HY	RM	-	HD[GA-SM]	O	S	-	C	-	-
Bottani and Rizzi (2006)	-	D	DST	CS	FP	-	HD[FZ-OT]	S	S	-	-	-	-

Notes: **Perishability*; P – perishability
**Product types*; C – cheese, D – dairy and milk, I – ice cream, Y – yoghurt [SE-set or ST-stirred], O – others
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2.3 Production and distribution planning

In the dairy industry market demand is no longer confined to local or regional supply. The strong competition in dairy food market, product variety and short shelf lives force the companies to a closer coordination of production and distribution activities for more flexible utilisation of resources and faster response to demands while reducing production costs, and increasing throughput. Especially, there are tight shelf life restrictions for dairy products, and customer prefers the product that has maximum available shelf life. To avoid excessive inventories and to allow a quick response to customer enquiries are important aspects that require more attention. Therefore, an efficient integration of production and distribution plans into a unified framework is critical to achieve competitive advantage. In the remainder of this section, we classify the production and distribution research in dairy industry based on solution methodologies. These classifications are analytical methods, approximate methods and hybrid approaches.

2.3.1 Analytical methods

Most of the seminal publications reported in the literature address the integrated production and distribution planning problem from a strategic and tactical point of view (Mellalieu and Hall, 1983; Benseman, 1986; Pooley, 1994). Mellalieu and Hall (1983) present a long term planning model focusing on processing and transportation operations of dairy industry. They introduce a network formulation with the objective function which maximises net revenue based on product prices, variable process and transport costs, subject to factory capacity, product demand and raw material supply constraints. Benseman (1986) develops a MILP model for medium-term production planning problem. A milk collection and distribution process is considered in addition to milk production and allocation to maximise the profit by taking into account transportation costs and the variable production costs. Pooley (1994) considers production and distribution facility network planning problem in dairy processor company. A tactical level MILP model is proposed to minimise total supply chain cost consisting of fixed and variable costs corresponding to production and distribution activities.

MIP has been widely used to formulate production and distribution planning problem in the dairy industry. Wouda et al. (2002) present an MILP model to optimise a supply chain network. The focus of the research is to evaluate the regionalisation, product and process specialisation strategies with the real life industrial scenarios. The objective is to find optimal number of plants, their locations and allocation to the product portfolio in order to minimise the total production cost and the transportation cost. Subbaiah et al. (2009) present a supply chain model mainly focusing on production and distribution activities in the dairy industry. The model consists of four echelons as raw milk suppliers, plant, warehouse and customers and incorporates the purchase plan of raw milk, production plan of product mix and final product transportation. They propose a LP model with a single objective function handling various supply chain costs. The objective function is to minimise the total supply chain cost consisting of material, production and transportation costs. The research contributes to the literature by presenting a real world application of the coordinated supply chain planning model. The model developed by Kopanos et al. (2012a) appears as the most comprehensive model in dairy industry. They present a novel MILP framework based on a hybrid discrete/continuous time representation for the simultaneous detailed production and distribution planning problem of multi-site, multi-product, semi-continuous food processing industry. The novelty of the proposed mathematical formulation is the integration of the different modelling approaches and consideration of the detailed production and distribution operations.

Recently, Van Elzakker et al. (2013a, 2013b) present a tactical production distribution planning problem of fast moving consumer goods and develop a MILP model which is also applicable to dairy industry. While, one of the main challenges is the size of the problem considered by Van Elzakker et al. (2013a), Van Elzakker et al. (2013b) account additionally shelf life restrictions and waste. Van Elzakker et al. (2013a) propose a decomposition algorithm to be capable of solving real sized case. In the decomposition, sub-models containing single stock keeping unit are optimised sequentially while a penalty cost is introduced for violating capacity. The penalty cost is increased after each optimisation until it becomes high to obtain a feasible solution. Van Elzakker et al. (2013b) present computationally efficient methods to accurately track the shelf life (e.g. direct, indirect and hybrid). In the direct method, age of each product is tracked. While the direct method can guaranty the optimal, it is computationally inefficient. In the indirect method, products are forced to leave inventory at the end of shelf life. Indirect method cannot guaranty the optimal but it reaches close results to optimal. Hybrid method combines the advantages of these two approaches. Product age is handled directly in the first stage while considering the shelf life indirectly in the second stage. It provides near optimal solutions with respectively efficient computational times. In addition, Yu and Nagurney (2013) develop a network-based food supply chain model under oligopolistic competition and perishability, with a focus on fresh produce. They introduce a network-based model which is highly relevant to dairy products. This paper differs from the literature with several aspects such as capturing the deterioration of fresh food for entire supply chain, exponential time decay, oligopolistic competition with product deterioration, disposal of spoiled foods with associated cost and assessment of alternative technologies.

2.3.2 Hybrid approaches

Hybrid approaches usually considers a combination of optimisation and simulation models. As a preliminary research, Sonesson and Berlin (2003) present scenario-based analysis on the environmental impact of milk supply chain. The scenarios are handled with simulation experiments and the analysis is mainly based on LCA methodology. The objective of the study is to assess the potential environmental impact of various supply chains for dairy products as well as to test and develop the material flow approach to analyse the sustainability of food supply systems. Li et al. (2008) introduce a simulation and optimisation-based DSS to cope with the complexity and uncertainties. The production activities are handled in order to meet the market demand and minimise the difference between supply and demand. In addition, the supply and collection of raw milk from farmers is implemented as a VRP. The main contribution of the paper is to incorporate the production and distribution planning by using optimisation with simulation model to deal with uncertainty. Amorim et al. (2012) present multi-objective MIP models using block planning approach to solve an integrated production and distribution planning problem integrating the economic aspects and freshness at an operational level. The models are formulated for two distinct cases with a fixed and a loose shelf life of rapidly deteriorating goods. While the first objective is concerned with minimising the total costs over the supply chain covering transportation, production, setup and spoilage costs, the second one maximises mean remaining shelf life of products at the distribution centres over the planning horizon. They propose a simple hybrid genetic heuristic to solve the problem where the shelf life is loose. Amorim et al. (2012) is the pioneering research that addresses the integrated production and distribution planning of perishable dairy products in a multi-objective framework.

Recently, Bilgen and Celebi (2013) consider an integrated production scheduling and distribution planning problem in yoghurt production. They present a hybrid method combining MILP and simulation approaches. The model obtains optimal production and delivery plan and hybrid approach is introduced to explore the dynamic behaviour of the real world system. Operation times are considered as a dynamic factor and adjusted using optimisation and simulation in an iterative manner. While in the most of the previous studies the problem parameters are accepted as deterministic, they handle the stochastic failures on operation times to obtain more realistic solutions. Jouzdani et al. (2013) present a dynamic facility location problem for transportation of raw milk and dairy products and under consideration of traffic congestion and demand uncertainty. They consider possible changes in transportation network, facility investment cost, and monetary value of time changes in production process. Fuzzy LP and mixed integer nonlinear programming (MINLP) are used as solution approaches.

2.3.3 Research directions

To summarise the reviewed literature on production and distribution planning research, Mellalieu and Hall (1983), Benseman (1986) and Pooley (1994) are the pioneering research papers that consider the strategic, tactical network models, respectively. In the last decade, the research papers present integrated production and distribution models considering tactical level decisions by using fundamentally LP and MILP methodologies (Kopanos et al., 2012a; Subbaiah et al., 2009; Wouda et al., 2002). The perishability and deterioration issues have been recently taken into account in MILP models in tactical decision level. These models are more realistic models which are capable of representing the specific dairy industry characteristics (Van Elzakker et al., 2013a, 2013b; Yu and Nagurney, 2013).

Besides, there are hybrid approaches taking into account the environmental issues using simulation and LCA methodologies (Li et al., 2008; Sonesson and Berlin, 2003). Recently, hybrid approaches have begun used in yoghurt production process to get advantage of mathematical programming and metaheuristic approaches and to tackle with perishability issues (Amorim et al., 2012). Since there are few papers in the literature, the simulation and approximate methods-based applications are still promising areas (Bilgen and Celebi, 2013). Apart from these, Jouzdani et al. (2013) present an MINLP example using approximate methods. Table 3 summarises the reviewed literature of production and distribution within the dairy industry. The papers are listed in the order presented in the review. For each research, the table illustrates the different characteristics in a systematic manner. Abbreviations are also explained in the nomenclature.

Table 3 Summary of production and distribution planning research

Reviewed literature	*Perishability*	*Product types*	*Supply chain processes*	*Fictitious data/case study*	*Product stages*	*Production stages*	*Solution approach*	*Decision levels*	*Objective*	*Shelf life*	*Capacity and time constraints*	*Labour, working time, overtimes*	*Setups*
						Analytical methods							
Mellalieu and Hall (1983)	-	D	PRD-DST	CS	RM-FP	O	OT	O	S	-	CT	-	-
Benseman (1986)	-	D	PRC-PRD-DST	CS	FP	O	MILP	O	S	-	C	-	-
Subbaiah et al. (2009)	-	D	PRC-PRD-STR-DST	CS	RM-IP-FP	O	LP	T	S	-	-	-	-
Kopanos et al. (2012a)	-	Y	PRD-STR-DST	CS	FP	P[MP]	MILP	O-T	S	-	CT	-	G-SD and P-SI
Pooley (1994)	-	D	PRD-DST	CS	FP	O	MILP	T	S	-	C	-	-
Wouda et al. (2002)	-	D	PRC-PRD-DST	CS	RM-FP	P	MILP	T	S	-	-	-	SI
Van Elzakker et al. (2013a)	-	OT	PRC-PRD-DST	HY	RM-IP-FP	O-P	MILP	T	S	-	-	-	G-SD and P-SD
Van Elzakker et al. (2013b)	P	OT	PRC-PRD-DST	HY	RM-IP-FP	O-P	MILP	T	S	SL[IC]	CT	-	G-SI and P-SI
Yu and Nagurney (2013)	P	OT	PRD-DST	CS	FP	O	OT	T	S	-	-	-	-
						Hybrid approaches							
Sonesson and Berlin (2003)	-	D	PRD-DST	CS	RM-FP	O	HD[SM-LCA]	O-S	S	-	-	-	-
Li et al. (2008)	-	D	PRC-PRD-DST	CS	RM-FP	P	HD[SM-HE-OT] and DSS	O	M	-	CT	-	-
Amorim et al. (2012)	P	D-Y	PRD-DST	HY	FP	P[MP]	HD[MILP-MINLP and GA]	O-T	M	SL[IO-IC]	CT	-	G-SD and P-SI
Bilgen and Celebi (2013)	P	Y	PRD-DST	CS	FP	P[MP]	HD[MILP-SM]	O	S	SL[IO-IC]	CT	O	P-SD
Jouzdani et al. (2013)	-	D	PRC-PRD-DST	CS	RM-FP	O	HD[FZ and MINLP]	T-S	S	-	CT		

Notes: **Perishability*; P – perishability
**Product types*; C – cheese, D – dairy and milk, I – ice cream, Y – yoghurt [SE-set or ST-stirred], O – others
**Supply chain processes*; PRC – procurement, PRD – production, STR – storage, DST – distribution
**Fictitious data or case study*; HY – hypothetical application, CS – case study
**Product stages*; RM – raw materials, IP – intermediate products, FP – final products
**Production stages*; F – fermentation, I – incubation, P – filling and packaging [SP-single packaging line or MP-multiple and/or parallel packaging line], O – other production processes
**Solution approach*; DSS – decision support system, MIP – mixed integer programming, MILP – mixed integer linear programming, MINLP – mixed integer nonlinear programming, LP – linear programming, IP – integer programming, NLP – nonlinear programming, SP – stochastic programming, HE – heuristic, MH – metaheuristic, FZ – fuzzy, HD – hybrid approaches, HI – hierarchical solution approaches, SM – simulation, AN – analytical methods, LCA – life cycle analysis, TA – timed automata, GA – genetic algorithm, OT – other
**Objective*; S – single objective, M – multi objective
**Shelf life*; SL – shelf life [IO-in objective function or IC-in constraints]
**Capacity and time constraints*; C – capacity, T – time, CT – capacity and time
**Labour, working time and overtimes*; L – labour, W – working time, O – overtime
**Setups*; G – product group (family) setups, P – product setups, SD – sequence-dependent, SI – sequence-independent.

Table 4 illustrates the reviewed literature by presenting number of research with the classification scheme used in the review.

Table 4 Number of research

Solution approaches / *Problem types*	*Analytical methods*	*Approximate methods*	*Simulation*	*Hybrid approaches*	*Total*
Production planning and scheduling	30	5	1	5	41
Vehicle routing and distribution	5	10	2	6	23
Production and distribution planning	9	-	-	5	14
Total	*44*	*15*	*3*	*16*	*78*

3 Conclusions and future research directions

In this paper, we have reviewed quantitative operations research literature on dairy SCM to reveal major trends, to explore research opportunities. Moreover, we have identified the characteristics that a model should have to address adequately dairy SCM planning needs. The reviewed research is classified by problem types based on the solution approaches.

As can be easily seen from the various tables throughout the review, the most widely used solution approaches are analytical methods and they are extensively accepted tools in the dairy industry for well-defined problems. In addition, most of the research addresses case studies and real-life problems in the literature. Due to the nature of the dairy industry problems, the models and methods should meet the requirements of practical applications which consist of complex scenarios. Although analytical approaches have advantages on providing mathematical frameworks to represent specific characteristics of problems and to get optimal solutions, they may be not powerful enough to handle real sized problems with regard to the computational efforts. Another inadequacy of some analytical approaches is that it is not easy to model uncertainty mathematically by analytical methods. Alternatively, simulation approaches are capable of introducing more flexible and handling real cases in the dairy industry. However, complex simulation models could require large amount of installation and running time. Approximate methods have been proven useful in many cases since they overcome the computing time limitation. Approximate methods provide less computational efforts, however optimum cannot be guaranteed. They are especially convenient to analyse real cases. On the other hand, hybrid methods integrate the best capabilities of the solution approaches for the effective decision making.

For each of the problem types examined in this review, some generalised results can be concluded in terms of the quantitative methods. Production planning and scheduling issues are extensively solved by analytical methodologies. Most of the formulations in this field are in the form of MILP models with several assumptions. Much research is still needed on application of approximate methods, simulation, and hybrid approaches. The areas of vehicle routing and distribution issues, integrated production and distribution problems in the dairy industry have also received much attention. The most widely used solution approach in application of VRP is the metaheuristics. A number of applications on integrated production and distribution planning are formulated as MILP models. It is an evidence gap that there is no research using approximate-based methods and simulation approach to tackle with integrated production and distribution planning problem within the dairy industry.

Traditional production scheduling focuses on the determination of schedules for production such that some performance measures are optimised without considering the distribution planning. Very few works have been devoted to investigate the coordination of production scheduling and delivery planning for dairy products. Therefore, the coordination of production scheduling and distribution planning becomes an important issue in the dairy industry and needs further studies. The literature integrating uncertainty in dairy SCM is still scarce. In particular, very few papers address stochastic parameters combined with other aspects. Another aspect that requires more attention is the integration of postponement strategies within dairy SCM problems.

Future research directions are stated with respect to different perspectives;

3.1 Multi-stage production planning perspective

The vast majority of the papers in dairy production planning process focus on the packaging process. The structure of the production process is considerably simplified. However, the integrated modelling and simultaneous optimisation of all stages (e.g., fermentation/incubation and packaging) needs to be considered. The integrated models should be introduced to get advantages of simultaneously optimisation of production, fermentation, incubation, filling and packaging processes. Another finding that can be drawn from the reviewed research is that there is abundant literature on supply chain planning of dairy products at operational decision level. Another aspect requiring more attention is the integration and/or the hierarchical structure of the tactical and operational planning levels in the dairy SCM context.

3.2 Sustainability perspective

Until recently, the models very often fail to incorporate especially perishability and shelf life issues. Perishability issues are extensively taken into account in terms of final products within the literature. The consideration of perishability constraints on raw materials and/or intermediate products is a promising area. Incorporation of perishability and batch dispersion, traceability, food safety considerations are promising research directions. Other promising research areas are to take into account waste minimisation and the environmental considerations within the optimisation models in the dairy industry.

3.3 Integrated production distribution planning and scheduling perspective

Another aspect that requires more attention is the full integration of production, distribution planning and scheduling activities within dairy SCM. The dairy industry characteristics should be taken into account more intensively by the integrated production, distribution planning and scheduling models.

3.4 Single, multi-objective perspective

The consideration of multi-objective functions within the models requires more attention. The most of the reviewed literature consider the problems which have only single objective mainly expressed as a cost or cost related function. However, in real applications, there exist multiple conflicting objectives. Therefore, the multi-objective treatments need to be considered to represent the conflicting objectives corresponding to joint procurement, production and inventory planning decisions.

3.5 Uncertainty perspective

In real life applications, consideration of stochastic parameters is more common owing to uncertain environment. Hence, stochastic parameters such as demand, waste, production delays, machine failures, and process times should be included into the problem. Scenario-based analysis can support the decision making process effectively. The risk assessment is a promising research area for the more realistic scenarios. Robust designs and optimisation approaches can be added as promising research directions to tackle with the unexpected events that severely impact performance.

The further research also should be directed towards the incorporation of uncertainty in the mathematical framework. Stochastic programming, which models optimisation problems that involve uncertainty, and multi-parametric programming techniques, where some of the parameters vary between specified lower and upper bounds, may be important application areas within the dairy SCM. To best of our knowledge, there is no research handling stochastic parameters by using stochastic or multi-parametric programming techniques with perishability consideration within the dairy industry.

Simulation approach is a suitable solution technique to study the impact of stochastic environment. To best of our knowledge, there are very few studies combining the mathematical programming approach with simulation within the perishable dairy SCM.

Some of the researchers have attempted to solve dairy industry problems by the well-known traditional static and deterministic models. Nevertheless, optimising the dynamic systems comprising continuous changes has been a difficult task for the researchers. In this concept, though the analytical methods can provide optimal results, they cannot effectively handle dynamic and stochastic situations separately. Instead of these methods, approximate methods, simulation and hybrid methodologies may be more convenient and development of real time optimisation tools can be promising research direction to address the dynamic and stochastic nature of the dairy supply chain problems.

3.6 Alternative solution techniques perspective

Recently, constraint programming receives considerable attention as a common alternative method to mathematical programming technique for solving optimisation problems by offering a more flexible modelling framework. To the best of our knowledge there is no research that uses constraint programming on production, distribution planning and scheduling within the dairy industry SCM. The application of the constraint programming may provide an important contribution to the corresponding literature.

The MIP techniques are extensively used in production distribution planning and scheduling problems of perishable products. However, there are respectively few studies using heuristics, meta-heuristics or hybrid solution methodologies. These methodologies emerge as promising solution alternatives especially on computational efforts and future research needs to introduce detailed procedures to use advantages of these alternative solution mechanisms.

The complexity of the MIP models increases significantly with the number of products, length of planning horizons, number of demand points. Efficient decompositions schemes and hierarchical methodologies can be introduced to tackle with the complexity of the problems. In addition, to improve the computational efficiency of the MIP models for solving large scale problems, MIP-based decomposition heuristics, especially such as fix and optimise, fix and relax, rolling horizon approaches can be suggested for large sized instances.

3.7 Postponement and decoupling point theory perspective

Postponement and decoupling point theory practices are fairly low in the dairy industry in contradiction to other industries. Hence, the application of postponement and decoupling point theory under consideration of the special characteristics in the dairy industry is one of the promising future research directions.

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