VALENTAS GRUŽAUSKAS

SUPPLY CHAIN RESILIENCE IN THE CONTEXT OF SUSTAINABLE FOOD INDUSTRY

DOCTORAL DISSERTATION

Kaunas
2020

KAUNAS UNIVERSITY OF TECHNOLOGY

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Doctoral dissertation
Management (S 003)

2020, Kaunas

The dissertation was prepared at Kaunas University of Technology, School of Economics and Business, Digitalization scientific group, during the period of 2016–2020.

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This doctoral dissertation has been published in: http://ktu.edu

Editor:

dr. Armandas Rumšas (Publishing Office "Technologija")

KAUNO TECHNOLOGIJOS UNIVERSITETAS

VALENTAS GRUŽAUSKAS

TIEKIMO GRANDINĖS ATSPARUMAS DARNIOS MAISTO PRAMONĖS KONTEKSTE

Daktaro disertacija
Socialiniai mokslai, Vadyba (S 003)

2020, Kaunas

Disertacija rengta 2016-2020 metais Kauno technologijos universiteto (fakulteto/instituto pavadinimas) fakultete (katedros/padalinio pavadinimas) katedroje. Mokslinius tyrimus rėmė (pvz., Lietuvos mokslo taryba – jei buvo gauta stipendija už akademinius pasiekimus).

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Interneto svetainės, kurioje skelbiama disertacija, adresas:
http://ktu.edu

Redagavo:

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Abbreviations

ABM – Agent-based modeling

CAS – Complex adaptive systems

CT – Complexity theory

CPS – Cyber-physical systems

FI – Food industry

FSRSCM – Framework for Sustainable and Resilient Supply Chain Management

SCM – Supply chain management

SCR – Supply chain resilience

Introduction

Research relevance

The demand for food products has been rapidly increasing due to the growing world population and the soaring average age. The world's population is expected to reach 9.8 billion by 2050 (United Nations, 2015). The Average Life Expectancy in Europe in 2050 will be 82 years (Conrad, Alan, and Katherine, 2015). However, the current supply chain management approaches are ineffective, and it produces lot of food waste. Nearly one-third of the food produced in the world for human consumption is lost or wasted annually. In the developing countries, 40% of losses occur at the post-harvest and processing stages, while in the developed countries more than 40% of losses occur at retailer and consumer levels (Food and Agriculture Organization, 2011). Food losses and waste cost the global economy around USD 990 billion annually (Council of the European Union, 2016). The ineffectiveness of the food supply chain is mainly related to two aspects: from one perspective, it is disruptions and dynamic environment, whereas, from the other perspective, it is the length of the supply chain and the necessity to make trade-offs between sustainability and cost-effective performance. Urbanization will continue at an accelerated pace, and about 70 percent of the world's population will be urban, compared to 49 percent today (United Nations, 2014). The complexity of the food supply chain will increase because the United Nations is promoting SMEs collaboration (small-scale farmers satisfy over 70% of the world's food needs) (Food and Agriculture Organization, 2017). The necessity to make trade-offs in the food supply chain even further reduces the food waste levels. "As the entire farm-to-fork cycle is being squeezed to provide short lead times and efficiency, supply chain designs have to rely heavily upon logistics and warehousing functions that provide temperature conditioned transport and storage, and increased use of advanced information and communication technologies. Recent research states that in perishable-product supply chain design, a trade-off should be made between transportation costs, shortage costs, inventory costs, product waste and expected shelf-life losses and quality decay" (Dani, 2015). Magalhães *et al*. (2018) conducted an empirical research to identify the main causes of food waste. Their research indicated 15 main food waste causes, with the most importance being assigned to 6 main causes, such as: lack of infrastructure and technical management; ineffective storage management; lack of coordination and information sharing; pricing strategies and promotion management; overproduction and inadequate demand forecasting (Magalhães, Luís, and Cristóvão, 2018). In the recent years, more local production and online grocery business models have rapidly gained recognition. The Internet retailing market size in 2016 was 1.17 trillion USD, and, by 2020, it was estimated to grow to the level of 2.1 trillion with an AAGR of 13.33% (Euromonitor International, 2017). However, currently, the last-mile deliveries are considered the least effective process of e-grocery. The last-mile of the supply chain is the least efficient due to comprising up to 28% of the total costs of logistics (Ranieri, Digiesi, Silvestri, and Roccotelli, 2018). Constant disruptions even further negatively influence the sustainability of the FI in terms of food waste. Some researchers argue that minor disruptions do not influence the supply chain processes, however, Calvert and Snelder (2018) indicated that minor disruptions in traffic and transport systems can also play an important part in reducing efficiency (Calvert and Snelder, 2018). Patterson (2014) stated that a robust supply chain is supposed to efficiently manage demand or production fluctuations (Patterson, 2014). World economic forum survey on the supply chain resilience indicated that 80% of companies are concerned about resilience, while one of the causes due to the issue is the fact that 30% of companies are facing information technology problems (Forum, 2013).

Research level of scientific problem

To increase the supply chain resilience, researchers mainly recommend to develop robust network designs, to implement flexibility and redundancy approaches, and to promote collaboration. From the network design perspective, the problem is that this approach requires to make trade-offs between economic benefits and sustainability; it is important to limit the trade-offs. Thus, in the thesis, a management framework shall be provided which can increase the sustainability of the food industry without additional resources. Another problem related to the supply chain resilience research is related to the factor that recommendations are mainly proved through macro level disturbances, whereas only a limited amount of research recognises the influence of micro distributions. “While it is clear that major calamities and disasters can have a considerable effect on traffic and transport systems, there is an awareness that more minor disturbances in traffic and transport systems can also play an important part in reducing the efficiency of such systems” (Calvert and Snelder, 2018). “Travel times between customers are not deterministic but uncertain and differ during the day regarding traffic volumes and stochastic events like congestions” (Köster, Ulmer, and Mattfeld, 2015a). Thus, the thesis shall focus on micro level disruptions rather than on macro level. From the theoretical perspective, researchers recommend to apply flexibility and redundancy approaches which are believed to improve the supply chain resilience (Mensah and Merkuryev, 2014), (Gonçalves and Chicareli, 2014), (Chowdhury and Quaddus, 2016), (Barroso, Machado, Carvalho, and Machado, 2015). Other researchers promote collaboration together with flexibility and redundancy when seeking to increase the supply chain resilience (Jüttner and Maklan, 2011), (Novotny and Folta, 2013), (Scholten and Schilder, 2015), (Nagashima, Wehrle, Kerbache, and Lassagne, 2015), (Gonul, 2015), (Tukamuhabwa, Stevenson, Busby, and Zorzini, 2015), (Reyes Levalle and Nof, 2015). However, empirical evidence indicates that collaboration tends to fail due to lack of strategies, collaborative technologies and impropriated commitment levels (Herczeg, Akkerman, and Hauschild, 2018), (Adams, Richey, Autry, Morgan, and Gabler, 2014), (Arvitrida, Robinson, Tako, and Robertson, 2016), (Gunasekaran, Subramanian, and Rahman, 2015), (Pettit, Croxton, and Fiksel, 2013). In order to control the supply chain complexity, technological approaches should be integrated in the management process. However, researchers indicate that usually the organization dimension is missing when implementing technological advancements (Hoske, 2015). Adams *et al*. (2014) indicates that the effectiveness of collaboration as a supply chain resource has been questioned due to concerns associated with

Collaborative Technologies. Arvitrida *et al*. (2016) states that firms' strategy and behavior in supply chain collaborations are identified as the main causes of the supply chain failure. Ambulkar (2015) analyzed supply chain disturbances from the perspective of strategic focus on innovations, and the research indicated that "although they may be committed to innovation, firms may differ in the degree to which they actively support the innovation efforts taking place across the network on its behalf. If suppliers are not well integrated or if there are alignment issues with the firm's strategy, innovation focus can lead to less coordinated actions within the supplier network and thereby greater disturbances in fulfilling market demand." Thus, it is important to develop a framework which would focus on collaboration, technological implementation and clear benefits of the application; hence, a properly defined methodological approach is also needed for the application of such a framework in practice.

Research question – How to strengthen the supply chain resilience in the context of sustainable food industry through information sharing by adapting cyber-physical systems?

Research object – Supply chain resilience in the context of sustainable food industry.

The main goal of the thesis – To develop a management framework for supply chain resilience in the context of sustainable food industry through information sharing by adapting cyber-physical systems.

Objectives:

1. To conceptualize supply chain resilience in the context of sustainable food industry;
2. To develop a conceptual model of supply chain resilience approaches for sustainable food supply chains;
3. To define the philosophy and methodological approach of agent-based modeling for sustainable food supply chain analysis;
4. To identify the main food industry scenarios to validate the proposed management framework;
5. To adapt an agent-based model for the flexibility approach of sustainable food supply chains;
6. To adapt an agent-based model for the redundancy approach of sustainable food supply chains;
7. To propose a management framework for supply chain resilience in the context of sustainable food industry.

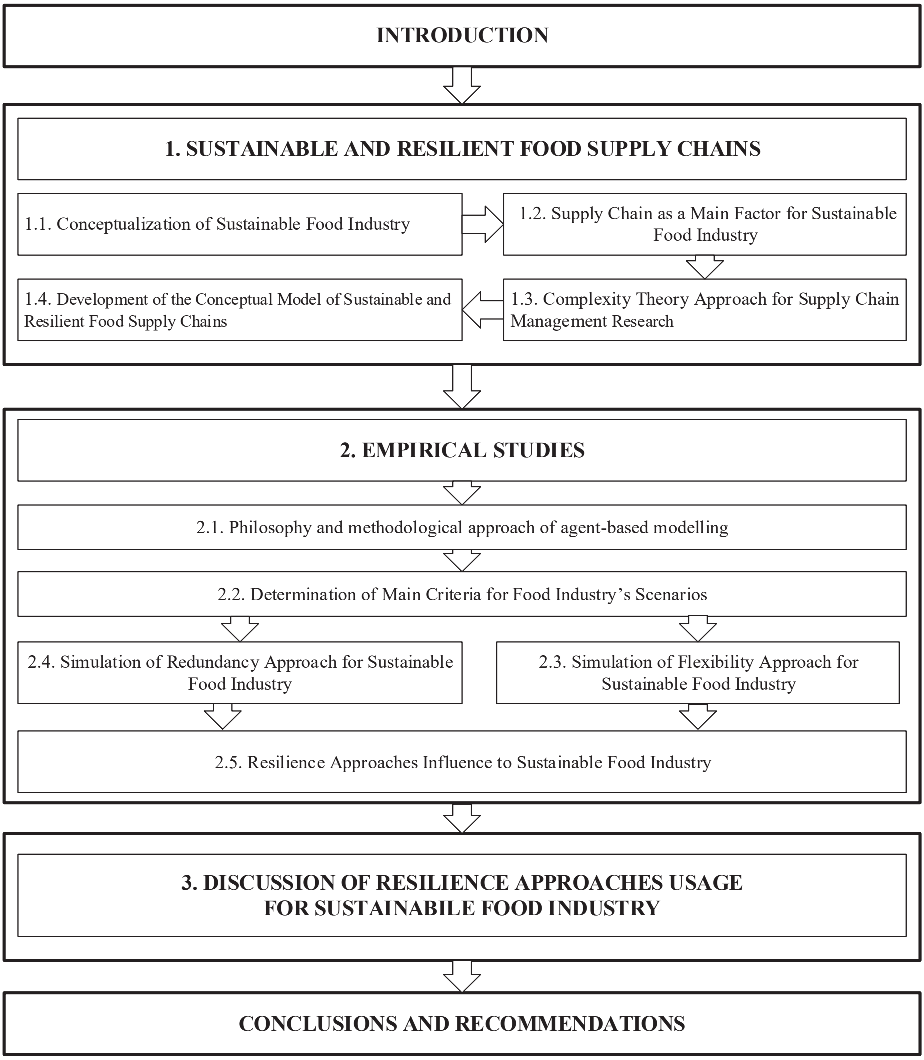


Fig. 1. Logical scheme of the research

Novelty and knowledge gap

The main knowledge gap in the thesis is being filled by recommending supply chain management approaches for disruption environment since the majority of previously developed approaches have been developed in a stable environment. For this purpose, the following theoretical assumptions have been made and validated in the empirical study section:

1. The food supply chain complexity is growing, and it can be managed by adapting the complex-adaptive system theory;
2. The supply chain resilience is positively influenced by such approaches as flexibility and redundancy;
3. Information sharing, which is achieved as a result of collaboration thus increasing the efficiency of flexibility and redundancy;

4. If a disruption cannot be managed, it creates the ripple effect downstream thereby impacting the supply chain sustainability;
5. Disruptions in the food supply chain cause reduction in food quality and increase in food waste;
6. The complexity of the decision-making process increases dramatically; therefore, the implementation of cyber-physical systems in the supply chain management is necessary.

Based on the scientific literature analysis and empirical evidence, the influence of the supply chain resilience on food industry sustainability was identified. The determined relationship identified that companies should focus on implementing flexibility and redundancy approaches so that to manage their processes by promoting information sharing and applying cyber-physical systems for complexity management. In this thesis, it is recommended to integrate cyber-physical systems in the food supply chain. The integration of a cyber-physical system would allow gathering information, analyzing it and would also allow the system itself to utilize it without human interference. The implementation of cyber-physical systems in the supply chain management has only recently gained attention in scientific literature (Klötzer and Pflaum, 2015). The research results contribute to the supply chain management theory in terms of the following aspects:

1. The research focuses on daily disruptions rather than on *force majeure*; this aspect has only recently started gaining recognition in scientific literature;
2. The relationship between resilience and sustainability in the food supply chain is quantified in multiple scenarios;
3. The proposed management framework integrates the technological approach with the organizational dimension;
4. The implementation of flexibility and redundancy approaches in the food supply chain together with cyber-physical systems and information sharing allows maintaining higher food quality and nutrition levels;
5. The proposed management framework allows automating tactical and operational levels of the food supply chain while managing processes through strategic level variables. This approach provides adaptation abilities to the food supply chain and causes emergence of resilience and sustainability. However, the strategic level variables will be defined in future investigations while this thesis is limited to the operational and tactical levels.

Novelty of practical significance

The developed *Framework for Sustainable and Resilient Supply Chain Management* provides a practical methodological approach to help implement cyber-physical systems in daily operation management. The proposed model firstly defines which data can be shared by the supply chain members in the logistic cluster. This data consists of various market level indicators, such as the demand pattern, the infrastructure, the country- and industry-level information, and so on. The integrated data in the logistic cluster can be utilized through the application of cyber-physical systems with the objective to limit the involvement of humans in the management process. To effectively allow automation, the processes of the supply chain should be simulated in a cyber environment so that to understand the best course of action when planning routes or deciding on inventory levels. The operations must be simulated based on the market conditions; thus an approach considering how to define the scenarios of the environment was proposed. Lastly, the proposed framework provides key metrics based on sustainability aspects which can be used as a main measurement unit when allowing cyber-physical systems to make decisions. The defined process allows achieving sustainable food industry by automating daily operations with cyber-physical systems. The proposed application uses autonomous vehicles for route scheduling and information sharing while seeking to improve the inventory management policy. The integration of machine learning with reinforcement learning in this process creates a self-organizing system which adapts to the changing environment and maintains system resilience.

Research methodology

The concept of supply chain resilience is characterized by a non-linear behavior and has limited data available, thus social simulation is chosen as the main research method (Davis, Eisenhardt, and Bingham, 2007). The research methodology is based on the generative approach for theory development; it uses the initial principles to generate a particular set of data that can create a general theory (Conte and Paolucci, 2014). In the thesis, secondary data is used to develop input data for the simulation; later on, an agent-based model is implemented to quantify the effectiveness of flexibility, and redundancy approaches for sustainability in different FI scenarios. The model is based on an abstract environment which represents multiple FI scenarios based on macro indicator analysis. Disruptions in the environment are simulated through traffic congestions and historical sale data. Lastly, the relationships between the agents are defined by considering e-grocery business model operations (Hübner, Kuhn, and Wollenburg, 2016).

Research limits

1. The research focuses on food supply chain processes from the distributor to the final consumer and simplifies the processes of harvesting and processing;
2. The research is conducted in the e-commerce distribution strategy, during which, consumers often return products back to the producer. In this thesis, only the products that were not delivered on time are counted in, whereas the research does not include products returned by end-consumers. Thus, reverse logistics aspects are not analyzed in the thesis.
3. In the empirical part of the research, a generic approach to the product category is chosen rather than specific food products;
4. The proposed approach focuses on inter-organizational relationship rather than on individual organizations; however, agent-based modeling methodology is used to analyze the macro level outcome rather than individual behavior;
5. The agent-based models use distribution functions fitted on empirical data rather than real data in the simulation. In general, the agent-based modeling methodology is sensitive to the input data.

6. The developed framework for sustainable and resilient supply chain management focuses on integrating collaboration with tactical and operational level decisions, while only marginally considering strategic level decisions.

Research result publication

The research has been published in 19 publications (Web of Science and Scopus 7 publications) and presented in 6 conferences.

1. Sustainable and Resilient Food Supply Chain

1.1.Conceptualization of Sustainable Food Industry

1.1.1. Challenges of the food industry

The main goal of this chapter is to provide motivation for the research by focusing on the challenges of the FI which is the most difficult industry to manage since its products suffer from short shelf-life. Firstly, the evolution and the main problematic areas related to the FI shall be overviewed. Secondly, the current megatrends of the FI shall be overviewed with particular focus on the application of e-commerce in the FI.

The first industrial revolution began in the late 18th century when hand-work shifted to machine work. The innovations which stimulated the first industrial revolution included energy sources used for machines, such as water and coal. One of the key industries at that age was textile, which, due to mechanized cotton spinning, greatly increased productivity. The second industrial revolution began from 1840 when steam engines were invented. Steam engines increased the efficiency of energy consumption 10 times, which, as a result, greatly decreased production costs and maximized productivity. The industrial revolution also led to the development of machine tools which provided the capability to process metal. More advanced processes of using natural resources caused even more growth of the economy. The most common production processes were job-shop and batch production before the second revolution. Due to technological innovations, mass production was introduced to the market, which again revolutionized the industry by lowering costs. Even greater efficiency was achieved when plastic was invented, which decreased the production costs even further. The third industrial revolution began in the 21st century.

The third industrial revolution began when information technologies were invented. Information technologies (IT) allowed transaction costs to be reduced. Ronald Coase published a paper in 1937 titled “The nature of the firm.” He predicted the rise of multi-national companies by amplifying the scale of the economy concept as competitiveness advantage regarding reduction of costs (Coase, 1937). However, at that time, it was necessary to have one accountant for three employees, which raised the transaction costs dramatically. Due to the invention of IT, transaction costs plummeted, which even today is still causing the rise of small and medium enterprises (SMEs). For example, SMEs are the backbone of Europe’s economy as they represent 99% of all businesses in the EU (European Commission, 2017).

These technology development trends are leading to the fourth industrial revolution which is characterized by a fusion of technologies, that is, blurring the lines between the physical, digital, and biological spheres is being observed. The whole economic cycle is based on expenditures, income, credit, and how fast everything is done. Newer production methods, processing types, and information flow are increasing the productivity, which directly influences the growth of economy; therefore, innovations increasing productivity are inevitable.

The best innovative technology which made a huge impact on the world's economy is the internet. The internet allowed to distribute information much faster and cheaper. The result of that is *globalization* whose pressure is being experienced by every enterprise. The internet allowed all people to easily access products and services from around the globe. Such companies as Amazon or Uber would not have been possible in the past. Uber is the world's largest taxi company which owns no vehicles. Facebook is the world-popular media owner which creates no content. Alibaba is the most valuable retailer which has no inventory. Companies with minimal owned capital are growing rapidly. Currently, the competitiveness advantage shifted from cheap production to the distribution of services, information and products.

One of the key industries which are going to face challenges in the future is the FI. Consumers are demanding qualitative food which should be organic and fit their needs. The obesity problem has been rising dramatically, especially in the USA. Unfortunately, the problem is still not solved, and in the future it can get even worse because of several reasons. Firstly, the world's population is expected to reach nine billion by 2050 (Parfitt, Barthel, and Macnaughton, 2010), which will increase not only the food demand but also the necessity to reduce the lead time.

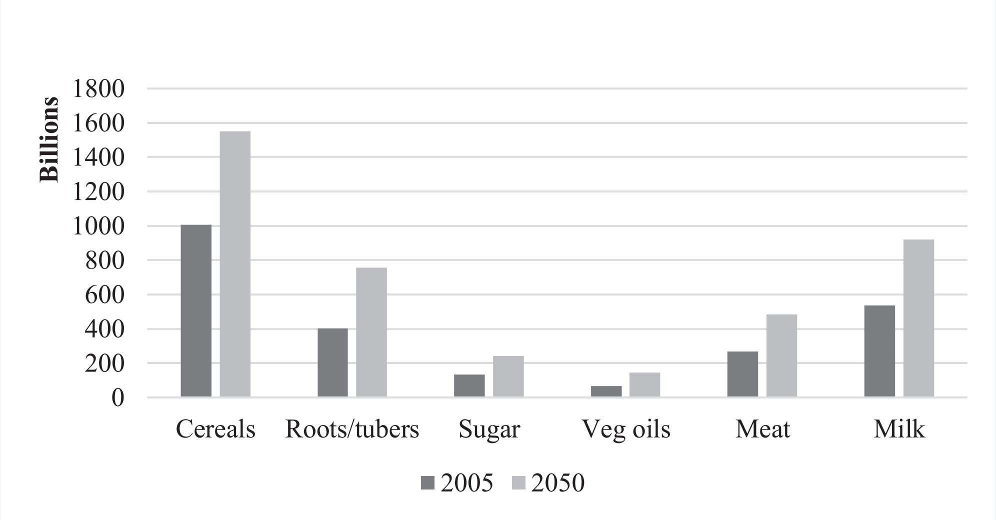


Fig. 2. Food consumption, major commodities (kg/year), (Food and Agriculture Organization, 2015)

Consumers not only need a variety of food, but also organic food with as little as possible chemicals and pesticides. The demand for food demand will increase dramatically (see **Fig. 2**) due to the population growth. "Industrial food has shifted from being 'scientific' and 'safe' (as well as 'cheap') to being 'toxic' and potentially detrimental to our long-term health" (Campbell, 2009). It can be seen that the demand for organic food has been growing because of these issues. "Globally, fresh food volume sales are predicted to rise by 17% over 2017–2022, at a CAGR of 3%" (International, 2018).

Currently there is a huge problem in the FI because the lead-time and efficiency is not sufficient; therefore, there is a lot of waste of food. “Between the farm and the fork, roughly a quarter of food calories are lost or wasted” (World Resources Institute, 2013). The lack of infrastructure in many developing countries and poor harvesting/growing techniques are likely to remain major elements in the generation of food waste (Parfitt *et al*., 2010).

The shift towards more local producers must also come because a lot of food products are also wasted in the processing part of the supply chain. “FAO statistics suggest that nearly one-third of the food produced in the world for human consumption is lost or wasted annually. In developing countries, 40% of losses occur at the post-harvest and processing stages, while in developed countries more than 40% of losses occur at retailer and consumer levels” (International, 2018). Addressing food waste issues is also important in the EU. “The collection and analysis of data from across Europe for this study generated an estimate of food waste in the EU-28 of 88 million tonnes. This estimate is for 2012 and includes both edible food and inedible parts associated with food. This equates to 173 kilograms of food waste per person in the EU-28. The total amounts of food produced in EU for 2011 were around 865 kg/person, this would mean that in total we are wasting 20% of the total food produced” (Stenmark, Jensen, Quested, and Moates, 2016). In the EU, part of the food waste is wasted in the households, while the other part perishes in the processing phase. “The sectors contributing the most to food waste are households (47 million tonnes ± 4 million tonnes) and processing (17 million tonnes ± 13 million tonnes)” (Stenmark *et al*., 2016).

Another difficulty that awaits the FI is the urbanization level. Urbanization will continue at an accelerated pace, and about 70 percent of the world’s population will be urban (compared to 49 percent today) (Food and Agriculture Organization, 2015). Thus the concept of sustainable FI has gained more recognition in recent years. Sustainability in the FI has been defined by the Food and Agriculture Organization (FAO, 2018), (see. Fig. 3).

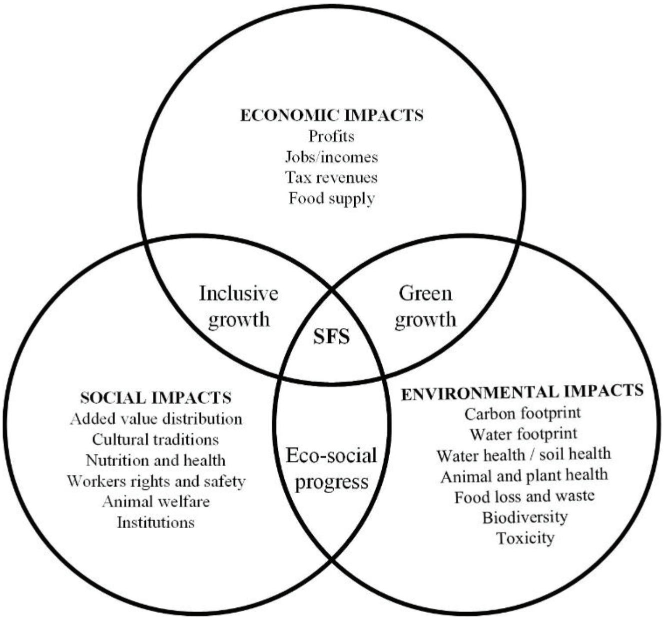


Fig. 3. Concept of sustainable food systems, (FAO, 2018)

To achieve a sustainable FI, new approaches must be taken into consideration. The European project FIT4FOOD2030 has provided the following definition of FS "The definition of FS goes beyond the production and delivery of sufficient food for all (quantity) to include the provision of safe and nutritious food for healthy and sustainable diets (quality). Underpinned by sustainability, linking land and sea, encompassing the entire "food value chain" (FIT4FOOD2030, 2018a):

1. the sustainable use of land, soil, inland and marine waters, and biodiversity as providers of ecosystem services upon which food production relies;
2. primary production practices of agriculture, aquaculture and fisheries providing food and animal feed, including production-specific inputs of nutrients, energy, seeds, plant protection issues, and equipment, harvesting, and storage;
3. food processing of primary and added value food and feed products, including packaging, distribution and logistics;
4. food preparation and consumption;
5. the handling of food and related non-food waste streams. Food systems should be environmentally sustainable, in terms of issues such as climate change, biodiversity, water and soil quality.

Research and innovation will play a critical role in making our food system future-proof (FIT4FOOD2030, 2018a):

1. Sustainable: with respect to natural resource scarcity and in respect of planetary boundaries;
2. Resilient: with respect to adapting to climate and global change, including extreme events and migration;
3. Responsible: with respect to being ethical, transparent and accountable;

4. Diverse: with respect to being open to a wide range of technologies, practices, approaches, cultures and business models;
5. Competitive: with respect to providing jobs and growth;
6. Inclusive: with respect to engaging all food system actors, including civil society, fighting food poverty, and providing healthy and sustainable diets for all."

The past breakthroughs which influenced the FI before in terms of sustainability. Domestication of animals and plants was the initial step in human development. At the beginning of human history, the inhabitants of the world only hunted and gathered, only later did they learn how to grow and breed their own food. Another necessary breakthrough was the discovery of vitamins, which, together with food, provides additional health benefits that are essential for human development. Thus, the quality of the food products is essential. The third agricultural revolution began when research and closer collaboration in the agriculture sector started leading to improved processes and added value. Currently, there is a trend for food e-commerce, which provides even more convenience to the end-consumer required to reduce the length of the supply chain and maintain higher quality. Further trends leading to the food system were defined by the FIT4FOOD2030 project (see Table 1), (FIT4FOOD2030, 2018a, 2018b).

Table 1. List of identified trends in different sectors in and beyond the food system, (FIT4FOOD2030, 2018c)

MEGATRENDS	**AGRICULTURAL PRODUCTION**
• Climate Change • Malnutrition • Rise of Non-Communicable Diseases • Urbanization • Demographic Change • Migration • Scarcity of Natural Resources • Rise in Energy Consumption • Industry 4.0 – Digitization in Food Production • Big Data Analysis • Economic Globalisation	• New and Game-Changing Digital Technologies in Agriculture • Alternatives to Conventional Pesticides • Changes in Farm Structures • Agricultural Pollution • Biodiversity Loss • Transboundary Pests and Diseases • Organic Farming • Genome Engineering • Bio-Fortification • Indoor Cultivation Systems • Urban Agriculture/ Urban Farming • Food from the Sea • Closing the Loop in Aquaculture • Permaculture

FOOD PROCESSING • Blockchain Technology for Secure Food Supply Chain • Cultured/ In-Vitro Meat • New Technologies in Food Production • High/ Ultra Processed Food • Clean Eating/ Transparent Labels • Novel Food • Natural Preservatives and Milder Processing Methods • Alternative Protein Sources • Functional Foods incl. Pro and Prebiotics	**CONSUMER TRENDS** • Health and Food Consciousness • Responsible Consumers • Special Diets, such as Vegetarian, Vegan or Low Carb • Destabilized Consumer Trust • Fast and Convenient Food • Low Prices, High Calories • ‘Free-from’ Products • Smart Personalized Food • Changing Households and Food • Globalisation of Diets • Consumer Engagement • Traditions and Do It Yourself • Social Media and Food
MARKET ECONOMY, RETAIL AND LOGISTICS • Concentration in Food Retail Markets • New Shopping Behavior • Short Food Supply Chains • Chain Clustering Along the Food Supply Chain • Physical Internet (Logistic)	**PACKAGING AND WASTE** • Biobased Packaging • Packaging 4.0 • Reduction of Plastic Packaging • Packaging and Health • Food Waste Recovery Up-Cycling/ Waste Cooking
POLICY AND OTHER TRENDS • Women’s Empowerment • Responsible research and innovation (RRI) • Food Regulation	

The main focus in the thesis will be on the following megatrends (FIT4FOOD2030, 2018c):

Food e-commerce. The e-commerce type business models are popular because they allow reducing costs and limiting the usage of assets, it also provides added value to the end-consumer due to improved customer service and delivery to the door. Due to these conveniences, the FI must also adapt its operations towards the e-commerce type of business. However, if the whole FI should operate based solely on e-commerce, new SCM approaches are essential.

Logistics. Innovations in the logistics develop opportunities for the development of new business models. For example, the physical concept of internet would allow maintaining closer integration with end-consumers and allow to purvey more personalized food products. In addition, technologies provide smart traceability and transparency in the food supply chain, which improves customer awareness for healthier products.

Information and Communication Technologies (ICT) applied to the Food System. Such high connectivity and data integration allows using new data analytic approaches together with artificial intelligence. Because of these technologies, it is possible not only to gather information and analyze it, but this factor also allows the system itself to utilize the information through CPS.

Food Industry 4.0. The Industry 4.0 concept mainly focuses on the production process, thus the FI will be affected as well. For example, new mild processes with low energy consumption could be applied. Rapid manufacturing technologies with 3D printing will also decrease the length of the supply chain by providing more local production possibilities. Healthier preservation methods are being developed, such as high pressure, cold plasma, and so on. Such preservation technologies have been used previously, however, currently, the costs are decreasing rapidly. Lastly, new packaging methods also allow maintaining superior food quality. Food quality by the definition of the Food and Agriculture Organization includes all the attributes that influence a product's value to the consumer, such as spoilage, contamination with filth, discoloration, off-odors, and positive attributes such as the origin, color, flavor, texture, and the processing method of the food (Food and Agriculture Organization, 2003). In the thesis, we shall focus on food quality mainly from the spoilage perspective by presuming that at some point food can become food waste.

To summarize, it was identified that the FI is one of the essential industries of the economy because it is related to the well-being of people. The current trends in the business environment are forcing the FI to change its management approaches. The main reasons for this are the growing food demand, growing urbanization levels, and changing consumer habits of consumption and living style. The main megatrends in the FI were overviewed, and it was identified that it is essential to focus on the e-commerce distribution channel and innovative technology application in the FI in order to develop a sustainable FI.

1.1.2. Supply Chain as the Main Factor for Sustainable Food Industry

The objective of this subchapter is to identify the importance of SCM in the FI because only by achieving SCR can sustainable FI be developed. To ground this statement, firstly, the current state of the e-commerce will be overviewed. Secondly, the growing complexity of the food industry will be identified as it increases food waste levels. Thus, particular focus on SCM is needed in order to develop a sustainable FI. Some passages of this chapter have been published previously (V. Gružauskas, Gimžauskienė, and Navickas, 2019).

Application of e-commerce and direct delivery to home is generating even more difficulties in the FI. "The direct selling of food from producers to consumers is not a new development. The possibility of buying food via regional markets, via catalogues or direct at the farm existed before. But the internet enhances the direct access to the consumer" (Saskia, Mareï, and Blanquart, 2016). The internet retailing market size in 2016 was 1.17 trillion USD, and, by 2020, it was estimated to grow to the extent of 2.1 trillion with an AAGR of 13.33% (Euromonitor International, 2017). "By 2025, the share of online grocery spending could reach 20%, representing $100 Billion in annual consumer sales" (Nielsen, 2017).

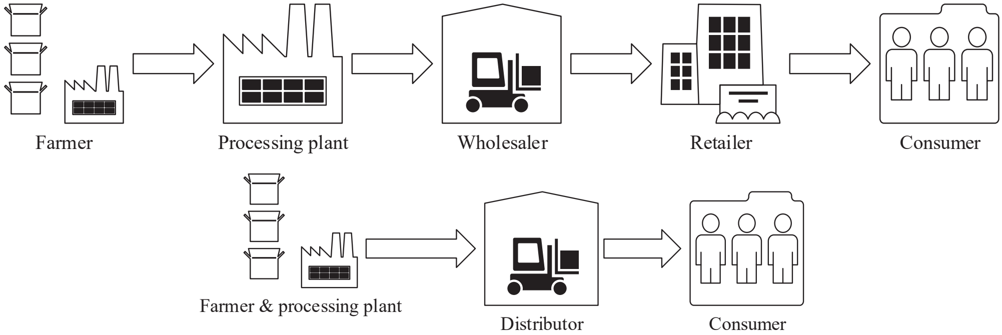


Fig. 4. Comparison of the traditional supply chain length with e-commerce

Figure 4 represents the supply chain of the food industry. At the upper level, the traditional supply chain is indicated which consists of suppliers or farmers, production or processing plants, a wholesaler, retailers, and supermarkets or HoReCa facilities. The lower level of Figure 4 indicates the reduced length of the supply chain based on e-grocery. Currently, the majority of the FI is applying the traditional supply chain approach which requires extensive storage time and delivery time of food products. Thus there is a lot of food waste being created due to ineffective supply chain processes and household behavior. Food losses and waste cost the global economy around USD 990 billion annually (Council of the European Union, 2016). The European Commission has launched a project for food system development which focuses on increasing nutrition levels and promoting more local production (Commission European, 2017). The growing complexity of the FI is increasing the challenges on the management systems even more. The complexity of the food supply chain will increase because the United Nations are promoting SMEs collaboration (small-scale farmers produce over 70% of the world's food needs) (Food and Agriculture Organization, 2017). From the supply chain infrastructure perspective, these changes should consist of more local distribution facilities and local farmer initiatives (DHL Customer Solutions and Innovation, 2016). In order the FI could shift towards organic products, it must decrease the lead-time and maintain high product quality. To accomplish such a shift of operations, the FI must adapt the e-commerce type of the distribution approach, i.e., it must increase the local production and decrease the length of the supply chain. To analyze the efficiency of such an approach, a computer simulation must be developed which would consider different contingencies of the FI.

European Union has been selected as reference for the determination of the singularities of the market. EU has been chosen because the organic food market is gaining more attention in the EU, and the EU also provides publicly available data. Europe has the second largest market for organic food and drink after North America (Willer and Lernoud, 2016). In 2014, European consumers spent about 23.9 billion euros on organic food (DOVLEAC, 2016). The European organic market grew by double digits, and the organic sector reached 13.5 million hectares in 2016 (FIBL, 2018).

As mentioned above, in the previous subchapter, urbanization will cause huge problems to the supply chain. The delivery of low quantity products to multiple delivery points increases the last-mile delivery costs dramatically. This issue is especially relevant in areas where the urbanization levels are high. Currently, the urban logistics costs involve 28% of the total logistic costs, which makes it the largest part (Lau, 2014). High density cities cause the supply chain to be vulnerable to disruptions, which decreases the quality of food products.

Consumers not only demand quality and fresh products, but they also expect delivery to their doorstep because everyone lacks time. This problem can be resolved by promoting small-scale farmers who should fulfill the food demand. "Small-scale farmers produce over 70% of the world's food needs (United Nations, 2015)". This trend will cause the supply chain to be even more complex, and the increased complexity will limit the supply chain's ability to cope with disruptions. In the future, disruptions to the supply chain will increase even more due to the decreasing population density and changing climate. Chistopher and Holweg (2011) stated that the current SCM models emanate from a period of relative stability, and, secondly, that there is considerable evidence that we will experience increasing turbulence in the future (Christopher and Holweg, 2011). For the supply chain to be effective in the future, collaboration and open data must be promoted; however, then, many difficulties await which must be dealt with by using computers and not human interference. Otherwise, it will be impossible to reduce the food waste and maintain a high quality level.

The growing complexity of the FI because of e-commerce adaptation would not be a problem in a stable environment, however, the rapid population growth, traffic jams and other malfunctions are causing the current supply chain to be less and less effective. In the past few years, the growth of the research related to SCR has increased. SCR is defined as "the ability of a supply chain system to reduce the probabilities of a disruption, to reduce the consequences of those disruptions once they occur, and to reduce the time to recover normal performance" (Zobel and Cook, 2008). The problem is that previous SCM strategies were developed in a more stable environment than today (Christopher and Holweg, 2011). Previously, the supply chain used to deliver large quantities of products to processing plants, warehouses and retail stores. However, the trend for e-commerce requires the supply chain to change to small quantity and high variety product distribution. This problem has become an even bigger concern for the FI. The common supply chain models in the e-commerce are presented in Figure 5. To provide delivery to the end-consumer, the warehousing and picking approaches should be improved to fit the food system concept. Especially, demand for organic products has been rapidly growing.

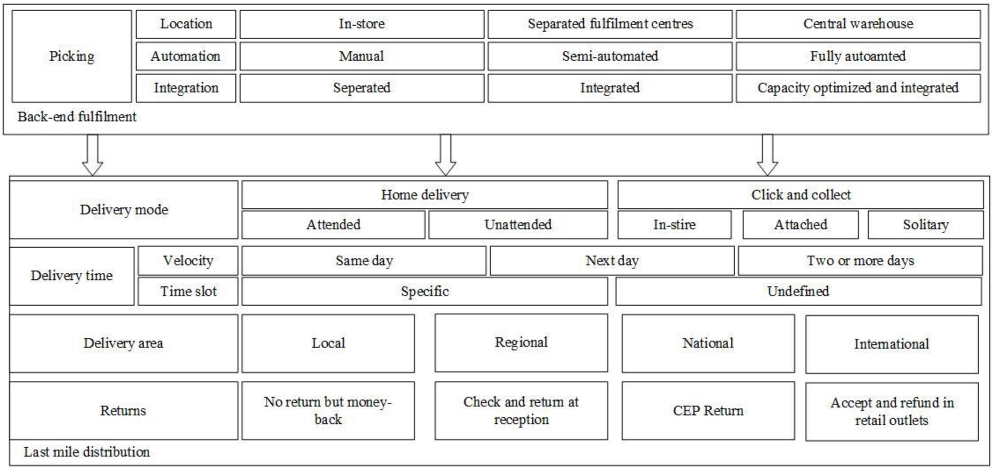


Fig. 5. E-commerce supply chain models (Hübner *et al*., 2016)

The main difficulties in the sense of the e-commerce type of adaptation towards the FI are related to the lack of infrastructure and high distribution costs (Siyodia and Yelamanchili, 2016). The supply chain infrastructure should shift towards more local producers with distribution centres servicing them. The statistics related to the food waste amplifies the importance to change the food SCM approaches. The demand for organic products from the consumer's perspective will even further diminish the effectiveness of the current SCM approaches.

The changes require decreasing the lead-time of food in order to maintain high quality and minimize food waste. "The current linear system of production and consumption is unsustainable. In the food sector, despite the fact that valuable natural resources are intensively used to produce and distribute food products, little is done to upcycle residues generated along the supply chain. Circular economy strategies are crucial for restructuring the take-make-dispose model through the active participation of all actors of supply chains" (Borrello, Caracciolo, Lombardi, Pascucci, and Cembalo, 2017). To fulfill this approach, researchers amplify two main approaches. One approach is to decrease the length of the current supply chain. This can be accomplished by implementing e-commerce type of supply chain in the FI. "Offering products via the internet is affecting the traditional 'bricks and mortar' retail structure. However, as selling online products is not successful for all types of articles, not all retail branches are affected similarly by internet sales. Groceries are still a niche in online trading but are expected to grow fast" (Saskia *et al*., 2016). For the FI to adapt the e-commerce type, it should shift towards direct selling and more involvement of the local producers. "The direct selling of food from producers to consumers is not a new development. The possibility of buying food via regional markets, via catalogues or direct at the farm existed before. But the internet enhances the direct access to the consumer" (Saskia *et al*., 2016).

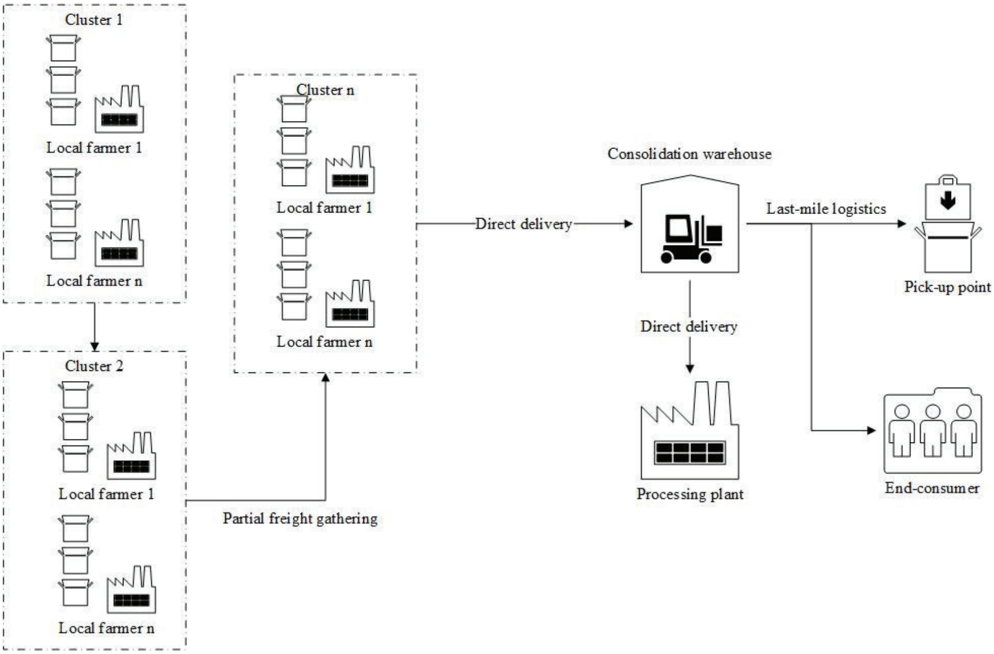


Fig. 6. E-commerce adaptation in the FI for local production

Figure 6 shows the adaptation of e-commerce type distribution strategies for the FI. Firstly, small-scale farmers should be clustered based on computability, i.e., similar products and production processes. Then, the products should be gathered by autonomous vehicles from multiple delivery points. Afterwards, all the raw materials should be delivered to a consolidation warehouse. Near the consolidation warehouse, there should be processing plants. Afterwards, the products should be distributed directly to the end consumer or pick-up points. It is important to amplify that the distribution processes should be done with autonomous vehicles. The implementation of such a distribution strategy would decrease the length of the supply chain and would allow small-scale farmers to share their resources in order to maintain competitiveness.

Online grocery shopping is currently a growing industry; however, it is suffering from severe ineffectiveness and hence currently is not suitable to fulfill the food demand for the country level market. To reduce the food waste and maintain short supply chains, a hyper local market approach is recommended to be implemented. "Hyperlocal companies operate in one or more than one states with more specific regional focus, the main objective of the business to cater to wider market within certain geographical boundaries so as to become strong player. Demand for instant delivery due to changing lifestyle, easy access to internet, Increase in geo-location aware devices and easy payment option have paved the way for hyperlocal businesses" (Siyodia and Yelamanchili, 2016). "Local production is becoming an increasingly important food attribute for consumers due to *inter alia* recent food scandals and the growing complexity of food production. Especially in the organic food market, local production is seen as an important additional value" (Wägeli and

Hamm, 2016). The term *hyper local* describes how food should be grown in local markets by small and medium-scale farmers. However, this would mean that the companies would lose economy of scale, without which, in the long run, it would be impossible to compete with international companies.

Because of this growing complexity and higher demand for healthy food, the concept of resilient and sustainable food supply chains is growing. “The key to ensuring a sustainable and resilient supply of the essential ecosystem services on which humanity depends on is by enhancing the resilience of socio-ecological systems, instead of optimizing isolated components of the system” (Barrientos and Idalia Flores, 2016). Therefore, it is essential to analyze the FI as a food system. “The sustainability of a food system is most often defined in reference to the three pillars of sustainability (environmental, economic and social), in an often static and normative way, while the notion of resilience is defined in reference in a more dynamic way, in terms of the ability to cope with shocks and stresses” (Lamine, 2015). In the case of this thesis, we focus on the SCM aspect since it is necessary to reduce the length and complexity of the supply chain. Thus new management approaches must be developed. Figure 7 illustrates the complexity of the FI, which involves various organizations and aspects of the FI.

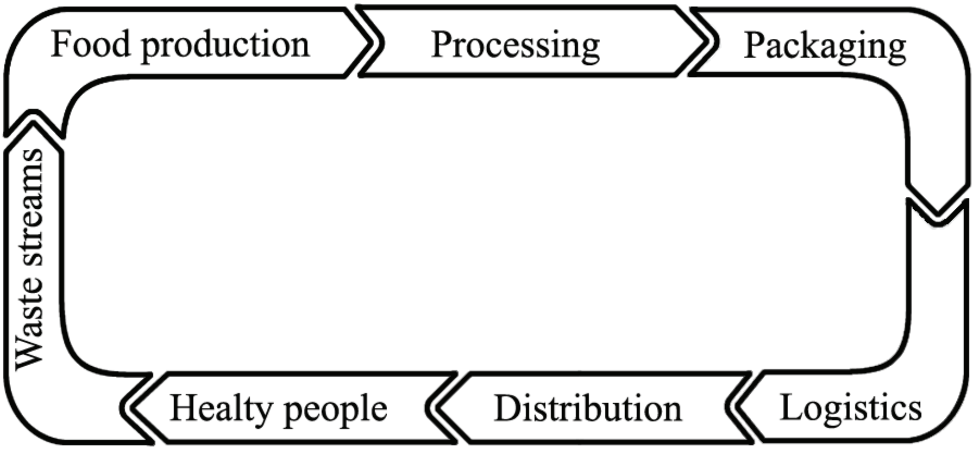


Fig. 7. Processes of the food industry (Broerse, 2018)

The effective management of the food supply chain should lead to the sustainable development of the FI. Because of the growing complexity of the FI, the concept of SCR has been gaining more attention in the recent years. Kamalahmadi and Parast (2016) defined SCR as “the adaptive capability of a supply chain to reduce the probability of facing sudden disruptions, resist the spread of disruptions by maintaining control over structures and functions, and recover and respond by immediate and effective reactive plans to transcend the disruption and restore the supply chain to a robust state of operations” (Kamalahmadi and Parast, 2016). A sustainable food system is a food system that delivers food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition for future generations are not compromised (FAO, 2018). In the thesis, we see SCR as an approach to achieve *Sustainable FI*. Figure 8 illustrates the concept of a sustainable and resilient food system which was developed based on research of sustainability and resilience in the food system (Green, Worstell, and Canarios, 2017), (Lamine, 2015), (IPES FOOD, 2015), (Magalhães *et al*., 2018).

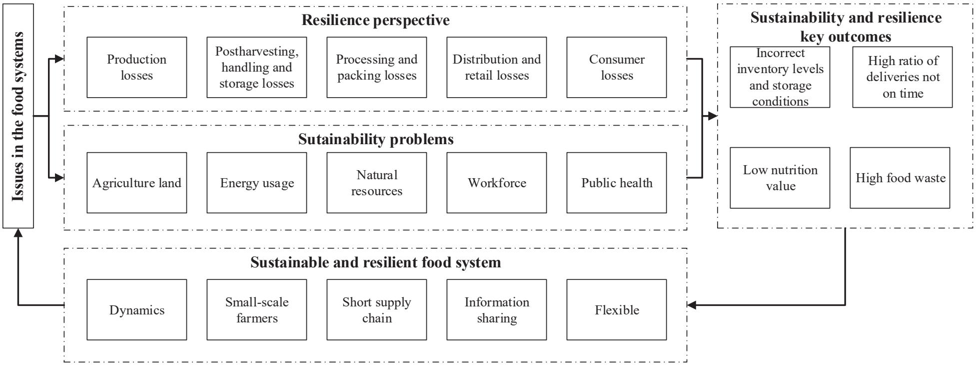


Fig. 8. A sustainable and resilient food system

In summary, it was identified that the e-commerce distribution approach must be adapted to the FI in order to cope with the arising issues. Secondly, it was concluded that SCR firstly must be achieved before the FI can become sustainable. Traditional SCM approaches have been developed for a more stable and less complex environment, thus, in the next chapter, more focus on SCM will be provided.

1.2. Peculiarities of Supply Chain Management

1.2.1. Theoretical approaches to Supply chain management

The goal of this chapter is to briefly describe the theoretical perspective of how SCM can be analyzed. In the further chapters, in-depth analysis of the main theoretical approach will be conducted.

SCM is considered to be a key aspect of many businesses, especially in the information age. During the last decades, the concept has changed. Previously, SCM was considered rather as a goal to transport goods and products at the right time at the right cost and to the right place, together with some planning. However, today, due to the globalization in technological development, the concept has evolved, and it now covers inter-organizational relationship with large network management. The most accurate SCM definition has been proposed by Ho *et al*. (2002) “SCM is a philosophy of management that involves the management and integration of a set of selected key business processes from end user through original suppliers, that provides products, services, and information that add value for customers and other stakeholders through the collaborative efforts of supply chain members” (Ho, Au, and Newton, 2002). The main concept of SCM has remained, however, different goals are presently being tried to be obtained depending on the priorities of the companies. For example, due to the sustainability trend, companies focus not only on profitability but also take into consideration sustainability dimensions as described in the previous chapter. Machado and Duarte (2010) focused on the other goals of SCM and defined the dilemma of trade-offs when managing supply chains (Machado and Duarte, 2010). The research paper described different supply chain paradigms, such as lean, agile, resilience, and green. Machado and Duarte (2010) state that some of these approaches are contradicting each other. For example, the lean approach requires maintaining zero inventory, while resilience promotes robustness, i.e., extra inventory levels. From the theoretical perspective, different goals require managing SCM differently, thus it is important to consider the theoretical approach when managing supply chains (see Table 2). The main theoretical approaches were comprehensively analyzed by (Fayezi and Zomorrodi, 2016).

Table 2. Theoretical approaches for Supply chain management, adapted from (Fayezi and Zomorrodi, 2016), (Carter, Rogers, and Choi, 2015), (Tukamuhabwa *et al*., 2015), (Touboulic and Walker, 2015)

Characteristics	Key assumptions	Problem orientation	Primary focus of analysis
Transaction cost economics	Bounded rationality, opportunism	Efficient governance structure: why do firms exist?	Transaction attributes (e.g., asset specificity)
Agency theory	Bounded rationality, asymmetric information, goal conflicts	Contract design: what is the most efficient contract?	Contracts and incentives
Resource-based view	Bounded rationality, trust	Internal competence development: why do firms differ?	Resource attributes
Resource-dependence theory	Existence of coalitions, uncertainty (variability and complexity in acquiring resources)	Reduce uncertainty and manage dependency: why do firms form strategic alliances?	Inter-firm dependence
Network theory	Bounded rationality, trust	Network relationships: why do firms need to establish networks?	Dynamic network connections
Stakeholder theory	Activities of companies affect both internal land external parties.	What is the role and influence of stakeholders on SCM practices?	Firm activities and decisions as shaped by external stakeholders' pressure

Relational exchange theory	Embeddedness, trust	Why can moral control diminish opportunism?	Norm as an internal form of governance
Complex adaptive system theory	Self-organizing system, changing over time	How individual interaction of agents emerges towards system level output?	Evaluation of supply chains

Transaction cost economics is one of the fundamental economic approaches when analyzing organizations which focus on including all the costs of SCM, even the hidden ones. In addition, the scale of economics is an important concept in the transaction cost economics theory since it focuses on the size of the firm. Today, this theoretical approach has some limitations since the appearance of the internet has reduced the costs of SCM. The agency theory focuses more on the legislation issues of SCM management, e.g., how to align the commitment level of the supply chain members. The agency theory today has gained importance since the dynamic and globalized market requires to maintain flexibility, but at the same time to maintain proper commitment levels of the supply chain members. The resource-based view states that companies should acquire tangible or intangible capabilities which would allow the achievement of competitiveness. Due to the dynamic environment, the resource-based view has evolved towards the contingent resource-based view which states that the right capabilities depend on the market situation. The resource-dependence theory has further expanded the theoretical view from single-firm to inter-organizational relationships and to the analysis of outsourcing aspects and sharing resources between the supply chain members. The sharing of resources and information between the supply chain members has influenced the appearance of the network theory which focuses on the structure of the supply chain while focusing on the analysis of the connectivity issues, the weakest points in the network, etc. Globalized supply chains require dealing with the multi-cultural environment, thus, the relational exchange theory focuses on how to manage the processes of SCM effectively by considering the moral dilemmas of the members. For example, when analyzing the level of information to be shared, the requirement is imposed to decide between personal and group benefits. Due to the rapidly changing environment, the theoretical approaches towards SCM must be further adapted, thus the CAS theory approach is being promoted, which focuses on the interaction between the supply chain members and takes into consideration their adaptation and evolution over time, while other theories mainly focus on a static environment (G. Wang, Gunasekaran, Ngai, and Papadopoulos, 2016). Table 3 lists the most popular theoretical approaches, however, Walker (2013) listed even more theoretical approaches, such as the structuration theory, population ecology, etc. (Touboulic and Walker, 2015). However, in the thesis, more focus will be provided to the relevant approaches required to develop sustainable food industry. When applying these theories to analyze the supply chain resilience, a problem related to reasoning is encountered. In general, the previous theories recommend stabilizing the supply chain processes and trying to reduce variable costs as much as possible; however, this is true in stable environments only, which in the current dynamic market is no longer possible. “All these approaches (e.g., lean, Six Sigma) help to eradicate variability, prevent costly dynamic distortions such as the ‘bullwhip’, and spread the operational risk. The key objective is to reduce cost through increased control, which in a stable world certainly does enhance profitability. In a volatile environment, however, control efforts result in a rigidity of supply chain structures and interactions” (Christopher and Holweg, 2011).

In summary, it can be seen that the evaluation of SCM requires developing new management approaches in order to maintain sustainability in the long run. Thus, in the following chapters, it will be amplified why SCM is a crucial aspect in order to achieve a sustainable food industry.

1.2.2. The Theoretical Relationship between Sustainability and Resilience

In the previous chapter, it was concluded that FI complexity is rapidly increasing due to disruptions, the shortened supply chain length and the growing number of decisions between the supply chain members. In this chapter, more emphasis will be provided on the current research conducted in the field of sustainability and resilience in the FI and SCM.

The competitive environment has changed dramatically in the past years and is continuously becoming more complex and less stable, which leads to companies losing their competitive advantage in terms of the supply chain. The majority of SCM approaches have been developed in a more stable business environment (Christopher and Holweg, 2011) and are inefficient under the current conditions. The business environment is expected to become even more unstable due to the future population growth and increasing urbanization (Srovnalikova & Ditkus, 2016). Therefore, the supply chain will have to become even more complex. Consumers’ demand for low quantities, a high variety and direct delivery to their homes with minimal costs has made the entire supply chain more sensitive to costs. This problem is an even bigger concern regarding the aspect of the last-mile delivery (e-commerce), which constitutes 28% of the current total logistics costs due to uncertainty and disruptions (Lau, 2014). Currently, the food supply chain is inefficient because of abundant food waste and low nutrition level due to inability to cope with disruptions (Borrello *et al.*, 2017), (Managa *et al.*, 2018). In addition, the growing demand for organic food and sustainable products further reduces the shelf-life of perishable products. “As the entire farm-to-fork cycle is being squeezed to provide short lead times and efficiency, supply chain designs have to rely heavily upon logistics and warehousing functions that provide temperature conditioned transport and storage, and increased use of advanced information and communication technologies. Recent research states that in perishable-product supply chain design, a trade-off should be made between transportation costs, shortage costs, inventory costs, product waste and expected shelf-life losses and quality decay” (Dani, 2015). In order to fulfill the food demand in the future, the Food and Agriculture Organization promotes small and medium farmer collaboration – “small-scale farmers produce over 70% of the world’s food needs” (United Nations, 2015). The contribution of small and medium farmers will increase even more in the future due to the rising demand for organic food products (Srovnalikova and Ditkus, 2016). Because of these trends, the traditional approach to product distribution must change, and the supply chain must be able to fully adapt in order to provide direct delivery to consumers. Rapid implementation of e-commerce in the FI may help to reduce costs and food waste.

The sustainability of the supply chain in the recent years has received more attention due to the tendency to decrease the negative effect on the environment and maintain higher resource utilization. This concept has been studied more from the environmental and strategic level perspective, however, from the system resilience perspective, only a limited amount of research has been done (Jabbarzadeh, Fahimnia, and Sabouhi, 2018), (Murino, Romano, and Santillo, 2011). The concept of resilience is mainly analyzed from the *force majeure* perspective, however, Calvert and Snelder indicated that "Minor disruptions in traffic and transport systems can also play an important part in reducing efficiency" (Calvert and Snelder, 2018). Hofa and Pawlewski (2014) also indicated that traffic congestions and road accidents are several aspects of disruptions in the supply chain which decrease the effectiveness of the system (Hoffa and Pawlewski, 2014). Because of the complexity and rapidly changing environment, it is important for any supply chain to possess the ability to quickly adapt to the disruptions.

Only a limited amount of empirical research has been done to identify the relationship between resilience and sustainability. For example, a research has been conducted with the objective to develop a sustainability/resilience index for a local food system (Green *et al*., 2017). The research focused on measuring the relationship through the following constructs: Connectivity, Local self-organization, Innovation, Maintenance, Accumulation, Transformation, Ecological integrity, Diversity. In the case of this research, we are mainly focusing on self-organization through the supply chain perspective, more specifically, in the light of information sharing and the demand/supply alignment. If a supply chain cannot cope with disruptions, it will result in the system-level overproduction, which will directly increase the negative impact on the environment by decreasing the effective utilization of resources. On the one hand, this problem may require food products to be delivered multiple times, which will decrease the quality and nutrition levels of the products. On the other hand, if a supply chain cannot cope with market fluctuations, it will tend to order insufficient or excessive amounts of food products, which will result in over-storage. Tendall *et al*. (2015) stated that sustainability is the measure of system performance, whereas resilience can be seen as a means to achieve it during times of disruption, thus resilience and sustainability are complementary concepts (Tendall *et al*., 2015), (see Fig. 9). In the topic case of the present thesis, we focus on SCR, which is part of the FI, thus the measurement and achievement approaches are the same as described by Tendall *et al*. (2015); however, the concepts are at different levels of the system.

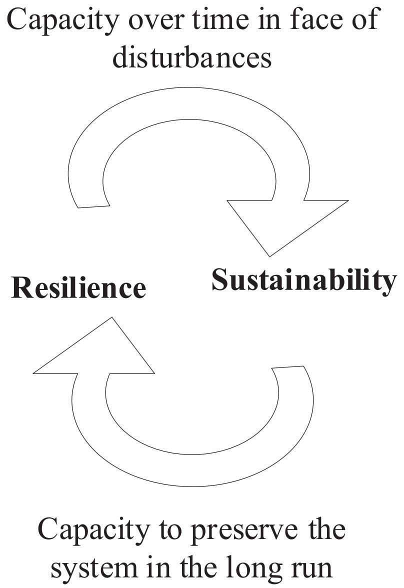


Fig. 9. Resilience and sustainability as complementary concepts (Tendall *et al.*, 2015)

Another research amplified the necessity to analyze the food system from the perspective of system resilience, i.e., the relationship between all the members of the food system (Lamine, 2015). Therefore, in the simulation model, the necessity to increase collaboration between consumers, distributors and farmers will be shown. Himanen *et al.* (2016) analyzed the relationship between the food system members by stimulating adaptive capacity planning (Himanen, Rikkonen, and Kahiluoto, 2016). Their research concluded that adaptivity could increase the food system resilience, however, more empirical research still needs to be conducted. In summary, the exact relationship between sustainability and resilience has not been defined yet, however, at least some relationship between these concepts can be identified.

Magalhães *et al.* (2018) conducted an empirical research to identify the main causes of food waste. Their research indicated the 15 main causes of food waste, while singling out 6 key causes, specifically, lack of infrastructure and technical management; ineffective storage management; lack of coordination and information sharing; pricing strategies and promotion management; overproduction and inadequate demand forecasting. The reduction of food waste can be handled from several aspects and scientific fields. For example, from the food science perspective, food quality can be increased by analyzing alternative agriculture processes which would allow more robust planning of yields. This would allow improving longterm forecasting approaches. From the engineering perspective, the quality and nutrition level of food products can be improved by developing better temperature control technologies for storage and transportation. An alternative would be to develop more sustainable packages in order to maintain superior product quality and nutrition levels. On the one hand, the problem lies at the strategic level of planning, such as the supply chain design related to facility location and storage area planning. On the other hand, the problems are related to planning and coordinating operational and tactical level activities. In this case, it is important to increase collaboration and promote supply chain analysis. The proposed research method takes this approach one step ahead and amplifies that the daily decision making process should be based on computers rather than humans as this would increase information utilization possibilities. Therefore, it is proposed to promote the collaborative demand forecasting approach through machine learning implementation and information sharing.

In summary, it can be concluded that, without SCR, achieving Sustainable FI is impossible. Thus, in the following chapter, more focus on SCR will be made.

1.2.3. Conceptualization of Resilience of the Food Supply Chain: focus on flexibility and redundancy approaches

The goal of this chapter is to define the SCR concept and identify the main approaches used for achieving SCR. Some passages of this chapter have been previously published (Gružauskas and Vilkas, 2017).

The e-commerce trend has led to new challenges for the industry. Today, consumers' desire for personalized products getting just-on-time right to their doorstep and with minimal costs. However, the challenge of the shifting trends and constant disruptions of the market increases the instability of the supply chain. Recent scientific literature amplifies the SCR problem and recommends various strategies to cope with disruptions (Ambulkar, Blackhurst, and Grawe, 2015; Elleuch, Dafaoui, Elmhamedi, and Chabchoub, 2016; Gonçalves and Chicareli, 2014; Kim, Chen, and Linderman, 2015; Mensah and Merkuryev, 2014; Munoz and Dunbar, 2015; Nikookar, Takala, Sahebi, and Kantola, 2014). There is a variety of approaches to define and measure resilience in the supply chain. SCR defines the ability of the chain to cope with disruptions and maintain their original state (Croxton, 2010; Fiksel, 2007; Lengnick-Hall, Beck, and Lengnick-Hall, 2011; Zobel and Cook, 2008). However, the resilience concept is still new, and it is not saturated. Moreover, due to the growing world's population, more people will live in urban regions, which will make the e-commerce supply chain even more complex (Food and Agriculture Organization, 2015). Constant traffic jams, weather conditions and IT malfunctions cause disruptions to the supply chain, which dramatically raises costs and increases the lead-time (Baylis *et al.*, 2015). "The Last leg of the supply chain is least efficient, comprising up to 28% of the total logistics cost" (Lau, 2014). SCR can be achieved by different capabilities of the supply chain (Ambulkar *et al.*, 2015; Gonçalves and Chicareli, 2014; Kim *et al.*, 2015; Mensah and Merkuryev, 2014).

The SCR approaches have already been analyzed, however, the field is still underresearched. Nikookar *et al.* (2014) stated that there is a significant gap between experiences and expectations of practices for SCR. Elluech *et al.* (2016) amplified the necessity to develop resilience practices for the optimal allocation of resources. One of the practices that were amplified is collaboration, which positively effects resilience; however, it functions from the redundancy approach rather than from the flexibility approach. Ambulkar *et al.* (2015) indicates the necessity to possess flexibility and agility to effectively manage the infrastructure of collaboration.

Croxton *et al.* (2013) provides empirical evidence which reveals that low collaboration, lack of excess capacity and minimal flexibility are the major causes of ineffective SCR. Park (2011) delivers empirical evidence which identifies that resilience and redundancy practices positively affect SCR. However, the influence of a combination of these practices on SCR must still be considered. Wieland and Wallenburg (2012) identified that communicative and cooperative relationships have a positive effect on resilience, while integration does not exhibit a significant effect. Without the capability to utilize information effectively, the high collaboration level is ineffective because the collaboration becomes too complex and loses flexibility. However, Liu *et al.* (2013) indicated that IT integration capabilities can improve redundancy, however, integration does not necessarily improve flexibility.

There are main two approaches to achieve resilience. On the one hand, resilience can be achieved by reorganizing the current resources quickly, which is a flexibility-based approach (Ponis and Koronis, 2012). The other approach is to increase the commitment of the chain by finding more suppliers and increasing the inventory level, which is called redundancy or increasing robustness of the chain (Leat and Revoredo-Giha, 2013). Research of different approaches which can help achieve SCR has been performed. One of the most amplified approaches is collaboration (Zhao, Liu, Zhang, and Huang, 2016), (Bosona and Gebresenbet, 2011), (Kim *et al.*, 2015), (Wang *et al.*, 2016). Collaboration is based on certain computability, commitment and capabilities. Members of the chain must be denoted by certain characteristics that would enable effective collaboration. These characteristics can be defined as depending on the situation e.g., the geographical position, the main industry, etc. The commitment level of the collaboration members may offer various economic and competitiveness benefits. Collaboration may commit participants to share general information, share equipment, or make strategic plans with other collaboration members. The benefits and approaches to collaboration have been widely researched, however, the main research gap is that the most amplified resilience strategy is based on collaboration which enables the supply chain members to share information as well as commitments and gain resilience. However, the strategy is based on unclear commitments and decreases the turnover rate of the working capital because it recommends gaining flexibility by increasing redundancy (Zhao *et al.*, 2016), (Bosona and Gebresenbet, 2011), (Kim *et al.*, 2015), (Wang *et al.*, 2016). A large number of members in the collaboration process can provide better efficiency levels in terms of costs, however, it limits the ability of collaboration to cope with disruptions by increasing complexity and limiting visibility.

The majority of the previously conducted research highlights the necessity to make trade-offs in SCM (Esfahbodi, Zhang, and Watson, 2016), (Morrison-Saunders and Pope, 2013), (Beckmann, Hielscher, and Pies, 2014), (Seuring, 2013), (Winn, Pinkse, and Lydia, 2012). In order to understand the trade-offs, it is important to focus on the paradigms of the supply chain management. The classic approach to the supply chain management is based on lean management which focuses on stabilizing the processes and creating a continuous flow of production which theoretically achieves cost-effective performance (Christopher and Holweg, 2011). The second paradigm of the supply chain management focuses on agile approach which states that a supply chain should focus on having flexibility to cope with the fluctuating demand (Machado and Duarte, 2010). However, the two paradigms are ineffective in a rapidly changing business environment because it requires developing surplus infrastructure or maintaining other additional assets in order to cope with the change in the business environment. Thus, research has been focusing on SCR which aims to provide adaptation abilities to the supply chain and to quickly re-establish its processes while maintaining its regular functions.

The majority of the research conducted on SCR is theoretical and focuses on large companies (Tukamuhabwa *et al*., 2015). There are different approaches of how it is possible to achieve SCR, however, only a few researches actually analyze how a combination of supply chain approaches can influence resilience. Moreover, the development of innovative technologies is influencing the concept of the supply chain capabilities. The development of the Industry 4.0 concept has a significant impact on the supply chain. This concept involves the Internet of Things (IoT) that is responsible for information gathering, big data analytics (information processing) and autonomous vehicles (information utilization) (Swafford, Ghosh, and Murthy, 2008), (Chen, Cheng, and Huang, 2013), (Navickas and Gružauskas, 2016), (Zhao *et al*., 2016), (Klötzer and Pflaum, 2015). Thus, the proposition is that SCR can be achieved by integrating redundancy and flexibility approaches together with innovative technologies, such as CPS.

Firstly, it is important to define what exactly SCR is before analyzing the approaches which can influence resilience in the chain. The Resilience concept has been analyzed not only in the context of the supply chain but also at a more general organization level. Fiksel (2007) describes resilience as the capacity of an enterprise to survive, adapt and grow in the face of turbulent change. Hall *et al*. (2011) identifies the firm's ability to effectively absorb disruptions, develop situation-specific responses in order to ultimately engage in transformative activities so that to capitalize on the distributive surprises that potentially threaten the organization's survival. Other research identifies the resilience concept in the context of the supply chain. Croxton (2010) identifies that SCR is the capacity of complex industrial systems to survive, adapt, and grow in the face of turbulent change. Zobel and Cook (2008) also highlight the ability for a supply chain to reduce the probability of destruction by identifying upcoming risks. "SCR is the ability of a supply chain system to reduce the probabilities of a disruption, to reduce the consequences of those disruptions once they occur, and to reduce the time to recover normal performance." Ponis and Koronis (2012) provide an even more widely adapted description of SCR: "The ability to proactively plan and design the Supply Chain network for anticipating unexpected disruptive (negative) events, respond adaptively to disruptions while maintaining control over structure and function and transcending to a post-event robust state of operations, if possible, more favorable than the one prior to the event, thus gaining competitive advantage." Researchers differently describe the concept of SCR depending on the situation and the context. In this thesis, the definition is focused on SCR according to Kamalahmadi and Parast (2016) that it is "the adaptive capability of a supply chain to reduce the probability of facing sudden disruptions, resist the spread of disruptions by maintaining control over structures and functions, and recover and respond by immediate and effective reactive plans to transcend the disruption and restore the supply chain to a robust state of operations" (Kamalahmadi and Parast, 2016) because it involves the flexibility and redundancy approaches to resilience.

Table 3. Main literature review publications of SCR

Topic	Author
Analyzes the supply chain risk, vulnerabilities and disruptions	(Elleuch *et al.*, 2016)
Defines SCR	(Ponis and Koronis, 2012) (Jüttner and Maklan, 2011)
IT approach to supply chain resilience	(Klötzer and Pflaum, 2015) (Zobel and Cook, 2008)
Defines macro or strategic view of resilience	(Demmer, Vickery, and Calantone, 2011) (Mensah and Merkuryev, 2014)
Analyzes supply chain risk, vulnerabilities and disruptions	(Leat and Revoredo-Giha, 2013)
Analyzes supply chain design relationship with resilience	(Kim *et al*., 2015)
Analyzes the impact of approaches on SCR	(Gonçalves and Chicareli, 2014) (Croxton, 2010) (Proper, 2011)

The context of SCR has been analyzed from different perspectives, however, it is still under research with only a limited amount of publications. Our literature analysis identifies that the concept of SCR is still gaining recognition and lacks theoretical and empirical evidence. Table 3 indicates the research done regarding the content of SCR which covers different aspects of SCR. There are many researches that analyzed these aspects of the supply chain, therefore, Table 2 indicates the most diverse aspects of the research. Several authors conducted a profound literature review related to resilience. Elleuch *et al*. (2016) conducted a literature review based on resilience and vulnerability and identified that the optimal allocation of resources needs to be more developed for selecting an efficient resilient supply chain with the trade-offs between vulnerability reduction and resilience capacities enhancement because there is lack of practices for SCR achievement. Menash and Merkuryev (2014) identified the main factors which are essential for SCR: decision making, strategy and tactics (DMST), and proposed practices to gain resilience: Lean production with JIT delivery and low inventory, Six sigma supply chain, Increasing SC flexibility, and Developing a strong corporate culture. Nikookar *et al*. (2014) indicated that there are significant gaps between experiences and expectations of the implementation performance of resilient practices. Therefore, there is a need to understand the approaches to the supply chain resilience to provide better orientation to practices. Ponis and Koronis (2012) analyzed the approaches to SCR and indicated that the best-grounded antecedents of SCR are agility, flexibility, velocity, visibility, availability, redundancy, mobilization of resources, collaboration, and the supply chain structure knowledge. They proposed a framework consisting of flexibility, collaboration, and agility, however, they did not consider IT integration and visibility which are essential approaches of the Industry 4.0 concept. The proposed framework lacks empirical evidence, therefore, its validity is also questioned. Peck and Christopher (2004) analyzed the SCR concept and focused on the supply chain approaches to dealing with risk by promoting flexibility and agility, however, they did not consider the redundancy and IT integration aspects of the supply chain. The collaboration benefits, commitments and compatibility issues are widely researched and provide theoretical and empirical evidence for the benefits of collaboration. Leat and Giha (2013) reduced the supply chain vulnerability through horizontal collaboration amongst producers and also reduced the vertical collaboration with the processor and the retailer. The collaboration generated greater security of the supply of assured quality, improved the communication with suppliers, and reduced the demand risk as they could assure consumers regarding quality, animal welfare and product provenance; however, this particular research amplified more the supply chain design and redundancy concept, yet it did not consider flexibility. Feliu *et al*. (2013) used the simulation approach to promote collaboration; they indicated that it is necessary to develop decision support systems that involve all the decision makers concerned by preparing them to be predisposed to discussion and convergence through consensus. The decision support system for information gathering and processing is not enough, there is a need to optimize the capability of utilization of the information, which would increase the resilience of the supply chain. There is other segment of research which also amplifies the collaboration benefits (Zhao *et al*., 2016), (Bosona and Gebresenbet, 2011), (Kim *et al*., 2015), (Wang *et al*., 2016). The collaboration approach is based on the theoretical aspect of improvement of the efficiency of the chain, e.g., partial freight collection, information sharing, etc. However, from the practical point of view, the implementation of the collaboration frameworks is limited, and lack of research of how the supply chain approaches influence collaboration is evident. The majority of the researches listed above identifies how it is possible to achieve SCR by increasing redundancy and commitments of the chain, however, Ambulkar *et al*. (2015) indicates that the supply chain disruption orientation alone is not enough for a firm to develop resilience. Supply chain disruption-oriented firms are required to possess the ability to reconfigure resources or have a risk management resource infrastructure to develop resilience.

Table 4. Main publications of SCR

Topic	Main contribution	Author
Measures SCR	Proposed a deterministic modeling approach to evaluate the supply chain resilience index.	(Soni, Jain, and Kumar, 2014)
	Proposed a resilience measurement approach which would include multiple	(Munoz and Dunbar, 2015)

	tiers rather than focus on single-firm level.	
	Developed a measurement tool *Supply Chain Resilience Assessment and Management.*	(Pettit *et al.*, 2013)
	Used the Integral of the Time Absolute Error as a resilience measurement when analyzing inventory planning aspects.	(Spiegler, Naim, and Wikner, 2012)
	Conceptualized Supply Chain Resilience.	(Ponis and Koronis, 2012)
Defines resilience practices	Stated that the most important strategies for resilience are flexibility, redundancy and collaboration and indicated that the Complex Adaptive Systems theory is the most suitable for the analysis of resilience.	(Tukamuhabwa *et al.*, 2015)
	Measured risk in the supply chain management through the SCOR model and the application of Bayesian network.	(Liu, Ke, Wei, and Hua, 2013)
	Proposed integration of lean, agile, resilient and green supply chain management.	(Cabral, Grilo, and Cruz-Machado, 2012)
	Defined the main resilience approaches, such as flexibility and redundancy, and provided a measurement approach for them.	(Park, 2011)
Defines macro or strategic view of resilience	Identified that supply chain disruption oriented firms are required to possess the ability to reconfigure resources or have a risk management resource infrastructure in order to develop resilience.	(Ambulkar *et al.*, 2015)
	Focused on relational competences and concluded that communicative and cooperative relationships have a positive effect on resilience.	(Wieland and Wallenburg, 2013)
	Stated that companies must focus more on resilience achievement through flexibility due to the trends towards the creation of increasingly complex networks of interdependent organisations.	(Christopher and Peck, 2004)

Table 4 indicates empirical evidence related to the approaches of SCR. Park (2011) analyzed the influence of flexible and redundant supply chain practices on SCR. Park defined the supply chain practices as flexible and redundant, which consisted of information sharing, security compliance, the extent of collaboration, contingency planning, safety stock, and slack capacity. The empirical evidence was mainly related with the ways how flexibility and redundancy practices influence the approaches of SCR. The obtained results indicated that both SCR practices are positively associated with the approaches of SCR. The more firms implement SCR practices, the more likely it is they are to formulate approaches of SCR. However, this research did not consider the extent to which the combination of flexibility and redundancy practices influences SCR. Croxton *et al.* (2013) analyzed SCR relationship with the supply chain performance. The research developed a measurement tool titled SCR Assessment and Management. The data gathered from seven global manufacturing and service firms was used to validate SCR Assessment and Management by using qualitative methodology with 1,369 empirical items from focus groups reviewing 14 recent disruptions. Their empirical evidence concluded that the firms in this study reported capability strengths in the areas of Market Position, Recovery and Financial Strength. However, consistent reports of low Collaboration, lack of excess Capacity and minimal Flexibility raised serious concerns (Pettit *et al.*, 2013). This research provides evidence that the collaboration, redundancy and flexibility approach must be addressed in a more specific way in order to better utilize the approaches for SCR. Wieland and Wallenburg (2012) analyzed the influence of relational competencies on SCR. They identified that communicative and cooperative relationships have a positive effect on resilience, while integration does not have a significant effect. Integration in this research referred to the process of combining efforts “to integrate supplier and customer information and inputs into internal planning.” Without the capability to utilize information effectively, the high collaboration level is ineffective because collaboration becomes too complex and loses flexibility.

Hefu *et al.* (2013) analyzed the influence of the flexible IT infrastructure and IT assimilation approaches on the firm’s performance through the absorptive agility approach. The results strongly support the claim that a firm’s IT capabilities can help the firm improve its absorptive capacity. However, the results of this study do not support the hypothesis on the association of the IT capabilities and the supply chain agility. This empirical evidence indicates that the IT capabilities influence the robustness of the supply chain or redundancy. However, it does not provide agility which is a component of flexibility. The influence of the IT capabilities to agility was limited because the research did not consider the information utilization possibilities which are possible with CPS or self-driven vehicles. Fang *et al.* (2006) analyzed how information technology (IT) improves the supply chain process. The evidence suggested that the investment in IT does not guarantee enhanced organizational performance. This study proposes that IT-enabled supply chain capabilities are firm-specific and hard-to-copy across organizations. Prajogo and Olhagerr (2012) investigated the integrations of both information and material flows between the supply chain partners and their effect on operational performance. They found that logistics integration has a significant effect on the operations performance. Information technology capabilities and information sharing both exert significant effect on logistics integration. However, they did not consider the aspects of collaboration and resilience. Wang *et al*. (2016) analyzed the interpersonal relationship to supply chain integration through interorganizational cooperation. Their extensive literature analysis indicated that interpersonal relationship including personal affection, communication, and credibility has positive influence on the supply chain integration, and these links are mediated by inter-organizational relationships including trust, commitment, and power. However, this research did not provide empirical evidence and did not consider SCR.

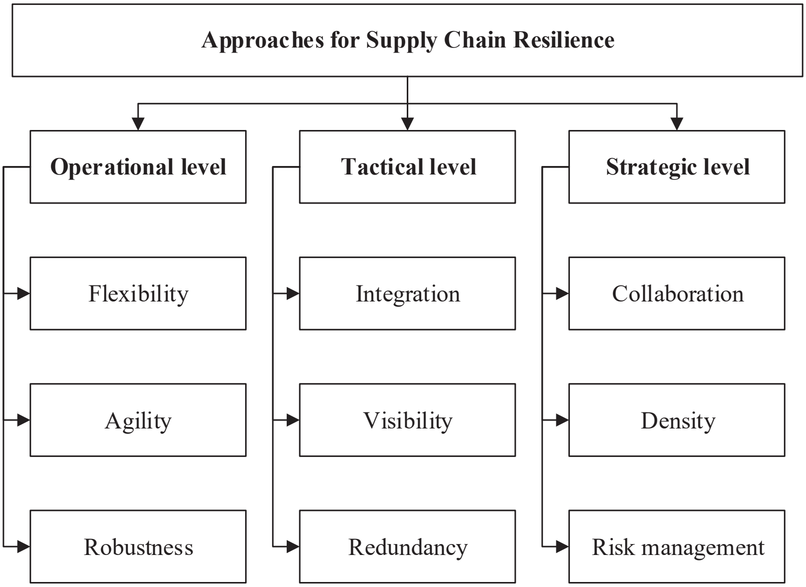


Fig. 10 Approaches towards achieving SCR

Gonçalves and Chicareli (2014) identified the approaches which made the largest contribution to resilience flexibility (supplier; product; process; transportation), collaboration (information sharing; joint decision making; working together); the structure of the chain (physical; information), and agility (visibility; velocity). This research amplifies that those empirical studies which analyze the relationship between the management approaches need to verify what is more relevant before, during and after a disruption in the supply chain. Figure 10 the main approaches of the supply chain that are categorized based on approaches to SCR. These approaches involve the approaches to SCR covered before. The main approaches which are necessary for the integration of the Industry 4.0 concept are: collaboration, flexibility and redundancy.

The collaboration benefits have a theoretical and empirical background, however, there is lack of the practical implementation and management aspect of the SCR approaches. Flexibility is the ability of the chain to cope with disruptions much faster and return to its original state, which was proved by the benefits. The redundancy capability mainly focuses on the increasing supplier number or inventory, which creates robustness for the supply chain and increases costs. Lastly, the integration capability must be addressed so that to provide a SCR approach towards the Industry 4.0 concept.

In summary, it can be concluded that SCR can be achieved mainly by focusing on collaboration, flexibility and redundancy. However, these approaches require to maintain a high information level between the supply chain members and the ability to quickly utilize the information; thus, collaboration is an important factor when it is necessary to achieve sustainable food industry through SCR.

1.2.4. The importance of collaboration for supply chain resilience

In this chapter, the importance of collaboration towards achieving a sustainable FI shall be discussed. Firstly, the contradiction research of collaboration will be overviewed. Secondly, the benefits of information sharing will be stated. Lastly, several theoretical approaches to improve collaboration will be provided.

The current food supply chain is ineffective due to the high waste of food (Food and Agriculture Organization, 2015), (Parfitt *et al*., 2010). The food wastage problem will become an even bigger problem when the world population increases together with the urbanization level (United Nations, 2015). An increase in the population density, and the demand for low quantity products has caused the current supply chain to be even less effective in the FI. The trend of organic food gaining in popularity requires to decrease the length of the supply chain so that to cope with the necessary lead times, however, the complexity of the food chain which is caused by small and medium farmers is causing even more complexity in this issue (Mari, Lee, and Memon, 2015), (Dani, 2015). The United Nations identified that small-scale farmers produce over 70% of the world's food needs (Food and Agriculture Organization, 2015). The author of the thesis amplifies that one of the SCM approaches is to promote collaboration and form logistic clusters so that to decrease the ineffectiveness of the supply chain and maintain competitiveness (Lau, 2014), (Pettit *et al*., 2013), (Costa, Soares, and De Sousa, 2016), (Scholten and Schilder, 2015), (Fawcett, McCarter, Fawcett, Webb, and Magnan, 2015). There exist clusters of various types, however, in the thesis, we shall focus on logistic clusters (Navickas, Baskutis, Gruzauskas, and Kabasinskas, 2016). Logistic clusters are mainly formed to share equipment and schedule group deliveries. There is empirical evidence which identifies that this strategy decreases the management costs and provides competitiveness in some cases. However, other researches identify that there are problems related to logistic cluster activities in the long term (Fawcett *et al*., 2015). In some cases, the cluster becomes too complex, which decreases the effectiveness of the cluster when seeking to maintain its activities after disruptions (Mari *et al*., 2015). These disruptions can be simple malfunctions or drastic *forces majeures* which are caused by weather conditions, terrorists attacks, etc. (Institute of Business Continuity, 2015). In other cases, the problem is related to the lack of trust and commitment of the logistic cluster members (Andreas Wieland and Marcus Wallenburg, 2013), (Childerhouse, Kang, Huo, and Mathrani, 2016).

Implementation of a system thinking in the food supply chains collaboration between the supply chain members should be promoted, and official logistic clusters should be formed. "Collaboration ensures the exchange of information between supply chain partners and reduces uncertainties and complexities. Collaboration through appropriate partnership and information sharing in the early stage of the supply chain operations would reduce the uncertainties and complexities" (Gunasekaran *et al.*, 2015). Only by integrating information and innovative technologies, can a resilient and sustainable supply chain be achieved. The integration of such approaches can provide self-organizing abilities to the food supply chain. "The adaptive capability of a supply chain to reduce the probability of facing sudden disruptions, resist the spread of disruptions by maintaining control over structures and functions, and recover and respond by immediate and effective reactive plans to transcend the disruption and restore the supply chain to a robust state of operations" (Kamalahmadi and Parast, 2016). Cordes and Hülsmann indicated that, from the CAS perspective, supply chains obtain self-healing processes, which is related with the robustness of SCR. They further imply that additional research is needed related to the empirical and simulation-based methods (Cordes and Hülsmann, 2013).

If the food supply chain has to adapt, formation of a logistics cluster is essential as small-scale farmers without any form of collaboration would be overrun by multinational corporations. A logistic cluster is a formal collaboration system which focuses on sharing information, equipment or cargo so that to provide economy of scale abilities to the members of the cluster or some other value. In this case, the logistic cluster would increase information sharing between the supply chain members, which would be used for collaborative demand forecasting. In this light, the results of a recent empirical study indicating that organizations consistently report minimal collaboration, excessive capacity and minimal flexibility are especially concerning (Pettit *et al.*, 2013). As stated above, the majority of SCM approaches have been developed in a more stable environment (Christopher and Holweg, 2011), and the constant disruptions in the supply chain network decrease the competitiveness of the supply chain members. Therefore, there is need to determine how to reduce the negative effects of constant market fluctuations and thus identify how the supply chain members can maintain competitiveness. Due to these trends, SCR has been gaining more attention. There are two main approaches as to how to reduce the negative effect of disruptions. The first approach relies on making the supply chain as flexible as possible. "Flexibility ensures that the changes caused by a risk event can be absorbed through the supply chain through effective reactions" (Ishfaq, 2012). When a problem occurs, the supply chain should be able to quickly redesign itself and minimize the negative effect and maintain the SCR. The second approach relies on the redundancy approach – forecasting and being prepared for the upcoming market fluctuations (Juttner Maklan, 2011). In this case, information sharing between supply chain members is essential. Therefore, the existence of logistic clusters is necessary for the effective application of the redundancy approach. The redundancy approach can provide resilience to the system, which in the long run results in sustainable development for the logistic cluster members. The implementation of this strategy in the FI would reduce food wastage since the demand and supply alignment would be improved.

Extensive literature analysis related to logistic clusters and information sharing identified that there is a limited amount of empirical evidence related to these concepts. Marshall (2015) indicated that information sharing in a SCM is still an evolving field (Marshall, 2015). Lotfi *et al*. (2015) concluded that there is lack of information sharing within companies nowadays, which results in inefficiency of coordinating actions within the units in the company or organization (Lotfi, Mukhtar, Sahran, and Zadeh, 2013). Nagashima *et al*. (2015) states that it is the lack of collaboration in particular that negatively impacts the forecast accuracy, while positive interaction effects are to be found only for the life cycle stage and product category (Nagashima *et al*., 2015). In this thesis, we shall focus on the impact of information sharing on the forecasting accuracy in different contingencies. A more precise SCM framework will be formed through future research. The majority of papers published in this area focus on the algorithm perspective (Nagashima *et al*., 2015), yet they do not take into account such factors as the market type, structure or consumer integration when comparing the benefits of information sharing within logistic clusters. This research shall focus on a more innovative scientific approach which analyzes problems as a system and not as separate elements. The CT in this case will provide an interdisciplinary approach which integrates economics and business research. Another issue is that the involvement of the entire supply chain in the information sharing process is rather problematic since, apart from suppliers, producers and distributors, a supply chain also includes consumers. It will provide a strategy how to increase information sharing for better alignment of the demand and the supply, i.e., for the achievement of higher nutrition levels and lower food waste levels. Therefore, the supply chain integration including internal and external integration is essential (Flynn, Huo, and Zhao, 2010). External integration also involves consumers, and in this research we shall also focus on consumer integration. Therefore, we shall distinguish between random consumer behavior and loyal behavior. The collaboration of the whole supply chain is essential in order to properly cope with possible disruptions, such as demand fluctuation.

The research conducted up to this point promotes collaboration and amplifies its benefits. However, some researches state that collaboration tends to fail due to lack of commitment and technological applications. Forming official clusters is an example of a higher and more complex form of collaboration. Clusters can vary depending on the goal which they were expected to serve. For example, some companies form research and development clusters in order to boost technological development aspects. There is a need to focus on logistic clusters with the aim to provide competitiveness advantage to the members of the cluster based on the SCM. A logistic cluster is a formal collaboration system which focuses on sharing information, equipment or cargo so that to provide economy of scale abilities to the members of the cluster or to deliver some other value. Pujawan *et al*. (2016) concluded that logistic clusters facilitate collaboration-related benefits, offer added value services, career mobility for the logistics workforce within the cluster, and promote job growth at multiple levels within the cluster (Pujawan, Arief, and Tjahjono, 2016). Croxton *et al*. (2013) conducted an empirical study related to the SCR and concluded that there is consistent lack of collaboration on top of insufficient capacity levels and minimal flexibility (Pettit *et al*., 2013). While the theoretical benefits of logistic clusters are undeniable, empirical evidence contradicts theoretical assumptions due to the limitation of the human factor, i.e., the process of information gathering, analysis and quick decision making. As a result of the current innovative technology development, such as Internet of Things, big data and autonomous vehicles, logistic clusters must be analyzed at greater depth. A previous research by Haviernikova, Strunz, Navickas and Gruzauskas identified the importance of clusters for SMEs, especially if they want to adopt innovations more quickly (Gružauskas, Baskutis, and Navickas, 2018), (Navickas and Gružauskas, 2016), (Navickas *et al*., 2016), (Vojtovič, Navickas, and Gruzauskas, 2016). One of the most significant benefits of logistic clusters is information sharing which increases the comprehensive understanding of the supply chain. For logistic clusters to be effective, the members must share their information (orders, sales forecasts, points of sale data, customer surveys) both upstream and downstream so that the information should be available for all the supply chain members (Kifer and Lozinskii, 2005), otherwise it is difficult to properly prepare for the upcoming disruptions. Therefore, it is essential to involve all the members of a supply chain in the logistic cluster.

The members of a supply chain usually do not have information available from the remaining members of the supply chain, which makes the managing of information sharing very difficult. Moreover, the end-consumer is often the least known member of the supply chain because of the limited impact that an individual is perceived to have on the supply chain as a whole. As a result, the planning phase usually ends at the retailer's level, whereas consumer information is used only for marketing purposes. However, an e-commerce supply chain can reduce the overall length of the supply chain. In the case of the FI, it is possible to reduce the supply chain to small-scale farmers with processing plants and distributors collecting products and delivering them directly to end-consumers. The benefits of consolidation warehouses were analyzed in a research conducted by Navickas *et al*. (2016) who concluded that "the implementation of a consolidation warehouse in a logistics cluster can provide environmental and economic benefits, what makes the cluster more attractive" (Navickas *et al*., 2016). Therefore, the formation of logistic clusters together with an e-commerce type supply chain could increase resilience by improving information sharing between the logistic cluster members.

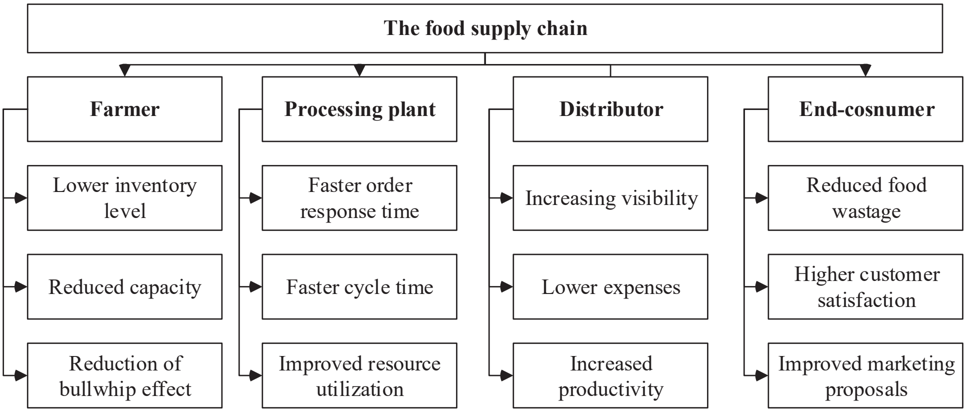


Fig. 11. Benefits of information sharing

Figure 11 presents the benefits of an e-commerce type supply chain with 4 members. Information sharing can provide better inventory management for farmers due to the readily available information on the demand history thus making it possible not only to reduce the inventory levels, but also to determine optimal capacity limits. On the other hand, one has to remain committed to properly reducing the bullwhip effect. When it comes to the processing phase, equipment can be optimized thus providing better services for consumers. Sharing of precise information could help implement just-in-time production, reduce the inventory levels to the minimum, and improve equipment utilization. Distributors could plan their entire supply chain more effectively by decreasing costs and increasing productivity. In addition, the involvement of the end-consumer is also essential. The end-consumer should be treated not merely as a consumer, but, instead, as a partner. Proper strategies for end-consumer involvement could be beneficial and provide better information sharing abilities to the logistic cluster. However, virtually no research has been done which would analyze information sharing from this perspective; the majority of researches focus on marketing and consumer surveys rather than on the strategic involvement of consumers in the planning phase. The concept of sales and operational planning usually covers a time period of 2 to 18 months, when certain policies and rules must be implemented by the supply chain members. Consumer integration minimizes the bullwhip effect thus simplifying the planning of the whole operation.

Information sharing can reduce the negative effects of the rapidly changing business environment. Disruptions in the supply chain, whether caused by traffic jams, weather conditions, IT malfunctions or market fluctuations, dramatically raise costs and increase the lead-time (Baylis *et al*., 2015). Within this research, attention is mainly given to the market demand fluctuations originating due to the changing consumer demand. The best example of this aspect is the FI because it involves a wide variety of frequently purchased products. The spikes in demand can cause suboptimal inventory levels and dramatically increase costs. Nevertheless, by implementing proper redundancy strategies, we can also improve SCR and decrease this negative effect. The adaptation abilities of the system would eventually result in resilience, which, in the long-run, would provide the logistic cluster members with possibilities of sustainable development. We also look into forecasting the demand depending on the scope of shared information in the cluster. While some previously conducted studies emphasize the benefits of collaborative demand forecasting, other researchers conclude that forecasting can become ineffective with increased complexity (Galbreth, Kurtuluş, and Shor, 2015). However, virtually no research has analyzed the relationship between the forecasting accuracy and the scale of a logistic cluster. Other arising issues include implementation difficulties due to innovative technologies, lack of employee classification and lack of trust among the members of a logistic cluster. In other words, it is still necessary to identify the computability and commitment aspects of a logistic cluster.

To sum up, it can be concluded that information sharing and collaboration theoretically provide benefits to the supply chain members; however, there is lack of collaborative technologies. What is more, improper commitment levels between the logistic cluster members constitute an additional challenge. Thus the process of technological implementation in the SCM process is essential.

1.3. Complexity theory perspective on sustainable and resilient food supply chains

1.3.1. Impact of Technologies on Supply Chain Management

The goal of the following chapter is to provide grounding that technological application in SCM increases information sharing between supply chain members, which results in higher complexity of the system. Part of the information presented in this chapter has been previously published (Navickas and Gružauskas, 2016).

Firstly, it is essential to understand the background of the business environment. Porter amplified the necessity for companies to maintain the competitiveness advantage through the economies of scale principles. Porter in Harvard business review published a paper *Strategy and the Internet* in 2001, where he highlighted that internet is merely a new tool, a new layer on the old economy. He stated that it is dangerous to assume that the internet will change everything. However, today we see that these statements were not true. The economies of scale amplify the benefits of mass production and advertising, however the principles of economies of scale still work, but only partly, therefore there are additional rules added which appeared due to the developing information trends (Porter, 2001). Marc Andreessen published a paper *Why Technology is Eating the World* in 2011 (Andreessen, 2011). The paper clearly describes the trends of the internet and business process automation which are dramatically changing the business environment. Today, we are moving even forward, it is a movement from the world wide web to the mobile media mode which was described by Frank Feather (Feather, 2002). These technologies allow consumers to get instantaneous access to every single producer around the globe.

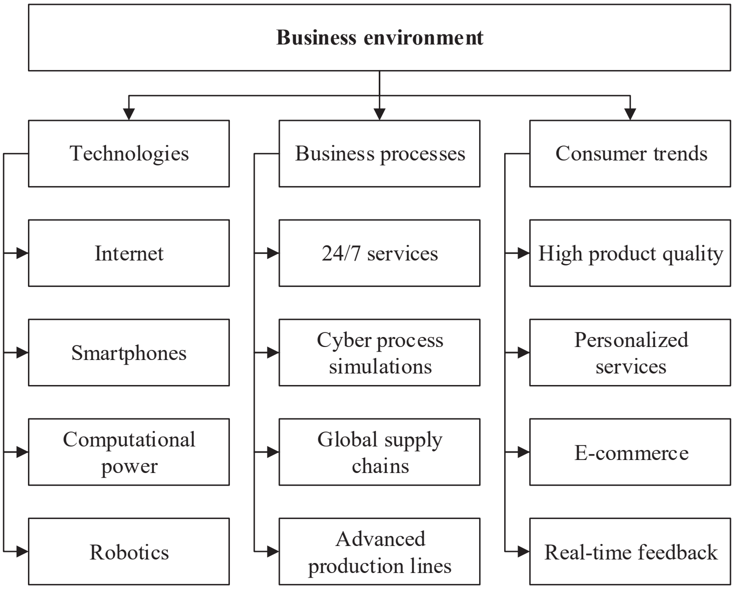


Fig. 12. Impact of technological development on the business environment

Figure 12 indicates the impact of technological development on the business environment which began because consumers started demanding more added value services, such as customer service, direct delivery to the doorstep, etc. One of the most prominent changes in disruption developed because of mobile apps which allow consumers to order products for 24 hours, 7 days per week. Moreover, due to globalization, products can be ordered from any place in the world, and it is the businesses' responsibility to make the delivery as cheap as possible. At the same time, the development of smartphones and social media consumers feedback related to the product design has increased, which requires that companies should constantly develop and change their product assortment faster than ever before. Another key change due to technology development is related to the testing of production or other business processes. In the past, businesses usually had to develop real simulations or product launch. Today, due to simulations and high computational power, these tests can be done in the cyber space. Simulations have also dramatically influenced SCM because the possible decisions can be analyzed virtually. In the past, SCM decisions were usually based on experience and expertise, however, presently, the shift is moving the system towards complete automation and analytics.

Technological development has also affected the trends of social demography. Today, the world population is rapidly growing and is estimated to reach 9 billion by 2050. Therefore, the current customer demand greatly exceeds the levels offered by the traditional supply chain models. This problem raises even a more serious concern for the food supply chain which is ineffective and produces a lot of food waste. "About one third of all food produced annually – some 1.3 billion tons – is not consumed, wasting energy, land and water and creating carbon emissions as it decomposes" (Board, 2014). Because of the trend for organic food, the wastage will increase even further, unless the SCM approaches get changed. These trends require that the industry should develop towards new approaches of management, which would increase the resilience in the system. Otherwise, constant disruptions and change will decrease the competitiveness advantage of the organizations. Because of these technologies, the business environment has dramatically changed.

The world's economy is growing rapidly, and new companies are entering the market. The working style has changed in comparison with the previous decades as now the biggest profits are made not from manufacturing but rather from distributing products throughout the world. Therefore, a new perspective to the SCM is needed. For an enterprise to be competitive, it needs to adjust strategies of its activities depending on various factors. This chapter is oriented to the supply chain. All industries have been affected by the internet, but new factors, such as internet consumers, have appeared. The most prominent impact on the supply chain has been made in the FI. This is because food products are being ordered online, and a proper distribution system is required. There are many regulations that require food products to be tracked, to be in high quality, and to be delivered on time (Olsson, 2004). Other industries are simpler because they do not impose such restrictions for the expiry date. Thus, a unique level of optimization is needed to this particular market. This problem is even more concerning when companies are working in international markets. This is the effect of globalization and the internet that a small market has a possibility to distribute its products around the world.

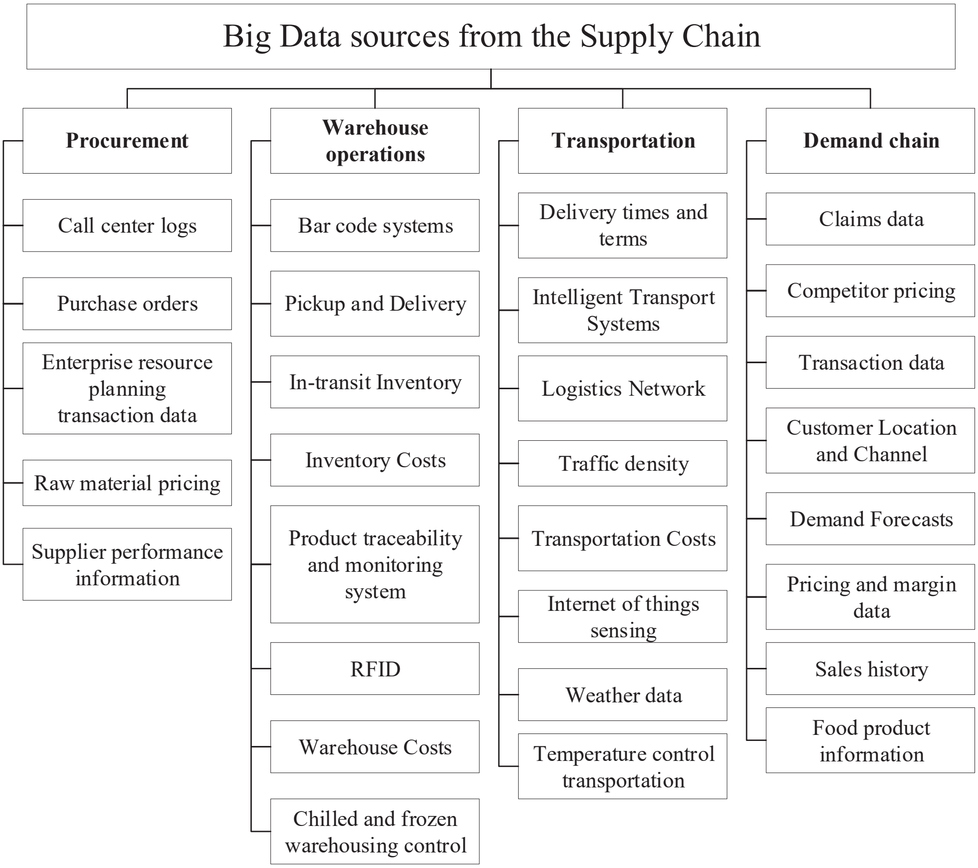


Fig. 13. Big data sources from the supply chain

The distribution process may be complicated, especially in the FI. The four main types of information gathering methods in the supply chain are procurement, warehousing, transportation and demand (see Fig. 13). Firstly, it is important to overview the SCM from the beginning. The chain begins from the suppliers that distribute raw materials. The FI is a wide topic in itself, so this data can be gained from various types of suppliers – raw meat, vegetables, berries, grains, etc. All of these products are food products but they impose very different requirements. First of all, the suppliers may come from various regions, and there may be a high number of them. Dealing with them and maintaining proper communication is a hard challenge. Nevertheless, many problematic aspects are manifesting ahead – transportation, warehousing of raw materials, humidity, etc. One of such issues is how to transport raw materials to the warehouse. *Transportation* can impose different requirements, because some products need temperature restrictions, while others may require a different type of vehicle. For example, grain may require a specific type of truck that does not fit any other product category. The next challenge is *the warehousing of raw material*. A warehouse will be needed for all products because even though just-in-time production may be possible in the FI, nevertheless, distributors will not always achieve this level, and ultimately at least partial warehousing will be needed.

However, the requirements for the products will not change. For instance, specific temperature and humidity will be needed. Usually, there are a few types of temperature inside the warehouse – frozen at -18 C^o, chilled at about +5 C^o, or no temperature requirements are presented at all (just normal room temperature), whereas some products demand deep frost at -24 and below. These requirements depend on the product type and the manufacturer. Another important factor is *humidity* which is also important so that the products should maintain the right quality level. In addition, the final difficulty is the distribution of the food products. If comparing the classical economy system featuring supermarkets, distribution is not so complicated because large quantities of products are distributed. However, this problem may differ in small markets because partial cargo is commonly distributed that requires grouping of different products. In addition, the most difficult case of distribution is via the internet because there is a requirement for high quality, low lead time, and a very low product quantity.

The heavy flow of freight through the supply chain requires other abilities in order to properly manage the chain. There may be several problems regarding the situation. The most common ones could be assigned to three parts: cost, lead time, and transparency (Accenture, 2014). Firstly, it is important to determine what exactly the supply chain is. It serves to distribute products and services to the right people at the right time and at the right cost. Therefore, cost is one of the priorities of the chain. Those companies that can maintain lower costs can thus increase their competiveness. The second aspect is the lead time that is essential especially for online food shops because product validity may expire. In addition, transparency is also important, especially with a large quantity of customers and suppliers. Transparency is even more important if the enterprise is working in the international market (Ventana, 2007). An issue could arise if products are being transported to different countries or regions – reverse logistic transportation costs could increase dramatically. Another problem could be a simple misplacement of a few boxes, and the manufacturer, supplier or customer could cancel the contract because of poor service level. Therefore, the information flow is essential to be known and understood. These are only a few of the basic aspects of the supply chain. Another aspect is risk evaluation and management. The information that is gathered can help maintain lower costs and strategies regarding forces majeures. When companies are operating in the international market, there may be a constant flow of cargo every week ranging from a few trucks to 50 trucks, and the biggest crisis can appear regarding forces majeures. Difficulties may arise if a warehouse burned down or there were a flood, and a part of the main road were blocked. The information flow regarding cargo and its regular evaluation can help minimize the losses in such situations (Benyoucef and Jain, 2009). Thus it is essential for enterprises to manage the supply chain by using computerization technologies, and this is even more important while working in the international market. Small markets without international markets would not have possibilities to increase profit and maintain proper competiveness levels.

It is important to review various information gathering technologies. Analysis of information can be conducted when the information is available in a database. Therefore, there are many methods to gather information from physical entities. The concept of the internet of things (IOT) is essentially a computing technology which offers communication between a machine and a physical object, an infrastructure unit, environment, or another intelligent system. There are many different methods of IOT operation that were used in the past, and new concepts are still being created. These methods will be overviewed in terms of the case of the supply chain.

Barcodes. The main area of the supply chain is the raw material order and the distribution of products. Because of the large flow of products and raw materials, it is hard to maintain the process and not to mix the orders. This problem was often manifested in the old times, but people developed ways to identify the products by using numerical systems. Nowadays, the technologies have changed, and alternative possibilities have been developed. One of them is barcodes. The barcode is optical machine-readable representation of data relating to the object to which it is attached. The common barcode consists of numbers that indicate the product type, the supplier, the warehousing place, or any other important information. When scanned, the system inputs the code into the database, and this process helps maintain precise information for the enterprise.

Radio frequency identification. Other similar methods were later developed, but they are used at a more advanced level; also, their usage has expanded widely. Radio-frequency identification (RFID) is the wireless use of electromagnetic fields to transfer data for the purposes of automatic identification and tracking of tags attached to objects. Tags contain electronically stored information. Some tags are powered by electromagnetic induction from magnetic fields produced near the reader. Some types collect energy from the interrogating radio waves and act as a passive transponder. Other types have a local power source, such as a battery, and may operate hundreds of meters away from the reader. Unlike the barcode, the tag does not necessarily need to be within the line of sight of the reader, and may be embedded in the tracked object. These technologies have changed dramatically the process of ordering and manufacturing. While barcodes need to be scanned at a short distance, the RFID only needs a transmission station and an antenna. In addition, this can be done by satellites. Because of this, the lead time of information processing has changed dramatically. They can be used while transporting goods or ordering. Packages marked with RFID chips carry more information inside than the barcode would provide. This helps to maintain the flow of goods even better because RFID could be used worldwide, and when a truck enters a port, the RFID system can identify that the process will be handled soon. The usage of RFID helps dealing with safety issues, and thus companies can prevent thefts even easier because it will be hard to remove any goods through the front door or any other doors as a transmission antenna can be mounted which would indicate if the goods are transported not by schedule or in the wrong way. In addition, some authors analyzed how the RFID technology can help optimize handling and make decisions in the supply chain. Their research concluded that the RFID network system can detect the condition of perishable products as they are being moved downstream the supply chain before undesired total loss of products occurs (Mejjaouli and Babiceanu, 2015).

Fleet management. Usage of the RFID technology could be combined with the GPS signal and other receivers to transform a fleet management system. Fleet (vehicle) management can include a range of functions, such as vehicle financing, vehicle maintenance, vehicle telematics (tracking and diagnostics), driver management, speed management, fuel management, and health and safety management. Fleet Management is a function that allows companies which rely on transportation in business to remove or minimize the risks associated with vehicle investment, improvement of efficiency, productivity, and reduction of their overall transportation and staff costs while providing 100% compliance with government legislation (duty of care) and other relevant requirements. These functions could be dealt with by either an in-house fleet management department or by an outsourced fleet management provider. These technologies are essential for the big data concept because mathematical optimization methods can better solve the fleet management problems. That are related with various aspects of the chain – product quality, lead time, and costs (Bielli, Bielli, and Rossi, 2011).

Warehouse management system. The above outlined computerization ways assist in transporting materials when materials are being transported, and manufactured goods need to be stored. Depending on the industry, the type and the duration of the storage, the quantity and other factors may be different. The FI may require temperature control. The chemical industry may impose specific regulations because the materials could be toxic. Moreover, if a company works with a large variety of products, they, possibly, cannot be stored together, for instance, chemical products and food or perfume with cosmetics, etc. as the products may get damaged and become unsuitable for distribution. Because of this information, it is importuned to equip the warehouse with computerized systems; otherwise, it may be difficult to maintain a large flow of cargo. Some companies may have 100 trucks per day with 3300 pallets transported per day. Moreover, this could lead to more than 53000 thousand boxes movement per day. In the context of such numbers, with this rate of flow of products, a computerized system is a top priority. A previous research has already highlighted the performance levels and enhanced productivity of manual warehouses by developing a warehouse management system framework and cost benefit analysis. The study proved that, with the WMS implementation, the cycle time of cargo movement inside the warehouse was reduced from 773 minutes to 236 minutes (Ramaa, Subramanya, and Rangaswamy, 2012).

Ordering processes. The following important aspect that needs to be overviewed is the ordering process. This includes raw material ordering, goods distribution, and reverse logistics. As mentioned above, the quantity of goods may run into thousands of boxes per day. The Amazon Company during the Christmas period may distribute 426 items per second. Because of a large flow of orders, it is essential to computerize the ordering process. In addition, the history of orders is also important because of the reverse logistics concept. Reverse logistics is a process when products are being returned because of a variety of reasons. Shipping can be late; products may get damaged or mixed up, etc. Because of this, it is important to store the information about the products for 6–12 months or even more depending on the industry and the warranty time. If the money were returned, the enterprise must be aware what amounts and where are needed to be sent.

These information gathering technologies are essential for the internet-of-things concept. IOT in the future will help provide a possibility to transport goods without human intervention from the producer to the consumer, and the manufacturers will have direct feedback on the market's needs (European Commission, 2008). This will dramatically change the competiveness of enterprises because companies will have even more precise information for their usage. Nevertheless, gathering information is not enough as it is important to evaluate the data and to achieve optimal solutions of any arising issues.

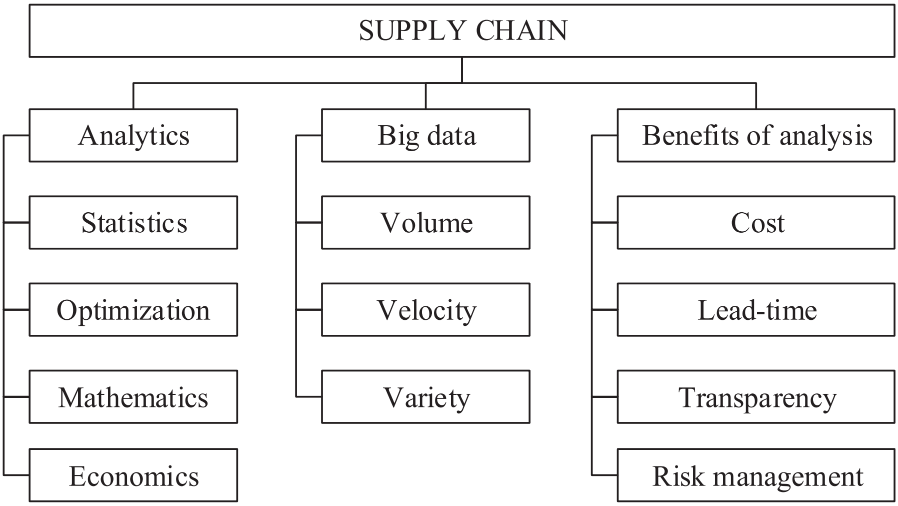


Fig. 14. Big Data Analytics in the supply chain

It is important to understand the importance of analysis services in the supply chain (see Fig. 14). The Big data concept has gained popularity only recently, but many companies started implementing the concept in their business. Big data can be explained in three terms (Cecere, 2013). The first and most common one is the data quantity; as mentioned in the previous chapter, the supply chain gathers information from various aspects of the business, additionally, if an enterprise is working in the international market, the volume may increase even further. This can be a problem for some companies because the storage of bigger amounts of data may increase the costs of data servers. However, there are new technologies decreasing the costs, such as cloud servers. Cloud servers store information online and do not require such costly equipment as the traditional servers would. Research indicates the importance of cloud servers, However, their usage is fairly low in small markets because of the difficulty of adapting to the latest technologies and higher capital investment requirements (Truong, 2014). Another crucial aspect is the variety. This is particularly true for the FI because the supply chain consists of a high number of parts, such as suppliers, warehouses, distributors, manufacturers, customers, government institutes, RandD centers, etc. Furthermore, this variety needs to be optimized. For this purpose, enterprises are using data warehouses. Data warehouses can be combined to use analytic services for proper optimization of the supply chain (White, 2013). Moreover, the final aspect of big data analytics is the acceleration of information. The extent and variety of information has dramatically increased, and also the speed of the information flow has dramatically gone up as well. However, this may not be particularly true with some companies that work only with a few clients. Nevertheless, many companies are trying to specialize in a larger variety of activities – from manufacturing to selling. In addition, there is a trend to form clusters and produce large networks for competitive advantage maximization. For this purpose, combined information can be analysed, and proper strategies may be created (Bosona and Gebresenbet, 2011).

The Big data concept is concerned with the data size from one point of view, but the other is its more essential aspect – analysis, evaluation and decision-making. The data analysis process can require specific knowledge of mathematics, economics, statistics or programming. Therefore, this is the area that the smaller markets tend to have less knowledge about. However, there are researches that indicate the importance of the Big data concept in small and medium enterprises. Small and medium-sized businesses are realizing that the amount of data they handle could be very large and important in their decision making and planning. One paper explored the options of handling large amount of data in small and medium enterprises and offered cloud computing as a possible solution (Schaeffer and Olson, 2014).

The methods used during the analysis stage may vary from simple calculations, such as finding the mean, dispersion, or other basic characteristics to complex optimization problems. The methods that may be used depend on the task. There are many mathematical methods that can be used for optimization problems – clustering, regression, time series, etc. Even machine learning can be used in the SCM optimization process. These are general methods that can help solve a number of supply chain problems. Other technologies that need to be mentioned have been appearing and developing rapidly in the recent years. One of them is artificial intelligence. Artificial intelligence is not necessarily a robot, but it can be a complex program combined with machine learning. The best case where artificial intelligence could be implemented would be regular software for a freight loading system. While there may be many suppliers and customers in an enterprise, and employees could have difficulties, for optimizing the process, computerized software can help do the job. Other new technologies that already have prototypes in use are quantum computers. These are computers with extensive calculation possibilities. The main idea is that a bit in the traditional computers can have two symbols – 1 or 0. Yet, the quantum computer can have 1 and 0 at the same time because atoms are moving very fast. However, the technology is still being developed as it requires a lower temperature to work for this type of computer. Nevertheless, in the future, the quantum bit computers will change the industry dramatically (Schuld, Sinayskiy, and Petruccione, 2015).

The main idea is that the Big Data concept is essential for every company in order to maximize its competiveness. However, these possibilities are more employed in large industries, and, because of the usage of complex technologies, the enterprises that work with Big Data will prevail even more, whereas the companies that are still not using Big Data may not feel much difference today. However, when, in the future, quantum computing, machine learning and artificial intelligence will be changing the industry, the differences between large multinational companies and small businesses will expand even more.

The manifestation of the 4th industrial revolution has caused enterprise activities to change dramatically. Those enterprises that will not adapt to the altered environment will get bankrupt, therefore, a proper competitiveness strategy must be developed in order to maintain sustainability and low management costs while at the same time applying the Industry 4.0 concept. The Industry 4.0 concept consists of several aspects. Basically, it means that all things are connected to each other, and total integration and transparency of information and data plays a huge role. This kind of technological development has led to more advanced business decisions, first of all to autonomous and self-controlled devices and processes, flexible adaptation of business operations, as well as flexible human resource planning. The benefits of Industry 4.0 will only unfold with a clever combination of all these technologies.

Another side of Industry 4.0 concept is big data analytics. It is not enough to gather the data from the world around; it is essential to process the data and reveal new patterns or minimize faults. Effective usage of the available data offers a comprehensive overview of business processes. Analysis of the clients' demands enables future products that are perfectly tailored to the clients' needs. Big data analytics consists of several areas: descriptive, predictive, diagnostic and prescriptive statistics. Wang *et al.* (2016) developed a framework of a supply chain that consisted of functional, process-based, collaborative and agile supply chain analytics. IoT can help gather all the data; however, a business intelligence system must be developed and adapted to the logistic cluster. Only real-time information can help to make better decisions. This is especially handy in the agriculture industry since its products are denoted by a short expiry timeframe. Diagnostic statistics is used to simulate various business processes and to explain mathematically how the market might affect the decisions. Lastly, all of this must be summarized and transformed into business language. The Industry 4.0 concept must be adapted to the operational and business strategies. For example, big data models in the field of process control can be applied to pollution control and sustainable management of natural resources and thus develop optimal strategies for improving the eco-efficiency of the green SCM (Zhao *et al.*, 2016).

The idea of big data analytics and IoT has led to even greater innovations. Autonomous vehicles are now possible to be employed in the industry. The overall competitiveness strategy is displayed in Fig. 15. The approach consists of 4 steps. During the first phase, operations of the supply chain members should be defined and visualized. The operations consist of various aspects, such as procurement, warehousing, different transportation modes. During the second phase, more detailed organization analysis should be conducted in order to determine the willing organizations which are suitable to form a logistic cluster. During the 3rd phase, operations should be computerized across the entire supply chain. The focus of the management strategy should consider information gathering, processing and utilization possibilities. During the last phase, the key aspects of the cluster should be constantly evaluated and monitored. The cluster can achieve better cost effective performance and sustainability levels by introducing autonomous vehicles and big data analytics in the management processes. Moreover, flexibility and redundancy possibilities can be improved by introducing autonomous vehicles and big data analytics in the management process. Constant analysis of the approach would provide adaptive abilities, which could help make better decisions in real time.

1.3.2. Application of cyber-physical systems for food supply chain management

The goal of the following chapter is to identify how the application of cyber-physical systems can be used to manage the complexity of the supply chain. Part of the information presented in this chapter has been previously published (Navickas, Kuznetsova, and Gruzauskas, 2017).

Autonomous vehicles as more environmentally friendly automobiles are capable of sensing their navigation without human input, thus the costs, emission level and working time can be reduced dramatically. Moreover, autonomous vehicles can be used not only for long distances, but also for the operational level of the supply chain. The development of autonomous vehicles is also recognized by some countries as an important factor of economic growth. In the US, officials have recently suggested that Google Cars' Artificial Intelligence system could be considered as a driver under federal law (Bacon, 2016).

To achieve flexibility, supply chain processes should be completely visible, and the information should be used to make decisions independently and without constant human interference. The vehicle routing problem when moving perishable products was investigated by Osvald and Stirn (2008). Their research was based on using time-dependent optimization and included the costs of food waste in the goal function (Osvald and Stirn, 2008). Another research conducted by Rong *et al.* (2011) focused on optimizing the supply chain by considering the process from production to retail. The main contribution of this paper is related to the measurement of food quality loss based on product flow and quantity (Ronga, Akkermanc, and Grunowc, 2011). A recent research analyzed the influence of food quality loss in urban logistics with a focus on inventory management strategies and delivery time (Fikar, 2018; Waitz, Andreas, and Fikar, 2018). A part of the approach described in Fiskar and Waitz's (2018) research will be included in the present research, e.g., the measurement of the food quality, and the inventory management strategy. However, in the thesis, we shall expand the model by including the traffic flow and accident information and by focusing mainly on urban logistics rather than on the whole supply chain, similarly to Fiskar's (2018) research. One of the possible approaches to reducing the effect of disruptions regarding food quality is the use of autonomous vehicles which could adapt in real time to the changing environment. The application of autonomous vehicles in urban logistics is related to the approach of autonomous logistics. One of the researches that focused on this type of approach was conducted by Rasmus *et al.* (2015), which specifically focused on the delivery of bananas by sea and not land transport. Their approach measured the initial food quality and determined routes by optimizing the quality level (Haas, Dittmer, Veigt, and Lütjen, 2015). In a similar approach, autonomous vehicles can be used in the urban logistics context to improve the food quality levels. Brent *et al*. (2018) stated that the food products distribution industry is likely to be an early adaptor of autonomous vehicles (Heard, Taiebat, Xu, and Miller, 2018). Wadud *et al*. (2016) stated that autonomous vehicles, when traveling on highways, can reduce energy intensity by 10–25%. However, the possibility in the urban logistics context related to the food quality has not been determined yet (Wadud, MacKenzie, and Leiby, 2016). Moreover, autonomous vehicles can be shared between the supply chain members to improve even more the utilization of roads and equipment. For example, the implications of using shared autonomous vehicles in the public transport have been analyzed previously, and it was concluded that shared autonomous vehicles could provide inexpensive mobility on-demand services (Krueger, Rashidi, and Rose, 2016a), (Fagnant, Kockelman, and Bansal, 2015). However, full implementation of such a concept still lacks infrastructure and legal areas (Fragnant and Kockelman, 2015). However, Euromonitor International estimated that the first commercial autonomous trucks will reach the market by 2025 (Euromonitor International, 2016).

Therefore, our research focuses on urban logistics and measures food quality levels in a dynamic environment by considering traffic accidents as disruptions to the system. We propose to use autonomous vehicles for improved information sharing abilities which can be used to optimize delivery routes by developing a self-organizing system. In practice, autonomous vehicles can gather more information than merely traffic flow and accidents. For example, a research conducted by Velázquez-Martínez *et al*. (2016) included altitude, cargo weight, and truck power when optimizing routes (Velázquez-Martínez, Fransoo, Blanco, and Valenzuela-Ocaña, 2016). Therefore, the gathered information can be expanded to include various sources for improved optimization. In addition, the effectiveness of the proposed approach can be improved by stabilizing the demand patterns of households, i.e., by developing new business models. Girota and Kabra (2016) analyzed different revenue models in online grocery retail and indicated that subscription-incentivized smaller and more frequent grocery orders reduce food waste and create more value to the customer (Belavina, Girotra, and Kabra, 2016). Akkas and Simichi-Levi analyzed retail packaged goods and also indicated that sales incentives can improve the product expiration time (Akkas, Gaur, and Simchi-Levi, 2018). This aspect has also been analyzed from the perspective of operational effectiveness, but, in our research, we shall also consider its benefits for improving optimization by providing more stable orders.

The revolution of autonomous vehicles can provide benefits in terms of several aspects. A large part of the supply chain is transportation. During the transportation process, there are risks involved that the cargo can be damaged. Therefore, the implementation of autonomous vehicles can reduce the risk of damaging products. Statistical data shows that up to 90% of road traffic accidents are caused by the driver (Heutger and Kuckelhaus, 2014). On the other side, the environmental impact is also reduced because the fuel consumption is optimized, and, by forming paradigms of driving close distances consistently with the consumption rate, this rate can be reduced even further, which is not always possible with the standard ground vehicles. However, indicating the potential environment benefits precisely is fairly hard.

Currently, there is no available fuel economy testing procedure which could correctly evaluate fuel economy ratings. Mersky and Samaras (2016) evaluated the environmental pollution and energy use of light vehicles. Preliminary studies regarding fuel economy have been done and indicated up to 10% fuel efficiency when traveling in convoys. The current fuel economy testing procedure does not involve a mechanism to evaluate the impacts of the available autonomous vehicles technology on the potential fuel economy ratings. Therefore, more detailed calculations for specific autonomous vehicles must be performed. However, the analysis of the literature can indicate that autonomous vehicles do provide environmental and economic benefits. Another important factor regarding autonomous vehicles is the utilization of transport. Usually, trucks are not used efficiently. After all, by removing the driver, the rest time is eliminated as well. Moreover, there is a possibility to share the autonomous vehicles between the logistic cluster members. Shared autonomous vehicles can provide cost effective mobility services. Krueger *et al*. (2016) provided analyses of the implementation possibilities of shared autonomous vehicles in the public transport industry. The sharing method described in the paper could also be implemented in a logistic cluster. Moreover, the implementation of big data analytics, cloud computing and the IoT concept together with the autonomous drive technologies can improve the road safety and make transportation more accessible for both suppliers and customers. The cloud solution allows stores much more historical data than a standalone system and gives enough accuracy to understand the fuel consumption trends, and to make smart(er) decisions. Cloud computing analysis tools enable to convert fuel consumption to costs or CO_2 emissions, to check energy usage per tonne of production, and to monitor the energy consumption of each individual vehicle. Kuo and Chen (2010) presented a model related to the multi-temperature joint distribution system in a food supply chain. The proposed model covers facilities for joint distribution systems, which can lead to better thermal protection of food products during shipment ant transportation. Therefore, the efficiency and reliability of temperature controlled transportation allows the FI to take advantage of the extension of supply chains due to the significant variety of goods in circulation.

Globalization, as well as the appearance of new products and services in the world markets, has dramatically effected the competitiveness environment. Today, consumers demand for high quality products with a high variety and delivery directly to their doorstep. The appearance and development of the internet allows consumers to receive information about products and services from the entire globe and expect delivery from different continents. Because of this, the production process as well as logistics and services are required to optimize their operations and reduce costs to the minimum, while at the same time maximizing the output. These trends require companies to change their operational and tactical level strategies so that to cope with these challenges. More and more research is being conducted which analyzes approaches aiming to limit the negative effect(s) of globalization and high demand for variety and low costs. The research mainly focuses on the Industry 4.0 concept, which amplifies the necessity to automate business processes and utilize the available assets in a more efficient manner and to allow mass customization (Karaköse and Yetiş, 2017). The concept of Industry 4.0 has been developed in Germany since 2011. It outlined the necessary criteria for companies to achieve in order to maintain their competitiveness. These criteria involved mass customization, high quality and low production costs (Rojko, 2017). However, at that time, there were only limited technologies available allowing to achieve such criteria in the production process. Such concepts as the Internet of Things (IoT), Big Data and artificial intelligence moved towards the Industry 4.0 concept, however, a more advanced concept of CPS today can be considered as the main factor contributing to the development of Industry 4.0. "CPS are systems of collaborating computational entities which are in intensive connection with the surrounding physical world and its ongoing processes, providing and using, at the same time, data-accessing and data-processing services available on the internet" (Monostori, 2014). The majority of researchers amplify the impact of CPS to advanced manufacturing in the context of Industry 4.0. "In particular, CPS is the core technology enabling the transition from Industry 3.0 to Industry 4.0 and is transforming global advanced manufacturing" (Trappey, Trappey, Govindarajan, Sun, and Chuang, 2016). Other research provides more scope of application and benefits of CPS usage for production. For instance, "utilizing advanced information analytics, networked machines will be able to perform more efficiently, collaboratively and resiliently. Such a trend is transforming manufacturing industry to the next generation, namely Industry 4.0" (Lee, Bagheri, and Kao, 2015), (Roadmap, 2013). Other researchers highlight the process control approaches with CPS. "CPS can radically improve functionally of monitoring systems and reduce the cost of its implementation" (Oborski, 2016). However, there are problems related not only with the production processes which reduce company competitiveness. The continually increasing demand requires more efficient logistic performance and lower logistic costs; it thus requires production enterprises to plan and control their order processing in a more efficient way (Seitz and Nyhuis, 2015). Other researches emphasize the CPS usage for the service industry. "Many manufacturing systems are not ready to manage Big Data due to the lack of smart analytics tools. As more software and embedded intelligence are being integrated in industrial products and systems, predictive technologies can further intertwine intelligent algorithms with electronics and tether-free intelligence to predict product performance degradation and autonomously manage and optimize product service needs" (Lee, Bagheri, and Kao, 2014). There is a growing number of researches related to the CPS usage for other industries than production, however, only a minor share of research is related to the transportation services in the context of all the processes of customer service. The successful implementation of CPS in the supply chain sector could provide greater competitiveness advantages for companies. Personalised transport service addresses on-time access and multiple provider resource management for the capacity of transport operators in cities (Vegah, Wajid, and Adebisi, 2016). The novelty of this research is that CPS is the main factor contributing to the full realization of the Industry 4.0 concept. Moreover, the identification of the limited amount of research of the CPS usage for other industries than production offers further research possibilities. Therefore, it is necessary to define the CPS concept in the context of Industry 4.0 in various industrial sectors, such as transportation, services, etc. The research methodology consists of in-depth literature analysis, and analysis of the possible CPS applications in the industry so that to amplify the necessity to research the CPS concept for more efficient organization management.

The literature analysis indicated that the research of CPS has been growing exponentially since 2011 when the concept of Industry 4.0 started being promoted more intensively. Since the Industry 4.0 concept started being developed due to the necessity to increase the quality and provide mass customization, the research has mainly focused on advanced manufacturing concepts. A more precise description has been provided, and the essential elements of CPS based on previous research have been summarized by the authors and represented in Figure 15 (Klötzer and Pflaum, 2015), (Karaköse and Yetiş, 2017), (Trappey *et al.*, 2016), (He and Jin, 2016), (Monostori, 2014). The CPS base level begins from sensors which are used to gather information from the physical world. These sensors have been widely used in the IoT concept as described in the previously outlined literature. "IoT is an integrated part of Future Internet. According to the agreed protocol, any article can be connected and talk to each other. This can be achieved through a vast number of methods and technologies, including radio frequency identification, near field communication, infrared sensors, and many more" (Chan, 2015). The next level of CPS is controllers or, more specifically, the Programmable logic controller which is used to distribute the sensor-provided information correctly. Due to the variety of sensors, the data velocity, variety and volume can be difficult to handle (Bhadani and Jothimani, 2017), therefore Programmable logic controllers are used to control the flow of information. In some cases, it might be wise to collect information at intervals in order to reduce the load of the network. The network is the next level of CPS which gathers, stores and distributes the information to High-performance Computers. Currently, researchers are focusing on algorithms and simulations when analyzing the CPS concept. The ability to conduct business process simulations in the digital environment allows evaluating multiple scenarios without any failures to lose quality and reduces the risk of making mistakes in the real-world environment. Therefore, simulations allow maintaining the zero defect rate, reducing production costs dramatically, and even optimizing various business processes. One of the research groups amplifying these benefits is the Warwick Manufacturing Group which is based in the UK. "Much has been published about potential benefits of the adoption of CPS in manufacturing industry. However, less has been said about how such automation systems might be effectively configured and supported through their lifecycles and how application modeling, visualization, and reuse of such systems might be best achieved" (Harrison, Vera, and Ahmad, 2016). When conducting simulations, it is essential to maintain the robustness of the system. "As CPS become more common in our society and directly interact with humans, it must be assured that they robustly behave as intended, which has a particular bearing when artificial intelligence (AI) is utilized" (Mosterman and Zander, 2016). When evaluating multiple scenarios, usually, the stochastic approach is used based on the previous data, therefore, there are limitations when implementing CPS. In order to choose the best results during simulations and to choose them periodically, it is necessary to run the same scenario multiple times. However, it might be difficult to correctly compare the current and past scenario results due to this variability. It is possible to limit the deviation of the simulation by using High performance computing approaches, however, it is still possible that the process involves a trade-off between time, accuracy, robustness, CPS infrastructure development costs and management costs which are mainly composed of energy sources due to cooling.

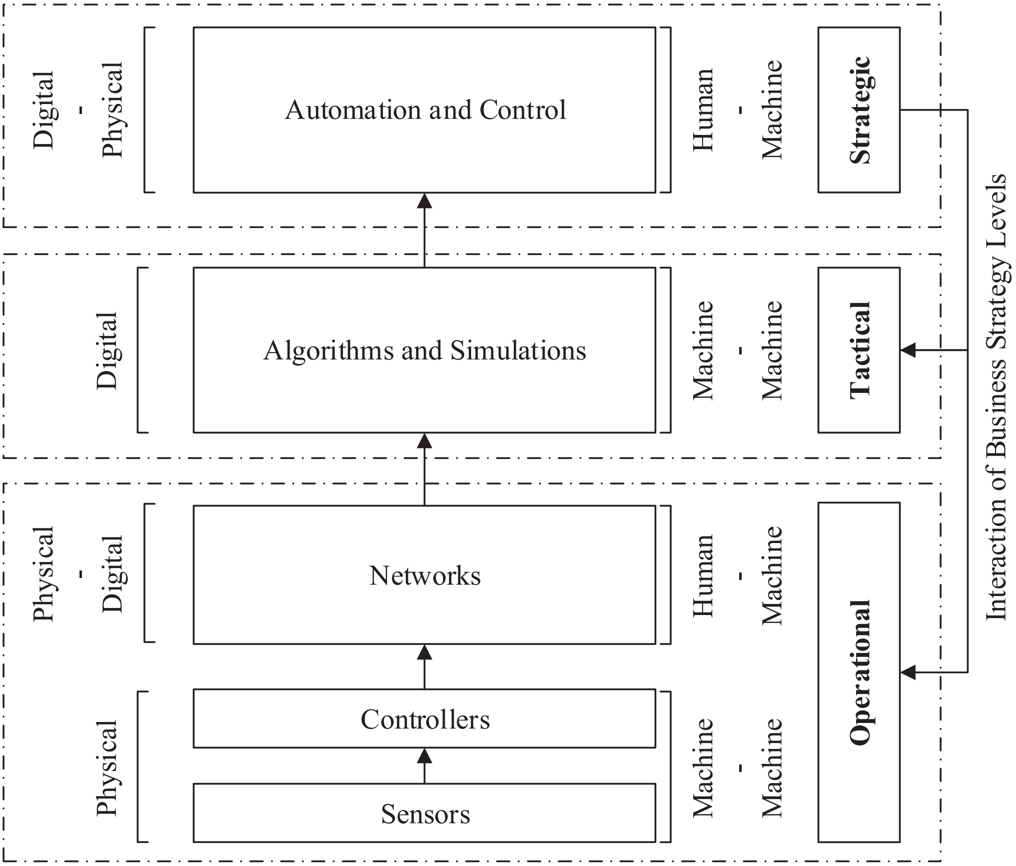


Fig. 15. Elements of CPS

After running simulations in the digital world, the decisions are transmitted to the automation and control element of CPS. In this element, the system re-evaluates the recommendations of the algorithms so that to better adapt them to the strategic level of the company. The final decision is then directed to the tactical and operational levels, which causes the system to function without human interference. Then, the systems develop adaptive abilities, which is caused by the loop of information between the physical world to the digital world, and then back again to the physical world. This information exchange would not be possible without Human-Machine Interaction, Machine-Machine interaction and Machine-Human interaction.

The identification of the main elements of CPS is based mainly on the advanced manufacturing concept. The implementation of CPS in other types of processes is also possible, however, the difference is the management aspect of the CPS rather than its elements. A comprehensive CPS architecture has been developed (Lee *et al.*, 2015).

The architecture consists of 5 levels, specifically, Connection, Conversion, Cyber, Cognition and Configuration. The levels describe possible applications in the advanced manufacturing concept by using CPS. However, architecture implementation in the service industry could also provide a new type of applications which are more efficient than the presently available ones.

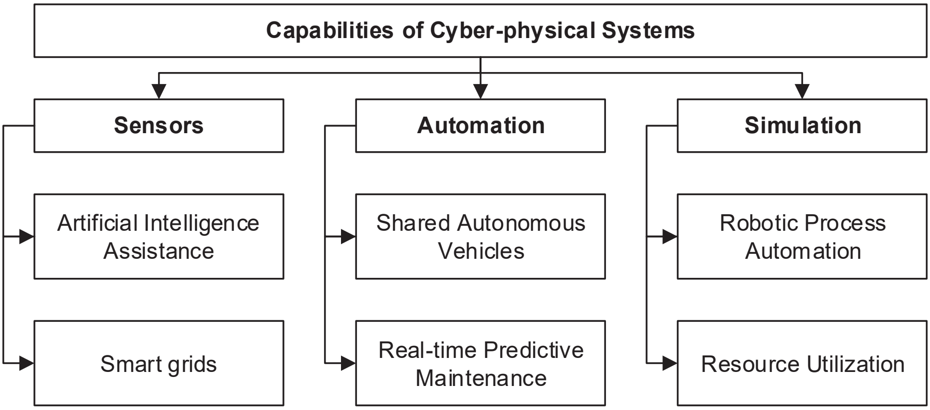


Fig. 16. CPS Usage Applications in Service Industries

The main adaption of the architecture to the service industry is related to the missing link of human importance in technologically-based approaches. “Technically driven approaches tend to neglect that the organizational dimension plays an important role for the application of CPS as well, particularly in a professional context” (Hoske, 2015). When correctly involving professionals in the strategic level development and then combining the strategic level with operation and tactical levels, more added value services can be achieved. Possible applications of the CPS usage for the service industry are represented in Figure 16. For example, by gathering personalized information of consumers, personalized insights for improved customer service could be achieved. An artificial intelligence assistance system might provide recommendations for purchases, leisure or other activities in real time. This application might also provide useful insights regarding product purchasing, which might be used for new product development. Other industries, such as the energy sector, might benefit from advanced smart grids which could relocate power to more efficient usage and storage. On the other hand, CPS could offer a high level of predictive maintenance services to the energy industry as well, and not only regarding the advanced manufacturing concept. “By integrating Industry 4.0 and CPS, smart devices are able to access and analyse abundant data of themselves as well as other items and thereby automatically react to current health condition” (He and Jin, 2016). CPS could also be implemented in SCM in order to utilize higher efficacy vehicles; this concept is called ‘shared autonomous vehicles’. The problem is that the current vehicles are not utilized effectively because, for a lot of time, transports are not used due to malfunctions, or due to legislation requirements for drivers to rest. CPS usage in managing transport fleets could utilize the resources in a more efficient manner. Lastly, this approach might also be used for other processes which are repetitive and worth getting automated. This process is called Robotic Process Automation, which could reduce manual work and provide more efficient resource utilization in various areas.

Innovative business models are appearing after every industrial revolution. Internet, IoT, Big Data, CPS and further development towards Industry 4.0 are causing even more rapid growth of new business models. In some cases, these technologies are reinventing past business models, while in other cases they are creating new business models. “We are currently experiencing the fourth Industrial Revolution in terms of CPS. These systems are industrial automation systems that enable many innovative functionalities through their networking and their access to the cyber world, thus changing our everyday lives significantly. In this context, new business models, work processes and development methods that are currently unimaginable will arise. These changes will also strongly influence the society and people. Family life, globalization, markets, etc. will have to be redefined” (Jazdi, 2014). Due to these developments, various businesses have arisen, or are laying ground work for development of new disruptive industries. For example, application of CPS in SCM provides new business possibilities, which were not possible before.

Currently, the main research is being done in the field of the advanced manufacturing concept. For example, BASF is using Industry 4.0 applications in its deployment of connected systems and advanced analytics models for predictive asset management, process management and control, and virtual plant commissioning (BASF, 2015). Okuma Corporation and Hitachi announced that they have embarked on collaborative creation aiming to establish an advanced high-efficiency production model that supports mass customization while making use of the IoT and setting up an experimental model. The target of this demonstration experiment is to increase the productivity twice and to reduce the production lead time by 50% (Hitachi, 2017). These developments are more oriented towards operational management, mainly to resource planning. However, other technologies, such as flexible manufacturing systems integrated with CPS, can be used for decision support in the production process, which provides companies with continuous efficiency growth and reduces breakdowns.

Other approaches which also involve CPS are called additive manufacturing technologies. Additive manufacturing applications allow building products layer-by-layer through addition of material. The implementation of CPS in this process could offer great potential. For example, customers could order personalized products which would be manufactured on the spot with additive manufacturing technologies. CPS in this case would allow high flexibility and customization. Lastly, CPS allows human-computer interaction in real time during production processes. “Remote robot control becomes relevant not only in rescue operations but also in cyber and/or cloud manufacturing environments where distant operations can be done quickly and economically” (Wang, Torngren, and Onori, 2015). The advances in the production process are increasing productivity and decreasing the defect rate as well as the lead time.

However, in order to fully automate the entire processes, their integration of production and logistics must also be researched. For instance, robotics company

Symbotic has developed a system to automate warehouse jobs formerly done by humans. The system has cut labor costs by 80% and reduced the warehouse size by 25% (The Wall Street Journal, 2016). Technological innovation will affect not only warehousing but also the transportation sector. One of the largest distribution companies, i.e., DHL, indicated that self-driven vehicles will be able to travel 24/7 without requiring driver rest time and, compared with today's driving, could achieve overall cost reductions in the region of 40% per kilometre (DHL Trend Research, 2014). Because of the increasing rate of assets utilization, it is important to share the equipment between multiple organizations as, otherwise, autonomous vehicles might be utilized not to the fullest potential. CPS in this context is essential because it allows integration and control of all the processes. However, the CPS usage in the context of SCM has only received a limited amount of research.

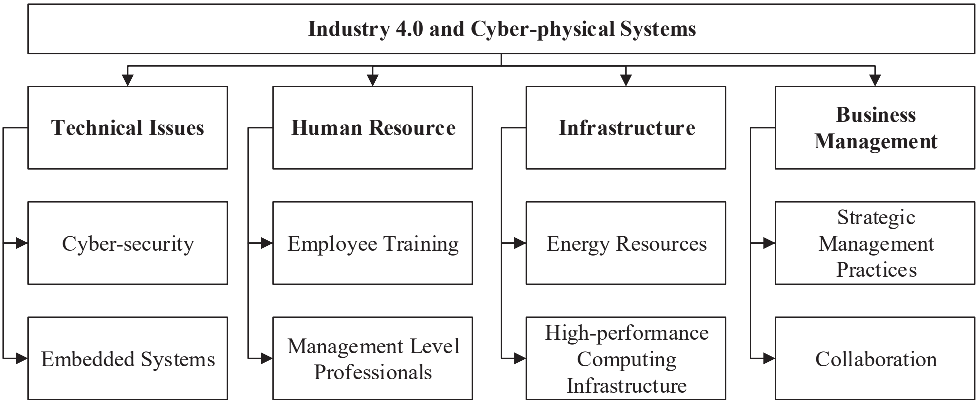


Fig. 17. Trends and problematic areas of CPS and Industry 4.0 integration in industry

The growing usage of CPS in various sectors of Industry 4.0 is causing problems which must be addressed in the near future (see Fig. 17). For example, CPS implementation in the production and SCM generates new problems in the energy sector. Embedded systems require constant energy sources which would allow gathering, processing and utilizing information in an efficient way. Moreover, High-performance computing requires cooling equipment which takes a lot of power. "It is estimated that 90% of power consumption during breaks in production is accounted for by machinery such as robots, extractors and laser sources and their cooling systems" (CRO Forum, 2015). Because of the high demand for electricity, CPS enables to use smart grid systems in order to control the flow and storage of electricity more effectively. Smart grids are electric networks that employ advanced monitoring, control, and communication technologies to deliver reliable and secure energy supply, enhance operation efficiency for generators and distributors, and provide flexible choices. The next phase of the Industry 4.0 concept growth involves the service industry. Full automation without customer service and constant feedback would not be possible, therefore, the implementation of CPS together with artificial intelligence in the service industry is also a must. Artificial intelligence can be used to develop bots or assistance agents. Lastly, the usage of CPS in Industry 4.0 raises new problems, for which, solutions must be found. One problem is related with the employee training because understanding and skills required to work with CPS require specific technical knowledge. Today, companies are already identifying this gap and focusing on providing solutions to the industry. The solutions are currently focusing on the technical employee training, however, there is only a limited amount of focus on manager level professionals who could monitor and control all the business processes involving CPS. Moreover, CPS is extremely vulnerable to cyber-attacks. A fully automated business could become a victim of hackers and involve huge financial loses and leakage of confidential information. Therefore, the cyber-security sector has been growing rapidly. According to a Nasdaq report, the global cyber security market was valued at USD 105.45 billion in 2015, and it is expected to reach USD 181.77 billion in 2021; it is anticipated to grow at a CAGR of 9.5% between 2016 and 2021 (Nasdaq, 2017).

In summary, CPS is dramatically influencing the further growth of the Industry 4.0 concept. Further research towards the CPS usage in SCM by considering human interaction and effective energy management is essential for the full realization of Industry 4.0.

In the past, the most efficient supply chain strategy was to collaborate with wholesalers and retailers, which would provide convenience to the end consumers. However, currently, the key convenience for the consumers is the internet. Today, consumers can purchase items online from any place and expect delivery directly to their doorstep. The traditional SCM approach is not suitable anymore because low quantity orders cause ineffectiveness and decrease the competitiveness of companies. Many consumers tend to purchase products online or use the traditional retail shops in order to simply see and touch the product but then make the final purchase online. Euromonitor International reports that the world internet retailing market size in 2016 was 1.17 trillion USD, and, by 2020, it was estimated to grow to a size of 2.1 trillion with an AAGR of 13.33% (GMID, 2017). Because of this infectivity, it is essential to shorten the supply chain. Today, more and more companies are removing wholesalers and retails from their supply chain and leaving only the production and direct delivery to the doorstep. Because of these factors, the changing trend is posing new problems in the logistic context. “Most current SCM models emanate from a period of relative stability, and there is considerable evidence that we will experience increasing turbulence in the future. This calls into question whether current supply chain models that feature some dynamic flexibility, yet are built on the general premise of control, will be suitable to meet the challenge of increased turbulence” (Christopher and Holweg, 2011). Other researchers started to analyze the last mile delivery concept which today is ineffective and takes about 30 percent of the total logistic costs (Lau, 2014). The infectiveness of the last mile delivery is related to the constant disruptions and growing urbanization levels around the globe. To decrease the negative effect of these disruptions, several main strategies outlined in the literature analysis were determined. Based on the resource-based view, companies must possess certain abilities which would allow to maintain competitiveness and reduce the negative effect of disruptions (Brandon-Jones, Squire, Autry, and Petersen, 2014), (Park, 2011). Firstly, the supply chain must have the ability to be flexible, which requires to have a vision of all the supply chain processes and the speed to change the current operations quickly (Ambulkar *et al.*, 2015). Another approach is based on redundancy, which allows the companies to anticipate and be prepared for upcoming disruptions (Park, 2011). These strategies cannot be implemented in an individual organization without information sharing between the other supply chain members. "Specific collaborative activities (information-sharing, collaborative communication, mutually created knowledge and joint relationship efforts) increase SCR via increased visibility, velocity and flexibility" (Scholten and Schilder, 2015). Therefore, many authors amplify the necessity to increase collaboration and form logistic clusters. The principal idea seems efficient and would increase competitiveness and resilience of the supply chain, however, there is a constant report of low collaboration and lack of commitment (Pettit *et al.*, 2013) "Firms' strategy and behaviour in supply chain collaborations are identified as the main reasons for supply chain failure" (Arvitrida *et al.*, 2016). Moreover, the increased collaboration between the supply chain members also increases the complexity of the chain which limits the ability to cope with disruptions (Mari *et al.*, 2015). "However, the effectiveness of collaboration as a supply chain resource has been questioned due to concerns associated with collaborative technologies, and thus prior research has called for a deeper examination of the role that technologies play in facilitating integration" (Adams *et al.*, 2014). The complexity of the logistic clusters creates negative effects because there is lack of the decision making speed in the process. To decrease the limits of the decision making speed, new innovative technologies must be implemented in the logistic cluster. These innovative technologies mainly consist of CPS which provides the ability to gather, analyze and utilize information. The authors highlight the benefits of IoT and Big Data Analytics, however, the missing link in these approaches is information utilization. A large amount of data can be processed so that to provide useful insights, however, the traditional SCM approaches still require people to make decisions. The implementation of CPS in SCM processes could decrease the decision making speed. However, "CPS strongly rely on technological advancements, the creativity, flexibility and problem solving competence of human stakeholders is strongly needed for their operation" (Frazzon, Hartmann, Makuschewitz, and Scholz-Reiter, 2013).

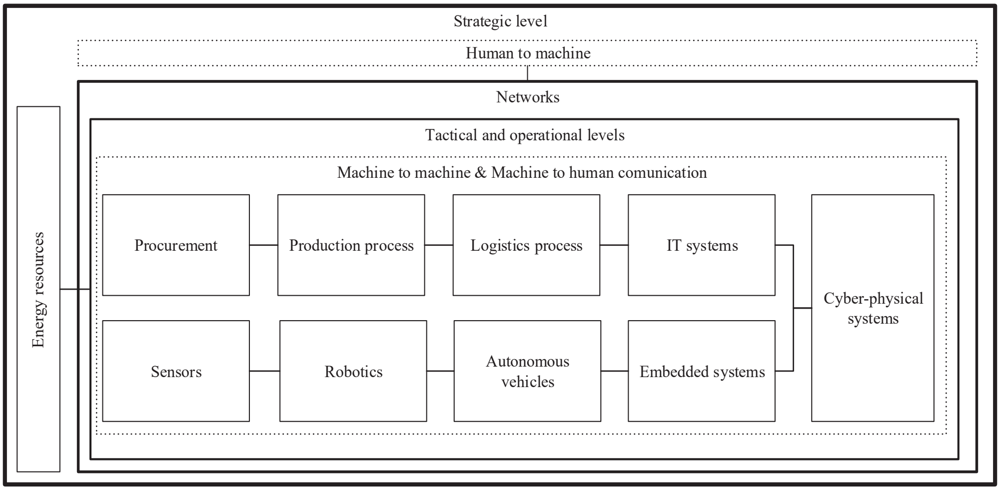


Fig. 18. CPS usage in logistic clusters

Figure 18 indicates the implementation area of CPS. IoT and Big Data concepts allow to provide useful decision making information, however, decisions are still being made by people. “Artificial intelligence was introduced to develop and create ‘thinking machines’ that are capable of mimicking, learning, and replacing human intelligence. Despite its widespread acceptance as a decision-aid tool, Artificial intelligence has seen limited application in SCM” (Min, 2010). Therefore, this process is done by machines and is using machine-to-machine or machine-to-human communication. The network represents a logistic cluster member. In each network, the technologies are considered as key actors, and each network should be operated independently, however, entities should still have the possibility to connect to each other. The entire logistic clusters or networks of networks should be controlled by a centralized station, which would allow the logistic cluster members to input strategic level decision for the CPS so that to allow the machines to follow a previously designed strategy. In this case, the communication from the central management points to networks will be done by using the human-to-machine interaction.

The authors of this publication conducted several empirical studies regarding these approaches. One study analyzed the information sharing impact on logistic cluster activities. The model used an agent-based approach and determined the benefits of collaborative demand forecasting. The model determined that information sharing could increase the demand forecasting and optimize the inventory level. This model provided evidence of the redundancy approach. The second model analyzed the importance of selecting the right distributions strategies. The explored model consists of international freight forwarding which was based on the European Union FI. The model compared Just-on-Time, consolidation warehouses, and partial freight gathering distribution strategies. It was determined that the most effective disruption strategy is to gather partial freight in the region and consolidate it in a central warehouse. Between the regions, multi-modal logistic methods can be used – trains or ships. The model also compared the traditional trucks with autonomous vehicles. It clearly showed the benefits of costs and minimal environment effect, which, in the long run, increased the company competitiveness advantage. “Shared autonomous vehicles (SAVs) could provide inexpensive mobility on-demand services” (Krueger, Rashidi, and Rose, 2016b). The concept of information sharing will even further optimize the tactical and operational strategies because autonomous vehicles can be used to optimize the route scheduling at an even higher level.

In summary, it was concluded that, in order to manage the complexity of the FI, it is essential to implement CPS in the management process. However, CPS is effective only if it can utilize the gathered information by itself and learn in the process. Thus, in order to explain this management approach, adaptation of the complex-adaptive systems theory is essential.

1.3.3. Complex-adaptive system approach towards food supply chains

The changing consumer trends are driving the supply chain towards becoming more complex and sensitive to disruptions because of the necessity to decrease the lead time and maintain the high product quality. To cope with these issues, key approaches and their integration with CPS must be identified.

Previously, the business environment was more stable, and the companies tended to deliver high quantity products to only a few retailers. However, today, there is a tendency to deliver a high variety of products to multiple consumers directly to their doorstep. The world population is growing rapidly, while a large part of it is living in urban regions; therefore, the density of the population is causing even more ineffectiveness in the distribution process(es). During recent years, multiple researchers have started focusing on resilience which is necessary for organizations to achieve in order to maintain competitiveness. This can be achieved through supply chain strategies. The supply chain strategy has 3 levels: strategic, tactical, and operational. The strategic level defines how the supply chain is designed, the supplier relationship and other aspects, and which decisions are making the long term influence. The tactical level is the medium length tasks, such as the order management, product assortment, pricing decisions, etc. The operational level is the daily operations; this level mainly focuses on the warehousing and delivery processes. There are main three categories of the supply chain strategies: proactive, reactive, and anticipation/awareness (Pires Ribeiro and Barbosa-Povoa, 2018). Proactive strategies are those which focus on minimizing the negative effect after disruptions have already occurred, while reactive strategies focus on preparing for a disruption ahead of time. Anticipation and awareness are separated as a third strategy due to the supply chain abilities to adapt and evolve based on previous experience. Other researchers categorize approaches towards resilience as responsiveness and recovery. Responsiveness is defined as the ability to possess speed and quickly respond to disruptions, while recovery focuses on how to recover after a disruption without losing control of operations (Chowdhury and Quaddus, 2016).

More precisely, the strategies have been defined from the scientific literature analysis. For instance, some researchers note that SCR can be achieved through the supply chain design, i.e., by developing certain supply chain networks in order to increase robustness and decrease the interaction between the supply chain members.

“The complexities and uncertainties can be overcome by optimal supply chain configuration in terms of integrating the activities of number of tiers of suppliers and customers and the number of partnering firms at each tier” (Gunasekaran *et al*., 2015). Other researchers encourage using innovative technologies, such as the Internet of Things (IoT). The Usage of IoT can provide visibility to the supply chain processes, which is directly related to the response and adaptations to the disruptions. “The Internet of Things (IoT) has a major role to play in continuous monitoring of supply chain functions and increase visibility in order to reduce the negative impact of uncertainties” (Gunasekaran *et al*., 2015). However, gathering data is not enough as there is need to provide analysis in order to formulate insights for better decision making. Therefore, the supply chain analysis functions best when there is availability of real-time data collected through the supply chain operations. However, key indicators still need to be developed in order to measure the SCR levels in the supply chain (Gunasekaran *et al*., 2015). Another strategy which requires a trade-off between the reactive and proactive strategies is flexibility and redundancy. The supply chain flexibility is defined as the ability of a system or a supply chain to respond to the unexpected and unpredictable changes due to uncertain environments in order to meet a variety of customer needs or requirements while still maintaining customer satisfaction without adding significant cost (Angkiriwang, Pujawan, and Santosa, 2014). Meanwhile, supply chain redundancy entails maintaining capacity in the firm in order to respond to disruption (Usage *et al*., 2017). In other words, flexibility is the ability to maintain high visibility of the supply chain processes and the speed to adapt to them. In this context, redundancy is the ability to anticipate the upcoming disruptions and be prepared for them. However, for the effective use of these strategies, it is necessary to maintain the supply chain collaboration for information sharing and information asymmetries (Hwang and Rho, 2016). “Collaboration ensures exchange of information between supply chain partners and reduces uncertainties and complexities. Collaboration through appropriate partnership and information sharing in the early stage of the supply chain operations would reduce the uncertainties and complexities” (Gunasekaran *et al*., 2015). Researches identify that these strategies are improving SCR, however, Croxton *et al*. (2013) provides empirical evidence which reveals that low collaboration, lack of excess capacity, and minimal flexibility are the major causes of ineffective SCR (Pettit *et al*., 2013). Arvitrida *et al*. (2016) indicates that the firms’ strategy and behavior in supply chain collaborations are identified as the main reasons for supply chain failures (Arvitrida *et al*., 2016). These issues could be analyzed from two perspectives. On the one hand, the collaborating members lack information about the benefits of information sharing. Incentive alignment is difficult when companies are forced into contracts without knowing the potential risks and benefits of participating in collaboration (Herczeg *et al*., 2018). Because of lack of vision, the collaborating members tend to commit to the collaboration less, and unequal input of the members decreases the efficiency of collaboration. “Although collaboration emphasizes joint efforts and collective benefits, companies do not always share these equally, potentially leading to conflicts. Moreover, companies do not necessarily depend on each other to the same extent, leading to asymmetrical relationships. Because of low benefits and/or high risks, companies may not participate or exit the network" (Herczeg *et al*., 2018). Therefore, proper commitment levels and knowledge of the potential benefits and the required investments are leading to higher effectiveness of collaboration and information alignment. On the other hand, there is a problem with the technology usage in collaboration. "Technically driven approaches tend to neglect that the organizational dimension plays an important role for the application of CPS" (Hoske, 2015). Adams *et al.* (2014) indicated that the effectiveness of collaboration as a supply chain resource has been questioned due to the concerns associated with Collaborative Technologies (Adams *et al*., 2014). Even such common technologies as radio frequency identification (RFID) are still underestimated. "To date, companies have mostly been using RFID systems to streamline and improve their internal operations, rather than to improve inter-dependent processes involving transaction partners in supply chain networks" (Hwang and Rho, 2016).

A combination of the strategies is important in order to manage the complexity and maintain SCR. "There is a need for a better understatement which conditions are beneficial to combine or generate trade-offs between redundancy and flexibility, and when flexibility should be combined with visibility in the supply chains" (Usage *et al*., 2017). For instance, when moving beyond flexibility and redundancy, it is important to maintain connectedness and risk sharing among the supply chain members as the traits that enhance resilience (Azadegan and Jayaram, 2018). However, researchers amplify the necessity to make trade-offs while choosing the appropriate strategy. It is proposed that companies should first analyze their competitive strategies in terms of market competition and develop their different supply chains accordingly without losing sight of the assumed risks. Companies might require a supply chain based on cost reduction versus responsiveness (Sáenz, Revilla, and Acero, 2018).

The main determinants consist of collaboration, flexibility, redundancy, and CPS. These characteristics should be operationalized because a combination of them would eventually emerge to sustainability. Therefore, the integration of strategic, tactical and operational levels is necessary, which would help choose the appropriate supply chain strategies for resilience. Moreover, the implementation of innovative technologies, such as CPS, Big data and IoT, would decrease the trade-off between these strategies. "Internet technologies allow supply chains to use virtualizations dynamically in operational management processes. This will improve support for food companies in dealing with perishable products, unpredictable supply variations and stringent food safety and sustainability requirements. Virtualization enables supply chain actors to monitor, control, plan and optimize business processes remotely and in real-time through the Internet, based on virtual objects instead of observation on-site" (Verdouw, Wolfert, Beulens, and Rialland, 2016). The influence of CPS, Big data and Artificial intelligence on SCM has been analyzed by a number of authors in previous publications (Navickas and Gružauskas, 2016), (Navickas *et al*., 2017), (Gružauskas, Vojtovic, and Navickas, 2018), (Gružauskas *et al*., 2018). Lastly, it is necessary to provide clear benefits and necessary commitment so that to implement such strategies and to promote collaboration, therefore, the ABM approach should be used in order to provide theoretical and practical contribution. Therefore, supply chain organizations should focus on using redundancy and flexibility strategies which should be integrated with high information sharing between the supply chain members. Lastly, the implementation of CPS would allow the system utilizing the information by itself, which, in the long run, would cause the evolution and emergence of resilience. These adaptation abilities would allow the supply chain members to maintain sustainability by reducing the negative disruption effect. In order to implement CPS, there is need to use a specific framework so that organizations could focus on the strategic level while tactical and operational levels should become completely automated.

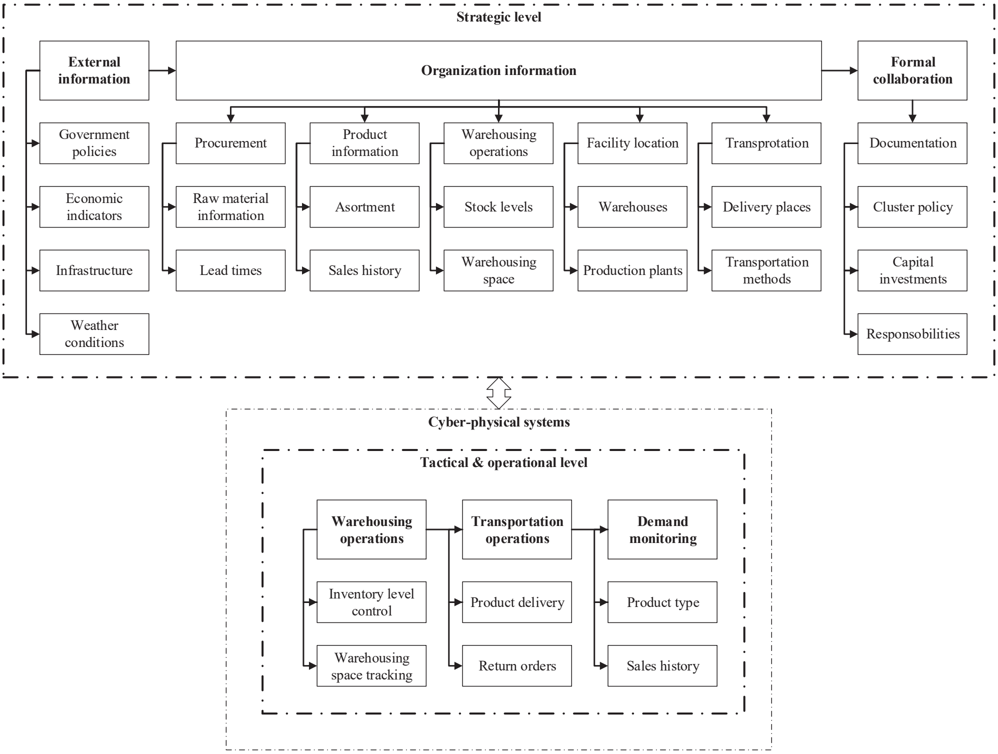


Fig. 19. Conceptual model of integration of strategic, tactical and operational levels

Figure 19 shows the possibility to integrate the tactical, operational and strategic levels. Firstly, it is necessary to analyze the external information which might influence strategic level decisions. Then, it is important to determine the computability of the potential supply chain members. Lastly, formal collaboration, such as a logistic cluster, should be formed. The strategic level decisions should focus on the supply chain design, product assortment, and other long-term decisions. Meanwhile, the operational and tactical levels should be computerized by adapting CPS for daily operation management. However, the implementation of the proposed approach requires precise analysis of every situation. It means that it is not enough to use system thinking, but it must be adapted to the contingent. Therefore, an ABM should be used for more practical implementation of the proposed strategy.

In summary, the supply chain capabilities, such as redundancy and flexibility integrated with collaboration, can increase SCR, which directly influences sustainability. However, CPS must be applied in order to control the complexity of such a logistic cluster. In the long run, if organizations manage to maintain the proper interaction level of the supply chain capabilities, collaboration and CPS emergence of sustainability through resilience is possible.

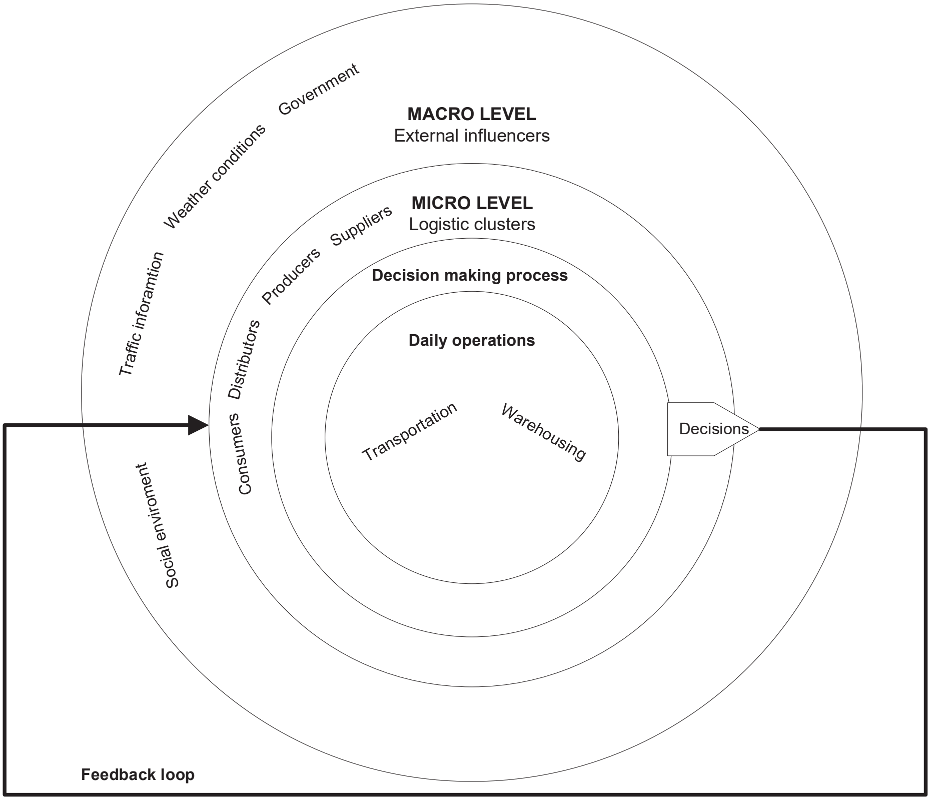


Fig. 20. System Thinking Adaptation to SCM

Figure 20 describes the system-level thinking towards social systems. Basically, there are two levels of information, the macro level, and the micro level. The macro level consists of the environment in which the business operates; this information is from external influencers, upon which, the business does not exert much influence. The micro level is rather related to the business environment and daily operations. As mentioned before, traditional approaches usually focus on some specific aspect and state/presume that the other aspects are not changing, i.e., *ceteris paribus*. The complexity of the systems mainly depends on several aspects. The quantity of the elements, their diversity and the relationships between them are thus essentially ignored. In SCM, the elements consist of suppliers, distributors, producers, consumers, etc. The quantity of the elements depends on the market, while the relationships between them in the thesis are defined as daily operations. The macro and strategic level information shall be overviewed mostly from the theoretical perspective. Without adaptation of the complexity theory, it is impossible to develop SCM strategies for a dynamic environment. In order to better understands how CT fits to SCM, the key characteristics of CAS are identified and adapted to the supply chains.

Table 5. Characteristics of CAS in the Supply Chain Context

Characteristic	**Expression**
Distributed control	The logistic cluster does not have centralized control
Inter-dependent agents	Organizations have multiple interdependent interactions between themselves
Non-linearity	Influence of logistic cluster activities on resilience and sustainability is not linear, i.e., it is chaotic
Not predictable in detail	Constant disruptions cause the logistic cluster to become unstable
Adaptability	Individual decisions of organizations increase resilience and sustainability
Self-organization	Organizations without central control form patterns and order, i.e., they increase resilience and sustainability
Emergence	Individual interactions of organizations cause industry level outcome

From the complexity theory perspective, the supply chain can be defined as a CAS (see Table 5). There are seven main characteristics describing CAS. Wycisk *et al.* (2007) indicated that the supply chain can be called CAS. The research identified that supply chains are vulnerable to all the nonlinear and extreme dynamics found in CAS within the business world. These possible outcomes have to be considered in the supply network management (Wycisk, McKelvey, and Hülsmann, 2008). Cordes and Hülsmann indicated that, from the CAS perspective, supply chains obtain self-healing processes, which is related with the robustness for SCR. They further imply that additional research is needed in relation to empirical and simulation-based methods (Cordes and Hülsmann, 2013). Therefore, in order to conduct a simulation, firstly, CAS characteristics in the supply chain context must be understood (Marchi *et al.*, 2014), (Chriss, Victoria, and Jolyon, 2013). CAS should have a distributed control system which can also be found in the supply chain. Without formal collaboration, a supply chain will not feature a centralized control unit; however, if formal collaboration is established it will not be able to influence the macro environment. However, as indicated by Palmberg, CAS cannot be controlled, but it can still be managed. The second characteristic of CAS is related to complex relationships between the agents, i.e., in the supply chains, there may be multiple suppliers, production processes, deliveries, policies and other processes which cause requirements to make multiple decisions. It is important to emphasize that these complex relationship between the supply chain members produce non-linear results and are similar to chaos, therefore, the processes cannot be predicted in detail. However, the most important part of CAS is that the agents in the system obtain adaptability and can self-organize. It means that simple micro level decisions can produce macro level outcome(s). These simple interactions between the supply chain members cause interesting phenomena to emerge, such as robustness towards resilience. However, it is not enough to simply understand CAS interpretation in the SCM context. It is important to develop a management mechanism to maintain order and not allow chaos to spread. Without order, chaos could merge, and the supply chain would lose its ability to function. To manage complexity, Aelker *et al*. (2013) identified that it is possible to reduce complexity, avoid complexity, or manage complexity (Aelker, Bauernhansl, and Ehm, 2013). “The key to ensuring a sustainable and resilient supply of the essential ecosystem services on which humanity depends on is by enhancing the resilience of socio-ecological systems instead of optimizing isolated components of the system” (Barrientos and Idalia Flores, 2016). Therefore, the developed FSRSCM will focus on managing complexity.

In conclusion, the adaptation of the complexity theory for SCM provides a more systematic management approach because it considers the interconnection between the elements and does not analyze the supply chain elements separately. Secondly, the main characteristics distinguished in the complex-adaptive system theory provide guidelines for organizations whose characteristics should be operationalized in order to allow the emergence of sustainability in the long run.

1.4. Development of the Conceptual Model of Supply Chain Resilience in Sustainable Food Industry

The thesis focuses on developing a supply chain management framework in order to provide sustainability and resilience to the food industry. The research mainly focuses on the operational and tactical level operations, mostly on the urban logistic aspects. Some assumptions based on agricultural processes are made, however, the focus is not inventory management and route scheduling. Furthermore, the research recommends to promote information sharing between the supply chain members. The gathered information should be used together with cyber-physical systems in order to control the supply chain processes. The promotion of collaboration with artificial intelligence application provides adaptation abilities to the supply chain members, which, in the long run, leads towards sustainability. Computer simulation focuses on identifying the relationship between SCR approaches, such as flexibility and redundancy, towards sustainability. In the simulation case, we shall focus on the food quality measurement as the main indicator of the food industry sustainability. The main concepts of the thesis are presented in the research triangle in Figure 21.

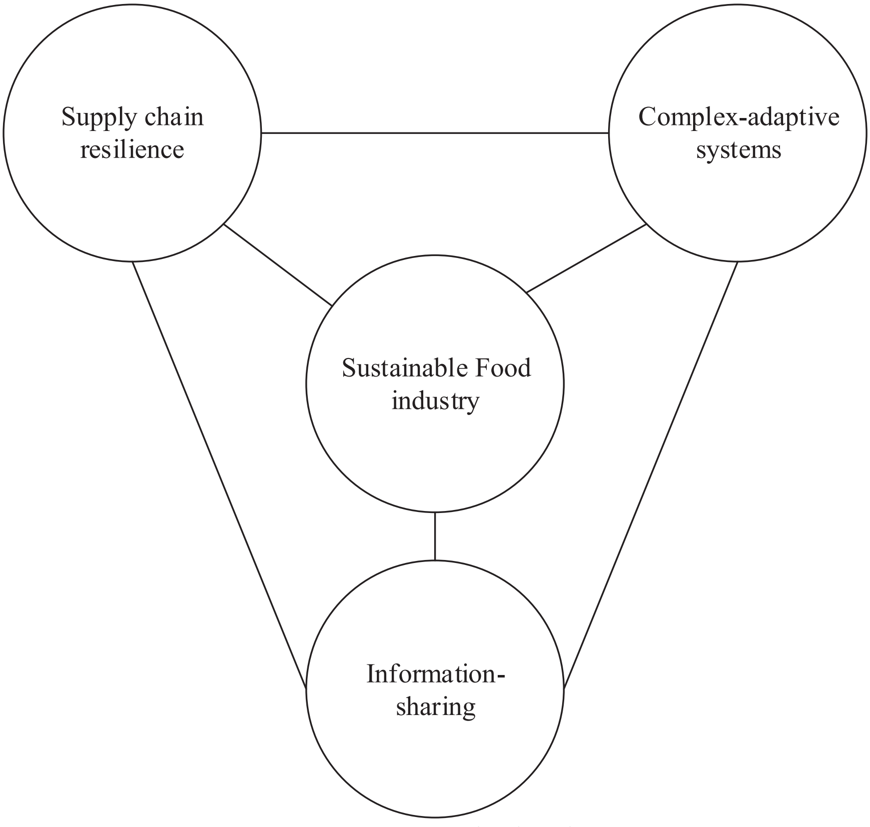


Fig. 21. Research triangle

The main theoretical assumptions of the thesis are presented in Table 6. Firstly, it is clear that the complexity of the FI is growing rapidly, and the system approach must be adapted to the food system. The main problematic area is the growing complexity and dynamic environment of the food system, thus SCR approaches should be adapted to the food system. The effectiveness of the flexibility and redundancy approaches can be improved by promoting collaboration and increasing information sharing between the supply chain members. This is important because unmanaged disruptions can cause impact throughout the whole supply chain. Lastly, in order to manage all this complexity and increased amounts of information, CPS should be adapted to the food supply chains in order to provide sustainability.

Table 6. Main theoretical assumptions of the thesis

Theoretical assumption	Authors
The food supply chain complexity is growing, and it can be managed by adapting the complex-adaptive system theory.	(Hearnshaw, 2013), (Arthur, 2013), (Cordes and Hülsmann, 2013), (Wollmann and Steiner, 2017), (Tachizawa, Alvarez-Gil, and Montes-Sancho, 2015), (Mari *et al*., 2015), (Food and Agriculture Organization, 2017), (Green *et al*., 2017), (Lamine, 2015), (Himanen *et al*., 2016), (IPES FOOD, 2015), (Gunasekaran *et al*., 2015).
Supply chain resilience is positively influenced by capabilities, such as flexibility and redundancy.	(Mensah and Merkuryev, 2014), (Gonçalves and Chicareli, 2014), (Chowdhury and Quaddus, 2016), (Mari *et al*., 2015), (Barroso *et al*., 2015), (Reyes Levalle and Nof, 2015).
Sharing of information which is obtained as a result of collaboration increases the efficiency of flexibility and redundancy.	(Jüttner and Maklan, 2011), (Novotny and Folta, 2013), (Scholten and Schilder, 2015), (Nagashima *et al*., 2015), (Gonul, 2015), (Tukamuhabwa *et al*., 2015), (Reyes Levalle and Nof, 2015).
If a disruption cannot be managed, it creates the ripple effect downstream thus impacting supply chain sustainability.	(Pires Ribeiro and Barbosa-Povoa, 2018), (Usage *et al*., 2017), (Jabbarzadeh *et al*., 2018), (Mari *et al*., 2015), (Nagashima *et al*., 2015), (Green *et al*., 2017).
Disruptions in the food supply chain causes reduction in the food quality and an increase in the food waste.	(Osvald and Stirn, 2008), (Ronga *et al*., 2011), (Fikar, 2018), (Waitz *et al*., 2018), (Haass *et al*., 2015), (Magalhães *et al*., 2018), (Moraes and Pereira, 2018).

The complexity of the decision making process increases dramatically, therefore, the implementation of cyber-physical systems in the supply chain management is necessary.	(Klötzer and Pflaum, 2015), (Frazzon, Silva, and Hurtado, 2015), (Hwang and Rho, 2016), (Johnson and Hernandez, 2016), (Karaköse and Yetiş, 2017), (Trappey *et al*., 2016), (Lee *et al*., 2014), (Oborski, 2016), (Vegah *et al*., 2016).

Thus the main conceptual model is presented in Figure 22. The model indicates that we encourage information sharing between the supply chain members and we analyze the dynamic environment influence on sustainability. The analysis on the one hand consists of the flexibility approach application and, on the other side, of the redundancy approach application. The flexibility approach is mainly influenced by daily disruptions, while the redundancy is affected by the rapidly changing environment.

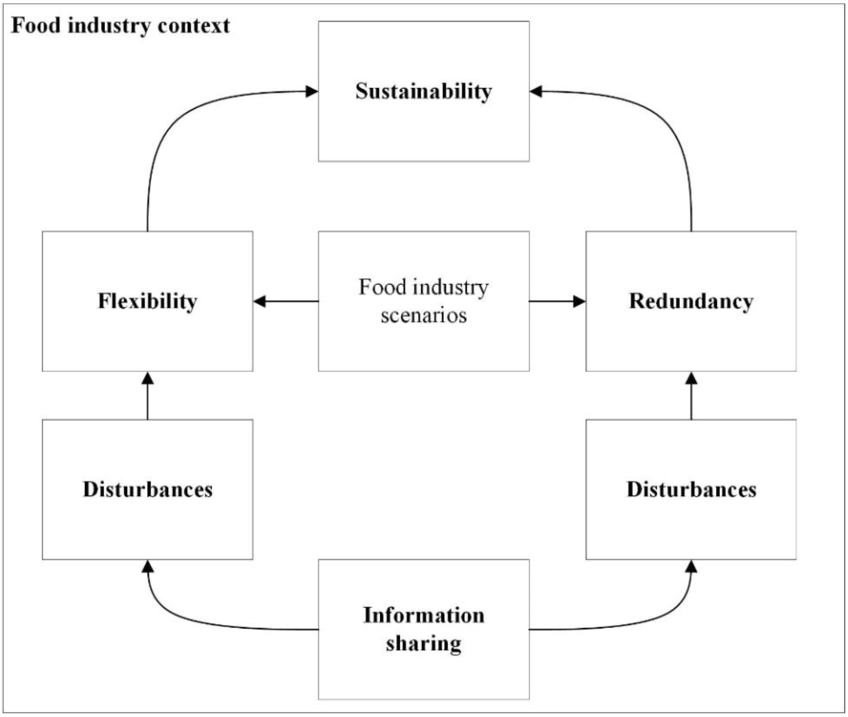


Fig. 22. Conceptual model of Supply chain Resilience in Sustainable Food Industry

Table 7 presents the main definitions of the conceptual model.

Table 7. Definition of the main theoretical constructs

Concept	**Definition**	**Author**
Collaboration (information sharing)	"Collaboration ensures the exchange of information between supply chain partners and reduces uncertainties and complexities."	(Gunasekaran *et al.*, 2015)
Disruptions	"Environment characterized by frequent changes in external factors beyond your control."	(Croxton, 2010)
Flexibility	"Flexibility ensures that the changes caused by risk event can be absorbed through the supply chain through effective reactions."	(Ishfaq, 2012)
Speed	"Fast reaction to perceived changes."	(Wieland and Wallenburg, 2013)
Visibility	"Knowledge of operating assets and the environment of the supply chain."	(Zhang, Dadkhah, and Ekwall, 2011)
Redundancy	Is a concept to keep some reserve resources to be used in case of a disruption."	(Jüttner and Maklan, 2011)
Anticipation	"Ability to discern potential future events or situations."	(Croxton, 2010)
Preparedness	"Resistance to forecasted changes."	(Wieland and Wallenburg, 2013)
Cyber-physical systems	"Cyber-Physical Systems are distributed, (among themselves) interconnected, networked embedded systems using real-time communication."	(Klötzer and Pflaum, 2015)
Sustainable food supply chain	"A set of interdependent companies that work closely together	(Henk and Hans, 1998)

	to manage the flow of goods and services along the added value chain of agricultural and food products, in order to realize superior customer value at the lowest possible costs.”	

In our empirical study, we shall verify the conceptual model, i.e., the operationalized model presented in Figure 23. The simulation process shall consist of two parts. In the first part, we shall verify the effectiveness of the flexibility approach in a disruptive environment. The disruptions in this summation case will be defined as traffic accidents which are irregular and cannot be estimated from the usual traffic flow data analysis. During these disruptions, we shall measure the influence of the food quality since these disruptions will impact the transportation time and the delivery rate. In the other part, we shall focus on the dynamic environment and analyze the effectiveness of information sharing in order to improve the forecasting accuracy. Based on the forecasting results, the inventory levels are planned, and improved accuracy will lead to optimized inventory levels and a higher food quality.

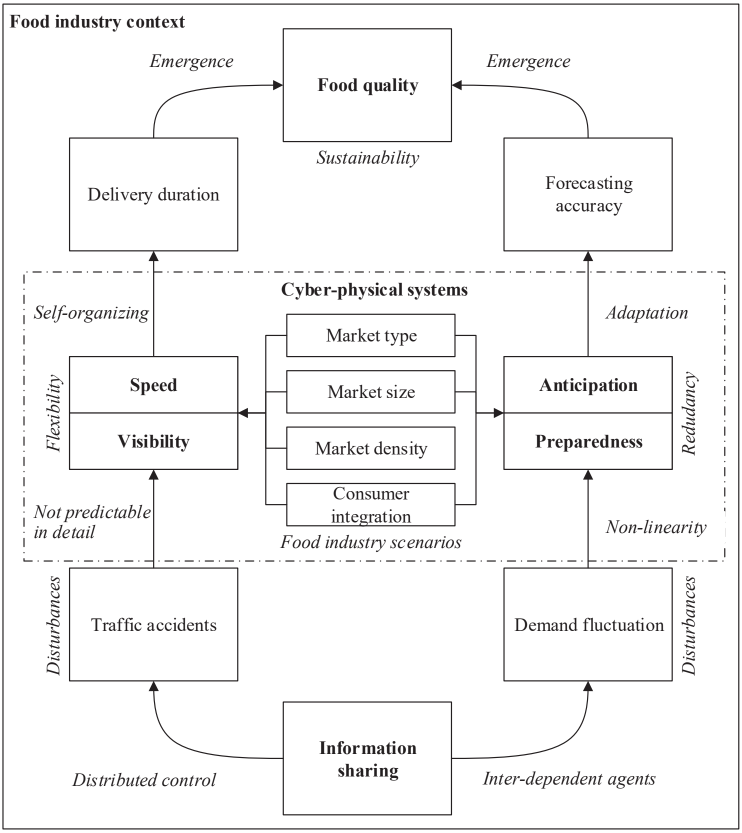


Fig. 23. Operationalized conceptual model

The proposed FSRSCM can be successfully established only when the supply chain members share information among themselves. This information may consist of various sources, such as demand, traffic accidents, etc. In the case of our simulation, we shall focus, on the one hand, on the perspective of the traffic flow and accidents, while, on the other hand, we shall deal with demand fluctuation. In order to increase resilience in the case of traffic disruptions, the flexibility approach should be implemented, which would allow obtaining visibility of the processes and the speed so that to quickly adapt to the disruptions. In the case of demand fluctuation, the supply chain members could share information of the demand history and use it to increase the anticipation thus improving the preparedness level with the intention to cope with this type of disruptions. The result of the integration of these approaches with information sharing would allow maintaining a higher sustainability level in the logistic cluster. However, in order to manage these disruptions quickly, cyber-physical systems should be implemented, which will allow gathering information from the supply chain members, analyzing it and rapidly utilizing the information by the system itself. This approach would increase the food level quality by utilizing the current resources with more efficiency, without additional assets. The validation of the proposed approach shall be conducted in the empirical evidence section.

2. Empirical Studies: Flexibility and Redundancy Influence Determination for Sustainable Food Industry

2.1. Philosophy and methodological approach of agent-based modeling

The supply chain management can be analyzed from, mainly, two perspectives. One perspective is based mostly on business management which focuses on the qualitative approaches and specific case studies. A more recent research field has developed which is called the operation research, and which focuses on computational methodology so that to improve decision-making. Usually, business management research focuses on social problems, while operation research deals with technological problems; however, a sub-discipline called the computational social science could be considered as a combination of the two. Computational social science is a sub-discipline which focuses on computational approaches towards social problems, business management, and other related problems. Computational simulations are a good choice of the research method when integrating analysis of collaboration (i.e., information sharing) with the technological approaches since this strategy allows high level flexibility in analysis The research field of the computation social science is considered to be operation research which focuses on the business problem solving.

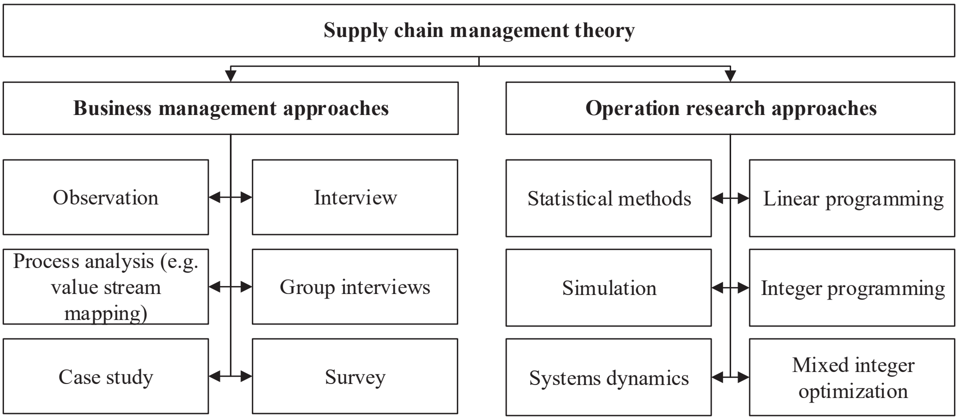


Fig. 24. Research methods for supply chain management

Figure 24 illustrates the basic research methods for SCM (Price, Zhu, and Hillier, 2017). There are mainly two approaches towards analyzing SCM. One approach focuses on business management, or social science, while the second approach focuses on operation research, i.e., it leads to computational approaches. Both approaches analyze the same problem, but the operation research approach is usually a more interdisciplinary approach connecting multiple scientific fields because it requires the understanding of the problem precisely in order to develop a mathematical model for dealing with it. The business management approach usually ends up being a more qualitative approach focusing on the explanation of phenomena, rather than solving a particular problem. The main methodological approach in this thesis is simulations which can be classified from the social science perspective mainly to system dynamics, agent-based modeling and cellular automata (Harrison, Carroll, and Carley, 2007). In general, system dynamic models focus on the system level interaction rather than on the individual agent, the cellular automata focus on the individual agent interaction; however, from the point of view of the basic perspective, agent-based modeling focuses on complex agent interactions. This chapter shall provide explanation of the philosophy and the methodological approach when applying agent-based modeling.

Research of economy and business at the beginning tried to find the most efficient equilibrium which would allow companies to achieve optimal output with minimal input. However, the approaches at that time analyzed phenomena by reducing the complexity and focusing on precise problems and elements. In a dynamic environment, there is no such thing as equilibrium because the environment is constantly changing and is non-linear. "Complexity economics sees the economy as in motion, perpetually 'computing' itself – perpetually constructing itself anew. Where equilibrium economics emphasizes order, determinacy, deduction, and stasis, complexity economics emphasizes contingency, indeterminacy, sense-making, and openness to change" (Arthur, 2013). The adaptation of the complexity science to a better understanding of the business management is necessary because organizations are constantly changing and adapting their strategies to the current market demand as there is no longer a stable environment. The explanation of these complex systems is possible only through computer simulations. Davis and Bingham indicated that computer simulations are useful when phenomena are non-linear; it is difficult to collect the data and it is especially useful for new theory development when there is only limited research done previously (Davis *et al.*, 2007). In order to better understand the theory development process through the complexity science, it is also important to understand the ways of philosophizing about science. There are three main belief systems: ontology, epistemology, and axiology. Ontology mainly focuses on the nature of reality or being, Epistemology deals with what is acceptable knowledge, whereas Axiology investigates the role of values (Saunders, Lewis, and Thornhill, 2016). In the complexity science, these belief approaches can be adapted when conducting a research. Today, the tendency to research social-technical systems which involve analysis of the interaction between the society and technologies in natural environments or are engineered is predominant. The complexity science allows viewing the society and a variety of agents interacting with each other. Due to the technological development, such as the Internet of Things or Big data, the tendency to focus on the social-technical systems is growing rapidly. The knowledge gained from understanding how the society and technologies interact can improve the policy making, business strategies and various other aspects (Deguchi, 2010). The interaction of social-technical systems can be viewed through every belief approach, it depends on the context that is being analyzed. For example, Axiology could focus on consumer shopping decisions depending on their values. Epistemology could focus on how organizations adapt certain technologies. In our research, we shall focus on Ontology which focuses on reality, more precisely, on the technical systems and organizations as a whole. Ontology, Epistemology and Axiology describe how the researchers interpret the phenomena or problems, however, conclusions are drawn based on science philosophies. The philosophies can be distinguished into 5 categories, such as positivism, critical realism, interpretivism, postmodernism, and pragmatism. Positivism mainly focuses on quantitative data analysis, critical realism, interpretivism and postmodernism mostly focus on the qualitative research methods. Meanwhile, pragmatism focuses on a mixture of methods of qualitative and quantitative research. The computational social science is still an emerging field, and the science philosophies are still being adapted to it. "This motivates a fascinating research problem in the computational social science: the algorithmic collection and representation of composite perspective. Properly representing multiple perspectives, with their differences and similarities, would be both a substantive and logical advance in the logic of the social sciences" (Benthall, 2016). It means that social computing is still trying to integrate business decision making with individual values and perceptions.

In this research, we shall mostly focus on pragmatism because the developed theoretical model shall be validated by using agent-based modeling. Moreover, our research contribution is not only theoretical but also practical, which closely aligns with the pragmatism philosophy. The limitation of our approach is lack of human level influence as the research is more focused on organizations than individuals. However, the results can still be validated and applied for practical use. Several approaches exist with the ambition to develop the appropriate theory through science philosophies. The traditional research methods of developing a theory are either inductive or deductive. Deductive reasoning works from the more general to the more specific, while Inductive reasoning works the other way, by moving from specific observations to broader generalizations and theories. However, the complexity science, and, more specifically, ABM, focuses on a third way of developing theories, which was difficult to implement before. However, now, with high performance computing, this approach can provide insights into theory development. The third way is called generative science which describes micro rules of agents and analyzes the macro output (Axelrod, 2005). In the course of the analysis, a huge amount of data is being generated which can be used to develop theories. The validity of the approach is maintained as well because it uses primary rules for developing social simulations. Therefore, this approach can generate data of complex social systems. Without the adaptation of CT, understatement of social-technical systems is difficult, therefore, it is necessary to adapt the system thinking towards business strategy development. "A company in a competitive environment that wishes to be a benchmark in the business world needs a management model that enables the development of systemic thinking on the part of its executives" (Wollmann and Steiner, 2017).

In order to validate the proposed framework in different scenarios and to provide practical usage guidelines, an ABM approach shall be discussed (see Fig. 25).

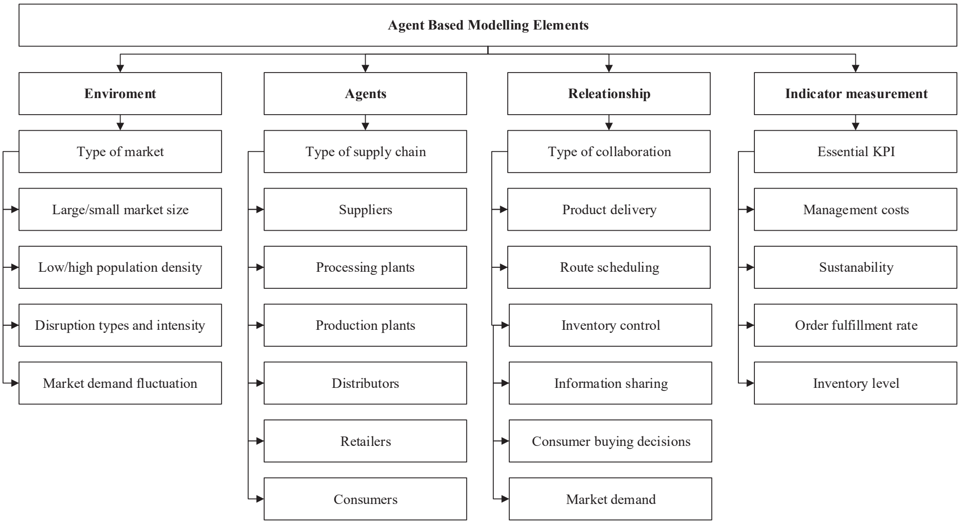


Fig. 25. Agent Based Modeling Elements for SCR Framework

ABM consists of mainly 4 categories: environment, agents, output variables, and relationships. In our case, the environment is dynamic, which involves different contingents depending on the market. Firstly, the market can be an oligopoly, perfect competition, monopoly, and monopolistic competition. The market type depends on the ratio of suppliers, producers, and consumers. The type of the market is important because it influences the extent of the information potential. Moreover, it exerts influence over consumer buying decisions because it describes how many alternatives the consumers might have. Basically, the market type describes the ratio between the demand and the supply; however, the size of the market is described by the quantity of the players. For example, the market could be like the USA, or smaller, such as Belgium. Another important aspect is the population density, especially in the e-commerce sense. As mentioned above, if the products are delivered directly to the doorsteps, the distances between the delivery points are important. The density of population is also causing many problems in a more turbulent environment. For example, in Singapore, there are 7,909 people living per square kilometre, while in the USA, 1,205 people live per square mile. Therefore, daily disruptions, such as traffic jams, might cause a more negative effect in a market with a high population density. With regard to this perspective, the problem could be minimized through effective inventory planning, however, the demand is also constantly fluctuating, which causes even more instability in the environment.

Another aspect is agents; it depends on the type of the supply chain. The supply chain depends on the relationship with the producers, suppliers, and processing plants; also, this aspect depends on the distribution channels (Mentzer *et al.*, 2001). For example, there might be a full supply chain which involves suppliers, producers, processing plants, wholesalers, retailers, and distributors. Alternatively, the suppliers, producers and processing plants could be consolidated and established as one unit. A direct supply chain takes this approach even further and removes the wholesalers and retailers, while it still leaves in the producers, logistics, and the consumer. The direct supply chain is usually used for e-commerce. Therefore, depending on the type of the supply chain, there might be different agents in the model. It is important to note that these agents will have their own variables which will involve capacity, stock levels, etc. Moreover, there should be an additional variable, such as an information system for storing the ABM history for the purposes of analysis. Which variables should be stored depends on the selected key performance indicators.

The last dimension of ABM is the relationships, which describes how agents interact with each other. The relationship between the agents depends on the commitment and computability of the supply chain members; in other words, the relationship depends on the extent of collaboration. The type of commitment of the supply chain members can be distinguished into three categories, such as cooperation, coordination, and collaboration. The highest level of collaboration, which is formal commitment, is called the cluster. In this research, we shall focus on logistic clusters. From the more tactical and operational strategy level point of view, these relationships merely consist of product ordering, delivery, stocking, monitoring, etc. From a more strategic perspective, these relationships depend on the level of commitment of the supply chain members. In other words, it is related to the supply chain integration. Supply chain integration is the degree to which a manufacturer strategically collaborates with its supply chain partners and collaboratively manages intra- and inter-organization processes (Flynn *et al.*, 2010). For example, some supply chains can have a more profound relationship with consumers by involving them into product design by providing loyalty programs, etc.

Agent-based modeling is a novel methodological approach which recently started to find a more standard way of developing. Leombruni and Saam (2006) discussed the issues of the agent-based modeling methodology in their paper which denoted the common pitfalls, such as connections with literature, description of the model structure, identification of the dimensions along which the model behavior is investigated, definition of equilibrium, parameters, sensitivity analysis, validation, description of the computer implementation of the model, and replicability of results (Richiardi, Leombruni, Saam, and Sonnessa, 2006). In order to properly define ABM, a popular methodology can be used which is called the ODD protocol and consists of three main parts. Firstly, it is important to overview the whole process by defining the purpose of the simulation, then, based on the purpose, the main variables and scales of the variables are presented. In the second stage, the design of the concept is presented to provide assumptions of what the simulation output should be. Finally, the detailed process of the initialization stage, input data and sub models of the simulation are presented (Grimm *et al.*, 2010), (Richiardi *et al.*, 2006).

In order to properly evaluate the FSRSCM theoretical and practical contributions, it is important to develop as mature as possible a model which must also maintain the balance between simplicity and complexity. Large scale-based simulations are necessary to properly explain the phenomena, however, in order to maintain practical usage usefulness, ABM cannot be too complex because, otherwise, it will be impossible to reproduce the results. “Since the field’s early days, a serious concern of Agent Based modellers and simulators is how to design large-scale agent-based simulations” (Conte and Paolucci, 2014). To properly maintain the simplicity and reproducibility of ABM, it is important to use computer algorithms, such as machine learning, to define the relationships. In a more standard way, it is possible to define every rule of how an ABM should interact, however, with machine learning, it is possible to define the input and output while leaving the computation part to solve for the computer itself. Therefore, due to the complexity of relationships and decisions between the agents, the machine learning approach must be adapted when developing agent-based models, which is considered a novel approach (van der Hoog, 2017). In recent years, there appeared a possibility to make large-scale social simulations by using graphics processing units (GPU). The usage of GPU in ABM allows making computations in non-linear fashion, whereas the usage of GPU increases the speed of computation and reduces the trade-off between the accuracy and the processing time. The appearance of such technologies allows using even more sophisticated algorithms, such as deep learning. Deep learning basically is a higher form of machine learning which consists of large neural networks, and integration with ABM could provide insights into social-technical system interaction (Foerster *et al.*, 2017). Large neural networks enable the computer to teach itself more accurate predictions than before. Also, by using GPU, we can make computations parallelly rather than linearly. This allows maintaining high accuracy and speed. Therefore, by adapting deep learning with ABM, a self-functioning social-system can be built. At the beginning, this system should be tested in the cyber space, but, after that, it can be launched in the real world by using the developed FSRSCM. Therefore, the provided ABM guidelines shall be used to validate the developed FSRSCM in theory. The results shall be analyzed, and a final FSRSCM shall be developed for practical usage.

2.2. Determination of Main Criteria for Food Industry Scenarios

2.2.1. Motivation and approach of food industry scenario determination

Freight forwarding simulations usually consider the number of households that are serviced in the model (Osvald and Stirn, 2008), (Nunes, Figueira, and Machado, 2012), (Emeç, Çatay, and Bozkaya, 2016), (Rong, Akkerman, and Grunow, 2011) , (Fikar, 2018), which depends on the industry sector; thus, in our research, we are focusing on macro indicators defining the market size of the food industry. When focusing on distribution simulations for the last mile, commonly, researches have focused on high density population which has a tendency for more frequent congestions and lower average speeds (Benhamza, Ellagoune, Seridi, and Akdag, 2015), (Mizuta, 2016), (Hoffa and Pawlewski, 2014), (Faccio and Gamberi, 2015), (Carling, Han, Håkansson, Meng, and Rudholm, 2015), (Pronello, Camusso, and Valentina, 2017), (Köster, Ulmer, and Mattfeld, 2015b). From the business model perspective, it is important to consider loyalty program participants, which causes consumers to be more integrated into the supply chain (Bradley, 2016), (Belavina *et al.*, 2016). On the other hand, the incentive to provide for consumer loyalty program participants depends on the market type which usually is defined as the ratio between the sellers and the buyers. This usually depends on the industry sector and the pricing strategy (Nagurney, Saberi, Shukla, and Floden, 2015). In our case, we assume that households choose from a generic type of product with the same pricing. These types consist of perfect competition, monopoly, oligopoly, and monopolistic competition. In our simulation, we shall focus on two cases, one of which is the perfect competition where households will have a possibility to make orders not from the cluster members, and oligopoly where we will have only a few buyers and thus households will always make orders from someone from the logistic cluster. The other types of competitions in the developed countries are less apparent (e.g., Monopoly), also, the selected types virtually represent the trends of other market structures because we are taking two extremes of the possible structures.

The influence of the supply chain resilience on sustainability shall be determined based on the ABM principles. In order to successfully conduct the computer simulation, the environment of the FI bust be analyzed and classified. In today's dynamic environment, it is essential to consider different scenarios where the relationship must be determined. Therefore, macro index analysis of the FI shall be conducted. For the analysis, the European Union has been chosen by considering 25 countries. Several countries were removed from the analysis due to many missing values of indexes. The selected EU countries are as follows: Austria, Belgium, Bulgaria, Czech Republic, Germany, Denmark, Estonia, Greece, Spain, Finland, France, Croatia, Hungary, Ireland, Italy, Lithuania, Luxembourg, Latvia, the Netherlands, Poland, Portugal, Romania, Sweden, Slovenia, the United Kingdom. The selected statistical analysis data was extracted from Eurostat and focused on agriculture, food processing, and population statistics (Eurostat, 2018b), (Eurostat, 2018c), (Eurostat, 2018a), and the selected key indexes are based on the identified contingencies of the food industry, such as the market size, the competitiveness environment, the population size and its density.

The indexes consist of three main types. The first category of indexes consists of: the total population, population density, population living in the urban and suburban area. The second category focuses on the agricultural industry and considers such indexes as the utilized agriculture area, number of farms, number of farms with livestock, farm livestock units, standard output, labor force, and import/export. The third category focuses on the food processing sector and takes into consideration the employment numbers, enterprise numbers, gross operating surplus, production value, turnover, added value, and the import/export. The period availability of the indexes involves the years from 2005 until 2015. The missing values were interpolated, and all the indexes were estimated up to 2015 by using the Facebook Prophet algorithm (Taylor and Letham, 2018). Then, a k-mean clustering algorithm was applied in order to identify different contingencies of the selected countries. The number of clusters has been chosen by following the elbow method, and, for validation, a silhouette score has been used. After assignment of cluster labels to the data, a decision tree classifier was used in order to determine the main features of the groups. Lastly, descriptive statistics of the identified clusters was provided.

2.2.2. Macro Index Analysis for Criteria Determination

Machine learning application in econometrics is still an evolving field with only a limited amount of previous research; however, it is estimated that machine learning in econometrics will be more applied in the future (Varian, 2014). In spite of the intense usage of machine learning, the collaboration between the computer science and economists is still evolving – "it remains to conclude that machine learning can and has certainly advanced econometric techniques but a lot of work remains to speed up their introduction into econometrics" (Thesling, 2016). However, the application of machine learning is estimated to enrich economic research by providing a useful way to obtain a one-dimensional statistic that summarizes a large amount of information about the entities being studied (Einav and Levin, 2013). "The appeal of machine learning is that it manages to uncover generalizable patterns. In fact, the success of machine learning at intelligence tasks is largely due to its ability to discover complex structure that was not specified in advance. It manages to fit complex and very flexible functional forms to the data without simply overfitting; it finds functions that work well out-of-sample" (Mullainathan and Spiess, 2017). Such approaches to machine learning have been implemented in economics, but only a limited amount of research has been discovered. For example, one empirical research illustrates the superiority of the machine learning methods in detecting irregular patterns, or 'noises', due to data heterogeneity for short-run prediction and demonstrates the ability of more standard econometric methods in identifying the regular trends which matter more in the long-run prediction (Liu and Xie, 2018). Other researches applied clustering algorithms for macro indexes, however, only a few applications have been found. Řezanková conducted cluster analysis of the macro level of EU consumers (Řezanková, 2014). Another research paper used the clustering approach in order to identify the key macro indicators contributing to Nigeria's economy growth (Kembe, 2017). Moreover, another research focused on the EU, but it only covered the perspective of its gross domestic product (Augustyński and Laskoś-Grabowski, 2017). However, none of these papers focused separately on the industry analysis or, more specifically, on the FI. Therefore, the application of the clustering algorithm for FI macro indexes has not been accomplished previously.

Firstly, the missing value analysis of macro indexes has been conducted. Several countries, due to the majority of the missing values, have been removed from the analysis, and we thus continued with 25 countries of the EU. Later on, the data was interpolated between the known values. Afterwards, an advanced time series algorithm Prophet was applied in order to estimate the macro indexes up to the year 2015. After data cleaning and preparation, a k-mean clustering algorithm was applied, and the optimal number of clusters was determined by following the elbow method and evaluated with the silhouette score of 0.749.

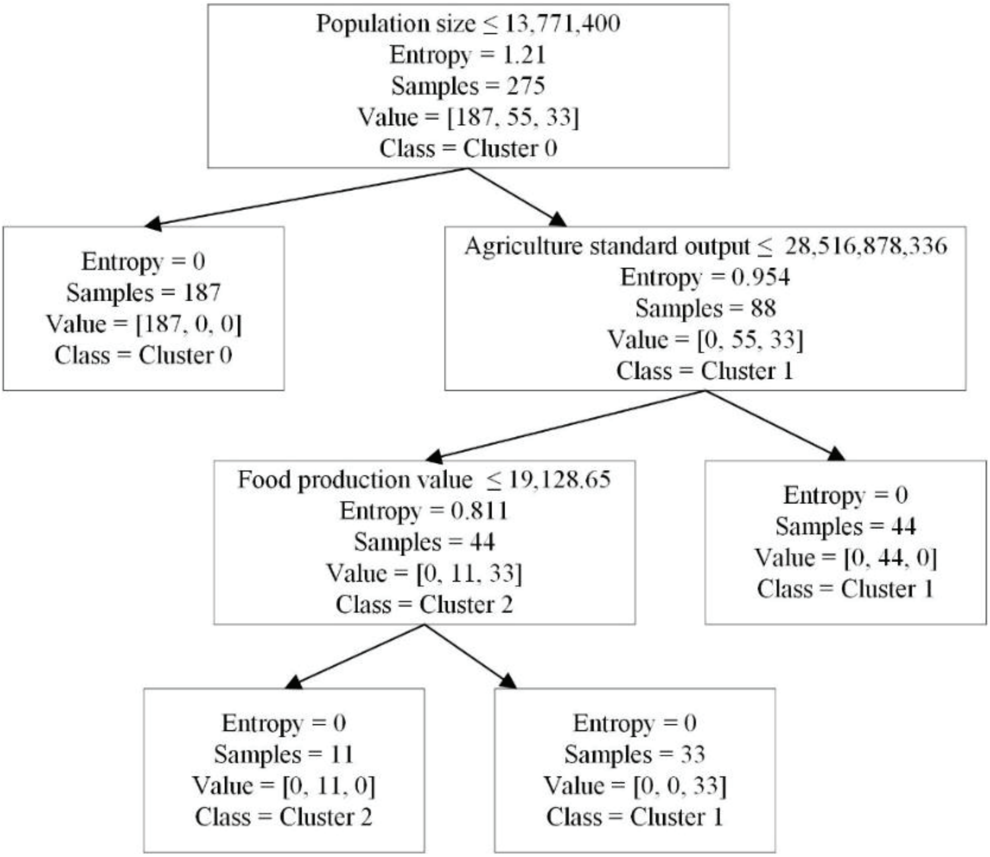


Fig. 26. Decision tree of cluster assignment

The results of the decision tree are represented in Figure 26. The first group is the countries whose population size is less than 13 million. If the population size is larger than 13 million, the agriculture output plays an important role; if it is higher than 28 million, cluster 1 is assigned. If the agriculture output is lower than 28 million, then the food production value is used, whereas if it is lower than 19 million, then cluster 2 is assigned, otherwise cluster 1 is used. The cluster groups by countries are represented in Figure 27.

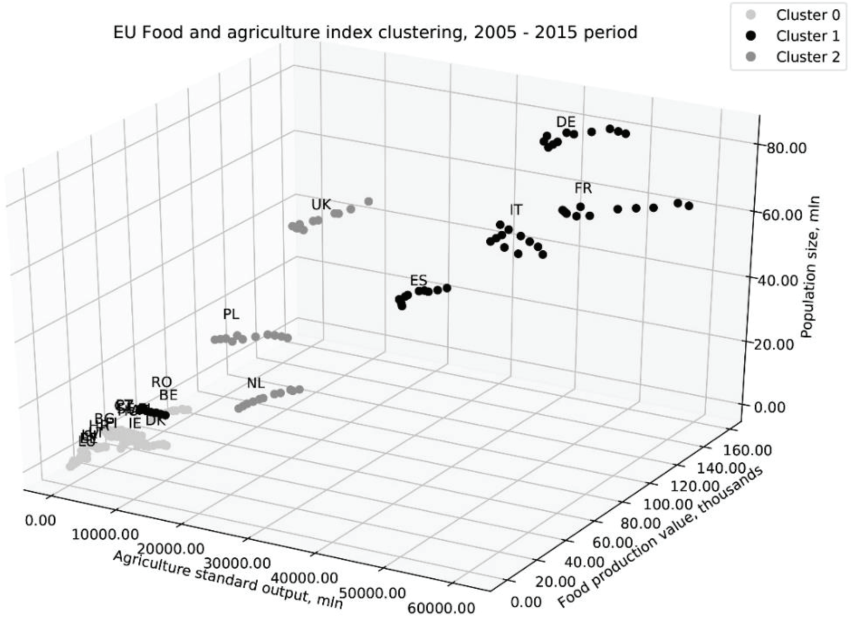


Fig. 27. EU food and agriculture index clustering, 2005–2015

Germany, France, Italy and Spain were assigned in the first cluster as these countries have high populations, agriculture outputs and food production values. The second cluster consists of the United Kingdom, Poland and the Netherlands. Cluster 2 has a lower population and a lower agriculture output. Lastly, the majority of the countries were assigned to cluster 0 which consists of Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Estonia, Greece, Finland, Croatia, Hungary, Ireland, Lithuania, Luxembourg, Latvia, Portugal, Sweden, Slovenia. Descriptive statistics of the clusters are provided in Tables 8–10.

Table 8. Cluster group description by population

Cluster ID	Count	Mean	STD	Min	Max	Indicator
0	187	99.58	79.55	17.20	371.80	Density
1	55	142.55	59.75	86.10	230.90	
2	33	291.40	154.88	121.90	502.90	
0	187	35.94	9.20	13.00	54.30	Distribution of Cities
1	55	43.95	6.19	31.90	51.90	
2	33	53.25	13.75	32.50	76.80	
0	187	41.45	13.21	4.00	66.60	Distribution of Rural areas
1	55	28.64	16.06	14.70	70.63	
2	33	21.11	17.60	1.90	46.70	
0	187	22.62	12.67	0.00	53.20	Distribution of Towns and suburbs
1	55	27.38	13.90	10.16	47.30	
2	33	25.64	8.92	12.90	40.20	
0	187	6,276,414	3,601,236	461,230	11,237,274	Population size
1	55	54,312,660	20,634,499	19,870,647	82,500,849	
2	33	39,059,159	19,076,976	16,305,526	64,875,165	

The first aspect of descriptive statistics was provided for the population size and population density. The population density is measured by persons living per square kilometre. Cluster 0 has a population density of 100, cluster 1 gives a value of 140, and cluster 2 yields 290. In cluster 2, more than 53% of the population is living in cities, in cluster 1 it is 44%, whereas in cluster 0 it is 36%. The average population in cluster 0 is very small, while cluster 1 has the highest population with the mean of 54 million. In the sense of population and population density, it can be concluded that cluster 2 has a lower population size than cluster 1 but higher than cluster 0 with the highest population living in cities. Cluster 1 has the highest population size with more population living in the rural areas. Lastly, cluster 0 has the lowest population size with the majority of population living in rural and suburban areas.

Table 9. Cluster group description by agriculture sector

Cluster ID	Count	Mean	STD	Min	Max	Indicator
0	187	2,021,263	2,080,939	153,530	10,280,029	Export
1	55	11,121,819	6,231,751	485,028	23,107,284	
2	33	11,447,328	11,561,161	1,706,615	33,829,101	
0	187	2,503,885	2,964,292	215,479	15,734,474	Import
1	55	15,080,060	10,179,639	545,376	38,717,332	

2	33	12,637,495	6,544,576	2,233,858	23,227,872	
0	187	182,943	207,709	2,000	860,150	Farm number
1	55	1,405,346	1,292,741	275,630	4,256,150	
2	33	678,492	827,362	64,253	2,476,470	
0	187	1,914,718	1,531,584	157,830	6,220,360	Farm livestock units
1	55	14,023,466	6,022,287	4,662,730	22,703,120	
2	33	9,996,526	2,904,914	6,388,100	14,330,310	
0	187	117,579	119,692	1,537	501,910	Farms with some number of livestock
1	55	801,364	1,110,203	125,179	3,453,010	
2	33	418,928	507,427	43,773	1,547,480	
0	187	170,080	153,787	3,417	624,660	Labor force directly employed, units
1	55	1,020,426	490,965	507,550	2,595,590	
2	33	822,706	881,552	110,370	2,273,590	
0	187	3,741	2,562	222	10,346	Standard output, mln euro
1	55	37,176	14,631	9,875	61,035	
2	33	19,568	1,981	16,084	23,671	
0	187	2,626,024	1,431,813	129,130	5,177,510	Utilized agricultural area in hectares
1	55	18,854,955	6,050,557	11,594,117	27,837,290	
2	33	11,142,115	6,718,096	1,831,050	17,623,857	

The second type of descriptive statistics focuses on the agricultural sector. When comparing the import and export, then cluster 0 is again the smallest, while the export is similar in clusters 1 and 2. However, the import is larger by 2.5 million in cluster 1 if compared with cluster 2. The highest number of farmers is in cluster 1 with 1.4 million, while cluster 2 contains 700 thousand, and cluster 0 has the lowest number of 183 thousand. A similar situation is with livestock. In addition, cluster 1 has the highest number of employees in the agricultural sector.

Table 10. Cluster group description by Food processing and manufacturing sector

Cluster ID	Count	Mean	STD	Min	Max	Indicator
0	187	5,048,917	6,850,754	341,311	33,286,320	Export
1	55	25,904,581	17,414,472	349,293	65,516,750	
2	33	24,781,001	17,307,867	6,637,106	61,249,222	
0	187	4,881,442	4,657,000	603,131	24,266,014	Import
1	55	27,189,741	16,067,051	1,655,316	59,401,626	
2	33	24,543,635	12,790,481	4,383,995	43,473,595	
0	187	57,282	31,030	4,152	117,844	Employment
1	55	448,982	212,547	161,945	817,024	
2	33	299,733	130,359	115,683	428,771	
0	187	3,873	3,845	128	16,071	Enterprise number
1	55	35,261	20,055	7,508	65,004	
2	33	8,423	4,213	4,105	16,050	
0	187	880	1,012	35	6,194	Gross operating surplus
1	55	6,426	3,035	125	10,558	
2	33	6,362	3,722	3,172	14,680	
0	187	9,315	8,413	362	38,615	Production value
1	55	92,411	48,876	6,299	157,322	
2	33	55,170	20,293	29,197	98,253	
0	187	10,276	9,167	470	41,070	Turnover
1	55	100,646	54,738	5,329	172,858	
2	33	61,116	21,496	28,674	106,104	
0	187	2,082	1,795	150	8,013	Added value
1	55	18,195	10,182	879	33,015	
2	33	13,275	7,797	5,221	28,979	

The final type of descriptive statistics is concerned about the food processing manufacturing sector. The export and import statistics are similar in cluster 1 and 2, while the lowest amount is found in cluster 0. The majority of employment is in cluster 1, yet with the high enterprise number of 35 thousand. Again, cluster 1 in terms of the production value which is the highest when compared to clusters 0 and 1.

After the analysis of macro indexes, it can be concluded that cluster 0 consists of small markets with a low population size and the majority of population living in suburbs. Cluster 2 is the intermediate cluster with a lower population size and FI. It is essential to highlight that approximately 44% of their populations lives in cities. Lastly, cluster 1 has high populations, high food production values, and, on average, 55% of the populations is living in cities. The tendencies show that, in the sense of population density, there are low density and high density countries in the review, which influences the distribution strategies. In addition, the number of enterprises operating in agriculture and manufacturing industries differs dramatically in the clusters. Therefore, when implementing the proposed FSRSCM, these different contingencies should be taken into consideration. The implementation of the proposed FSRSCM depends on the existing infrastructure of the country; therefore, the solution in some countries should be implemented in the already existing clusters, while, in others countries, the clusters should be formed. The development of the necessary infrastructure is essential in order to implement the proposed SCRIS. The framework represents how information sharing can provide more efficient utilization through CPS. These systems show how information should be gathered throughout the supply chain and how the system itself should utilize the information. The implementation of such an approach in the FI is possible through autonomous vehicles. The majority of research is currently focusing on autonomous vehicle use implementation for public transport; however, the current technological advancement will presumably allow to use these technologies for product distribution as well (Punma, 2018). Integration with the reinforcement learning algorithm will allow the system to learn and evolve in order to minimize the food waste levels (Nazari, Oroojlooy, Snyder, and Takáč, 2018). Therefore, the proper infrastructure preparation and information sharing is essential. On the other hand, information sharing abilities can be used to provide a better optimized inventory level for demand and supply, which directly related to food waste reduction. The implementation of the proposed SCRIS and would thus provide self-learning system abilities to the FI (DHL Customer Solutions and Innovation, 2016). In the future, a computer simulation will be conducted to validate the proposed framework.

The statistics of the growing world population and the increasing consumer expenditures for organic FI emphasize the changing business environment of the FI. Current business practices foreground the need to shift towards the e-commerce and hyper-local distribution strategies. The conducted macro index analysis identified three main types of contingencies of the FI which will be used to conduct an agent-based model in future research.

2.3. Simulation of the Flexibility Approach for Sustainable Food Industry

2.3.1. Methodology of the Flexibility approach

The Agent-based model is described by following the ODD protocol (Grimm *et al.*, 2006), however, the design concept is omitted since it is covered in the literature analysis section.

Purpose

The purpose of the agent-based model is to simulate the food industry's last-mile logistic processes and determine the relationship between resilience and sustainability. In this research case, the system resilience is related to disruptions which are defined as traffic accidents and which cannot be overseen from regular data analysis. Meanwhile, sustainability is the quality of food products and food waste levels. Therefore, the idea is to provide system adaptation possibilities which would provide resilience and maintain a higher sustainability level. The secondary goal of the model is to conduct a sensitivity analysis in order to identify the relationship of resilience and sustainability in various food industry scenarios. In Chapter 2.1, we provide analysis of the macro indicators of the EU. The analysis focused on the general indicators per country regarding the food and agriculture sector. The selected period from 2005 until 2017 in terms of macro indicators was chosen, and clustering analysis was completed. Three groups were classified by considering these macro indicators. The third group is the countries which, based on the findings, were considered as developing in the food industry sense, therefore, the main problems being faced there are not the last-mile delivery problems, but previous stage problems, i.e., encountered in the harvesting and processing stages. Meanwhile, the second and third groups fit the conditions of the last-mile problems more specifically. For example, the second group includes the United Kingdom, Poland, and the Netherlands, while the first group includes Germany, France, Italy and Spain. The first group of countries had a higher enterprise number in agriculture and food industries – 800 thousand and 679 thousand, respectively. The average population in group one was 62 million, while in group two it was 39 million. The population density in group one was 155 persons per square kilometre, while in the second group it was 291 persons per square kilometre. The ratio between the indicators will be used in the model in order to represent the two groups.

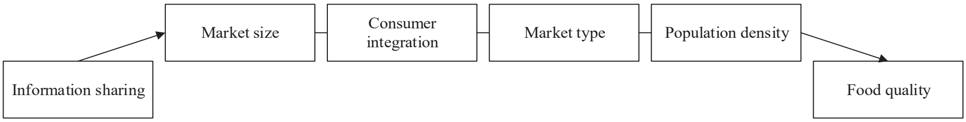


Fig. 28. Main model questions

Figure 28 illustrates the main question of the flexibility approach which will be defined as: what is the relationship between information sharing and food quality while mediating the market size, market type, consumer integration and population density in a dynamic environment?

Main variables and scale

Table 11. Scenario description

Scenario	Market size	Market type	Consumer integration	Population density
1	Large market	Oligopoly	Loyal	Low density
2	Large market	Oligopoly	Loyal	High density
3	Large market	Oligopoly	Random	Low density
4	Large market	Oligopoly	Random	High density
5	Large market	Perfect competition	Loyal	Low density
6	Large market	Perfect competition	Loyal	High density
7	Large market	Perfect competition	Random	Low density
8	Large market	Perfect competition	Random	High density
9	Small market	Oligopoly	Loyal	Low density
10	Small market	Oligopoly	Loyal	High density
11	Small market	Oligopoly	Random	Low density
12	Small market	Oligopoly	Random	High density
13	Small market	Perfect competition	Loyal	Low density
14	Small market	Perfect competition	Loyal	High density
15	Small market	Perfect competition	Random	Low density
16	Small market	Perfect competition	Random	High density

Table 11 represents in total 16 scenarios which will be used for autonomous trucks and traditional trucks, therefore, there will be a total of 32 scenarios. The goal of the publication is to identify the relationship; therefore, the exact numbers are not necessarily required to represent precise cases as it is important to maintain the relationship between them and change only the analyzed variables, which in economics is defined as *ceteris paribus*. Therefore, in this case, a large market size is defined as 400 households, while a small market size is defined as 200 households. The distance between consumers is a fixed number of grids which are used for spatial modeling in *NetLogo*. The proposition of these indicators is derived from the macro indicator analysis, as described above. The average speed of a car is 100%, which represents 60 km per hour with no traffic flow and accidents. In the low population density case, the speed is set to 90%, while in the high population density case it is set to 75%. Then, the market type and consumer integration is based on household interaction. In the oligopoly market, it is assumed that the cluster works with 80% of the market since there are only a few producers, while in the perfect competition market type, only 20% market share is maintained. This assumption is used for all producers in the simulation when the orders of the households are placed to other producers which are not involved in the logistic cluster – it is then assumed that the demand information has been lost. The truck number in the perfect competition market type is set to 1, while in the oligopoly market type is set to 2. Loyal consumer behavior means that the consumers maintain their orders daily from the beginning, while random behavior means that the households randomly decide to buy or not to buy every day. This approach is used to estimate the effectiveness of the proposed approach in different scenarios, but not only in the environment and business model.

Process overview and scheduling

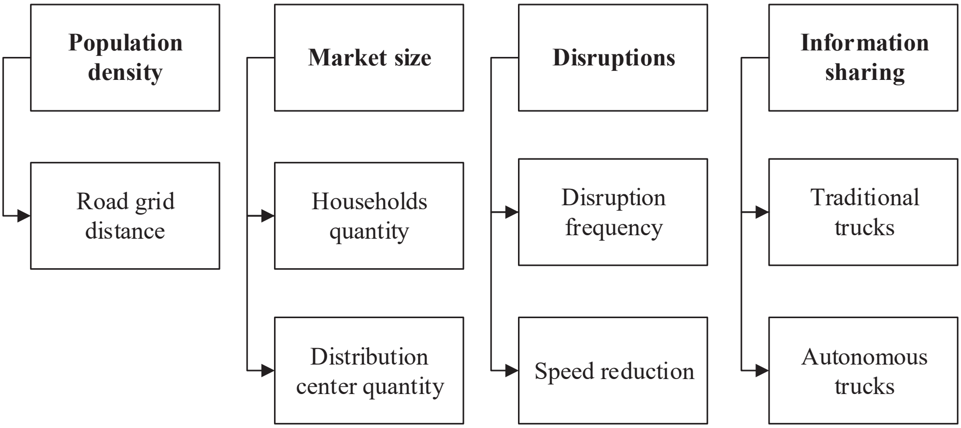


Fig. 29. Model initialization steps

Figure 29 represents the model initialization steps. Firstly, the road network distance is defined based on the population density, household numbers and fulfilment center. In the case of this simulation, the harvesting and processing stages are not considered. The distribution centers are placed outside city limits, i.e., in the suburbs. There will be seven types of disruption levels depending on the traffic accident levels and relationship with regard to the speed reduction and conjunction time. A more precise description of the disruption types is presented in the input section. The used type of trucks will define the information sharing abilities between the supply chain members. The scheduling process for the traditional vehicles will use the historical data based on the traffic flow information, while autonomous vehicles will additionally be estimated in terms of how unpredictable disruptions affect the food quality.

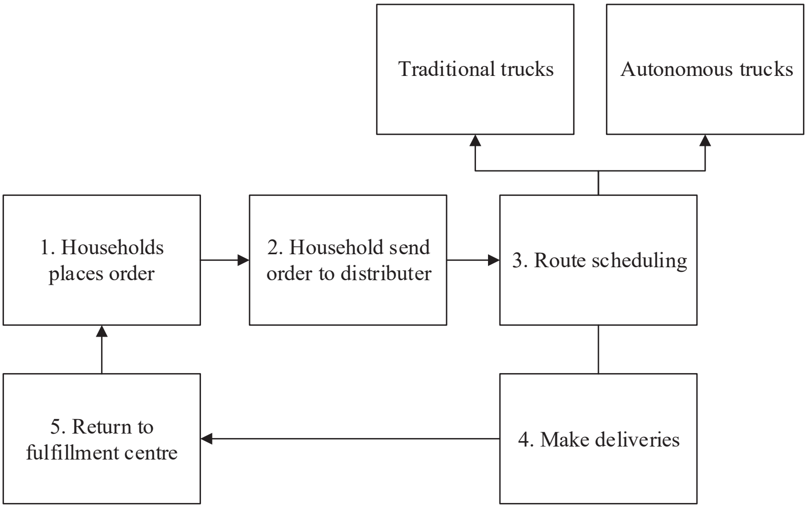


Fig. 30. The process of the model

Figure 30 shows the process of the agent-based model which is based on Hübner *et al*. (2015) and Fikar's (2018) research (Fikar, 2018), (Hübner *et al*., 2016). Firstly, the households make orders which consist of demand distribution and a 2-hour time window for delivery between 8:00 AM and 6:00 PM based on binominal distribution. Then, this order is received at the fulfilment center. With this information, the number of trucks is planned, and, depending on the selected truck type, route schedules for individual trucks are generated. Then, the deliveries are being made, and at 7:00 PM the trucks return back to the fulfilment centre; afterwards, the process is repeated. During the delivery time, the traffic flow and accidents will be generated which will disrupt the logistic processes and will cause deviation from the planned food quality levels. The speed of the trucks will decrease due to traffic accidents, and the influence to the food quality will be measured. In practice, companies usually allocate trucks to a particular region for deliveries. However, in this case, the companies would need more trucks than necessary. Another difference in practice is that smaller hubs are started to be placed within city limits in order to minimize the distance traveled by the trucks. In the case of this simulation, we are proposing to place a fulfilment centre in the suburbs so that to minimize the costs of the land and assets. This approach would provide recommendations on how to maintain higher efficiency without investments in additional trucks or hubs.

The main difference of the agent behavior is related to the truck route scheduling which is influenced by the information level of the network. In the case of the traditional trucks, only the general information of the traffic flow and speed limits is used. In practice, this is retrieved through GPS, city flow measurements, and satellite images. In the case of autonomous trucks, the information quantity increases. Currently, the majority of the research related to autonomous trucks focuses on how to travel from point A to point B. However, in the network optimization case, the gathered information can be used to optimize routes. In practice, the information can be gathered while being related to various sources, such as pedestrian flow, traffic light malfunctions, road quality and so on. In this simulation case, we are limiting the disruption information only to traffic jams which are caused by accidents. Data analysis of the traffic flow can provide information about the traveling time and the reduction of speed, however, additional data on traffic accidents in the route planning process could cause the system to be more resilient. Therefore, the gathered information from autonomous vehicles can be used to estimate these traffic jams to improve the route scheduling.

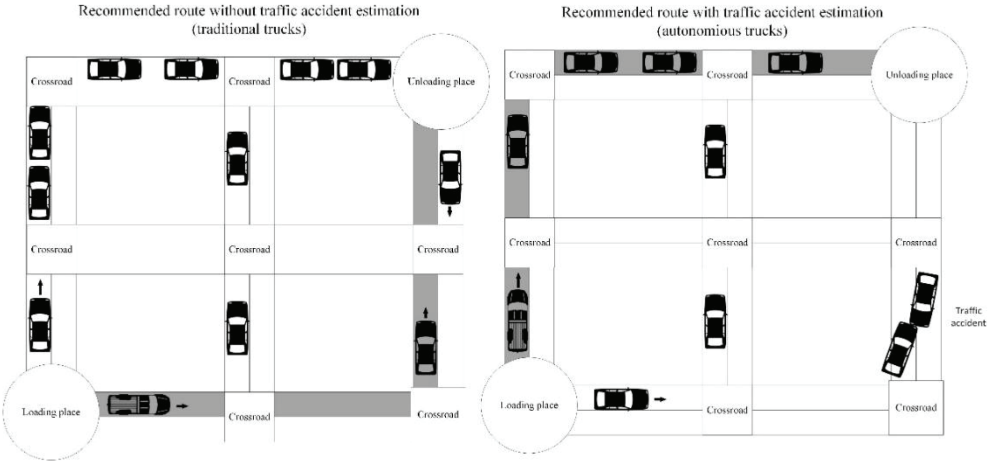


Fig. 31. Example of route scheduling approaches

Figure 31 shows the difference between the scheduling approaches of the traditional trucks and the autonomous trucks. In this example, it can be seen that if, within the city limits, the average speed is the same, and the distance is the same between the loading and unloading places. Then, the decision which routes to choose depends on the traffic flow current information. However, if autonomous vehicles could have historical traffic accident information, it could be possible to estimate traffic accidents and recommend routes based on this information. This concept can be explained as cyber-physical system usage in the supply chain management. Cyber-physical systems can be defined in three layers. The first layer is the physical world, from which, information is gathered with sensors and is transmitted to the cyber layer. In between them, there is a network which connects the physical layer with the cyber layer. In this case, the autonomous trucks feature in-built sensors which gather the information. Then, in the cyber layer, from the historical data, the traffic and accidents are estimated. Afterwards, the recommended decision is sent back to the physical layer, and the system adjusts itself. In this case, the flexibility approach for achieving system resilience is provided which, in turn, can be defined as a self-learning system. The authors in a previous publication elaborated more on the cyber-physical system and on the complexity theory adaptation to the supply chain management (Navickas *et al*., 2017), (Gružauskas *et al*., 2018).

Initialization, inputs and sub models

The urban logistics simulation focuses on online grocery ordering and aims to determine the relationship between the disruptions and the food quality. The model uses data from wholesale which represents different product categories (see Table 12). However, the generic food quality model developed by Tijksens and Polderdijk (1996) focuses on vegetables only. Since the data represents different product categories, a generic approach to products in the simulation will be used, i.e., conclusions for specific product supply chains will not be made, but general conclusions for the food industry will be developed instead.

Demand of consumers

The data was gathered from 5 food companies which represent 7 product categories and 838 products. The distributions were fitted by using the tdistrplus package in R (Delignette-Muller and Dutang, 2015). The model package analyzes pareto, log logistics, Burr and log normal distributions of the data. The distribution selections were made by choosing the Goodness of fit statistics. Selected distributions are represented in Table 12.

Table 12. Fitted distribution functions based on empirical data

Product category	**Distribution**	**Coefficient 1**	**Coefficient 2**
Frozen products	Pareto	8.02	10.83
Flour products	Log logistics	0.53	1.03
Ice products	Burr	0.84	2.11
Meat products	Burr	0.89	1.81
Milk products	Pareto	8.02	10.83
Pasta products	Log logistics	0.56	0.99
Spices	Log normal	0.56	0.99

Food quality

The food quality is evaluated by following the same approach as Fikar (2018) developed in an agent-based model (Fikar, 2018), (Waitz *et al.*, 2018). The approach uses Tijksens and Polderdijk (1996) generic shelf life model (Tijskens and Polderdijk, 1996).

$$k_i = k_{ref} * e^{\frac{Ea}{R}*\left(\frac{1}{T_{ref}}-\frac{1}{T}\right)} \tag{1}$$

i – index of evaluated product's shelf life
k – spoilage rate in days
T – temperature in Kelvin
k_{ref} – spoilage rate at reference temperature T_{ref} which is equal to 1
Ea – energy activation
R – gas constant

$$KQ_i = \frac{Q_0 - Q_L}{k} \tag{2}$$

KQ – remaining shelf life
Q_0 – current quality
Q_L – quality limit

Reference temperature T_{ref} is equal to 283.15 K (or 10 ^{0}C). Energy activation and gas constant ratio $(\frac{Ea}{R})$ is set to 12067.5 based on the average value of the table as presented by Tijskens and Polderdijk (1996). Spoilage rate (k_{ref}) is equal to 1. Current quality Q_0 of product is equal to 1. Q_L quality limit is equal to 1 day. The storage temperature of products in the fulfilment centre is equal to 283.15 K, while the storage temperature within delivery is equal to 277.15 K. Remaining shelf life KQ is reduced by 1 for each day, assuming linear kinetics.

The simulation does not include harvesting and food processing stages, therefore, it is assumed that 40% of the food quality is lost at the initial stage, and only 60% reaches the distribution center (Food and Agriculture Organization, 2011). Since the simulation uses generic products and does not distinguish between categories, we assume that the average shelf life is equal to 5. Therefore, the shelf life of the product once in the distribution center will have already lost 40% of its initial shelf life, therefore, the reference shelf life (KQ_{ref}) would be equal to 3 days. Therefore, if the deliveries are made late and if the product reaches the end-consumer when the remaining shelf life is 1 day, then the product is considered as food waste. In an organic food market, the consumer desires high quality food, therefore, this criterion is made to provide for higher consumer satisfaction. When a product is returned back to the fulfilment centre due to disruptions, the next day we ignore the product which could not be delivered on time before being assigned as waste and instead select the other product by following the first-expired-first-out (FEFO) rule (Waitz *et al.*, 2018).

Disruptions

Some researchers might argue that daily disruptions do not influence the efficiency of the system as much as major forces majeures. However, Calvert and Snelder (2018) indicate that minor disruptions in the traffic and transport systems can also play an important part in reducing efficiency (Calvert and Snelder, 2018). In the case of this simulation, disruptions are defined as traffic accidents and jams which cannot be overseen from regular data analysis. The traffic flow statistics are used from the traffic grid model which is included in NetLogo (Wilensky, 2003). The number of cars running in the city is set at 50% of the market size. Then, the speed of the traffic is reduced by 64% between 8:00 AM and 9:00 AM, and reduced by 68% between 5:00 PM and 6:00 PM (Tomtom, 2018).

Table 13. Traffic accident level

Cluster ID	Traffic accident	Vehicles involved	Probability per conjunction	Reduction to speed	Accident duration (min)
0	Low	Less than 4	0.000628	15%	60
1	Low	Less than 4	0.000596	15%	60
2	High	Less than 4	0.000008	70%	150
2	Medium	Less than 4	0.000128	30%	90
3	High	More than 4	0.000004	85%	180
3	Medium	More than 4	0.000006	65%	120
3	Low	More than 4	0.000046	30%	90

Table 13 represents traffic accident levels which are derived from the UK traffic accident statistics (Department of Transport, 2017). The higher is the intensity, the higher is the reduction in speed. The probabilities are derived from the analysis of the UK traffic accident statistics of the 2009–2014 period by considering only the London region. The statistics provides an evaluation of the traffic severity whose scale is a categorical variable from 1 to 3, where 1 is a fatal condition and 3 is slight. In our case, the severities are related to the intensity level of low, medium and high. Then, the statistics provides the number of vehicles involved in the accident, and the threshold level is estimated to be more than 4 vehicles involved in the accident or less. Afterwards, the accident statistics of the London region was clustered by using the k-mean algorithm, and, with the elbow method, the optimal number of clusters was determined. Then, the frequency of events in every cluster group were evaluated. The conjunction quantity of the accident statistics was determined by using the DBSCAN algorithm with the haversine metric and 100 meter radius. Then, the influence of these disruptions to speed was evaluated by analyzing the Finnish transport agency analysis results (Finnish Transport Agency, 2014). Lastly, the probabilities per conjunctions were increased by 2% because the traffic conflict increases with an increase in the traffic density (Wang, Zhou, Quddus, Fan, and Fang, 2018). The conjunction is assigned to a cluster with a specific accident probability (see Table 14).

Table 14. Probability of conjunction assignment to cluster

Cluster ID	Conjunctions quantity	Probability
0	7941	0.384
1	8916	0.324
2	10567	0.289
3	60	0.002

For every tick, each conjunction will have a probability based on the traffic accident level in order to change its state to the level once it changes the state, and the following cars driving through the conjunction will be affected by the speed reduction for a fixed amount of time. In reality, the whole traffic should stop and try to overtake the congestion, but, in this case, the speed will be reduced, which will affect all the cars behind thus making a ripple effect across the network.

Route scheduling approaches

The model initially uses the principal rules to define the main processes of ordering and delivery. Then, the environment is reproduced as a city with a traffic flow and accidents. Figure 33 provides a brief explanation of the importance of information sharing and the possibility to estimate traffic jams. In this part, a mathematical expression of the route scheduling approach shall be elaborated.

Traditional truck approach

At the beginning, two grids representing the suburban region and the urban region shall be generated. In the suburban region, we create a fulfilment centre and connect it with a road to the urban region. The size of the urban region is generated based on the selected market size. Currently, there is a tendency to focus on decentralized warehouse networks and to place hubs in urban areas, but, in our case, we want to show how it is possible to achieve effectiveness through information sharing by minimizing costs. Of course, for increased customer satisfaction, pick-up places in the city may be allocated. Further, we allow the traffic to flow freely in the region denoted by disruptions, but without any deliveries. We run this simulation for 3 days and evaluate the average speed per patch for every hour. By doing this, we obtain a graph (G) with households, fulfilment centres and intermediate stops with averaged times between neighboring stops at each hour. Afterwards, we re-evaluate the graph to fit only households and fulfilment centres by the time traveled for every hours and obtain a set of nodes RN. By using the initial simulation results, we construct the graph time traveling matrix as an approximation function set which represents the traveling time between the graph nodes at a specific time (see Formula 5).

$$RNM = \begin{bmatrix} f(RN_{1,1}, t) & \dots & f(RN_{1,n}, t) \\ \dots & \dots & \dots \\ f(RN_{n,1}, t) & \dots & f(RN_{n,n}, t) \end{bmatrix} \tag{5}$$

where function $f(RN_{i,j}, t)$ returns the traveling time from the i-th node to the j-th node at time t.

This way, we are representing the practice that is currently being used – companies analyze historical traffic data and plan their routes based on the obtained values. Then, we receive orders from households which consist of the order size and the selected 2-hour delivery time window between 8:00 AM and 18:00 based on multimodal distribution. We determine the truck number by considering the maximum number of customers served per truck (maximum customers: 25) and order information as well as the obtained traveled time. In this case, we are not specifying capacity constrains based on weight or product quantity, but rather on customers served since the online grocery industry does not commonly involve large weights. Then, by considering the truck quantity, the delivery time window and the obtained graph, we make the final schedules (*SH*) for every truck. The algorithmic approach is based on large neighborhood search for the pickup and delivery problem with time windows (PDPTW) (Emeç *et al.*, 2016), (Rong *et al.*, 2011), (Osvald and Stirn, 2008). The final schedule evaluation E for the traditional truck approach is described as the remaining shelf life of the household orders which depends on the storage duration and delivery duration (see Formula 6).

$$\mathrm{E} = \sum_{i=1}^{|\mathrm{HO}|} KQ_{HO_i} \tag{6}$$

Here, $|\mathrm{HO}|$ is the amount of the set of scheduled Household orders HO where KQ_{HO_i} represents the value of the remaining shelf line indicator (see Formula 2).

When the routes have been planned, we evaluate the food quality, food waste and emission levels and save them as the planned indicators. The deliveries in our situation must be made from 8:00 AM to 18:00, as afterwards the trucks are returned back to the fulfilment centre, and the products that were not delivered on time are sent back to the fulfilment centre. During the storage and transportation time, the quality of products is constantly decreasing and is therefore being measured. This assumption is made because the inventory management strategy is always the same, and the optimization approach changes only for deliveries. During the next day, products which will have expired before the start of the delivery time window are ignored during this selection, and other items are selected based on the first-expired-first-out (FEFO) rule (Waitz *et al.*, 2018).

During this process, we also evaluate the number of trucks and their utilization, i.e., the percentage of customers served per truck and the saving of the food quality as well as food waste levels as the actual indicators, while final actual evaluation E_a of the traditional truck approach is expressed as

$$\mathrm{E}_a = \sum_{i=1}^{|\mathrm{AHO}|} KQ_{AHO_i} \tag{7}$$

Here, $|\mathrm{AHO}|$ is the amount of the set of the actually served Household orders $\mathrm{AHO} \subseteq \mathrm{HO}$.

Autonomous truck approach

The autonomous truck approach uses the idea that trucks share the information of the current situation of the traffic, etc., and, by learning the historical data, they can take better decisions and thus improve the results obtained by the autonomous approach which are expressed in Formula 8. Of course, the best option for the minimizing of the food waste level would be to reschedule the trip at the current time 'in traveling' when the deviation of the scheduled time of the initial planned routes is detected, and, based on it, the appropriate decisions are made. Yet, in this publication, we want to show that even at the initial stage of planning, the truck schedules are constructed with information sharing, and that learning of the historical data could provide better results regarding the food quality level. Thus the idea could be expressed as the maximization of the target function which is used for the actual evaluation of the traditional truck approach (see Formula 8).

$$\max_{\{P\}} \mathrm{E}_a = \sum_{i=1}^{|\mathrm{AHO}|} KQ_{AHO_i} \tag{8}$$

Here, the additional parameters $\{P\}$ are added which are used to control the route scheduling process in order to get the optimal value of E_a. The parameters under analysis are the ones which influence the total system food quality level. For example, a particular order has specific parameters at the planning stage whose combination can produce different levels of food quality for this particular order and also for the entire system. The combination of parameters we choose presume the evaluation of the difference between the planned food quality and the actual quality. These parameters consist of the delivery interval, the order size category, the distance to the delivery point, the sequence of the delivered orders, etc. Hence, as the value or the average of E_a could be obtained only after simulation, some learning approach is necessary for the selection of the optimal parameters. The problem of the determination of the optimal combination of parameters could be denominated as the route scheduling optimization process based on historical data, where similar optimization problems of another route were encountered (i.e., the shortest path, the traveling salesmen problem TSP, etc.); here, the target function represents the food quality. In the literature, many approaches can be found towards solving similar problems, such as the citywide crowd flows prediction (Zhang, Zheng, and Qi, 2016), where a deep-learning-based model for forecasting the flow of crowds in the regions of a city based on the historical trajectory data, weather and events has been made. Here, the target function is expressed as an evaluation of the root mean square error of difference between the predicted and the actual data. In (Bello, Pham, Le, Norouzi, and Bengio, 2016), the paradigm of reinforcement learning and neural networks was combined to obtain the optimal value of the traveling salesman problem, where the parameters of the traveling salesman problemsolver were obtained in the course of the learning process. In (Hasselt, Guez, and Silver, 2016), it was shown that the policy of the sequence of action could be learned by using deep neural networks. In this work, the general scheme for the process of the autonomous truck approach is presented in Figure 32.

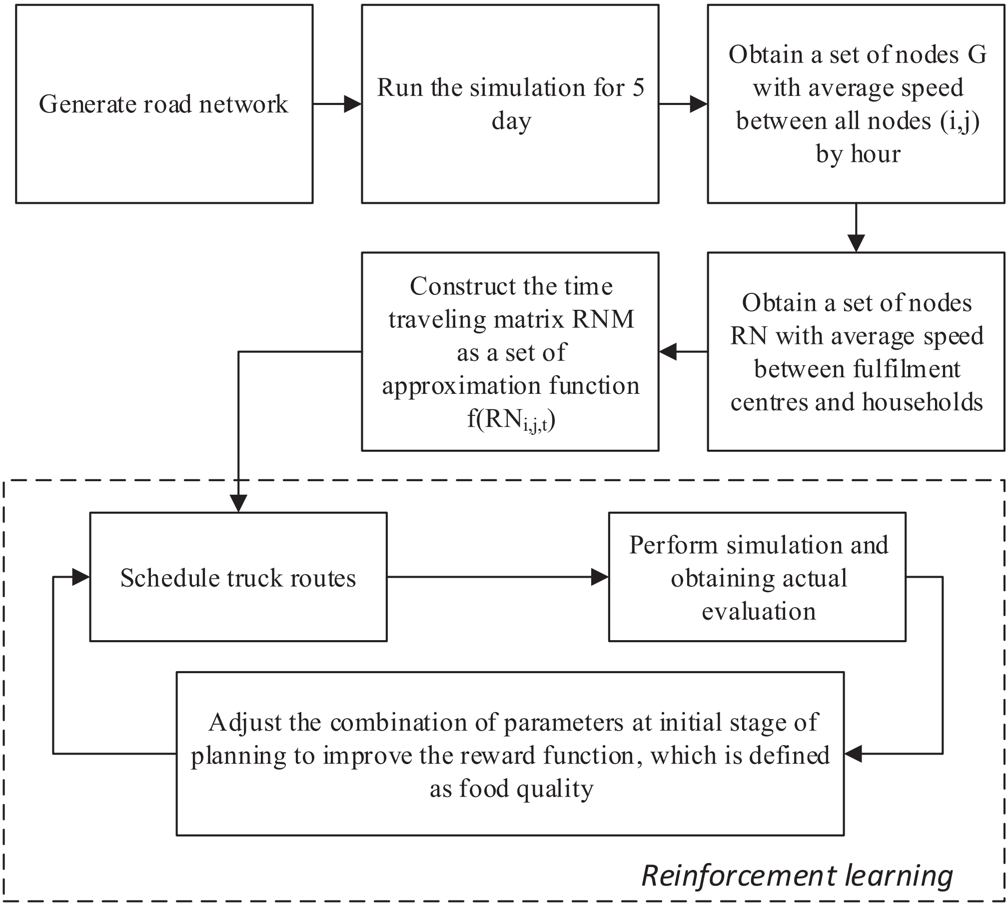


Fig 32. Route scheduling process of an autonomous truck

2.3.2. Results of the Flexibility approach

A constant random seed is set to maintain the variability in the model, and only different scenarios influence the output of the model. This way, the main environment variables are constant, and only the analyzed variables are changed (*ceteris paribus*). One simulation scenario was run for 67,500 ticks (or 10 days) by considering that all deliveries can be made from 8:00 AM till 7:00 PM. The model output results are presented in Tables 15–17.

Table 15. Model output indicators of traditional trucks based on social sustainability perspective

Scenario	Traditional trucks							
	Food quality				Food waste			
	Planned		Actual		Planned		Actual	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	84647	27967	78097	30240	14673	10679	18226	12877
2	83596	31737	77091	33900	15515	12476	18926	14820
3	84413	29522	77474	31422	15257	11101	19047	13260
4	86666	27767	79356	30851	14975	10287	19181	12996
5	25484	2556	25000	2383	188	120	272	163
6	23726	3079	23310	2788	232	126	301	156
7	31046	2091	29544	1766	507	322	1154	981
8	31568	1813	30475	1408	514	379	909	642
9	48944	10488	45338	11268	4634	3222	6300	3986
10	49186	9253	45940	9780	4489	2941	5992	3262
11	48841	10122	45040	11162	5071	3038	7006	4066
12	47739	10531	45006	10963	5152	3109	6382	3792
13	13182	1577	13118	1575	81	85	95	80
14	12598	1256	12308	1240	95	70	182	213
15	15629	1348	15527	1265	181	133	203	163
16	15413	1178	15230	1166	146	90	214	170

Table 15 represents the food quality and waste output for the traditional truck approach. When comparing the large market type of the oligopoly market type, it can be seen that, on average, the actual food quality is lower by 6,826 when comparing the actual value to the planned one, while the perfect competition is lower by 873.8, or by 8.8% and 3.3%. When comparing the food waste difference, it can be seen that in a large market of the oligopoly market type, the food waste level is on average higher by 3,740, while in the perfect competition market type the difference is 298.8, or 19.85% and 45.3%. When comparing the small market type of the oligopoly market type, the average food quality difference is 347, and for the perfect competition market type it is 150.8, or 7.4% and 1.1%. Meanwhile, the food waste difference is 1,584 and 47.8, or 24.7% and 27.5%.

Table 16. Model output indicators of autonomous trucks based on social sustainability perspective

Scenario	Autonomous trucks							
	Food quality				Food waste			
	Planned		Actual		Planned		Actual	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1	78383	29668	76836	30555	17840	12302	18884	13052
2	81400	27936	80674	28473	16697	11217	17132	11636
3	81417	26914	80163	27121	18158	11040	18975	11306
4	79270	28993	77956	29849	18156	11804	18997	12523
5	22785	2868	22548	2951	619	515	737	551
6	23971	2172	23824	2158	248	169	288	150
7	30827	1564	30687	1590	782	541	829	555
8	30876	2014	30519	1987	772	631	953	665
9	46746	9837	45901	9926	6163	3201	6586	3440
10	46030	9590	45553	9702	5405	2816	5640	2861
11	43828	11475	43262	11762	6297	4054	6578	4279
12	46362	10141	45451	10259	5871	3127	6359	3301
13	12081	1141	11989	1212	87	90	116	92
14	12006	1426	11903	1526	333	437	392	465
15	14921	1135	14810	1132	649	580	698	609
16	15242	1349	14947	1408	587	434	737	440

Table 16 represents the food quality and waste output for the traditional truck approach. When comparing the large market type of the oligopoly market type, it can be seen that, on average, the actual food quality is lower by 1,210 when comparing to the planned level, while the perfect competition is lower by 220.3, or by 1.5% and 0.8%. When comparing the food waste difference, it can be seen that in a large market of the oligopoly market type, the food waste level is on average higher by 784.3, while in the perfect competition market type it is higher by 701.8, or by 4.3% and 13.8%. When comparing the small market type of the oligopoly market type, the average food quality difference is 699.8, and the perfect competition market type difference is 150.3, or 1.6% and 1.1%. Meanwhile, the food waste difference is 356.8 and 81.5, or 5.7% and 16%. To compare the traditional trucks and autonomous trucks, a more absolute metric is needed.

Table 17. MAPE by main model scenarios, food quality and waste of the actual and planned values

Scenario	Traditional trucks		Autonomous vehicles	
	Food quality	**Food waste**	**Food quality**	**Food waste**
1	9.49	23.65	2.70	5.08
2	10.10	21.70	1.23	1.81
3	10.04	25.50	1.78	4.82
4	10.46	28.20	2.33	3.61
5	1.85	50.07	1.09	20.29
6	1.64	34.18	0.61	89.13
7	4.69	115.61	0.46	6.09
8	3.38	81.02	1.17	37.59
9	7.75	37.28	1.88	6.09
10	6.75	48.09	1.10	4.49
11	8.46	38.45	1.54	3.42
12	6.14	23.79	2.08	8.47
13	0.48	1134.11	0.81	124.64
14	2.22	66.39	0.95	22.06
15	0.61	8.29	0.76	8.74
16	1.18	35.74	1.97	41.79

Table 17 shows the absolute percentage error (MAPE) of the traditional and autonomous trucks. It can be seen that, in the majority of cases, the food quality and waste levels are lower in the case of autonomous trucks. Traditional trucks are more beneficial in cases where there is a small market with fewer households and orders, however, in larger scenarios, autonomous trucks are more beneficial. When comparing the MAPE of autonomous trucks by consumer integration, it can be seen that, in some cases, the food quality level is better optimized with the loyal consumer behavior rather than with the random one. Some scenarios might involve a higher metric of random behavior because of the stochasticity of the model. In several scenarios, the food waste MAPE indicator is extremely high when compared to other indicators. These cases are encountered in small markets, or in the perfect competition market type. When planning routes, virtually all the products should be delivered, however, during the actual delivery, multiple orders are not fulfilled, thus the food waste increases slightly, yet, when compared to the planned food waste levels, the percentage difference is huge. In such cases, it is better to compare food quality levels rather than food waste.

2.4. Simulation of the Redundancy Approach for Sustainable Food Industry

2.4.1. Methodology of the Redundancy Approach

This chapter presents the redundancy approach simulation which has been published previously (Gružauskas *et al*., 2019).

In order to identify the influence of information sharing on the forecasting accuracy, an agent-based model has been created. The data has been gathered from 5 companies involved in the FI. The companies provided us with their daily sales history from June 2014 until June 2017, while covering 7 product categories and 838 products with empirical data distributions representing market fluctuations. Firstly, a histogram of the data was generated, and possible distribution functions were hypothesized. For each distribution, the characterizing parameters are estimated, and the goodness-of-fit test is performed. Finally, the best distribution is chosen. The empirical data fitted distributions were generated with R code 3.3 version, R package *fitdistrplus* (Delignette-Muller and Dutang, 2015). The model included 16 scenarios in total and was made with NetLogo 5.3.1 and the integration of extension R. The predictions were made by using the machine learning approach, specifically, the extreme learning machine (ELM) algorithm for fast hidden layer computation (Ding, Zhao, Zhang, Xu, and Nie, 2015).

The agent-based model consists of 5 steps. At the beginning, the historical data is generated to allow the learning machine to train. In the first step, the distributor receives the delivery from the supplier. In the second step, the household selects the demand from the fitted distribution functions. The distribution functions represent seven product category trends which are randomly selected by the individual household each day. Then, the generated ratio of the distribution function is multiplied by the product quantity which is used to simulate the different sizes of households. Additional distribution functions with zero demand are provided, which simulates the perfect competition market type, i.e., consumers buy products from companies not involved in the logistic cluster. During the next step, the distributor sends the order to the household. Later, the distributor forecasts the demand based on the individual company history or group. The forecasting is accomplished by using ELM which is retrained every day based on the past history. In the last step, the distributor sends the order to the supplier, and everything is repeated again.

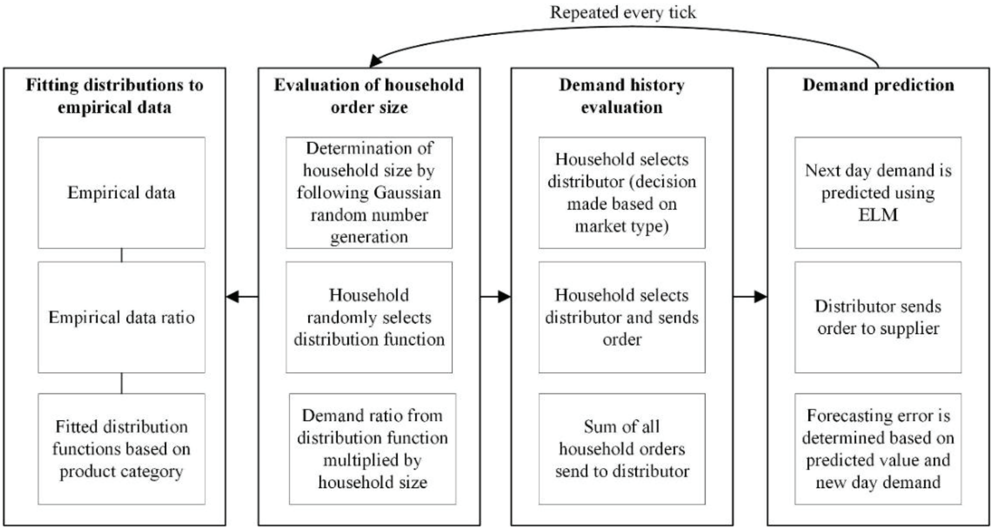


Fig. 33. Data generation and prediction in the agent-based model

Figure 33 illustrates the data generation and prediction approach. The limitation of the model stems from the lower complexity of the farmer-and-distributors type. Nevertheless, we believe that considering small-scale farmers ensures that its use remains appropriate for simulating the online grocery shopping industry. In addition, the agent-based model focuses on urban logistics operations and does not consider farming operations, i.e., it analyzes short-term forecasting. In addition, the model focuses solely on information sharing and demand analysis, but not on transportation methods. Therefore, a generic approach to product management was chosen instead of the precise product category.

Another limitation of the model is the usage of the distribution functions in the simulation instead of direct empirical data. The data from different companies was not perfect for the context of our research, therefore, the distribution function fitting was chosen instead of implementing the empirical data fitting into the model (the interpolation of the data would have skewed the demand seasonality trend). Distribution probabilities fitting to empirical data is a common practice in simulation models (Longo, 2011). The fitted distribution functions decrease the resemblance of market seasonality, however, in this publication, the goal is to determine the behavior of collaborative demand forecasting in different contingencies. These contingencies are constant (*ceteris paribus*), and the demand fluctuation approach is always the same (based on distribution functions with the constant random seed), and therefore the fitted distribution function approach does not reduce the validity of the results.

The final limitation of the model is that it focuses on the food waste problem more from the management science perspective rather than from the aspect of food technologies. For example, there are several researches which were done while focusing on the identification of the relationship between the food quality and the nutrition level between the delivery time and the storage time (Managa *et al*., 2018), (Fikar, 2018), (Waitz *et al*., 2018). In the case of this research, we assume that better alignment of the demand and the supply will optimize the inventory level. The benefits are identified through forecasting accuracy and do not directly consider the food quality, however, the relationship between the improved inventory level and the food waste and nutrition is clear.

In general, there are three ways how a theory can be developed. One type is deductive reasoning which starts from a statement and then moves towards empirical evidence. Another type is inductive reasoning which starts from empirical evidence, and then a theory is developed from the results. The final way is the use of the generative approach which employs the primary rules and generates data, from which a theory can be developed (Jackson, Rand, Lewis, Norton, and Gray, 2017). In our thesis, we shall use the generative approach with an intention to develop an in-depth theoretical methodology for the future research. An agent-based model is often used in social sciences for particularly this reason. An agent-based model consists of agents, interaction between agents and the environment. In our case, we prepared a food supply chain model based on distribution functions which are fitted on empirical data.

The provided model works with two agents representing an e-commerce supply chain. Firstly, households fill in the position of the end-consumer sending an order to the distributor. The order is selected from the fitted distributions from the data gathered by the company. The fitted distributions are ratio coefficients following the fluctuations of the market. Subsequently, the product (i.e., the quantity) is multiplied by the ratio. This approach simulates the variation in household sizes. Within the scope of our model, households are the less complex of the two agents, with only 3 main variables representing the order to a distributor, the selected distribution type from the fitted distributions, and the product quantity (or the household size). The second, more complex, agent with multiple variables is the distributor who receives orders from the households, controls the inventory level, and orders products from the suppliers with a one-day delay; i.e., the distributor is responsible for deciding how much to order from the supplier, for storing the incoming orders from the households, and for measuring the inventory levels as well as the backlog. Orders from suppliers are not differentiated, only the total sum of them is analyzed. One of the main principles of the agent-based model is to keep the model simple with the aim to identify the main relationship; it is not necessary to reproduce the reality completely. The model also allows verifying the quantity of households and distributors. In this case, we vary only the quantity of distributors, while the number of households will be set to 100 for each distributor in the model.

In order to identify the relationship between information sharing and demand forecasting, we shall simulate the primary operations of the supply chain in the model which is expected to describe the interaction between distributors and households (see Fig. 34)

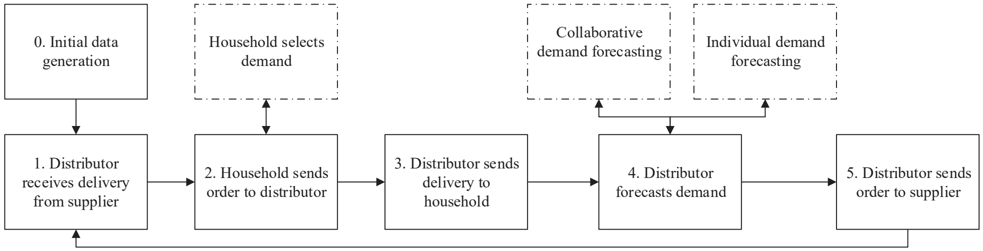


Fig. 34. Agent-based model process

Initial data generation

In order to use the machine learning approach, the first step must be data collection. During this step, households' orders, inventory levels and sales histories are generated for all agents.

Distributor receives delivery from supplier

The next step is receiving the order from the supplier. In this case, the received order is based on the previously generated initial data. The current available inventory for distributor k at time t is calculated by adding up the order from the supplier and the current available inventory (see Formula 9).

$$AI_{k,t} = AI_{k,t-1} + OFS_{k,t} \tag{9}$$

$AI_{k,t}$ – Available inventory of distributor k, at time t
$AI_{k,t-1}$ – Available inventory of distributor k, at time t-1
$OFS_{k,t}$ – Order from the supplier of distributor k, at time t

Household sends order to distributor

During this step, a household selects a fitted distribution based on empirical data. The data was gathered from 5 food companies which represent 7 product categories and 838 products. The distributions have been fitted by using *tdistrplus* package in R (Delignette-Muller and Dutang, 2015). The model package analyzes pareto, log logistics, Burr and log normal distributions to the data. The distribution selections are made by choosing the Goodness-of-fit statistics. Selected distributions are represented in Table 18.

Table 18. Fitted distribution functions based on empirical data

Product category	**Distribution**	**Coefficient 1**	**Coefficient 2**
Frozen products	Pareto	8.02	10.83
Flour products	Log logistics	0.53	1.03
Ice products	Burr	0.84	2.11
Meat products	Burr	0.89	1.81
Milk products	Pareto	8.02	10.83
Pasta products	Log logistics	0.56	0.99
Spices	Log normal	0.56	0.99

After households have selected the distribution functions, the product quantity is determined by using a Gaussian random number generator (integer from 1 to 10). This number is then used to simulate different sizes of households. Since the distributions represent the ratio between days and their frequency, the household order of a specific agent in time t is calculated by multiplying the product quantity by the ratio (see Formula 10).

$$HO_{n,t} = PQ_{n,t} * DF_{n,j=1:7\ or\ j=1:28} \tag{10}$$

$HO_{n,t}$ – Order of household n, at time t

$PQ_{n,t}$ – Product quantity of household n, at time t

DF_j – Distribution function ($j \in 1 \dots 28$) of household n which depends on the market type

In the case of the perfect competition market type, households might select a distribution which will request to order 0. This case simulates the possibility for the household to purchase products from distributors not included in the model. These scenarios shall be discussed in more detail further.

$$DDH_{k,t} = \sum_{n}^{t} HO_{n,t} \tag{11}$$

$DDH_{k,t}$ – Demand history of distributor k, at time t

$HO_{n,t}$ – Order of household n, at time t

Lastly, the household orders are saved to the distributor demand history (see Formula 11).

Distributor sends delivery to household

In the next step, we calculate the available inventory levels of distributor k at time t (see Formula 12) while determining if there is enough stock to fulfill the demand. If there is not enough stock, the backlog is evaluated (see Formula 13).

$$AI_{k,t} = AI_{k,t-1} - \sum_{n}^{t} HO_{n,t} \tag{12}$$

$AI_{k,t}$ – Available inventory of distributor k, at time t

$AI_{k,t-1}$ – Available inventory of distributor k, at time t-1

$HO_{n,t}$ – Order of household n, at time t

$$if\ (AI_{k,t} < 0)\ Then: B_{k,t} = |\mathrm{AI}_{k,t-1} - \sum_{n}^{t} HO_{n,t}| \tag{3}$$

$B_{k,t}$ – Backlog level of distributor k, at time t

$A\mathrm{I}_{k,t-1}$ – Inventory level of distributor k, at time t-1

Distributor forecasts demand

This step considers the information sharing aspect of the model. An extreme learning machine (ELM) algorithm (Ding *et al*., 2015) is used to make predictions based on the previous distributor demand history or the previous group demand history. The algorithm functional expression is indicated in Formula 14.

$$\hat{y}_{k,t} = W_2 \sigma(W_1 x_{k,t}) \tag{14}$$

W_1 – Matrix of Gaussian random noise weights

σ – Activation function of Sigmoidal

W_2 – Output weight matrix

$\hat{y}_k$ – Demand forecast of the distributor

x – Time series of demand history of distributor k, or, in the group demand, collaboration group demand history

The sales history is multiplied by a randomly selected weighted matrix whose output optimally represents the input data. The initial weights are selected by following a sigmoidal function. The selection of the weights takes an iterative approach to determine the optimal ones. This approach is used to evaluate the hidden layers of the neural network. The process is virtually the same in the case of information sharing, with the addition of the distributor information.

Distributor sends order to supplier

After forecasting the results, the distributor must send the order to the supplier since there is a one-day delay in delivery. The order to the supplier for distributor k, at time t, depends on the available inventory level (see Formula 15) which is based on the decision rule (see Formula 16).

$$OTS_{k,t} = AI_{k,t} - F_{k,t} \tag{15}$$

$OTS_{k,t}$ – Order to supplier of distributor k, at time t

$F_{k,t}$ – Forecasted demand of distributor k, at time t

$AI_{k,t}$ – Available inventory of distributor k, at time t

$$\begin{aligned} &if\ \left(AI_{k,t} - F_{k,t} < 0\right) Then{:}\ OTS_{k,t} = F_{k,t} - AI_{k,t} \\ &Else{:}\ OTS_{k,t} = 0 \end{aligned} \tag{16}$$

Since the model does not consider the capacity limitations of farmers, the backlog level (if it exists) is added (see Formula 17).

$$if\ (B_{k,t} > 0)\ Then{:}\ OTS_{k,t} = F_{k,t} - \mathrm{AI}_{k,t} + B_{k,t} \tag{17}$$

$B_{k,t}$ – Backlog of distributor k, at time t

$OTS_{k,t}$ – Order to supplier of distributor k, at time t

$F_{k,t}$ – Forecasted demand of distributor k, at time t

$A\mathrm{I}_{k,t}$ – Available inventory level of distributor k, at time t

Model scenarios

While the previous research analyzes collaborative demand forecasting from the algorithm perspective, it does not consider management criteria which are essential in order to develop a proper logistic cluster methodology. Therefore, we have created 8 scenarios (see Table 19) which are then bound to be used for both market types (oligopoly and perfect competition), thus, in total, we develop 16 scenarios.

Table 19. Scenario description

Scenario	**Market size**	**Market type**	**Consumer integration**
1	Large market	Oligopoly	Loyal
2	Large market	Oligopoly	Random
3	Large market	Perfect competition	Loyal
4	Large market	Perfect competition	Random
5	Small market	Oligopoly	Loyal
6	Small market	Oligopoly	Random
7	Small market	Perfect competition	Loyal
8	Small market	Perfect competition	Random

The first variable differentiating between the scenarios is information sharing which distinguishes between demand forecasting from an individual company's history and the group company history. The second criterion is the market size represented by the quantity of distributors and households. The small market size is set to 2 distributors and 200 households. The large market size is represented by 4 distributors and 400 households. The exact numbers do not make any difference because the essential part is the presence of influence on each other rather than the precise coefficients of influence. Finally, the consumer integration scenario is introduced so that to identify the difference in promotional strategies which can help to stabilize the market fluctuation and provide more resilience to the supply chain. The scenarios are then distinguished by the market type. The oligopoly market type represents a small market with only a few sellers, whereas the perfect competition market type represents a large market with multiple sellers. The market type also highlights the need for consumer integration. The categorical representation of the selected scenarios is presented in Table 20.

Table 20. Variable description

Variable	**Category**	**Value**
Information sharing	Collaborative forecasting	1
	Individual forecasting	0
Market size	Small market size	1

	Large market size	2
Market type	Oligopoly	1
	Perfect competition	2
Consumer integration	Consumer buying behavior is random	1
	Consumers select a particular distributor	0

In order to provide a proper logistics cluster development and management methodology, it is necessary to analyze the forecasting accuracy in these different scenarios. The methodology developed in this way would be much better suited to the current business environment.

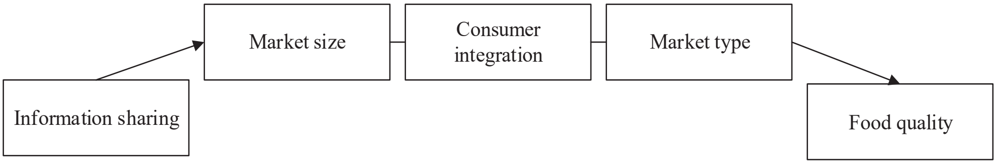


Fig. 35. Research question

Figure 35 illustrates the main question of the flexibility approach which will be defined as: what is the relationship between information sharing and food quality while mediating the market size, the market type and the consumer integration in a dynamic environment?

The forecasting accuracy in these different scenarios is evaluated by calculating the difference in percentages between the real market demand and the forecasted value (see Formula 18).

$$e_t = y_t - \hat{y}_{(t|t-1)} \tag{18}$$

e_t – Forecast error
y_t – Demand at time t
$\hat{y}_{(t|t-1)}$ – Forecasting result based on the previous history on time t

Based on the forecasting error, the mean absolute percentage error (MAPE) will be calculated by following Formula 19. Additionally, the standard deviation will be evaluated in order to identify the collaborative demand effectiveness more accurately in different contingencies.

$$MAPE = \frac{100}{n} \sum_{t=1}^{n} \left| \frac{y_t - \hat{y}_{(t|t-1)}}{y_t} \right| \tag{19}$$

y_t – Demand at time t, $\hat{y}_{(t|t-1)}$ – Forecast on time t, n – Total measurement size

2.4.1. Results of the Redundancy approach

An agent-based model is a stochastic model with probabilistic variables which are based on distribution functions fitted on empirical data. For the model to produce accurate results, 10 repetitions simulating 365 days were done for each scenario. The primary descriptive statistics of the demand accuracy based on the scenarios are represented in Table 21.

Table 21. MAPE comparison by level of information sharing and scenarios (%)

Scenario	Collaborative demand forecasting	Individual demand forecasting
	Mean±SD	**Mean±SD**
1	51.39±0.68	48.52±2.50
2	48.54±0.79	48.45±1.69
3	49.58±0.56	55.00±2.56
4	56.71±3.26	57.70±1.28
5	56.32±1.37	52.84±1.62
6	54.06±1.47	53.91±1.36
7	48.63±1.63	49.93±0.50
8	47.66±1.27	54.88±0.52

In general, the MAPE value is lower in the oligopoly market since this market involves fewer sellers. Therefore, one can assume that, in a small market, where demand fluctuation is lower, or where it is possible to involve a larger share of distributors in the logistic cluster, the demand accuracy is smaller. When it comes to comparing different scenarios within the oligopoly market type, the collaborative forecasting accuracy is lower in the scenarios that include information sharing. A similar situation can be observed when comparing information sharing in the perfect competition market type. Therefore, group demand forecasting reduces the forecasting accuracy. The small market size has a tendency to have a lower MAPE value when compared with the oligopoly market type. However, a larger market size shows a smaller forecasting error in the perfect competition market type. Scenarios with consumer integration in the oligopoly and the perfect competition market type show a smaller forecasting accuracy error, therefore, promotions and intensive programs can also influence lower demand forecasting.

We have used correlation analysis in order to determine the influence of information sharing on the forecasting error when taking into account such factors as the market size, the market type and consumer integration (see Table 22).

Table 22. Forecasting correlation analysis by category

Category	Sub-category		Individual			Collaborative	
				Total demand			Total demand
Market size	Large market size		**Forecast**	0.48		**Forecast**	0.47

	Small market size			0.67			0.69
Market type	Oligopoly		**Forecast**	0.16		**Forecast**	0.13
	Perfect competition			0.17			0.16
Consumer integration	Loyal		**Forecast**	0.6		**Forecast**	0.7
	Random behavior			0.67			0.6

In the first part, the correlation was determined by the variables relating to the distributor representing the demand history, forecasting values, and the forecasting error. The correlation is made with categorical variables of different categories (see Table 13). Our results show that a smaller market correlates with a smaller forecasting error. There is only a small difference in results between the different market types. Lack of consumer integration correlates with the lower demand accuracy.

When it comes to information sharing, the results are similar when comparing different market sizes and market types. However, an interesting finding is that the consumers who are more integrated are associated with a lower forecasting accuracy, which seems rather counterintuitive.

We also conducted in-depth analysis of the influence the market size has on the forecasting error. Our results show that there is indirect correlation between the market size and the forecasting error, i.e., the smaller oligopoly market reported a higher forecasting error, and the larger perfect competition market was associated with a smaller forecasting error.

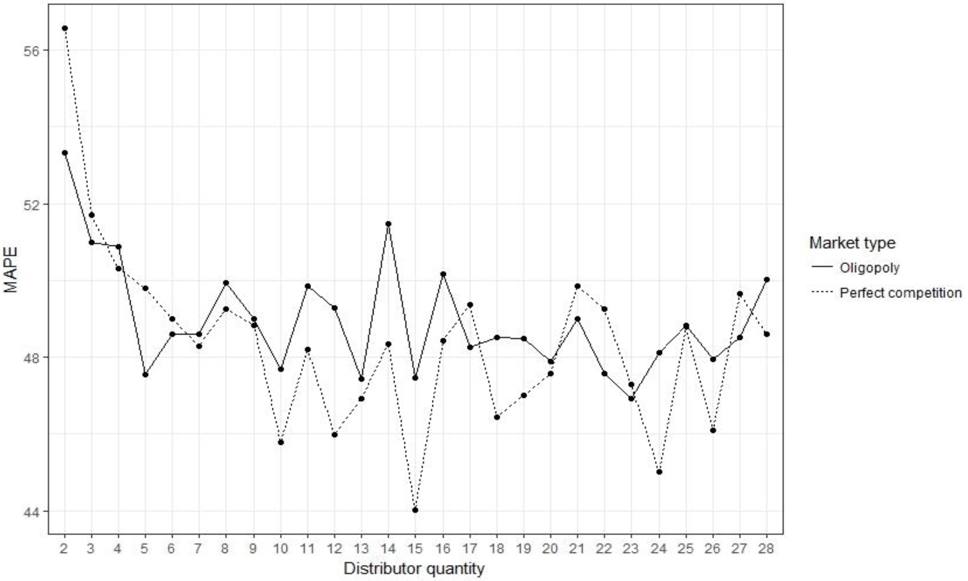
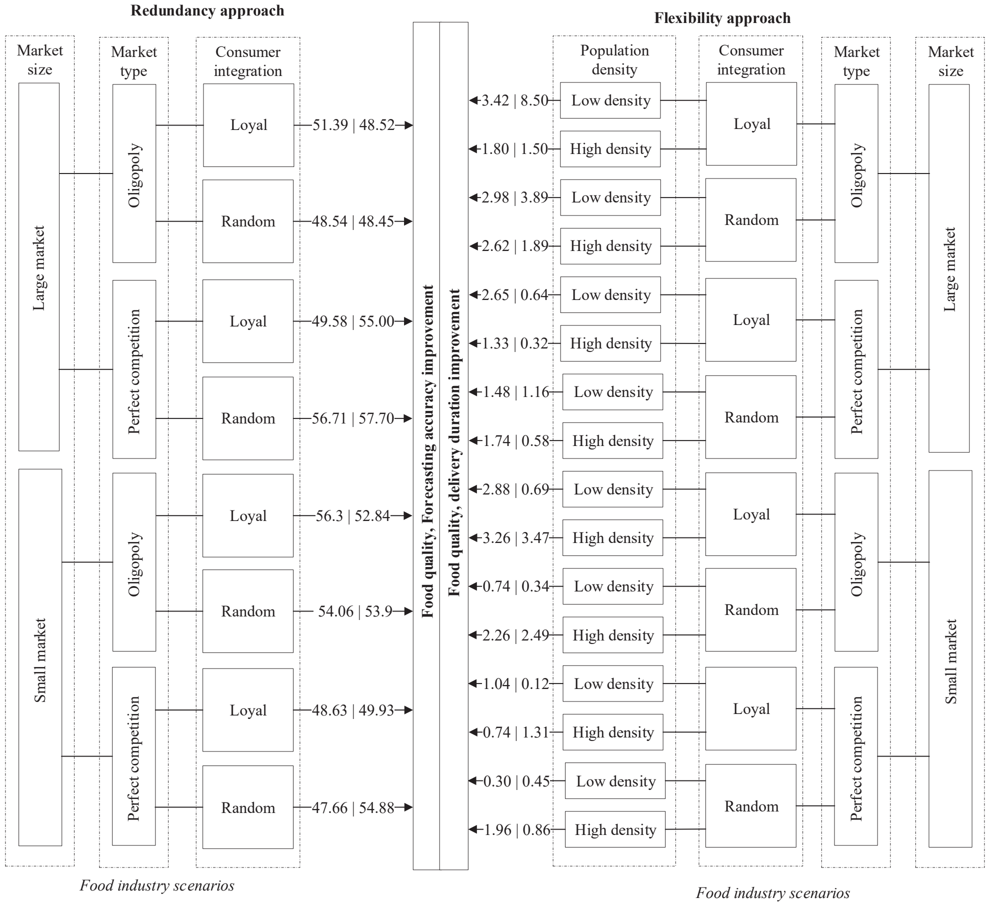


Fig. 36. Market size influence on forecasting accuracy by market type

The best scenarios were selected to estimate the most appropriate logistic cluster size. In this case, consumers are integrated, and cluster members are sharing information. The relationship between the forecasting error and the distributor quantity is displayed in Figure 36. The results show that there is a tendency for the MAPE to get lower when the distributor quantity increases. This is because the system does not consider multiple farmer types and simplifies the model with only one type of distributors delivering multiple kinds of products. Galbreth *et al*. (2015) identifies that "forecast accuracy drops over a large set of parameters," which is typical for more complex organizations (Galbreth *et al*., 2015). In our case, it can be seen that the MAPE went down at the beginning, however, from about 9 distributors, the MAPE tended to stabilize. It means that, by reducing the complexity in an organization, it is possible to lower the forecasting accuracy even more. By using an extreme learning machine algorithm which is denoted by low accuracy but quick computations, more precise algorithm development could be achieved for practical implementation.

2.5. Influence of the Resilience Approaches on Sustainable Food Industry



*Sequence of food industry scenarios is not important (associative)
** left side number represents information sharing, right side number – no information sharing
*** The output indicates mean absolute percentage error (MAPE)

Fig. 37. Influence of the supply chain resilience approach on the sustainable food industry

The simulation of flexibility and redundancy approaches allowed identifying the relationship to food quality. Figure 37 illustrates the correlation coefficients and the mean absolute percentage error of the obtained results. The provided output can be used as a management framework in order to determine which approaches could provide the best improvement in which food industry scenarios. For example, it can be seen that, while using the redundancy approach, loyalty programmes for consumers could lead to superior food quality improvement levels in the oligopoly market type rather than in the perfect competition market type. It can also be determined that information sharing while using the redundancy approach is more suitable for larger markets rather than smaller ones.

When analyzing the flexibility approach, it can be seen that information sharing is more suitable in the majority of cases. However, traditional trucks are more suitable in the large market type of the oligopoly market type, which indicates that the reinforcement learning algorithm has more difficulty when adapting to the environment when the size of the market (i.e., the order quantity) is large, thus, in this case, the algorithm should be trained more to provide better adaptation possibilities. This issue might also be related to the small market case since information sharing is also less effective in this scenario when comparing with the traditional trucks. Alternatively, more parameters might be used to train the algorithm; however, the computation time of training might grow exponentially due to the growing search scape. Another possibility to identify the effectiveness of such a system is not to use directly traffic accidents, but rather to use traffic congestions which are directly related to traffic accidents. However, in this case, the probability of these events should be increased. Lastly, the reinforcement learning algorithm in this case uses the average speed to schedule deliveries; however, in some cases, the actual average speed might be higher than the historical speed if no traffic accidents are present. In this case, an additional parameter should be introduced when planning schedules. This approach would allow the reinforcement learning algorithm to have a wider range of states to learn from. However, the recommended approach could increase the computational time.

In summary, information sharing combined with the flexibility and redundancy approach can increase the system resilience and provide higher food quality levels. However, when implementing the recommended techniques, the developed management framework should be used to identify which technique is more suitable depending on the market that the companies are going to operate in.

3. Discussion of Resilience Approaches Usage for Sustainable Food Industry

Sustainable and resilient food industry

Food systems in recent years have gained more recognition due to the consumer-manifested trend demanding a higher share local and healthier products (Wägeli and Hamm, 2016). The majority of researches conducted in systems related to food focuses on the horizontal collaboration and tries to integrate agents involved in the decision making process from farms to government institutes (Himanen *et al*., 2016), (Lamine, 2015). Mulcahy (2017) conducted a research regarding the analysis of food systems. He indicated several important questions which this thesis is addressing. The first question is related to the ways how to increase collaboration between small and large food companies in order to provide more sustainable and local production. The second question highlights that there is a limited number of practices of how to implement food systems in large population centers (urban areas) (Mulcahy, 2017). Our research fills in the missing gap from these perspectives. On the one hand, it focuses on the distribution to end-consumers. One of the key practices to increase the food access in the urban regions and maintain higher food quality levels is to shorten the supply chain. Aubry and Kebir (2013) indicated the importance of shortening the food supply chain (Aubry and Kebir, 2013). There is a tendency to promote the e-commerce channel for the food industry in order to decrease the length of the system even more (Hübner *et al*., 2016). On the other hand, it provides a collaboration approach which involves information sharing and application of cyber-physical systems in the food supply chain management. Ambulkar (2015) analyzed supply chain disruptions from the perspective of the strategic focus on innovations, and the research indicated that “although they may be committed to innovation, firms may differ in the degree to which they actively support the innovation efforts taking place across the network on its behalf. If suppliers are not well integrated or if there is alignment issues with the firm’s strategy, innovation focus can lead to less coordinated actions within the supplier network and thereby greater disruptions in fulfilling market demand” (Ambulkar, 2015).

Collaboration and information sharing

In order to increase resilience and sustainability collaboration is being promoted. “Specific collaborative activities (information-sharing, collaborative communication, mutually created knowledge and joint relationship efforts) increase supply chain resilience via increased visibility, velocity and flexibility” (Scholten and Schilder, 2015). “Supply chain’s ability to collaboratively share information with its supply chain partners is one of the most important factors that enhance a supply chain’s resilience” (Gonul, 2015). However, other researches indicate the problematic areas of collaboration. “Consistent report of low collaboration, impropriate capacity levels and minimal flexibility is the main cause of collaboration failure” (Pettit *et al*., 2013). The main problems of this thematic area are related to the strategy and technology integration. “Firms’ strategy and behavior in supply chain collaborations are identified as the main reasons for supply chain failure" (Arvitrida *et al*., 2016). "Collaboration between the supply chain members, increases complexity of the chain which limits the ability to cope with disruptions" (Mari *et al*., 2015). "The effectiveness of collaboration as a supply chain resource has been questioned due to concerns associated with collaborative technologies, and thus prior research has called for a deeper examination of the role that technologies play in facilitating integration" (Adams *et al*., 2014). Thus our research provides integration of collaboration (i.e., information sharing) with technology implementation in order to increase the resilience and sustainability in the food industry.

Complex-adaptive system for supply chain management

Supply chain management approaches are designed to reduce the variability and separate the processes into elements instead of analyzing them as a system. "All these approaches help to eradicate variability, prevent costly dynamic distortions such as the 'bullwhip', and spread the operational risk. The key objective is to reduce cost through increased control, which in a stable world certainly does enhance profitability. In a volatile environment, however, control efforts result in a rigidity of supply chain structures and interactions" (Christopher and Holweg, 2011). Thus the complexity theory approach should be integrated with the supply chain management. Several research papers analyzed supply chains from the perspective of the complex-adaptive system; however, their work is mainly theoretical and lacks empirical evidence (Marchi *et al*., 2014), (Cordes and Hülsmann, 2013), (Chriss *et al*., 2013). For example, Cordes and Hülsmann focused on the complex-adaptive system perspective when developing supply chain networks. Their approach describes how to achieve robustness of the network by implementing technological approaches, however, this particular research did not provide any empirical evidence (Cordes and Hülsmann, 2013). From the complexity theory approach, the agent-based modeling methodology is mostly suitable to test the prepositions of the theory. Such a method is useful for several reasons. Firstly, it is difficult to obtain data from a large system for the case of this thesis from the food supply chain (ZOTT, 2002). Secondly, the relationship of the food system involves multiple agents, which causes non-linear phenomena to emerge from the system (Davis, Eisenhardt, and Bingham, 2009). Finally, the supply chain resilience is considered an emerging theory, which makes it suitable for agent-based modeling (Davis *et al*., 2007).

Agent-based modeling approaches have been analyzed when focusing on the supply chain resilience. For example, Hoffa and Pawlewski described how to analyze agent-based modeling with traffic and weather disruptions (Hoffa and Pawlewski, 2014). However, this agent-based modeling approach was not integrated with the complex-adaptive system, i.e., with adaptation possibilities. Barrientos and Mota (2016) developed agent-based modeling integrated with the complex-adaptive system based on the game theory (Jeanmonod *et al*., 2016). However, the model focused more on the strategic level decisions, while our thesis model focuses on the missing gap, i.e., on the tactical and operational level decisions. For example, Fikar (2018) developed agent-based modeling analyzing food losses in e-grocery; however, the model did not integrate adaptation possibilities and was done in a static environment

(Fikar, 2018). Another trend when analyzing the supply chain resilience can be seen which mostly focuses on force majeure-type issues and analyzes network design issues. Only recently, cyber-physical systems started to be implemented in the supply chain management (Klötzer and Pflaum, 2015). Also, computation power development allowed producing large-scale simulations integrated with machine learning or reinforcement learning algorithms (van der Hoog, 2017). The development of such large-scale models is complex and requires the interdisciplinary research approach; thus only a limited amount of research is conducted while focusing on such an approach. This is mainly because the development of agent-based modeling requires to mathematically define the interaction between agents, which is often difficult to achieve. This problem makes agent-based modeling sensitive to the initial assumptions and input data. It is also important to note that such a system does not necessarily need to represent the reality fully, but instead it must be as simple as possible in order to provide insights into decision making. Tsioptsias and Tako (2018) conducted an experiment and indicated that it is possible to learn from wrong simulations and that attempts to reproduce reality precisely might reduce the interpretation possibilities (Tsioptsias, Tako, and Robinson, 2017). Thus, in order to maintain simplicity, we conducted two agent-based modeling models focused on the redundancy and flexibility approaches.

Flexibility approach

The flexibility approach focused on optimizing the transportation planning process so that to improve the food quality in an environment with disruptions. A vehicle routing problem which considered perishable products was conducted by Osvald and Stirn (2008). Their research was based on using time-dependent optimization and included the costs of food waste in the goal function (Osvald and Stirn, 2008). Another research conducted by Rong *et al*. (2011) focused on optimizing the supply chain by considering the process from production to retail; their main contribution is related to the measurement of the food quality loss based on the product flow and quantity (Ronga *et al*., 2011). A recent research analyzed the influence of the food quality loss in urban logistics with a focus on the inventory management strategies and delivery time (Fikar, 2018; Waitz *et al*., 2018). One of the researches focusing on this approach was conducted by Rasmus *et al*. (2015); it specifically focused on the delivery of bananas by sea instead of land transport. This approach measured the initial food quality and determined the routes by optimizing the quality level (Haass *et al*., 2015). However, a simulation which would integrate transportation in the food industry by considering traffic jams and accidents was not found (Kurihara, 2013), (Calvert and Snelder, 2018). Because of this reason, the agent-based modeling model of flexibility provides several contributions. Firstly, the application of autonomous vehicles in the industry has only recently received some recognition. Brent *et al*. (2018) stated that the food products distribution industry is likely an early adaptor of autonomous vehicles (Heard *et al*., 2018). The majority of researches being conducted currently focus on optimizing individual travel trips from point A to B (Sallab, Abdou, Perot, and Yogamani, 2017), but, in our case, we shall focus on autonomous vehicles application so that to improve the network level routes. The limitation of the simulation is that it only considers the traffic flow and accidents; however, a wider range of information from the environment can be gathered which would allow optimizing the routes more effectively. Such information sharing integration with reinforcement learning can allow adaptation possibilities to the logistic cluster members.

Redundancy approach

Analysis of the supply chain resilience in the research is usually more focused on the environmental crisis perspective, such as force majeure, and only a limited amount of research focuses on the operational or tactical levels (Sáenz *et al*., 2018). This research focuses on the demand fluctuation and redundancy approach for the supply chain resilience. Moreover, there is only a limited amount of empirical evidence related to the supply chain resilience because the majority of the research is theoretical (Ribeiro and Barbosa-Povoa, 2018). Zhu conducted an agent-based model of collaborative demand forecasting. The research provided sufficient information how the underlying demand to the supplier can significantly reduce this increase in variability (Zhu, 2008). Cheikhrouhou *et al*. (2011) developed a judgmental collaborative approach for demand forecasting in which the mathematical forecasts, considered as the basis, are adjusted by the structured and combined knowledge from different forecasters (Cheikhrouhou, Marmier, Ayadi, and Wieser, 2011). Dong *et al*. (2014) analyzed collaborative demand forecasting from the perspective of trust when sharing information (Dong, Huang, Sinha, and Xu, 2014). Their scientific contribution relates to strategic management. Ponte *et al*. (2017) conducted an agent-based model to inventory control policies (Ponte, Sierra, de la Fuente, and Lozano, 2017). The authors of the publication recommend to explore the design of a robust adaptive mechanism so that the agents could control their decisions (safety stock, forecasting rules). Our model implements the machine learning approach for demand of forecasting, however, it could be further expanded to represent an artificial market more precisely.

Only a few researches have been conducted in the segment of sensitivity analysis of the logistic cluster scale influence on forecasting accuracy. For instance, Galbreth *et al*. (2015) conducted a collaborative forecasting model and determined that forecast accuracy drops over a large set of parameters, which is related to the growing complexity of organizations or logistic clusters (Galbreth *et al*., 2015). The findings of Nagashima *et al*. (2015) indicated that it is particularly the lack of collaboration that causes negative effects of the forecast accuracy (Nagashima *et al*., 2015). Our research focused more on the strategic level strategies, such as logistic cluster formation and redundancy strategy implementation based on different contingents. Particularly, our research considers such environmental factors as the market type, its size, consumer integration and the logistic cluster scale when analyzing the potential of collaborative demand forecasting. Hoske (2015) indicated that technically driven approaches tend to neglect the fact that the organizational dimension plays an important role; this is where our research intended to fill the missing scientific gap (Hoske, 2015). It is important to note that food wastage is a concern due to the ineffective supply chain; however, only a limited number of researches analyzed the collaborative forecasting potential in the FI (Cheikhrouhou *et al*., 2011). The implementation of machine learning in the forecasting process also provided adaptation. It means that the algorithm learns from the demand fluctuation and adapts to it thus delivering emergence of resilience. In the long run, system resilience provides sustainable development possibilities for the logistic cluster members.

Thesis outcome

The novelty of the thesis from the theoretical perspective is the integration of collaboration, supply chain resilience approaches, and the application of cyber-physical systems whose interaction is grounded on the complexity theory. This integration explains how innovative technologies can be used in supply chain management so that to create a self-organizing system which can adapt to the changing environment and emerge towards sustainability in the long run. From the practical perspective, the proposed management framework provides a methodological instrument for companies operating in the food industry to form official logistic clusters and to have a possibility to measure the effectiveness of the approach in their activities. Thus the main contribution of the thesis is the proposition to integrate collaboration with innovative technologies in order to achieve sustainable food industry. In more detail, the proposed framework shows how information sharing together with cyber-physical systems in the food industry provides possibility to automate the tactical and operational levels. The complex-adaptive system perspective provided understanding that sustainability and resilience is an emergence process which is the outcome of inter-depended agents. The theoretical approach provided understanding that these relationships between the agents should be managed, which would allow adapting the agents to the environment, and the emergence of sustainability would arise. The complexity theory approach provided understanding that flexibility and redundancy approaches should be implemented in the food industry. Such an approach together with the cyber-physical system implementation would allow developing self-organizing systems which, in the long run, would cause the emergence of sustainability and increased resilience. Thus, the bottom-up approach should be used with the management food supply chains. The theoretical literature analysis and empirical evidence provides insights into the development of a new general purpose theory for supply chain management. The provided approach is based on the FI, however, it can be adapted to other industries which are denoted by a tendency to work with e-commerce type distribution channels (see Figure 38).

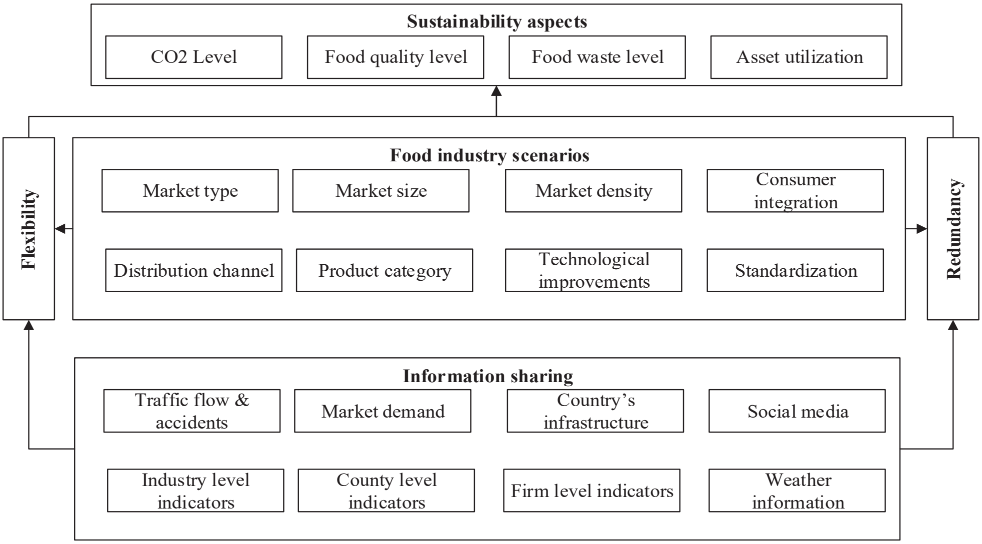


Fig. 38. Framework for Sustainable and Resilient Supply Chain Management

In Figure 38, we present the framework for sustainable and resilient supply chain management. The framework is elaborated based on the developed conceptual model and empirical research results. The model shows three levels, such as information sharing between the supply chain members. Then, the way how this information is utilized depends on the flexibility and redundancy approach in different scenarios. Lastly, the influence on the sustainability aspects can be measured.

Information sharing in our case included traffic flow and accident information so that we could simulate disruptions in the last mile deliveries, while market demand fluctuation was used to determine disruptions in the inventory planning. We used industry and country level indicators to simulate the scenarios in which we tested the empirical model; however, these parameters can be further expanded to include other sources of information. For example, the country's infrastructure can influence the logistic operations of the food industry; we should consider not only the current infrastructure, but also the possible expenditure, which are required to have the required infrastructure developed. Other information might include the social media which is directly related to customer integration and their feedback. Based on this information, the market demand could be estimated more precisely. The weather information might also cause influence on logistic operations, but this information is more important to the agriculture sector rather than to the last mile delivery; however, rain, snow, or other aspects might affect the speed of vehicles and increase the traffic accident likelihood. Thus various sources of information could be added to simulate the logistic operations more precisely, and, by collaboration, this information could be utilized more efficiently.

The usage of shared information can be simulated in different food industry scenarios which depend on the market type, size, and density. In the model, it is defined as the market type based on oligopoly and perfect competition; however, in the real world, intermediate types might be included with fewer or more buyers and sellers. The size and density of the market depends on the country of operation. In our case, we focused on the European Union; however, more precise analysis might be done to represent other markets more precisely, such as the USA, Asia, or Australia. In our simulation, we focused on e-commerce, however, other distribution channels might be taken into consideration, such as retail, wholesale, and so on. In the simulation, we used the generic approach to product management; however, the processes might depend on the product type, such as meat, fish and others. The management aspect for different product types might also depend on the standards available in the country which might require different temperature control approaches. Thus, in such contexts, food quality measurement should be adapted accordingly. Lastly, the technological approaches used for redundancy and flexibility should be included in the simulation. In our case, we used cyber-physical systems; however, only less technologically advanced systems might also be included in the simulation.

The selected approach subsequently provides output of the model which is measured through the sustainability aspect. In our case, we focused on the food quality and waste levels, however, other aspects of sustainability might also be considered. For example, the environmental effect today attracts a lot of attention, thus CO_2 emission might also be measured. From the economic perspective, it should be possible to utilize the available assets of the supply chain members, such as warehousing space, trucks, etc. Hence the utilization level should also be measured in order to increase the economic aspect of sustainability.

The proposed framework for sustainable and resilient supply chain management showed how to increase sustainability in the food industry through resilience approaches together with information sharing and cyber-physical systems application. The model has been developed for the food industry; however, adaptation to other industries which develop tendencies to work with the e-commerce distribution channel might also be beneficial after modifications.

4. Conclusions and Recommendations

1. Sustainability in the food supply chain can be measured through food quality, green gas emission level, or ineffective resource utilization when viewed from the perspective of resilience. Resilience in this case can be seen as approaches to achieving sustainability during daily disruptions. Disruptions in the supply chain influence the sustainability aspects of the food industry. The main approaches towards achieving sustainability were identified as the usage of flexibility and redundancy approaches together with information sharing which is obtained as a result of collaboration. The implementation of cyber-physical systems in the process creates self-organising behavior for the supply chain members which continuously adapts and leads to a higher level of sustainability. Moreover, this approach allows utilizing the same resources more effectively without additional resources.
2. The proposed conceptual model contributes to the supply chain management field by integrating theoretical approaches from multi scientific fields. The model integrates collaboration with the supply chain resilience practices through application of cyber-physical systems. The integration of the technological and organization dimension allows creating a sustainable food industry whose achievement can be explained by the complex-adaptive system theory. The proposed approaches allow the system to achieve self-organizing abilities which form the emergence of the micro level processes towards a sustainable food industry. The main theoretical contribution of the thesis is in the combination of the inter-organizational theory with the complex-adaptive system for the supply chain management in the context of sustainable food industry.
3. The main methodological approach in the thesis focuses on the application of agent-based modeling, which is a common simulation tool in the computational social science. In the thesis, the research focuses on how information sharing can improve sustainability by applying supply chain resilience approaches together with cyber-physical systems. The analysis of these elements is complex and non-linear, thus the traditional research approaches are not suitable for analysis. In general, agent-based modeling is sensitive to the input data and assumptions, however, if employed logically, it could provide insights into the analyzed phenomena. To provide reproducibility of the research, the methodology is grounded by the ODD protocol proposed by Grimm *et al*. (2006). The main novelty of the applied methodology is related to the integration of social behavior (information sharing) and the application of cyber-physical systems in the sustainable food industry.
4. Macro indicator analysis and scientific literature analysis was conducted to identify the main food industry scenarios. These scenarios included the market size, the market type, the population density, and the consumer integration levels. The clusterization process identifies the main categories in which the food industry operates – thus these scenarios can be used in other research simulations. The provided methodological approach of the way how the food industry scenarios were defined can be further used to determine other variables which

could cover less common variations in the market. In the case of our thesis, only the main variables of the food industry scenarios were identified, however, alternatives could be considered, such as distribution channels, different levels of technological implementation, etc. The provided methodological approach can contribute to the future agent-based model development.

5. The agent-based model of the flexibility approach identified that the application of autonomous vehicles improves information sharing which can be used to create a self-organizing system for the delivery process optimization. This application is especially useful in the last-mile logistics of the food supply chain. In the simulation, we mainly considered traffic accidents as disruptions in the system, and used the delivery time as a parameter to optimize the algorithm; however, more information input might be needed for the algorithm to increase its efficiency even further.
6. The agent-based model of the redundancy approach identified that information sharing between the supply chain members can improve the alignment of demand and supply in the food supply chain, which allows the members to maintain the proper level of inventory, reduce food waste levels, and maintain higher food quality. The simulation was conducted by application of machine learning, when the required time is adjusted to the changing demand pattern. Thus this process can be defined as collaborative demand forecasting. In the previous literature, collaborative demand forecasting from the perspective of the complex-adaptive system has not been analyzed, thus simulation provides empirical evidence regarding the effectiveness of the proposed approach.
7. Even though it is recommended to fully automate the supply chain processes, consumer integration in the supply chain management is crucial. In this thesis, it was identified that closer consumer relationship reduces the variability of data, which decreases disruptions and allows achieving higher resilience and sustainability levels with less prominent technological advancement. This is one of the key aspects of how technological and social aspects should be integrated.
8. The process which was used to develop an agent-based model in this thesis can be used to create a real-time analysis system for a logistic cluster. The development of such a system would completely automate the tactical and operational levels of the food supply chain and would allow managing the supply chain only through strategic level decisions; however, further research is needed to define the strategic level variables. The developed management framework can be adapted to other industries which are working with e-commerce; however, some adjustments should still be made. For example, instead of food waste used for biofuel, a reverse logistic model could be substituted to fit the selected industry more precisely.

Future research

1. The thesis focused on tactical and operational level automation. In the future research, there is a need to expand the scientific literature analysis by including strategic level decisions and to define the variables which can be

used to control the system while automating the tactical and operational levels. Currently, the thesis focused mainly on the tactical and operational level decisions, however, it is recommended to provide a more elaborate concept of how strategic level decisions could be simulated in the cyber environment more precisely. The proposed methodology identified how simulations of the tactical and operational level can be conducted, however, the strategic level could also be taken into consideration.

2. A large-scale agent-based model of the food and energy industry should be developed, which would allow estimating future market changes and plan strategic level decisions accordingly. Complete implementation of cyber-physical systems in organizations would allow estimating such changes in real time. The arising trend of the Internet of things and smart cities allows retrieving even more data from the environment. The integration of the data received from the environment in the proposed framework could allow the management of the supply chain processes to become even more efficient.
3. Integration with the brain-machine interface would allow controlling such a system in real time by changing the interaction between the agents. Afterwards, the simulated best decisions could be transmitted back to the cyber-physical system to let it reorganize itself in the physical world, thus brain-machine interface integration possibilities regarding the developed framework for sustainable and resilient supply chain management should be analyzed. For example, in 2019, *Neuralink* proposed a brain-machine interface integrated through electrodes which can be used for medical purposes (Musk, 2019). However, a similar approach can be used to test various supply chain-related decisions in the simulation. After the simulation being completed in the cyber environment, the decision can be automatically utilized in the physical environment through application of cyber-physical systems.
4. Rapid usage of cyber-physical systems dramatically increases the energy usage, therefore, more efficient energy aware cyber-physical systems should be developed. Alternatively, the Circular economy concept implementation in the food supply chain would allow using the food waste to produce biofuel and to reduce energy usage from natural resources for the cyber-physical systems. The crucial point in developing and implementing such a concept is to analyze the infrastructure aspect of the market. It is essential to determine the forest or agricultural areas which would be aligned with the growth of the region, and the infrastructure should be determined based on the dynamic environment.
5. E-commerce business models should be further analyzed to increase customer integration, which would outline more stable demand patterns and would increase the effectiveness of the usage of cyber-physical systems. The developed simulation was tested in multiple food industry scenarios. One of the variables used to develop the scenarios was consumer integration; it indicated that loyalty in this case decreases the bias in the demand patterns, which can subsequently increase the efficiency of artificial intelligence

algorithms. This insight is crucial when promoting collaboration and forming an official logistic cluster.

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List of Scientific Publications on the Topic of the Thesis

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2. [S1; GB] Gružauskas, Valentas; Baskutis, Saulius; Navickas, Valentinas. Minimizing the trade-off between sustainability and cost effective performance by using autonomous vehicles // *Journal of cleaner production*. London: Elsevier. ISSN 0959-6526. eISSN 1879-1786. 2018, vol. 184, p. 709-717. DOI: 10.1016/j.jclepro.2018.02.302. [Scopus; Social Sciences Citation Index (Web of Science); ScienceDirect] [CiteScore: 5.79, SNIP: 2.194, SJR: 1.467 (2017, Scopus Sources)] [M.kr.: 09T, 04S, 03S] [Contribution: 0.334]

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SL344. 2020-02-13, 19,5 leidyb. apsk. l. Tiražas 12 egz.
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