

# IMPROVING FLEXIBILITY IN AUTONOMOUS COOPERATING FOOD CHAINS

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**Abstract:** *Flexibility is a crucial performance indicator for supply chains, since it allows for a fast adaption to changing customer demands and environments. This is especially true for food chains, due to the direct interdependence between shelf life and quality of the product, and environmental factors, such as seasonal demand and temperature maintenance. Autonomous cooperation of logistic entities is considered as a concept to foster flexibility in supply chains. One realization of autonomous cooperation is the intelligent container, which is able to constantly monitor storage conditions like temperature and relative humidity of the cargo, while exchanging transport information with its environment and communicating with the freight owner. Hence, the question arises, how the intelligent container may enhance the flexibility of food chains. Therefore, the paper examines contributions and limitations of the intelligent container regarding the flexibility of a specific kind of food chain, namely the banana supply chain.*

**Keywords:** flexibility, food chains, supply chain management, supply chain flexibility, autonomous cooperation, intelligent container, banana, logistics

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## **1. IMPROVING FLEXIBILITY IN FOOD CHAINS**

In view of today's globally interconnected and volatile food markets, the management of food chains is a difficult and challenging task. Soaring food prices, changing consumption patterns and food scandals foster the unpredictability of demands for food (Nellemann et al., 2009). Managers of food chains have therefore to adjust quickly to changing market requirements and to assure flexibility in order to avoid excessive stock, food waste and to fulfil customer's expectations. However, food products additionally limit the flexibility of supply chains, due to their specific characteristics. Factors such as sensitivity to temperature changes, or limited shelf life reduce the choice of transport mode, duration of the journey, and initiation time of transport. Other determinants are for example seasonality or the length of production cycles, which further hinder fast adaptability to changing environmental conditions (van der Vorst et al., 1998).

The question is thus, how the flexibility of food chains can be improved to allow for an efficient and fast reaction to changing demand for food products. In comparison to other performance drivers in supply chains, such as costs and customer responsiveness, little attention has been paid to flexibility in the supply chain related research (Chan, 2003). However, the importance of flexibility should not be neglected, since it reflects how well companies are prepared to deal with uncertainties in their environment (Beamon, 1999; Aaker & Mascarenhas, 1984). Furthermore, flexibility fosters the creation of competitive advantages through retaining, developing and regenerating competences (Hülsmann, Grapp & Li, 2006). A recent concept to enhance flexibility in supply chains is the autonomous cooperation of logistic entities (e.g. Wycisk, 2009; Windt & Hülsmann, 2007; Hülsmann, Grapp & Li, 2006). By transferring decision-making, communication and information exchange (e.g. by integration of RFID and sensor networks) from the management level to the level of logistic entities, such as containers or packages, the flexibility of the entire system shall be enhanced (Wycisk, 2009). Therefore, this paper aims for an assessment of the effects of one autonomous cooperation technology, namely the intelligent container, on the flexibility of food chains.

In order to achieve this overarching aim, the first sub aim is the description and operationalization of the relevant concepts, hence of flexibility in supply chains, food chains and autonomous cooperation. The second sub aim is the analysis of cause-and-effect relationships between these components. The third sub aim finally is the deduction of hypotheses on the contributions and limitations of autonomous cooperation technologies for the improvement of flexibility in food chains.

Following the research aims, section two will begin with a description of different understandings and indicators of flexibility. Then, characteristics of food chains will be illustrated for the case of supply chains for bananas, to reveal challenges encountered in this sector. Following this description, flexibility will be analyzed in the context of supply chains for bananas to identify areas for improvement. In Section three, the concept of autonomous cooperation will be introduced as a solution approach, followed by the explanation of a concrete example, namely the intelligent container. Section four is dedicated to the assessment of the potential contributions and limitations of the intelligent container to enhance flexibility in food chains. Finally, in section five, implications and constraints of the solution approach to enhance flexibility in food chains will be discussed and starting points for future research will be depicted.

## **2. FLEXIBILITY IN SUPPLY CHAINS**

Flexibility is a strategic factor for the competitiveness of companies. It is the basis to adapt activities to changing environments by generating alternative action possibilities and by allowing their prompt realization (Burmam, 2002; Aaker & Mascarenhas, 1984). According to several authors, flexibility in supply chains is a key to success (Hülsmann, Grapp & Li, 2006; Beamon, 1999; Chan, 2003). It implies advantages, such as increased customer satisfaction, the ability to adapt to demand variations, as for example due to seasonality, and the ability to respond to poor supplier or delivery performance (Beamon, 1999). However, the concept of flexibility is in contrast to other performance indicators, such as costs, a qualitative measurement and difficult to quantify (Chan, 2003). Nevertheless, several approaches to quantify flexibility in supply chains exist, whereof some will be shortly presented in the next subsection.

### **2.1. Flexibility Concepts and Quantification**

First of all, flexibility of supply chains has no unique definition and may already therefore include different metrics. For example, ARAMYAN et al. (2006) state that “*Flexibility indicates the degree to which the supply chain can respond to a changing environment.*” (p. 54). BEAMON (1999) understands flexibility as “[...] *how well the system reacts to uncertainties [...]*” (p. 280). PRATER, BIEHL AND SMITH (2001) define flexibility as “*the degree to which the firm is able to adjust the time in which it can ship or receive goods*” (p. 824). And CHAN (2003) summarizes that “*Generally, it is about the ability or the adaptability of the company to respond to diversity of change.*” (p. 539). In this paper, the definition of BEA-

MON (1999) seems to be appropriate, since uncertainties are important performance drivers, especially in the case of perishable and seasonal food products (van der Vorst et al., 1998).

Because of the different understandings of flexibility, there is also a wide range of metrics to measure flexibility. For the purpose of this paper, the defined indicators have to be useful independently of real data, in order to allow for a general assessment of flexibility in food chains. Furthermore, they should be precise, thus measurable and comparable on the company and supply chain level. PRATER BIEHL AND SMITH (2001) for example divide flexibility into the promptness, and the degree, to which a firm is able to amend the supply chain speed, destinations and volumes. This definition is not applicable in the context of this paper, since the metrics are not operationalized. ARAMYAN et al. (2006) distinguish between customer satisfaction, volume flexibility, delivery flexibility and the number of back-orders, and lost sales. The authors elaborated a performance measurement concept explicitly for food chains and tested its suitability in case studies. Even though customer satisfaction was considered to be highly important by the participating companies, it turned out to be too unspecific, difficult to measure and ambiguous to allow for a comparison of companies (Aramyan et al., 2007). Therefore, the approach of BEAMON (1999) is chosen, which divides flexibility in the components volume flexibility, delivery flexibility, mix flexibility and new product flexibility. The author introduces quantifiable measures, which allows for an evaluation of the metrics also without data.

The indicators are defined as follows:

- Volume flexibility measures the proportion of demand, which can be met by a supply chain, limited by the maximum and minimum profitable output levels.
- Delivery flexibility is the percentage of slack time, by which the delivery time can be reduced.
- Mix flexibility is on the one hand the number of different types of product, which can be produced in a given time period. On the other, it is the time required to produce a new product mix.
- New product flexibility is either the time or cost it takes to introduce new products to the present product range (Beamon, 1999).

These measures help to determine, in which aspects food chains differ from other supply chains. The performance indicators will therefore be analyzed in the context of a specific food product, to reveal possible barriers to flexibility in food chains.

## 2.2. Status-quo of Flexibility in Food chains

In terms of transport requirements, there exist three types of food commodities, namely dry, frozen and chilled foodstuffs (Littek, 2005). For the purpose of this paper, chilled products are chosen, since they differ considerably from other products, which is mainly due to four reasons. First of all, they are natural commodities, implying that they need a certain period of growth, which is dependent on seasonal and weather conditions (van der Vorst et al., 1998). Secondly, perishables such as fruit and vegetables have to be transported within specific temperature ranges, to preserve their quality up to consumption (Frith, 1991). Thirdly, as the products continue to respire after harvest, which produces respiration heat and ethylene, the supply of fresh air has to be assured (Heap et al., 1995). And fourthly, the shelf life of perishable food stuffs may be relatively short, as for example strawberries only last for about seven days (Nunes, 1995). In consequence, the compliance with specific requirements of the food transported is of crucial importance, to deliver products with a decent shelf life and quality.

However, the requirements vary considerably between different food products, which might also change the level of flexibility of the food chain. Therefore, as an illustration case, this paper will try to assess the flexibility with regard to only one perishable product, namely bananas, for which firstly the specific supply chain requirements will be shortly presented.

In 2008, more than 17 million tonnes of bananas were exported on a global scale (FAO Stat, 2011). Bananas are optimally stored between 12 and 14 degrees and emit a considerable amount of ethylene. At the same time, they are highly sensitive to it and should not be stored with other ethylene emitting fruits or vegetables. Furthermore, they are also sensitive to chilling injuries and should therefore not be stored at lower temperatures. The shelf life of green bananas is about 2 to 3 weeks, whereas yellow bananas stored at 20°C can only be kept for about 2 days (Mercantila Publishers, 1989). The question now is, how these product characteristics may affect the flexibility of the food chain.

### *Volume Flexibility*

Between 2001 and 2008, the imports of bananas by the European Union increased by approximately 32% (FAO Stat, 2011). Though the growth of trade in bananas is considerable, volume flexibility is assumed to be relatively low. Since it takes more than a year, from the breeding of the plant till the harvest of the fruit (Mercantila Publishers, 1989), the production system cannot be quickly expanded to match rising demand. Neither can it be easily reduced, as the restricted shelf life does not allow for long-term storage. A reduction of the growth cy-

cle or the ability to influence the speed of ripening would allow for a better adaptability to fluctuations in demand.

### *Delivery Flexibility*

The ability to move the planned delivery date forward can be said to be limited. First of all, bananas are normally transported by ships from the producing countries to their destinations, due to their high demand (van de Kastele, 1998). These journeys take in general several weeks and frequently include stops at more than one harbour (van Dyk & Maspero, 2004). Furthermore, food products have to undergo hygienic inspections at borders, which are also time consuming (Meier, 1979). After customs clearance, bananas are stored for some days in ripening facilities, as they would otherwise arrive green at the supermarkets. During these processes, the owner of the bananas is generally unable to speed up the delivery. The only opportunity to accelerate the delivery is during the relatively short periods of transshipment, road transport and at storage or handling facilities. Nevertheless, it has to be assured that before changing the transport unit, the receiving unit is adequately pre-cooled, to guarantee a seamless cold chain (Hülsmann & Brenner, 2011). This limited delivery flexibility may also imply quality losses, since a loss of shelf life during transport cannot be compensated by an earlier availability in retail. The implementation of methods to increase the delivery flexibility could result in optimized delivery and sales, based on first-expired-first-out (FEFO) principles.

### *Mix Flexibility*

Sending bananas in mixed loads with other perishables is not recommended. As already indicated above, bananas emit a lot of ethylene and are at the same time highly sensitive to it (Mercantila Publishers, 1989). Therefore, they should never be transported or stored with other fruits and vegetables, which produce ethylene or do not support it. This context does not only apply to bananas, but to a wide range of fruits and vegetables (Mercantila Publishers, 1989). Apart from the emission of ethylene, different temperature requirements generally impede joint shipments in one container. To allow for mixed loads, containers would have to be modularised into different compartments, with individual temperature settings, monitoring equipment and fresh air channels.

There exist around 100 types of cultivated banana plants, which are in use for cooking, fresh consumption or textile production (Hambrusch & Ortner, 2005). All together, there exist

about 1100 named clones of bananas (Mercantila Publishers, 1989). Since bananas belong to basic foodstuffs, the importance of breeding a new product variety seems to be negligible.

### *New Product Flexibility*

Following the diversification model of ANSOFF (1958), new products can be either complementary to existing products for the same market (product development), or new products in new markets (diversification). The set-up of food chains, such as the purchase of reefer containers, ripening facilities, cooling equipment, etc. is expensive (Smith & Sparks, 2004). Furthermore, their operation requires specific knowledge regarding product handling, application of cooling equipment and documentation requirements. Therefore, product diversification on the one hand can be associated with considerable sunk costs, which reduce new product flexibility. On the other hand, there exist many perishables, which demand the same conditions during transport (e.g. temperature control, fresh air circulation, temperature monitoring) and can therefore foster new product flexibility. Increasing the adaptability of the food chain to differing requirements of perishables could increase product flexibility further.

Having depicted the specific challenges in food chains, the question is thus, how they could be reduced or better controlled to foster flexibility. The concept of autonomous cooperation technologies in logistics has recently gained a lot of attention by researchers and aims at increasing the robustness and flexibility of supply chains (Windt & Hülsmann, 2007; Wycisk, 2009; Lang et al., 2011). The concept, as well as one specific realization of the concept will be introduced in section 3.

## **3. AUTONOMOUS COOPERATION**

The invention of the reefer container was an important step for the improvement of temperature-sensitive food transport. The continuous cooling of perishables prolongs their shelf life, and is a key enabler of global food trade. Nevertheless, due to restricted temperature measurements inside the container, local hot spots and factual temperature of the produce are frequently not identified (Hülsmann & Brenner, 2011). Thereby, shelf life might be substantially reduced and possible quality issues are only detected upon opening the container, when it can be too late. Another trend is the development and application of Information and Communication Technologies (ICT) in food chain management. The use of ICT helps to inform supply chain actors well in advance about the status-quo of product deliveries and may result in a reduction of inventory levels (Stank, Crum & Arango, 1999). However, the use of ICT is still fragmented along the supply chain, which impedes the coordination of the information flow

and leads to a reduction of its use (Coronado Mondragon, Coronado Mondragon & Coronado Mondragon, 2009).

One concept, which is increasingly regarded as an enabler of flexibility in logistics systems, is the autonomous cooperation of logistic entities (e.g. Wycisk, 2009; Hülsmann, Grapp & Li, 2006). According to WINDT AND HÜLSMANN (2007), autonomous cooperation can be defined as “[...] *processes of decentralized decision-making in heterarchical structures. It presumes interacting elements in non-deterministic systems, which possess the capability and possibility to render decisions. The objective of Autonomous Control is the achievement of increased robustness and positive emergence of the total system due to distributed and flexible coping with dynamics and complexity.*” (Windt & Hülsmann, 2007 p. 8). This is primarily achieved by reducing the dependency of logistics entities on a centralized decision-making. By transferring parts of the information flow and decision making process to the logistics transport units, the decision-making becomes faster and shorter, which allows for a better ability to respond to changing environmental demands (Hülsmann & Wycisk, 2005). Since there are many ways, autonomous cooperation principles can be applied and combined to logistics entities, this paper will focus on one concept, which is currently developed: the so-called intelligent container.

The intelligent container combines a distributed agent platform, RFID tags and a wireless sensor network for the monitoring and decentralized decision making of the logistics entity. The agent platform is used for quality supervision inside the container and logistics planning and coordination along the supply chain. RFID tags are required for the monitoring and tracing of the shipment, whereas the wireless sensor network in the container assesses temperature, humidity, acceleration, concentration of certain gases or just the door opening and closing (Gehrke et al., 2006).

After loading, the system adapts automatically to the requirements defined by the product to be transported. During transport, sensor information is locally interpreted and pre-processed inside the container (Lang et al., 2011). This implies that data such as temperature and humidity may be constantly supervised and changing environmental conditions, such as solar effect, door openings or temperature changes, are taken into account. Thereby, the shelf life of the commodity is continuously re-calculated and if the system predicts the shelf life to fall below a given threshold before arrival, the transport manager will receive a notification (Jedermann et al., 2007a).

For this communication, the intelligent container is equipped with a wireless system for external communication, which allows for the sending of transport information, quality information and an online access for the freight owner (Jedermann et al., 2006). If the shelf life reduction is risking the saleability of the product, the agent may then decide to re-direct the container to the next cooling facility, where the product can be re-cooled and the transport mode eventually changed (Jedermann et al., 2007b).

In summary, the intelligent container thus combines the advantages of reefer containers with those of ICT, which leads to more choices and more abilities to influence the transport conditions and routings. The question now is, how these features may influence the flexibility of food chains.

#### **4. CONTRIBUTIONS AND LIMITATIONS OF THE INTELLIGENT CONTAINER TO IMPROVE FLEXIBILITY IN FOOD CHAINS**

If a manager has to decide on whether to invest in a new technology, he needs to compare the alternatives regarding their impacts on the strategic objectives of the company (Keeney, 1994). Therefore, the different components of flexibility will be analyzed regarding positive or negative changes induced by the intelligent container in comparison to the current system. Consequentially, contributions and limitations of the intelligent container for improving the status-quo of flexibility of banana supply chains will be analyzed.

##### *Impact of the Intelligent Container on Volume Flexibility*

As has been shown for the case of banana supply chains, volume flexibility is relatively low due to the inability to quickly adapt the production of bananas to changing demand. However, the production does not end upon harvest, since during the following distribution the maturation of the bananas is firstly intentionally reduced by cold storage and then enhanced in the ripening facilities, to provide bananas in the right maturity to the supermarkets. In the case of China for example, the lack of adequate ripening facilities hampers the provision of bananas to match rising demand (van de Kastele, 1998).

The intelligent container may influence volume flexibility in a spatial and a timely dimension. First of all, the shipment can be re-routed if the demand declines at the destination, or rises at another location. Thereby, the number of potential customers could be even considerably increased, allowing for virtual market places and probably the achievement of better prices. However, this positive effect is limited by shelf life and distribution costs, which have to be considered in the decision upon re-routing.

Regarding the timely dimension, by optimizing the temperature maintenance during transport, the maturation process can be slowed down more effectively, which also allows for enhancing shelf life and product quality (Hülsmann & Brenner, 2011). During phases of weak demands, the bananas could be stored longer to await rising demands and would thereby artificially reduce the supply. A more important aspect is the possibility, to transfer the ripening process from specialized facilities into the intelligent container. For example, if demand rises, shipments can be earlier pushed into the market, since the ripening can begin during transport. Furthermore, the dependency on ripening facilities decreases, which may also reduce distribution costs and change business patterns. However, the prolongation of shelf life may only be helpful during short slumps in demand, e.g. for some days. Additionally, intelligent containers are only capable to ripen a fraction of entire demand, whereas ripening facilities have a much larger capacity. The basic requirement to adapt the field production is also not influenced.

Nevertheless, in comparison to the status-quo, the intelligent container is able to enhance volume flexibility in banana supply chains.

#### *Impact of the Intelligent Container on Delivery Flexibility*

As in the case of volume flexibility, slack time can be reduced by ripening the bananas during transport, which allows for an earlier delivery of the shipment to the customer. Furthermore, the constant traffic supervision helps the truck driver to adapt the transport route in the case of congestions. Another important factor is the timely provision of information on the shipment at points of transshipment or at customs clearance. Since the intelligent container is connected to an information and communication network, it can forward information about the product and further transport information well in advance, which allows the reduction of information-based delays. However, during ship transport and customs clearance, the delivery cannot be substantially accelerated. The container could in urgent cases try to find faster transport modes, or routes with less ports of call, but this would most likely also increase the distribution costs.

In comparison to reefer containers, the intelligent container enhances delivery flexibility by faster forwarding of information and by adapting transport routes to external constraints.

#### *Impact of the Intelligent Container on Mix Flexibility*

The mix flexibility is most likely not affected by using the intelligent container. First of all, it does not have any impact on the production variety of bananas. Secondly, even though the

modularization of the storage space into different compartments is theoretically possible, this would imply the need to add more cooling units to the container. This would either reduce the cooling space available, or would impede handling methods, which are based on the standard ISO container sizes. Additionally, since the equipment for the intelligent container is more expensive than for regular reefers, modularization would only make sense in the area of luxury, low-volume perishables (e.g. pharmaceuticals) and not in the case of standard products like bananas.

Consequentially, the intelligent container does not allow for a higher flexibility in the mixing of products in comparison to regular reefers. However, it does not reduce mix flexibility either.

#### *Impact of the Intelligent Container on New Product Flexibility*

As already indicated in section 2.2, product flexibility concerning the use of the same infrastructure is relatively high, if one only considers perishable food. For horizontal product development, the intelligent container does not offer a unique selling proposition, since regular reefers are also used for different perishable foodstuffs. Consequentially, product flexibility in this sense is not enhanced by using intelligent containers.

However, in the case of diversification, i.e. new products for new markets, there are some more options for offering a competitive advantage. For example, pharmaceuticals, such as vaccines have also to be transported in specific temperature ranges (WHO, 2005). Currently, these products are normally shipped by air, but increased safety, traceability and temperature control, due to the wireless sensor network and ICT infrastructure of the intelligent container, might foster seaborne solutions. Thereby, distribution costs could be significantly reduced. Additionally, significant temperature variations during flight operations and freezing injuries by using cooling packs can substantially reduce the quality and effectiveness of pharmaceuticals (Matthias et al., 2007), which could be enhanced by the intelligent container. Considering the range and amount of perishable products flown, there might be some opportunities for amplifying the product range shipped by sea. Another advantage of diversification is that the food product flow, which is normally one-directional (Vega, 2008), can be balanced by returning with other types of products, which reduces distribution costs for shipping back empty containers. Nevertheless, it has to be kept in mind that the container transport is only one part of the supply chain. The diversification of the entire supply chain, including pre-cooling facilities, ripening facilities, etc. is not probable.

A limiting aspect regarding new product flexibility can be the higher costs of intelligent containers in comparison to reefer containers. For products having higher volumes and lower margins than the banana example, the use of more expensive transport modes would exceed the transport budget, which reduces the variety of products to be shipped.

Now that the four components of flexibility have been analyzed, table 1 summarizes the potential impacts of the intelligent container on flexibility encountered for the supply chain of bananas.

Impact of the Intelligent Container	Volume Flexibility	Delivery Flexibility	Mix Flexibility	New Product Flexibility
Contributions	X	X	--	X
Limitations	--	--	--	X

Table 1: Contributions and Limitations of the Intelligent Container to Flexibility in Banana Food Chains

## 5. CONCLUDING REMARKS

The intention of this paper is to analyze the effects of one autonomous cooperation technology, namely the intelligent container, on the flexibility of food chains. At this first stage of analysis, intelligent containers seem to enhance volume, delivery, and new product flexibility in banana supply chains. At the same time, they seem not to affect mix flexibility and may also limit new product flexibility

The underlying indicators and application examples, which have been used to enable the deduction of statements, show firstly that the intelligent container is indeed able to influence the flexibility in food chains. Secondly, there are some explanations supporting the assumption that the intelligent container fosters flexibility in terms of volume, delivery and new products (e.g. pharmaceuticals or cosmetics). In some cases, it may even create new business models and trading patterns (e.g. by using the intelligent container for the ripening process). Therefore, the implementation of intelligent containers in food chains should not only be regarded as a possible way to improve process flexibility, but may also be a way to generate new business opportunities.

Of course, there are some limitations to this statement. First of all, it has been shown that a positive impact on flexibility may be limited by other factors, e.g. shelf life. Which influence is more important, could not be clarified, yet. Secondly, the intelligent container may also reduce flexibility in terms of new product flexibility, by being more expensive than a reefer

container. Whether even the trade in bananas chosen for illustration purposes allows for higher investments in the transport modes, can also not be answered at the moment. It is therefore the question, for which products the intelligent container represents a realistic option. Thirdly, the direction of impacts may be dependent on the kind of foodstuff, food chain, or autonomous cooperation technology. For example, the influences can be different in the case of ground transportation of fresh fish. A final statement on the effects of autonomous cooperation technologies on the flexibility of food chains has to take further constraints into account.

Hence, decision makers on investments to improve flexibility in food chains should evaluate, whether the advantages of the intelligent container, such as increased volume and delivery flexibility outweighs the risks of reducing the profit margin. Furthermore, they should analyze potential flexibility benefits on the basis of products to be transported, as they might considerably affect the resulting performance. One more aspect to be considered is the opportunity to enter new markets and to diversify services and product range.

Therefore, further research is needed regarding the net-effect of the intelligent container or other autonomous cooperation technologies on flexibility in food chains. Furthermore, more indicators could be included to deliver a complete picture of the concept of flexibility. Then, other food chains should be analyzed, as well as different autonomous cooperation technologies. In order to quantify results and to show the effects in real-world food chains, empirical analyzes are also recommended.

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