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TNO report

TNO 2021 P12076

D2.1 Business models, business and use cases of IoT-enabled QCL of perishables

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Copy no	2021-STL-REP-100337878
Number of pages	65 (incl. appendices)
Number of appendices	1
Sponsor	TKI Dinalog
Project name	IoT4AGRI
Project number	060.41580

This publication is part of the project Quality controlled logistics in IOT enabled perishable supply chains (with project number 439.19.609) of the research programme Accelerator 2019 which is (partly) financed by the Dutch Research Council (NWO).

Summary

In the IoT4AGRI project we develop and apply dynamic Quality Controlled Logistics in a way we can monitor the shipment conditions based on relevant sensor data, use this in order to predict the quality decay upon arrival, and intervene accordingly if the situation asks for. This is relevant since product quality decay occurs during transportation, particularly on international trade lanes.

This concept of dynamic Quality Controlled Logistics is rather comprehensive, and too complex to demonstrate in an integrated way at once. We therefore split this comprehensive QCL concept into five use cases.

These five use cases provide the basis to be demonstrated in a proof of concept and include:

- UC1a - High quality ethylene monitoring during perishable shipment transport;
- UC1b - Low-cost IoT solution for real-time perishable shipment status sensoring;
- UC2 - Optimal sensor positioning in perishable shipment;
- UC3 - Sensor-enabled quality decay predictions of a shipment;
- UC4 - Decision support for logistics interventions driven by quality decay predictions;

This comprehensive QCL-concept can only work in an operational way if a data sharing infrastructure supports all the interfaces.

The business case analysis of the IoT4AGRI concept is applied to trade lanes of green beans, mangoes and Galia melons from Senegal/Morocco to the Netherlands. The results confirm this value generating potential of dynamic condition monitoring during transportation, and intervening accordingly.

The interventions considered include:

- Reducing the total lead time by 12 / 24 / 36 / 48 hours, resulting in a higher quality level upon arrival and less waste.
- Dynamically adjusting the conditioning parameters during transport, also resulting in higher quality level upon arrival and less waste.
- Rerouting the shipment and selling of the products via an alternative sales channel onto the local market along the route while dynamically adjusting the conditioning parameters during the transport.

However, this sensor-driven quality control concept comes with a price, it increases the logistics costs of a shipment with over € 1,000. The majority of these cost are composed by the price assumptions of the sensors being used. Moreover, some interventions may result in alternative cost for sourcing good quality products on the spot market in order to deliver to promise.

The net revenues in the reference situation was calculated for the different trade lanes of Van Oers United, ranging from €97,000 for the ready-to-eat Senegalese mangoes up to €15,7 million for the Moroccan Green Beans.

The net value of the different interventions depends on the product ripening characteristics, but shows promising results, see the table below. The lead time shortening option for Moroccan green beans results in a net loss of €313,000 for a 12 hour lead time reduction, a net gain of €176,000 for a 24 hour reduction, whereas a 36 hours and 48 hours reduction would generate an additional net value of resp. €1,1 million and €1,9 million. Similar results become apparent for the other trade lanes. The option of dynamically adjust the condition parameters based on the actual decay pace generates the highest net value. In case of the Moroccan Green Bean trade lane, the additional net value equals €3.5 million.

Table 1: The commercial characteristics of the IoT4AGRI perishable products, the net revenue, and net value difference with reference in brackets.

Net revenues (net additional value)	**Green beans Senegal**	**Green Beans Morocco**	**Mango Senegal**	**Galia Melons Senegal**
Net revenue in reference situation	€ 8,78 M	€ 15,76 M	€ 97,93 K	€ 362,9 K
Lead time reduction by 12 hr	€ 8,59 M *(- 187K)*	€ 15,44 M *(- 313 K)*	€ 103,60 K *(5,6 K)*	€ 364,73 K *(1,8 K)*
Lead time reduction by 24 hr	€ 8,87 M *(94 K)*	€ 15,93 M *(176 K)*	€ 116,39 K *(18,4 K)*	€ 402,14 K *(39,2 K)*
Lead time reduction by 36 hr	€ 9,48 M *(703 K)*	€ 16,91 M *(1,1 M)*	€ 130,49 K *(32,5 K)*	€ 444,14 K *(81,2 K)*
Lead time reduction by 48 hr	€ 9,99 M *(1,2 M)*	€ 17,68 M *(1,9 M)*	€ 146,58 K *(48,6 k)*	€ 493,39 K *(130,4 K)*
Dynamic condition control	€ 10,83 M *(2,04 M)*	€ 19,29 M *(3,5 M)*	€ 176,96 K *(79 K)*	€ 592,05 K *(229 K)*
Rerouting sea + local sales	€ 10,81 M *(2,02 M)*	€ 19,22 M *(3,4 M)*	€ 161,20 K *(63 K)*	€ 568,49 K *(205 K)*
Rerouting road + local sales	€ 10,29 M *(1,5 M)*	€ 18,85 M *(3 M)*	€ 112,09 K *(14 K)*	€ 481,83 K *(118.9 K)*
Rerouting all + local sales	€ 10,15 M *(1,3 M)*	€ 18,61 M *(2,8 M)*	€ 95,98 K *(- 1,9 K)*	€ 452,37 K *(89,4 k)*

The option of rerouting fast ripening shipments often does not generate any additional value, in many cases continuing the shipment route and accept the losses in Dinteloord is more preferable then intervening and rerouting. And if It results in net value creation, the effect is minimal.

Sensitivity analysis brings additional insight in the sensitivity of the model against certain assumptions. First of all, the model is rather sensitive to the number and quality level of the sensors. When using more than four sets of high cost sensors per shipment, the interventions no longer result in a positive net value. Not surprisingly, if low cost sensors would be feasible for reliable quality decay modelling, the business case becomes substantially stronger. When assuming a bad harvest with a higher share of vulnerable products, the positive effect of sensing and intervening becomes more apparent. Even the rerouting option for fast ripening shipments then becomes positive. We see similar effects if we adjust the base quality decay parameters upon arrival. The relative impact of the interventions and accordingly the net value generation become much stronger. Also if the probability of fast ripening shipments increase, the effect of sensing and intervening becomes more apparent.

In case the probability of fast ripening shipments rises from 10% to 35%, more volume needs to be bought on the spot market and positive net margins disappear. A similar pattern appears when the spot prices become higher.

Finally, the business case of embedding the sensors in crates for reuse in perishable trade lanes looks promising. It is more attractive to deploy four smart crates per shipment instead of four sets of five removable sensors. Moreover, the embedded crate sensors also offer considerable benefits in other parts of the value chain.

The business model analysis highlights that the integrated Quality Controlled Logistics service actually requires a combination and integration of different partial solutions, which each have their own value proposition and corresponding business model considerations. Some partial business solutions such as sensor data provision, quality decay prediction and providing data connectivity are good scalable, whereas other partial services such as logistic intervention decision support and development of interfaces for specific data connectivity are less scalable. Each of the partial solution providers could consider to offer the integrated service. This may put competitive pressure on the collaboration.

Concluding, the concept of dynamic Quality Controlled Logistics looks promising and can generate a sound commercial business case.

Contents

1 Introduction

1.1 Project background IoT4AGRI

Food supply is one of the main challenges our global society faces, and supply chain innovation is expected to contribute to a secure, efficient and sustainable food supply. The Netherlands plays a significant role in the global food supply system. Food waste and quality decay is among others caused by suboptimal management of the climate conditions during transport. By applying innovative IoT applications, we contribute to sustainable logistics. Moreover, the project addresses dynamic supply chain planning solutions, enabled by Internet of Things (IoT), and corresponding alternative logistics service offerings (e.g. dynamic en-route changes) based on the remaining perishable product shelf life. This will result in CO_2 savings, transport avoidance (avoiding overripe products that cannot be consumed anymore), and modal shift potential.

In supply chains of fresh and perishable food products even minor disruptions in storage/transport conditions can have considerable effect on product quality. A lack of insight in (changes of) product quality during storage and transport leads to challenges in managing the quality/shelf life of fresh produce, uncertainties in claim processes, food waste throughout the supply chain, and difficulties to deliver according to agreed product quality standards. The concept of quality controlled logistics (Vorst et al, 2007), addresses these challenges. Follow up research (Vorst et al., 2012) identifies the possibilities for making chain information directly and real time available and usable to support decision making of all partners in the horticultural network but concludes that an integrated approach of quality-controlled logistics is still lacking. Major barriers are the difficulty of precise prediction on remaining product quality/shelf life, caused by intrinsic biological variations of the perishable products and lack of knowledge of the initial post-harvest quality. By capturing sensor data and use it as input for quality decay models, we aim to overcome this barrier and anticipate in dynamic supply chains accordingly. As such, we apply quality controlled logistics in an integrated way. Traditional technologies are not able to provide accurate predictions, require labour-intensive treatment or are too expensive. Therefore investigating the potential use of the next-generation technologies such as IoT become relevant.

In this IoT4AGRI project, the consortium members recognise that IoT technologies are needed to extend the possibilities of monitoring and controlling the quality of perishable products, and to enable implementation of the concept of data driven quality-controlled logistics.

The project is structured around six work packages, being:

- WP1 IoT enabled Quality Controlled Logistics (QCL), including the QCL-concept, the state-of-the-art of supporting technologies and the SWOT analysis of this QCL-concept.
- WP2 Business analysis, including the use cases for demonstration, the business case analysis and the business model analysis.
- WP3 Design and Solution Development, including the development work needed to demonstrate a proof of concept in a real-life setting.

- WP4 Demonstrations, covering use cases in a maritime and a continental road trade lane.
- WP5 Evaluation and valorisation, make sure that the project knowledge is being disseminated among the target audience and support a broader valorisation of the project insights.
- WP6 Project Management, assuring an overall efficient execution of the project and organize and facilitate the cooperation between the consortium parties.

Each WP has a corresponding deliverable, that reports on the results. This report reflects the results of WP2 and is called D2.1 Business models, business and use cases of IoT-enabled QCL of perishables. Next section elaborates the scope of this report and what this report covers.

1.2 Scope and contents of the report

After this introduction chapter (chapter 1), the report starts elaborating the use cases in chapter 2. These use cases provide the basis for a proof of concept in a real life demonstration setting in the project. Next, chapter 3 deals with the business case of the IoT-enabled Quality Controlled Logistics. The business case provides insight in the value creation and the corresponding costs to implement the concept. The business case model has been developed and applied onto the Van Oers United trade lanes with green beans, mangoes and Galia melons from Senegal and Morocco to the Netherlands. The model was developed in a generic way in order to make it also applicable to other perishable products and alternative trade lanes. Chapter 4 elaborates different variants of how the concept could be implemented in practise and what it means for the roles of the different stakeholders. Chapter 5 summarises the main conclusions that can be drawn from the analyses.

2 The project use cases

In order to demonstrate a proof of concept of the overall dynamic Quality Controlled Logistics concept, we split the overall comprehensive concept into pieces. In real life demonstrations, these use cases are being demonstrated, showing a proof of concept of the different elements of the comprehensive dynamic QCL-concept.

The following five use cases have been defined as a basis for demonstration:

1. Monitor international shipments and capture and disclose sensor data in real time for quality decay modelling:

    a. ***UC1a - High quality ethylene monitoring during perishable shipment transport***; Monitor international shipment with high quality ethylene sensors in order to use this as input data to capture and disclose the data in real time for downstream processing and for quality decay modelling of the perishable cargo.
    b. ***UC1b - Low-cost IoT solution for real-time perishable shipment status sensoring***; Monitor international shipment with multiple low-cost sensors using novel IoT technology to capture and disclose the data in real time for downstream processing.

2. ***UC2 - Optimal sensor positioning in perishable shipment***; Apply sensors on different locations within a truck of container and analyse the differences in sensor values in order to advise on the number and location of different sensors and to provide Input for the feasibility of the business case of embedded sensors in pallets or crates.

3. ***UC3 - Sensor-enabled quality decay predictions of a shipment***; Provide quality decay predictions based on sensor values of relevant sensors attached to the international shipment(s) of perishables. Relevant sensors include sensors that measure quality decay indicators such as ethylene, temperature, O_2, CO_2 and relative humidity.

4. ***UC4 - Decision support for logistics interventions driven by quality decay predictions***; Configure possible logistics interventions and provide decision support on executing these interventions based on the quality decay predictions and remaining transport lead time of corresponding shipments.

The picture below shows how the use cases link to the key concept building blocks. These use cases are further elaborated in the following sections and will be used as basis for a proof of concept in real-life demonstrations.

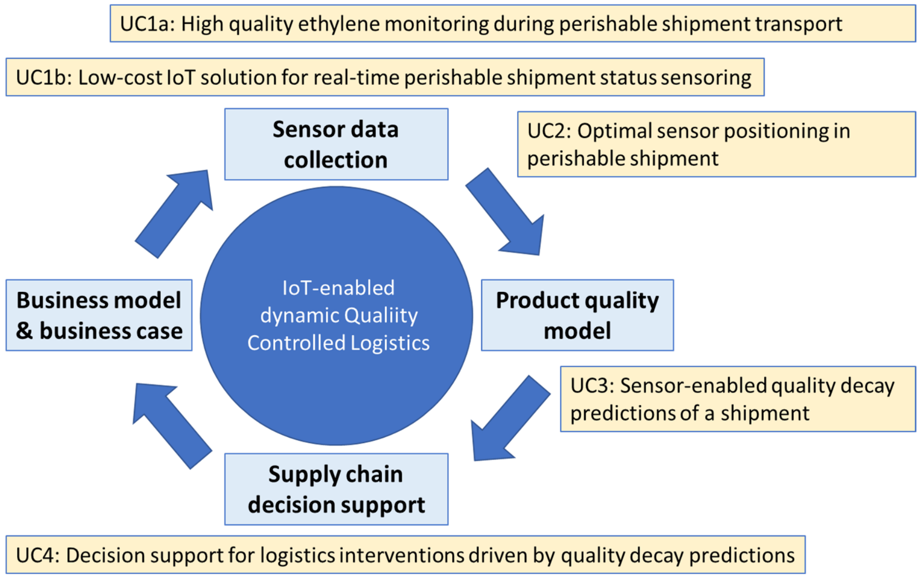


Figure 1: The link between the IoT4AGRI use cases and the conceptual building blocks of IoT-enabled dynamic quality controlled logistics.

2.1 High quality ethylene monitoring during perishable shipment transport (UC1a)

Quality decay is hardly being monitored during transport in perishable logistics. Relevant quality decay parameters for perishables include among others ethylene, O_2, CO_2, temperature and relative humidity. Today, reliable ethylene sensors are large and rather expensive, as a result ethylene sensors are not yet being used for transport monitoring purposes. Perishables that produce ethylene during ripening include among others mango, Galia melon and green beans, all being produced by Van Oers United. Other ethylene producing perishables include tomatoes and kiwi. This use case is aimed at monitoring ethylene production in international shipments of perishables with specifications allowing for sound quality decay modelling, using novel IoT solutions to model the quality decay during transport by using ethylene sensor technology in an international shipment.

This case is aimed to capture reliable sensor values for quality decay modelling and show the practicalities of applying a high quality ethylene sensor to an international shipment. This includes aspects like shipping the sensor to the place of departure (shipping costs, customs formalities, operational handling).

2.2 Low-cost data sharing sensory solution (UC1b)

The second alternative is aimed at showing the ease and cost-efficiency of capturing different sensor data during transport and communicating this sensor data real time for further processing, such as quality decay modelling. Here the focus is on showing the cost-efficiency of novel IoT technologies to capture and share sensor data in real time during transport of perishables. In this use case we include sensors within the lower bound (in terms of costs) or even sensors below the preferred specifications for the quality decay model.

The idea behind this is that it might also be a feasible development route to apply multiple very low cost sensors (below the preferred sensor specifications for the quality decay model) in combination with advanced (big) data analytics to provide acceptable quality decay predictions. Though it is beyond the scope of this project to perform this kind of advanced data analytics, the use case primarily demonstrates the cost-efficiency of applying IoT technologies to capture and share sensor data in real time in perishable logistics chains.

2.3 Optimise sensor positioning in truck or container (UC2)

This use case is aimed at positioning the sensors on the right location in the reefer container and / or truck and in the right quantity in order to collect reliable data about the context of the perishables in transit. In order to do so, multiple sensors will be placed in a shipment on different predefined locations. Analysis of the shipment sensor data compares the differences in sensor value and results in an advise on the number and location of sensors attached to a shipment.

This use case most likely will have a laboratory like set-up. This means that a transport of relevant products via reefer and / or truck is being simulated in a laboratory setting. The laboratory settings simulates as realistically as possible the shipping of these products (time, outside conditions, positioning of the cargo, ...) delivering all the needed data and information without actually transporting the products. This gives the researcher the flexibility within the research without having to cope with the operational issues and unknown factors associated with following an actual transport. Furthermore, this use case doesn’t focus on the practical aspects of data connection, IoT infrastructure, etc.

This use case helps improving the quality decay model predictions. Moreover, it provides useful insights for the business case of IoT-enabled Quality Controlled Logistics: how many sensors are needed per shipment? What should the position of the sensors be (proximity to the product)? What KPI is the most relevant for indicating product quality?, etc. And related to these main questions it should also give insight in the question if embedded sensors on truck/container level, pallet level or crate level would be feasible in comparison with removable sensors?

2.4 Sensor-enabled dynamic quality decay predictions of a shipment (UC3)

This use case is aimed at predicting the quality decay of a shipment with perishable products based on sensor values of relevant quality decay parameters measured in a shipment, such as ethylene, CO_2, O_2, temperature and relative humidity. The aim is (1) to determine for the researched products the limit value for the parameters mentioned (ethylene, CO_2, O_2, temperature and relative humidity) above which it has a negative influence on the product quality. Passing this limit could be a trigger for an alternative intervention. (2) To predict for the researched products what the product quality will be, given the state of the parameters during transport, upon arrival of the shipment and (3) if possible, and nice to have, to predict the remaining shelf life of the products at any given moment during shipment, in order to consider alternative interventions.

2.5 Dynamic decision support for logistics interventions driven by quality decay predictions (UC4)

This use case aims to support possible interventions during the logistics of a shipment in order to maximise the value of the shipment. This value maximisation may result from adjusting the conditioning parameters during transport, shortening the lead time or change the destination and the corresponding sales channel.
A logistic intervention model compares the expected value of the particular shipment in the reference supply chain configuration versus alternatives after intervention, given the actual quality decay predictions. It actually simulates the expected shipment value based on the quality decay predictions in several logistics intervention options and proposes an intervention advise.

2.6 Integration of the use cases

In order to valorise the comprehensive concept of IoT-enabled Quality Controlled Logistics, it requires a complete integration of the different use cases, see also igure 1. This project however breaks down this comprehensive concept into manageable pieces, use cases. Where possible, we try to integrate multiple use cases onto the same shipment. Reliable sensor data provides input to the quality decay model, whereas the quality decay model outcomes provide input to the logistics intervention model. This comprehensive QCL-concept can only work in an operational way if a data sharing infrastructure supports all the interfaces.

3 The business case analysis of IoT4AGRI

The business case is set up in a way it monetarises the value of internationally shipping perishable fruit and vegetables and compare the net value creation of alternative logistics interventions triggered by sensor data.

The business case is being developed in a generic way in order to:
- Apply the business case model also to alternative perishables and alternative trade lanes;
- Simulate the value creation of logistics interventions given the quality decay prediction model outcome.

The business case is limited to the cost and added value of product quality related sensory data, which includes product value (loss) during transportation between harvest sites and distribution centre in the Netherlands, and the associated costs of interventions.

It does not take into consideration possible benefits related to tracking and tracing in order to optimise subsequent supply chain processes (such as preparing the unloading personnel at the warehouse dock and avoid waiting times). Moreover, it does not consider possible benefits in trade compliance, such as supporting AEO or trusted trader schemes or reduced inspections by customs or phytosanitary inspection bodies. Moreover, it does not include any societal benefits related to reduction of food waste. Finally, it does not include any benefits in downstream activities, which is particularly relevant for the embedded crate sensor solution in section 3.7. So the business case for the complete end-to-end supply chain may even be more attractive.

3.1 The perishable trade lanes of green beans, mangoes and Galia melons

3.1.1 The different perishable trade lanes

The business case is applied to four trade lanes of project partner Van Oers United:

- Transport of green beans from Senegal to Dinteloord, partly being shipped by Sea via Dakar to Rotterdam or Antwerp and trucked from the port to Dinteloord (FCL shipments), partly being trucked by road via Gibraltar Strait ferry to Dinteloord (FTL-shipments). The average lead time of the maritime lane is ten days. The average lead time of the transcontinental road lane is eight days.
- Transport of green beans from Morocco to Dinteloord, partly being shipped by Sea via Tangier to Rotterdam or Antwerp and trucked from the port to Dinteloord (FCL shipments), partly being trucked by road via Gibraltar Strait ferry to Dinteloord (FTL-shipments). The average lead time of the maritime lane is seven days. The average lead time of the transcontinental road lane is 4.5 days.
- Transport of ready-to-eat mangoes (today Van Oers only produces unripe mangoes, but explores the possibility of producing ready-to-eat mangoes) from Senegal to Dinteloord, partly being shipped by Sea via Dakar to Rotterdam or Antwerp and trucked from there to Dinteloord (FCL shipments), partly being trucked by road via Gibraltar Strait ferry to Dinteloord (FTL-shipments).

The average lead time of the maritime lane is ten days. The average lead time of the transcontinental road lane is eight days.
- Transport of Galia melons from Senegal to Dinteloord, partly being shipped by Sea via Tangier to Rotterdam or Antwerp and trucked from the port to Dinteloord (FCL shipments), partly being trucked by road via Gibraltar Strait ferry to Dinteloord (FTL-shipments). The average lead time of the maritime lane is ten days. The average lead time of the transcontinental road lane is eight days.

The green bean trade lanes and the Galia melon trade lane are based on existing volumes and knowledge of the modal split and ripening parameters. The existing mango trade lane from Senegal to Dinteloord is harvesting, shipping and selling unripe mangoes that need a local ripening treatment. This volume is fully shipped by sea. Managing the ripening status using sensor technology would hardly provide any added value. Moreover, Van Oers is exploring the possibilities of producing and selling ready-to-eat mangoes, having a substantially higher sales price. Here, managing the ripening status would make sense, so we elaborated the business case for ready-to-eat mangoes assuming this transition has already taken place.

Table 2:The IoT4AGRI Trade lanes of perishable products.

Product	**Tradelanes**	**Modal split**	**Lead times**
Green Beans Senegal	Sea: Dakar – R'dam/Antwerp – Dinteloord Road: Senegal – Gibraltar Strait - Dinteloord	Sea: 30% Road: 70%	Sea: 10 days Road: 8 days
Green Beans Morocco	Sea: Tangier – R'dam/Antwerp – Dinteloord Road: Tangier – Gibraltar Strait – Dinteloord	Sea: 30% Road: 70%	Sea: 7 days Road: 4,5 days
Mango Senegal	Sea: Dakar – R'dam/Antwerp – Dinteloord Road: Senegal – Gibraltar Strait – Dinteloord	Sea: 70% Road: 30%	Sea: 10 days Road: 8 days
Galia Melons Senegal	Sea: Dakar – R'dam/Antwerp – Dinteloord Road: Senegal – Gibraltar Strait – Dinteloord	Sea: 60% Road: 40%	Sea: 10 days Road: 8 days

3.1.2 *Post-harvest quality sorting and modal split*

The natural products are subject to variations in ripening status after harvesting. Moreover, the breeding process can be subject to variations in climate conditions. And the timing of harvesting can make a difference. This all results in variations in harvest output quality. We distinguish between robust products and vulnerable products. We assume that robust products are preferably being shipped by sea, whereas vulnerable products are being shipped preferably by road as a result of average shipping costs and lead time differences. In practise, transport booking options and price differences may result in a different modal split then the split in robust versus vulnerable. Based on expert judgement the model assumes the following split in product robustness and modal split.

Table 3: The IoT4AGRI Trade lane characteristics (robustness and modal split).

	Product post-harvest robustness		**Modal split**	
	Robust	**Vulnerable**	**Sea**	**Road**
Green beans Senegal	80%	20%	30%	70%
Green Beans Morocco	70%	30%	30%	70%
Mango Senegal	70%	30%	70%	30%
Galia Melons Senegal	70%	30%	60%	40%

3.1.3 *Sales prices, additional sourcing and fines for delivery outside agreed specifications*

The producer and/or importer has contracts with customers to deliver an agreed quantity against an agreed quality level. Some products falling outside this agreed quality level can still be sold on the market via an alternative sales channel against an alternative (lower) sales price. And some products result in waste and cannot be sold anymore. Moreover, in some cases the producer/importer has to depreciate a share of the received products and cannot deliver all from its own inventory.
In those cases he has to source additional quantities on the spot market, obviously against higher prices.

In the basic model we assume the following price parameters. These are indicative prices, in reality there are much more variables determining the sales price for these products, which are subject to variations.

Table 4: The commercial characteristics of the IoT4AGRI perishable products (prices per ton).

Prices in € per ton	**Delivery within specs**	**Alternative sales channel**	**Waste**	**Spot market price**
Green beans Senegal	€ 2000	€ 1000	€ 0	€ 2400
Green Beans Morocco	€ 2000	€ 1000	€ 0	€ 2400
Mango Senegal	€ 2500	€ 1250	€ 0	€ 3000
Galia Melons Senegal	€ 1600	€ 960	€ 0	€ 1920

3.1.4 *Ripening parameters*

The ripening assumptions have been determined in a number of expert sessions with an R&D manager of Van Oers United. It needs to be stressed that this kind of data is not being stored in a structured way in the business systems of Van Oers United, so the estimates are based on expert judgement.

The model assumes that the products have a standard distribution over the three categories for respectively robust products and for vulnerable products. The far majority of the shipments follow this pattern. A small percentage of the shipments ripen much faster than anticipated, obviously resulting in a different distribution (e.g. faster quality decay and more waste). The model is built upon the following ripening assumptions, specified for the sea trade lanes (table 4) and the road trade lanes (table 5).

Table 5: The ripening parameters of the IoT4AGRI Sea trade lanes.

Sea trade lanes	**Green beans Senegal**		**Green Beans Morocco**		**Mango Senegal**		**Galia Melons Senegal**	
Shipments following a standard ripening pattern	95%		95%		90%		90%	
Product robustness	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.
% within specs	85.0%	65.0%	90.0%	70.0%	70.0%	55.0%	70.0%	55.0%
% alternative sales channel	7.5%	17.5%	10.0%	15.0%	15.0%	22.5%	15.0%	22.5%
% waste	7.5%	17.5%	10.0%	15.0%	15.0%	22.5%	15.0%	22.5%
Fast ripening shipments	5%		5%		10%		10%	
% within specs	15%		15%		10%		10%	
% alternative sales channel	15%		15%		10%		10%	
% waste	70%		70%		80%		80%	

The table shows that for the standard sea shipments, the majority of the products can be delivered according to specification, varying from 55% of the vulnerable Senegalese melon shipments up to 90% of the robust Moroccan green bean shipments. A small fraction of the sea shipments (5-10%) shows a fast ripening pattern, resulting in 70% to 80% waste. This is a result of high ethylene concentrations caused by ripening, which cause a further acceleration of the ripening process. As a consequence, the majority of a shipment could have a quality that is no longer suitable for the regular sales channels and should be treated as waste.

Table 6:The ripening parameters of the IoT4AGRI Road trade lanes.

Road trade lanes	**Green beans Senegal**		**Green Beans Morocco**		**Mango Senegal**		**Galia Melons Senegal**	
Shipments following a standard ripening pattern	92%		92%		90%		90%	
Product robustness	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.
% within specs	90.0%	70.0%	93.0%	75.0%	75.0%	60.0%	75.0%	60.0%
% alternative sales channel	5.0%	15.0%	3.5%	7.5%	12.5%	20.0%	12.5%	20.0%
% waste	5.0%	15.0%	3.5%	7.5%	12.5%	20.0%	12.5%	20.0%
Fast ripening shipments	8%		8%		10%		10%	
% within specs	15%		15%		10%		10%	
% alternative sales channel	15%		15%		10%		10%	
% waste	70%		70%		80%		80%	

This table shows that for the standard road shipments, the majority of the products can be delivered according to specification, varying from 60% of the vulnerable Senegale melon shipments up to 93% of the robust Moroccan green bean shipments. These percentages are all slightly higher than for the sea trade lanes, because the corresponding lead time is about two days shorter, assuming a similar level of control of the conditioning parameters. A small fraction of the road shipments (8-10%) shows a fast ripening pattern, resulting in 70% to 80% waste. For green bean transport by road, the fraction of fast ripening shipments is a bit higher than for sea transport (8% versus 5%). This is because road transport experiences higher variations in climate conditions (e.g. relative humidity) which may result in *'browning'* of the beans.

3.1.5 Fixed quality inspections

Van Oers United already applies post-harvest quality inspection as well as random quality inspection at arrival in its logistics reception facility in Dinteloord.

The post-harvest quality inspection allows a sorting process where products can be sorted in four categories:

- Robust export products;
- Vulnerable export products;
- Products for local market sales;
- Waste.

Based on this sorting the allocation of export products to different transport modes can easily be done.

We expect this already happens in the reference scenario. The model assumes that robust products are preferably being shipped by sea (lower transport costs), whereas vulnerable products are preferably being shipped by road (in order to reduce the lead time and keep further quality decay within acceptable limits).

Moreover Van Oers is inspecting the shipments upon arrival in Dinteloord.
This inspection allows Van Oers to sort the products in the three sales categories and deliver the products according to the agreed specs or sell them via alternative sales channels against an alternative sales price. In this way, they can avoid fines from customers. The agreed specifications allow for small deviations within boundaries. A thorough inspection upon arrival in Dinteloord is expected to avoid any serious customer complaints.

3.2 Logistic interventions

The previous section shows that fixed static inspections built into the supply chain only already result in a rather controllable supply chain, robust products can be shipped by sea, whereas vulnerable shipments will use quicker road transport. Moreover, control upon reception allows for sorting and deliver the products to the right sales channel. The key question in this project is what additional value might be created when monitoring the quality decay throughout the logistics chain and intervene accordingly.

Assuming that the sensor technology applied allows for reliable prediction about the product quality upon arrival, the following logistics interventions have been considered:

- Shortening the transport lead time by 12 hours;
- Shortening the transport lead time by 24 hours;
- Shortening the transport lead time by 36 hours;
- Shortening the transport lead time by 48 hours;
- Dynamic adjustment of the climate conditions during transportation;
- Reroute the shipment and find an alternative sales market along the route.

There are still many questions how to apply these measures in practice and if they are feasible. However, for this analysis we assume they are feasible and we investigate the net value implications if they would be implemented.

3.2.1 Shortening the transport lead time by 12 up to 48 hours

The idea is that if the sensor values give an indication that products ripen faster than anticipated, that the transportation lead time might be reduced by changing the priority of the shipment.

For sea transport, the sea leg is not expected to be shortened by speed adaptations of the vessel because of some fast ripening shipments on board. Moreover, it seems unrealistic to adapt the the stowage plan during sea voyage. However, container dwell time in the unloading terminal may be shortened. The idea of this dynamic priority treatment in terminals was discussed with a Rotterdam container terminal and was not infeasible, but mainly depends on the willingness to pay for this service. Nevertheless, it is not common practise today. Priority treatment in unloading sequence may be considered.

In a port call with huge call sizes it matters if a priority container would be unloaded in the first couple of hours or in the last batch. This can make a difference of up to two days, though most reefer containers often will be unloaded in the first phases of an unloading plan. Moreover, the stacking procedures also determine the dwell time of containers on a terminal. The assumption is that a priority treatment could result in a ‘crossdock-alike’ operation, where the container is being unloaded from the sea vessel and directly moved to the place where a truck is ready to load the container. Finally, preparatory activities to ensure a fast release, combined with a fast hinterland slot planning further offer opportunity to shorten the container dwell time. Of course, this kind of priority treatment would come with a price, a fee for a dynamic priority treatment terminal service is included in the cost assumptions for this type of intervention costs. Apart from that, this project does not have the operationalisation of this dynamic priority treatment in scope.

For road transport the lead time can be reduced by adding a truck driver and drive and rest simultaneously. Moreover, the trailer could be swapped to another truck-trailer combination halfway, whereas another truckdriver just had his resting hours and is able to continue the journey. This of course requires a tough planning and additional costs. An estimate for these additional costs has been taken into account in the intervention cost assumptions.

3.2.2 Dynamic adjustment of the climate conditions during transportation

If possible to control them, the climate conditions normally include fixed settings for temperature and relative humidity. The idea behind real-time monitoring of these conditions and the corresponding quality decay predictions is that the sensor data may give ground to dynamically adjust certain settings accordingly. Think of using ventilation, lowering the temperature, reduce the humidity levels, add ozone, or add fresh air / oxygen.

It would require monitoring the quality decay patterns of numerous shipments in order to optimise the settings accordingly. Here, we assume that this is possible when implementing this sensor solution, though this dynamic setting optimisation is out of scope for this project. It would require calibrating the decay model based on large volumes of real monitoring data and feedback loops. We simply assume that it is possible to dynamically adjust the settings, resulting in a slower quality decay. Obviously, this comes with a cost. An average cost estimate has been included in the model for this intervention.

3.2.3 Reroute the shipment and find an alternative sales market along the route

Ultimately, when ripening goes much faster than expected, shipping the goods to Dinteloord may result in a too high percentage of waste. Van Oers could in those cases decide to change the routing and find an alternative sales market along the planned route.

For the sea trade lane this would assume flexibility in changing the unloading port to Le Havre and sell the container shipment to a local wholesaler destined for the French market. It is highly questionable if this option could be executed at all, but worth exploring what it might deliver in terms of value creation.

For the road trade lane, there are more options. A truck shipment can in principle be rerouted every moment, depending on the location and the quality decay predictions. The shipment could then be sold to a wholesaler destined for the Spanish or French market.

3.2.4 Quality decay parameters of logistics interventions in the trade lanes

The logistics interventions are expected to slow down the foreseen decay. The expected impact on the ripening pace is reflected by adjustment of the ripening parameters, compared to the reference situation. This is done in an expert session with the quality manager of Van Oers United, so is based on expert judgement and common sense. When the sensor solution is being implemented on a larger scale, the parameter settings could be calibrated based on the actual ripening patterns.

The interventions result in a higher percentage deliveries within the agreed specifications and a lower percentage waste, compared to the reference situation, Also the probability of fast ripening shipments will be reduced by the interventions. The exact detailed model parameter assumptions are presented for the different trade lanes in Annex A for each of the interventions.

3.3 Cost assumptions

3.3.1 The sensor costs

In the alternative scenarios we assume equipping a shipment with 1 ethylene sensor, 1 temperature sensor, 1 CO_2 sensor, 1 Oxygen sensor and 1 relative humidity sensor is sufficient to achieve acceptable input data for the quality decay model. In the sensitivity analysis we make calculations with other multiple-sensor configurations, see section 3.5.1.

Since we have not yet enough information to determine which specifications are feasible for the quality decay model, we consider an upper bound and a lower bound for the sensor costs. The upper bound cost value is based on the ideal specifications for the quality decay model, as specified by a quality model expert of Wageningen Food & Biobased Research (WFBR). The lower bound costs are cost estimates found for sensors with lower specifications. In the reference scenario, we take the average of both.

Table 7: The cost ranges for quality decay sensors

Equipment	Ideal specs	Cost (low)	Cost (mid.)	Cost (high)	Source
Ethylene sensor	0-10ppm	€100[1,2]	€800	€1500	Lower bound: €149,66 (ME3-C2H4 WINSEN - Sensor: gas | C2H4; Bereik: 0÷100ppm; Serie: ME3; Press-Fit | TME - Elektronische Componenten) Upper bound extends beyond €1500 (e.g. €4000 F-950 Three Gas Analyser - Fresh Produce Instruments or €8000 F-900 Portable Ethylene Analyzer - Fresh Produce Instruments).
Temperature sensor	-10° to 50°C, accuracy 0.3°C		14,97	€27	AM2315 Temperatuursensor en luchtvochtigheidssensor I2C - Bits & Parts Elektronica (bitsandparts.nl) Temperature and humidity sensor, close to ideal specs
Temperature sensor		€2,95		€210	Lower: DS18B20 Temperatuur Sensor Waterdicht 1M | TEC voordeel (0.5° accuracy) Upper: Müller Temperature Sensor Hygiene HART - Sensors.nl (0.3°C accuracy – meets specs)
Oxygen sensor	1-22%, accuracy 0.5%	€5,17	€90	€175	Upper: Greisinger GOX 100 Zuurstofmeter 0 - 100 % | Conrad.nl (0.1% accuracy) Lower: Seeedstudio Grove Zuurstofsensor (MIX8410) - RobotShop
CO_2 sensor	0-10%, accuracy 0.3%	€23,12	€41,50	€59,95	Upper: CO2 and RH/T Sensor - SCD30, SEN-15112 - Antratek Electronics (range up to 40000ppm, also RH, temperature sensor). CO2 sensor that meets specs (>40000ppm) could not be found. Lower: Ndir co2 sensor mh-z14a pwm ndir infrared carbon dioxide sensor module serial port 0-5000ppm controller Sale - Banggood.com
Humidity sensor	30-100%, accuracy 1%	€4,45	€45	€86,07	Lower: DHT22 temperatuur & luchtvochtigheid sensor - Arduino - vanallesenmeer (accuracy 2-5%RH) Upper: T9602-3-a Humidity/temp Sensor, Analogue, 0-95%rh Amphenol Advanced Sensors - Sinuss.nl (2% accuracy, also measures temperature)
Raspberry pi zero		11,50	€18,25	25	Raspberry Pi Zero W - Raspberry Pi Foundation (kiwi-electronics.nl)
Protection shield	For raspberry pi	€4,21	€12,20	€20,25	Lower: RPIZ CANDY BK: Behuizing voor Raspberry Pi zero "Candy Bar", zwart bei reichelt elektronik Upper: RPIZ CASE ALU BS: Koffer voor Framboos Pi Zero, aluminium, zwart - zilver bei reichelt elektronik Plastic versus aluminium cover

[1] Experts in the consortium expect the lower bound cost for high quality specified ethylene sensors to be in the range of €250-500, but able to drop to €50-€100 in case of large volume application.

[2] Ma, L., et.al., A Low Cost Compact Measurement System Constructed Using a Smart Electrochemical Sensor for the Real-Time Discrimination of Fruit Ripening, published in: Sensors 2016, 16, 501.

The Raspberry Pie is a series of small single-board computers developed in the United Kingdom by the Raspberry Pi Foundation. It is widely used in many areas, such as for weather monitoring, because of its low cost, modularity, and open design. The Raspberry Pie Zero is the smallest version with limited input/output capabilities, but expected to satisfy the use in this demonstration.

When connecting several sensors to the Raspberry Pie, a protection shield is proposed to safeguard the sensors during transport.

3.3.2 *The data communication costs*

In order to communicate data we need additional hardware. We need a microcomputer able to log, store and process the sensor data, and a communication devise able to transmit the data. The Raspberry Pie Zero combines these two functions, it supports LoRa, WiFi and Bluetooth broadcast protocols.

In our project we intend to use the LoRa bandwith communication features. This would only require additional investment in a LoRa gateway. Such a LoRa gateway costs around €250 and would be deployed onto sea vessels (for sea monitoring) and in the trucks for in-truck monitoring. For sea transport, the communication infrastructure uses The Thing, an internet-based cloud communication infrastructure for LoRa-enabled IoT solutions. This The Things infrastructure aims to accelerate the deployment of IoT solutions and allows for low cost sensor data processing cost. These costs include €2 per shipment and could drop to €0.40 per shipment if the data warehouse solution would process data from 1000 sensors or more.

For the LoRa gateway cost, the sea vessels should be equipped with this technology. We assume Van Oers will book the sea containers with a preferred ocean carrier operating on the West Africa – North-West Europe lane, and we assume this carrier runs 5 vessels on this scheduled service that need to be equipped with this LoRa Gateway. We assume that container vessels already have a ship-shore communication interface. For the land corridor, we assume a fleet of 25 trucks should be equipped with a LoRa Gateway to handle all Van Oers road shipments.

3.3.3 *The interface costs*

We assume that all shipment sensor data is being captured by a device (Rasperry Pie or uController) and sent via the Things infrastructure to a central data warehouse supporting the complete Quality Controlled Logistics service. From this data warehouse, it requires a 2-way interface with the operator of the quality decay model (WFBR in our case), a 2-way interface with the operator of the logistics intervention model (in our case TNO), and a shipment dashboard with a secure web interface to access. This complete data sharing environment is expected to be configured against a cost of €16,000 (4 programmers each working 40 hours against a cost of €100/hour).

3.3.4 *The sensor handling costs*

These costs include shipping the sensors to the place of loading, sensor placement in the shipment, activation of the sensors and connect them to the Rasperry Pie, removal of the sensors upon arrival, and collection of the sensors and Raspberry Pie for reuse. A cost estimate is presented in the table below.

Table 8: Sensor handling cost estimates per shipment.

Category	Description	Cost estimate
Sensor shipment	Air freight parcel (up to 5 kg)	€ 25
Placement and activation	Per shipment (15 minutes a €40/hr)	€ 10
Removal and collection	Per shipment (10 minutes a €60/hr)	€ 10
Administrative system	Per shipment	€ 10
Total handling cost	**Per shipment**	**€ 55**

3.3.5 *The quality decay model use costs*

As can be seen in the business model elaboration in chapter 4, if the concept becomes operational, WFBR may no longer operate the quality decay model and sell the IPR to a service provider that will manage, maintain the quality decay model. A fee per shipment seems to be a feasible model for the revenue streams, see section 4.5 for further business model details. A rough estimate of the additional development costs would be about €50.000. Moreover we assume the model is being applied onto 10.000 shipments (several customers, several trade lanes, multiple shipments per customer per trade lane). This would result in an average fee (incl. 10% gross margin) for the quality decay model of €5,50.

3.3.6 *The logistic intervention model use costs*

The revenue stream model for this partial service is similar to the quality decay model service, also a third party that operates the model and calculates a fee per shipment (see also chapter 4). Here we assume it requires an additional investment of € 10.000 to make the model ready for commercial use. This investment is generic and could be split over 10.000 shipments. In addition, the logistic intervention model needs to be configured for each particular trade lane. We assume here a cost estimate of €250 per trade lane, and to be applied on average onto 100 trade lane shipment. This would result in an average fee (incl. 10% gross margin) for the logistic intervention model of €3.85.

3.3.7 *The costs of the interventions*

The logistics interventions are described in detail in section 3.2, so we just present an estimate of the associated costs of the different interventions.

We assume for priority treatment in terminals and the possibility of each of the priority treatment and an estimate of the cost of each shipment:

- 48 hour reduction: Unrealistic without changing the stowage and/or unloading plan. In order to calculate with this option, we assume it would come at an additional cost of €1000 per FCL
- 36 hour reduction: Also unrealistic without changing the stowage and/or unloading plan. In order to calculate with this option, we assume it would come at an expensive €800 per FCL
- 24 hour reduction: Possibly realistic, it would include an ultra-fast terminal release. In order to calculate with this option, we assume an additional cost €200 per FCL.
- 12 hour reduction: Realistic and would include a fast terminal release. In order to calculate with this option, we assume an additional cost of €100 per FCL.

For road transport, priority treatment in road transport is possible by the inclusion of an extra driver who possibly joins the first driver along the journey from Morocco/Senegal depending on how many days (or hours) need to be reduced. This comes at an additional cost of the second driver along with an assumption of where the driver would join.

This is assumed as follows:

- For the Senegal trade lanes, which is about eight days:
  - 48 hour reduction: The 2nd driver needs to be deployed for a major part of the trip distance for 5 days. In order to calculate with this option, we assume an additional cost of €1,395 per shipment.
  - 36 hour reduction: The 2nd driver needs to be deployed for half of the trip distance for 3.75 days. In order to calculate with this option, we assume an additional cost of €1,046 per shipment.
  - 24 hour reduction: The 2nd driver needs to be deployed for one-third of the trip distance for 2.5 days. In order to calculate with this option, we assume an additional cost of €697.50 per shipment.
  - 12 hour reduction: The 2nd driver needs to be deployed for less than one-third of the trip distance for 1.5 days. In order to calculate with this option, we assume an additional cost of €418.50 per shipment.
- For the Morocco trade lanes which is about 4.5 days:
  - 48 hour reduction: The 2nd driver needs to be deployed for a major part of the trip distance for 4.5 days. In order to calculate with this option, we assume an additional cost of €1,255.50 per shipment.
  - 36 hour reduction: The 2nd driver needs to be deployed for half of the trip distance for two days. In order to calculate with this option, we assume an additional cost of €558 per shipment.
  - 24 hour reduction: The 2nd driver needs to be deployed for one-third of the trip distance for 1.5 days. In order to calculate with this option, we assume an additional cost of €418.50 per shipment.
  - 12 hour reduction: The 2nd driver needs to be deployed for less than one-third of the trip distance for one day. In order to calculate with this option, we assume an additional cost of €279 per shipment.

Adjusting the conditioning parameters dynamically during transportation requires additional conditioning features (automated remote setting adjustment) and/or possible manual support from a vessel operator checking the reefer container or a truck driver executing some handlings (e.g. door opening). The service fee of such a service is estimated to be about €75 per FCL or FTL.

The option of rerouting and selling the products on the local market along the route is estimated to result in additional cost of €75 per FCL or FTL.

3.4 Business case findings for the IoT4AGRI trade lanes

The business case for each trade lane defines and compares different scenarios to show how the introduction of sensor technology would lead to more gain and less wastage.

The following scenarios are described in each of the trade lanes:

1. Reference scenario: This scenario is currently in place wherein, the robust part of the harvest is allocated to sea transport with an inspection at Dinteloord.
2. Alternative 1a: This scenario has a similar product allocation to the transport modes. But this scenario introduces sensing during transport and an intervention that ***reduces the total lead time by 0.5 day*** (12 hours).
3. Alternative 1b: This scenario has a similar product allocation to the transport modes. But this scenario introduces sensing during transport and an intervention that ***reduces the total lead time by one day*** (24 hours).
4. Alternative 1c: This scenario includes sensing along with a ***reduction in lead time by 1.5 days*** (36 hours). It has the same robust harvest allocated to sea transport.
5. Alternative 1d: This scenario includes sensing along with a ***reduction in lead time by two days*** (48 hours). It has a similar robust harvest allocated to sea transport.
6. Alternative 2: This scenario includes sensing along with ***dynamic climate control***, assuming to readjust the climate control parameter settings based upon the ripening status, in order to slow down the ripening. It has a similar robust harvest allocated to sea transport.
7. Alternative 3a: This scenario includes sensing along with dynamic climate control ***and rerouting fast ripening sea shipments***. It assumes the possibility of changing the destination on the bill of lading and corresponding port of unloading, and selling the risky products on the local market before they have become worthless. It has a similar robust harvest allocated to sea transport.
8. Alternative 3b: This scenario includes sensing along with dynamic climate control ***and rerouting fast ripening road shipments***, and sell the risky products on the local market along the route. The risky produce in this case is dumped on the local market. It has a similar robust harvest allocated to sea transport.
9. Alternative 3c: This scenario includes sensing along with dynamic climate control ***and rerouting fast ripening sea and road shipments***, and sell the risky products on the local market along the route.

In this section, for each scenario the model calculates the value implications of the logistics of the perishable fruit and vegetable. The value implications include harvest turnover, cost of interventions, depreciation of fast ripening shipments, and cost of additional sourcing.

The calculation of these value implications is described below:

1. Harvest turnover; For each scenario, the total possible turnover is first calculated from the selling of all produce keeping in mind the modal split ratios.
2. Extra turnover: The extra revenue that comes from selling the produce in an alternative market, i.e., when the fast ripening shipments are chosen to be sold in the local market along the route.
3. Extra intervention cost; The second step is keeping track of any interventions happening. In the reference scenario, the only intervention is the post-harvest sorting and the sorting at Dinteloord. This scenario does not include any sensor technology. All other scenarios include the costs of sensors and monitoring.

Intervention costs also include the cost incurred due to the shortening of lead time as seen in scenario 1a, 1b and 1c. In scenario 2, it has the extra costs of dynamic condition control (eg. airing, adding ozone or adjusting other settings). In scenarios 3a, 3b and 3c, since the vulnerable produce is rerouted and sold on the local market en-route, the extra costs of this intervention are also considered in this case.

4. Fast ripening depreciation; The third step is the calculation of the loss of revenue due to the fast ripening produce. This is calculated based on the assumptions of the fast-ripening produce for each scenario.
5. Extra sourcing; The next step is the calculation of extra sourcing that might be needed in case the produce delivered is outside the set specifications. This could either be done by sourcing on the spot market, which is more expensive or re-delivering from own inventory, which then cannot be sold elsewise.
6. Net turnover; The final amount is the gain (or loss) which takes into account all the aforementioned costs.

The following section describes the results for each trade lane and how each scenario compares to the other.

3.4.1 Green Bean import from Morocco

The trade lane for Green Beans from Morocco has been described in terms of the assumptions made and the various parameters for decay and ripening in Section 3.1, 3.2 and 3.3. This section presents the results of calculations for the different scenarios and shows how each factor impacts the overall gain (or loss) from the harvest. The following graph shows the contribution of each of the step defined previously and how they impact the net turnover for that particular scenario.

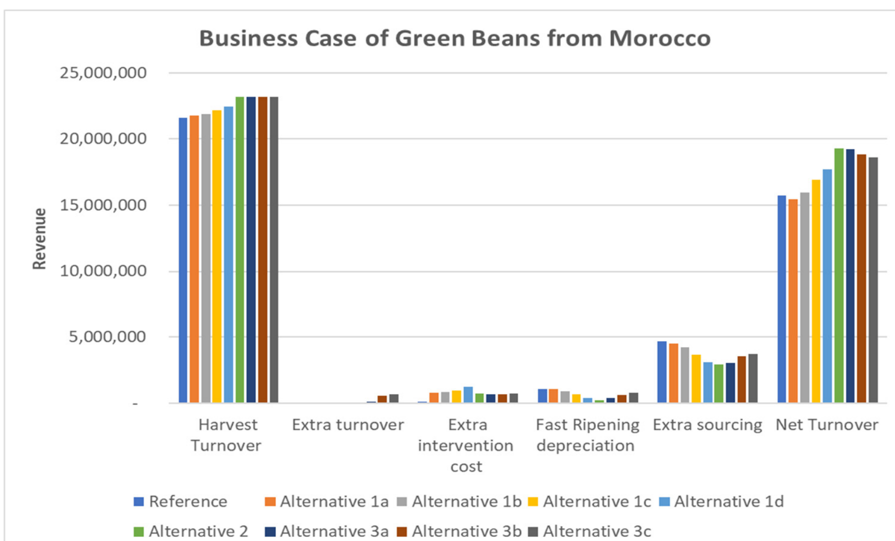


Figure 2: Business case for Green Beans from Morocco.

Harvest turnover
It can be seen that the total turnover increases as the sensor technology is introduced into the picture as it makes sure the ratio of robust produce is higher than in the reference case.

Extra Turnover
Extra turnover is only possible in cases where the produce is chosen to be sold on the local market, i.e., in alternatives 3a, 3b and 3c.

Extra Intervention Cost
The intervention costs naturally, are higher in the cases where sensor technology is used and lower for the reference case where there are no sensors but only sorting options used. The intervention cost is highest for alternative 3c, where re-routing is done via both sea and road. This is also the reason why the costs go up in this case.

Fast ripening depreciation
Alternative 2, which has the dynamic climate control seems to be the most effective in controlling the fast ripening depreciation. It is quite logical to assume that the dynamic climate change would help keep the produce fresher for longer and is much better than the other alternatives of rerouting. The re-routing option via sea also seems to be better at preserving the fast perishables.

Extra sourcing
As can be seen, the Alternative 2, with dynamic climate control seems to have the least necessity of having extra beans sourced. This is also known from the fact that this technology helps in keeping the product better for longer and does not lead to a lot of them being vulnerable. Also, the alternative 3a seems to be doing well due to the fact that the vulnerable is already dumped into the local market.

Net turnover
The net turnover of the green beans could now be calculated, taking into considerations the various factors. Reducing the lead time by 36 or 48 hours (alt. 1c and 1d) would – if possible in practise - result in a higher net value, compared to the reference.. A lead time reduction of 1 day (alt. 1b) has a similar net value as the reference while the lead time reduction of 0.5 days (alt. 1a) has a net turnover less than the reference case and hence it may depend on the actual ripening status of the shipment and the actual location to choose the right lead time reduction. Alternative 2 (dynamic climate control results in the highest net turnover of about €19.3 million, compared to the €15,7 million net turnover in the reference situation. Alternatives 3a/b/c all result in a lower value than alternative 2. This actually means that it would be preferable to accept the losses of fast ripening road shipments and truck them to Dinteloord anyway, whereas for fast ripening sea shipments it actually does not really matter in terms of net value.

Another way of presenting the findings is to relate the scenario findings to the reference scenario and present the net difference in net revenues. The net difference in revenue earned from each scenario from the reference scenario would be a good way to know which alternative is the most profitable.

Since Alternative 1a, 1b, 1d, 1d and 2 are derived from the reference, it is smart to compare them and since alternative 3a, 3b, and 3c are derived from alternative 2 as they have the extra re-routing option on top of the dynamic climate conditions, it is smart to compare them.

The following pictures give an indication of the net differences of the scenarios:

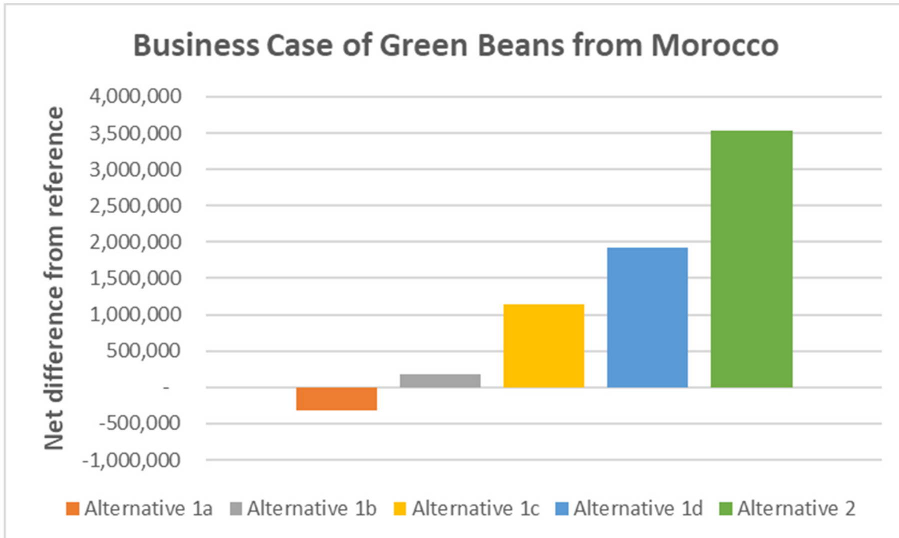


Figure 3: Net difference in revenue from Reference scenario.

As can be seen, the Alternative 2 (dynamic climate conditioning) is the most profitable with €3,5 million net revenue gain from the reference. Reducing the lead time by 12 hours (alternative 1a), which was described as the most plausible one seems to have a negative difference, implying a loss as compared to the reference scenario.

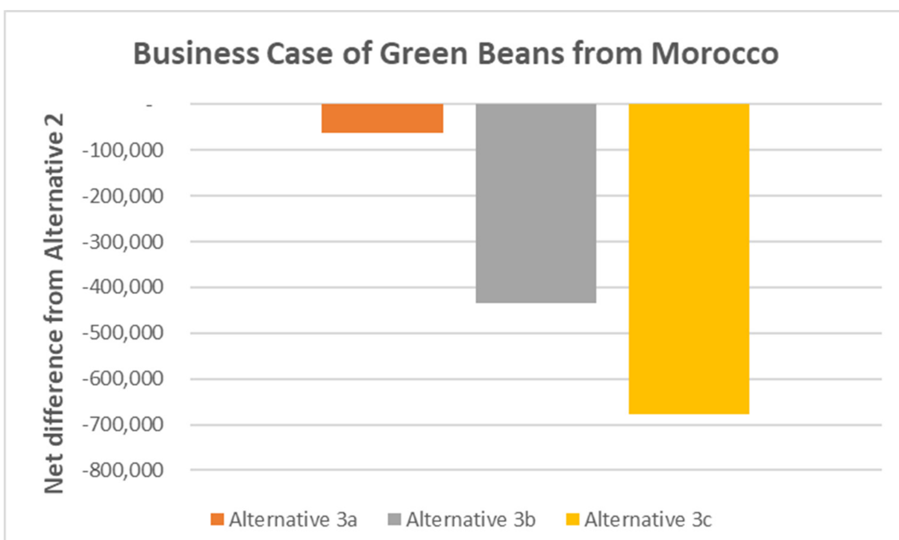


Figure 4: Net difference in revenue from Alternative 2.

As can be seen, it is not profitable to re-route the produce as it results in a loss as compared to the usual dynamic climate control alternative (Alternative 2). This goes on to say that the re-routing option, although it leads to selling the very vulnerable produce in the local market, does not cover up for the extra costs.

It can hence be concluded that the Alternative 2 (dynamic climate control scenario) seems to be the most profitable for this case study.

3.4.2 *Green Bean import from Senegal*

The trade lane for Green Beans from Senegal has been described in terms of the assumptions made and the various parameters for decay and ripening in Section 3.1, 3.2 and 3.3. In this section, the calculations for the different scenarios and how each factor impacts the overall gain (or loss) from the harvest. The following graph shows the contribution of each of each of the step defined previously and how they impact the net turnover for that particular scenario.

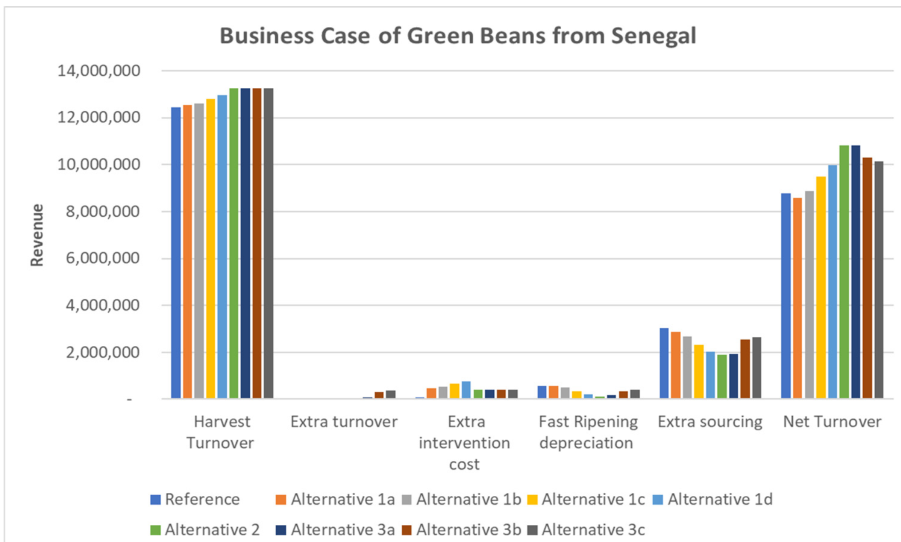


Figure 5: Business Case for Green Beans from Senegal.

Harvest turnover

It can be seen that the total turnover increases as the sensor technology is introduced into the picture as it makes sure the ratio of robust produce is higher than in the reference case.

Extra Turnover

Extra turnover is only possible in cases where the produce is chosen to be dumped on the local market, i.e., in alternatives 3a, 3b and 3c.

Extra Intervention Cost

The intervention costs naturally, are higher in the cases where sensor technology is used and lower for the reference case where there are no sensors but only sorting options used. The intervention cost is highest for alternative 3c, where re-routing is done via both sea and road. This is also the reason why the costs go up in this case.

Fast ripening depreciation
Alternative 2, which has the dynamic climate control seems to be the most effective in controlling the fast ripening depreciation. It is quite logical to assume that the dynamic climate change would help keep the produce fresher for longer and is better than the other alternatives of rerouting. The re-routing option via sea also seems to be better at preserving the fast perishables.

Extra sourcing
As can be seen, the Alternative 2, with dynamic climate control seems to have the least necessity of having extra beans sourced. This is also known from the fact that this technology helps in keeping the product better for longer and does not lead to a lot of them being vulnerable. Also, the alternative 3a seems to be doing well due to the fact that the vulnerable is already dumped into the local market.

Net turnover
The net turnover of the green beans could now be calculated, taking into considerations the various factors. Reducing the lead time by 36 or 48 hours (alt. 1c and 1d) would – if feasible in practise - result in a higher net value, compared to the reference A lead time reduction of 1 day (alt. 1b) has a similar net value as the reference the lead time reduction of 0.5 days (alt. 1a) has a net turnover less than the reference case and hence it may depend on the actual ripening status of the shipment to choose the right lead time reduction. Alternative 2 (dynamic climate control), and Alternative 3a (rerouting fast ripening sea shipments) result in the highest net turnover of about €10,8 million, compared to the €8,7 million net turnover in the reference situation. This actually means that it would be preferable to accept the losses of fast ripening road shipments and truck them to Dinteloord anyway, whereas for fast ripening sea shipments is actually does not really matter in terms of net value.

The comparison of the net revenue with the reference (for alternative 1a, 1b, 1c and 2) and likewise with alternative 2 (for alternatives 3a, 3b and 3c) is now discussed:

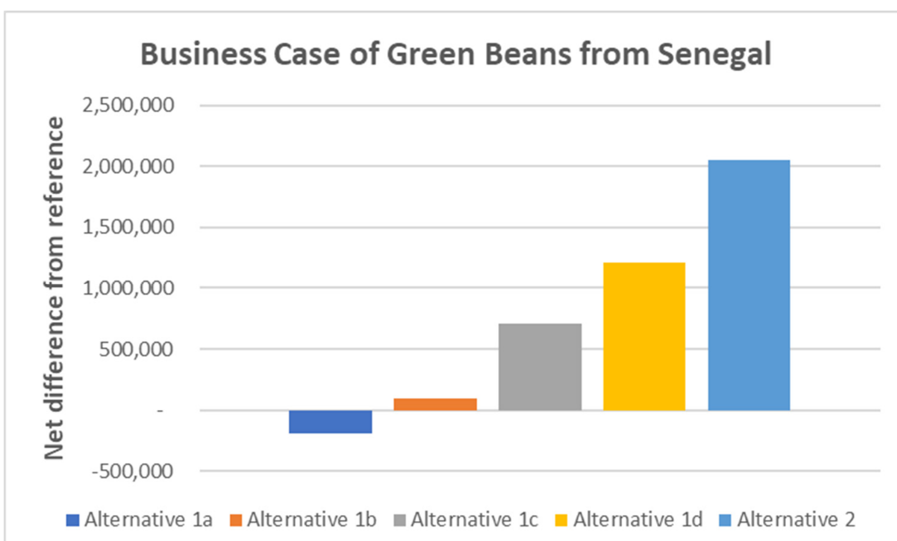


Figure 6: Net difference in revenue from Reference scenario.

As can be seen, the Alternative 2 (dynamic climate conditioning) is the most profitable with a €2 million net revenue gain from the reference. Reducing the lead time by 12 hours (alternative 1a), which was described as the most plausible one seems to have a negative difference, implying a loss as compared to the reference scenario.

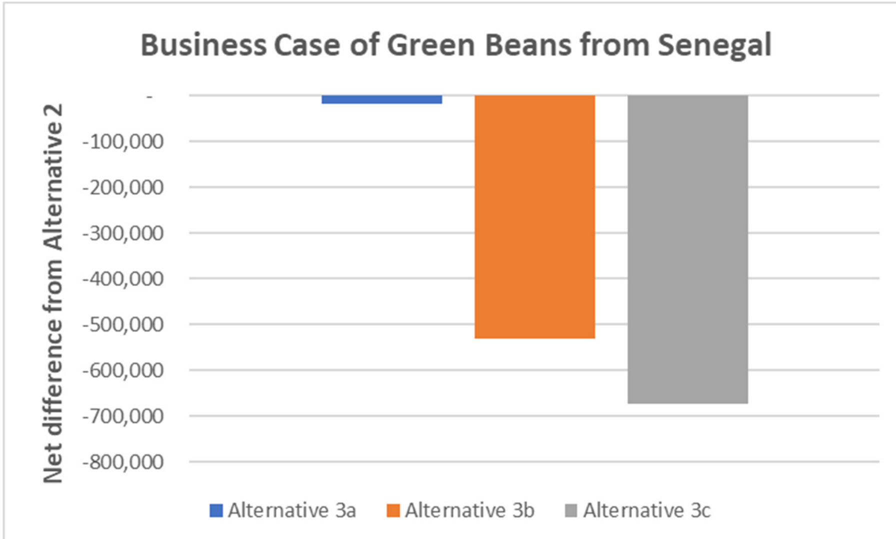


Figure 7: Net difference in revenue from Alternative 2.

As can be seen, it is not profitable to re-route the produce as it results in a loss as compared to the usual dynamic climate control alternative (Alternative 2) with alternative 3a being the next best alternative. This goes on to say that the re-routing option, although it leads to selling the very vulnerable produce in the local market, does not cover up for the extra costs.

It can hence be concluded that the Alternative 2 (dynamic climate control scenario) seems to be the most profitable for this case study.

3.4.3 *Galia Melon imports from Senegal*

The trade lane for Green Beans from Senegal has been described in terms of the assumptions made and the various parameters for decay and ripening in Section 3.1, 3.2 and 3.3. In this section, the calculations for the different scenarios and how each factor impacts the overall gain (or loss) from the harvest. The following graph shows the contribution of each of each of the step defined previously and how they impact the net turnover for that particular scenario.

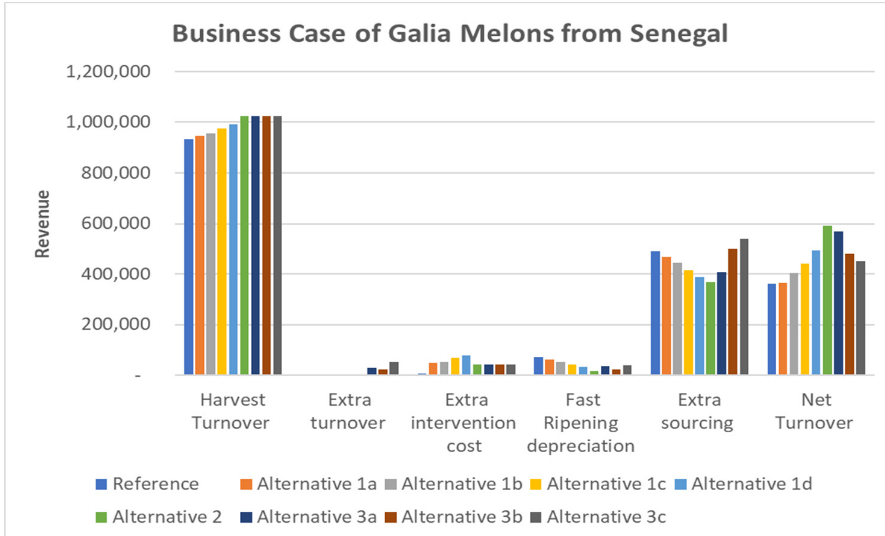


Figure 8: Business Case for Galia Melons from Senegal.

Harvest turnover
It can be seen that the total turnover increases as the sensor technology is introduced into the picture as it makes sure the ratio of robust produce is higher than in the reference case.

Extra Turnover
Extra turnover is only possible in cases where the produce is chosen to be dumped on the local market, i.e., in alternatives 3a, 3b and 3c.

Extra Intervention Cost
The intervention costs naturally, are higher in the cases where sensor technology is used and lower for the reference case where there are no sensors but only sorting options used. The intervention cost is highest for alternative 3c, where re-routing is done via both sea and road. This is also the reason why the costs go up in this case.

Fast ripening depreciation
Alternative 2, which has the dynamic climate control seems to be the most effective in controlling the fast ripening depreciation. It is quite logical to assume that the dynamic climate change would help keep the produce fresher for longer and is better than the other alternatives of rerouting. The re-routing option via road also seems to be better at preserving the fast perishables.

Extra sourcing
As can be seen, the Alternative 2, with dynamic climate control seems to have the least necessity of having extra beans sourced. This is also known from the fact that this technology helps in keeping the product better for longer and does not lead to a lot of them being vulnerable.

Net turnover
The net turnover of the Senegalese Galia melons could now be calculated, taking into considerations the various factors. Reducing the lead time would in all cases (alt 1b, 1c and 1d) result in a higher net value, compared to the reference. .
So if this is an option, it would by default be a good alternative, apart from dynamic sensing or rerouting. Reducing the lead time by 0.5 days leads to the same net turnover as the reference case. Alternative 2 (dynamic climate control) results in the highest net turnover of about €590,000, compared to the €360,000 net turnover in the reference situation. Again, it would be preferable to accept the losses of fast ripening road and sea shipments and ship them to Dinteloord anyway. This is caused by the relative high intervention costs and extra sourcing costs for Dutch customers.

The comparison of the net revenue with the reference (for alternative 1a, 1b, 1c and 2) and likewise with alternative 2 (for alternatives 3a, 3b and 3c) is now discussed:

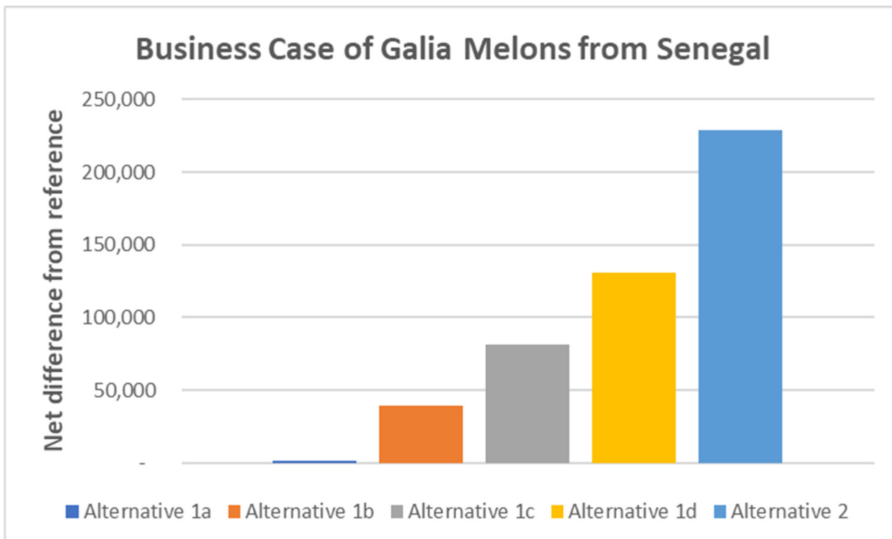


Figure 9: Net difference in revenue from Reference.

As can be seen, the Alternative 2 (dynamic climate conditioning) is the most profitable with a €230,000 profit from the reference. Reducing the lead time by 12 hours (alternative 1a), which was described as the most plausible one seems to have almost no difference, implying that it is not really an attractive alternative when compared to the reference scenario.

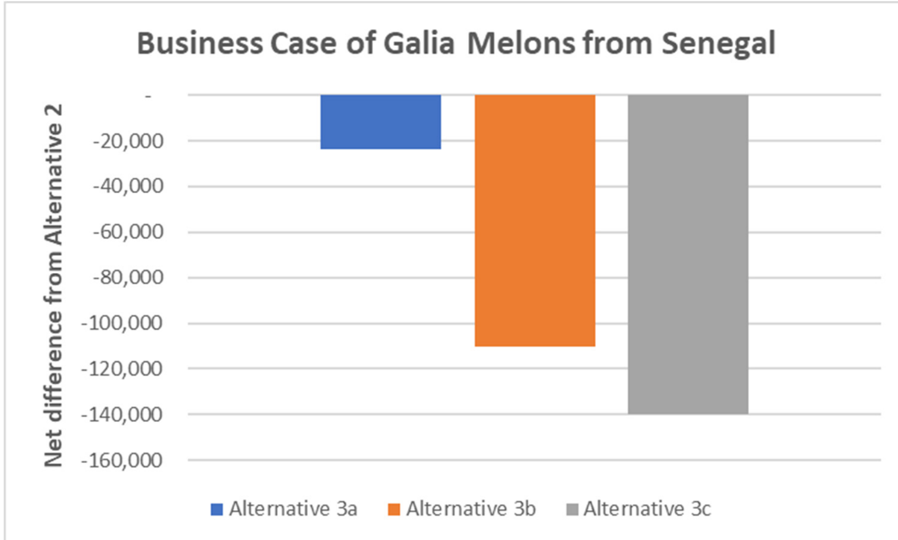


Figure 10: Net difference in revenue from Alternative 2.

As can be seen, it is not profitable to re-route the produce as it results in a loss as compared to the usual dynamic climate control alternative (Alternative 2). This goes on to say that the re-routing option, although it leads to selling the very vulnerable produce in the local market, does not cover up for the extra costs.

It can hence be concluded that the Alternative 2 (dynamic climate control scenario) seems to be the most profitable for this case study.

3.4.4 *Ready-to-eat Mango from Senegal*

The trade lane for Green Beans from Senegal has been described in terms of the assumptions made and the various parameters for decay and ripening in Section 3.1, 3.2 and 3.3. In this section, the calculations for the different scenarios and how each factor impacts the overall gain (or loss) from the harvest. The following graph shows the contribution of each of each of the step defined previously and how they impact the net turnover for that particular scenario.

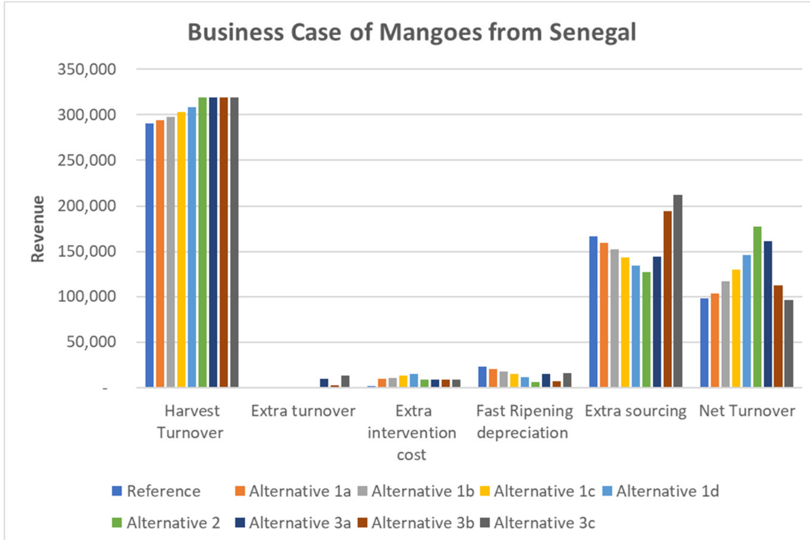


Figure 11: Business Case for Ready-to-eat Mangoes from Senegal.

Harvest turnover
It can be seen that the total turnover increases as the sensor technology is introduced into the picture as it makes sure the ratio of robust produce is higher than in the reference case.

Extra Turnover
Extra turnover is only possible in cases where the produce is chosen to be sold on the local market, i.e., in alternatives 3a, 3b and 3c.

Extra intervention cost
The intervention costs naturally, are higher in the cases where sensor technology is used and lower for the reference case where there are no sensors but only sorting options used. The intervention cost is highest for alternative 3c, where re-routing is done via both sea and road. This is also the reason why the costs go up in this case.

Fast ripening depreciation
Alternative 2, which has the dynamic climate control seems to be the most effective in controlling the fast ripening depreciation. It is quite logical to assume that the dynamic climate change would help keep the produce fresher for longer and is better than the other alternatives of rerouting. The re-routing option via road also seems to be better at preserving the fast perishables.

Extra sourcing
As can be seen, the Alternative 2, with dynamic climate control seems to have the least necessity of having extra beans sourced. This is also known from the fact that this technology helps in keeping the product better for longer and does not lead to a lot of them being vulnerable. Also, the alternative 3b seems to be doing well due to the fact that the vulnerable is already dumped into the local market.

Net turnover
The net turnover of the ready-to-eat mangoes could now be calculated, taking into considerations the various factors. Reducing the lead time would in all cases (alt 1a, 1b, 1c and 1d) result in a higher net value, compared to the reference. So if this is an option, it would by default be a good alternative.
It seems that Alternative 2, which includes the dynamic climate control, is the most profitable. This option has a net turnover of about €177,000 while the reference has a net turnover of only €97,000. It would be preferable to accept the losses of fast ripening sea shipments and ship them to Dinteloord anyway. For fast ripening road shipments, it does not really matter in terms of value creation to reroute them and sell them locally.

The comparison of the net revenue with the reference (for alternative 1a, 1b, 1c and 2) and likewise with alternative 2 (for alternatives 3a, 3b and 3c) is now discussed:

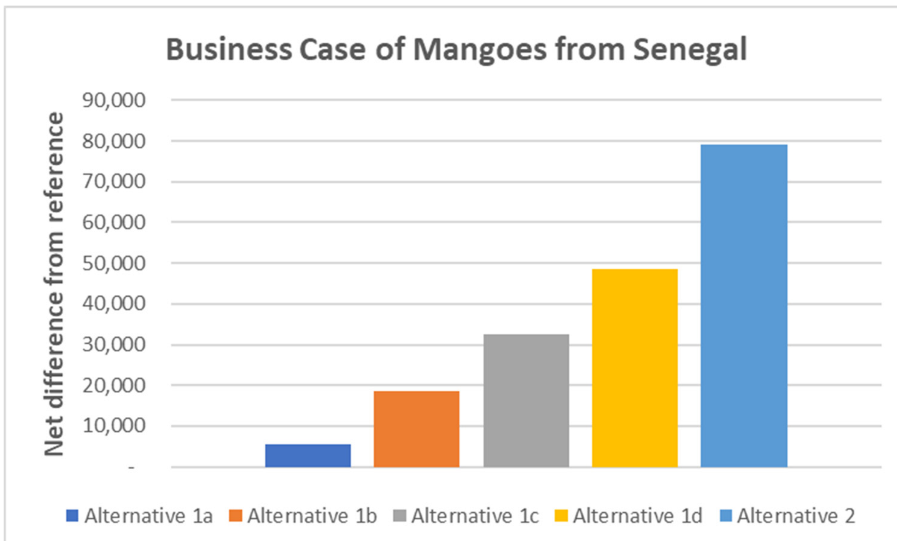


Figure 12: Net difference in revenue from Reference.

As can be seen, the Alternative 2 (dynamic climate conditioning) is the most profitable with about a €80,000 profit from the reference. Reducing the lead time by 12 hours (alternative 1a), which was described as the most plausible one seems to have almost no difference, implying that it is not really an attractive alternative when compared to the reference scenario.

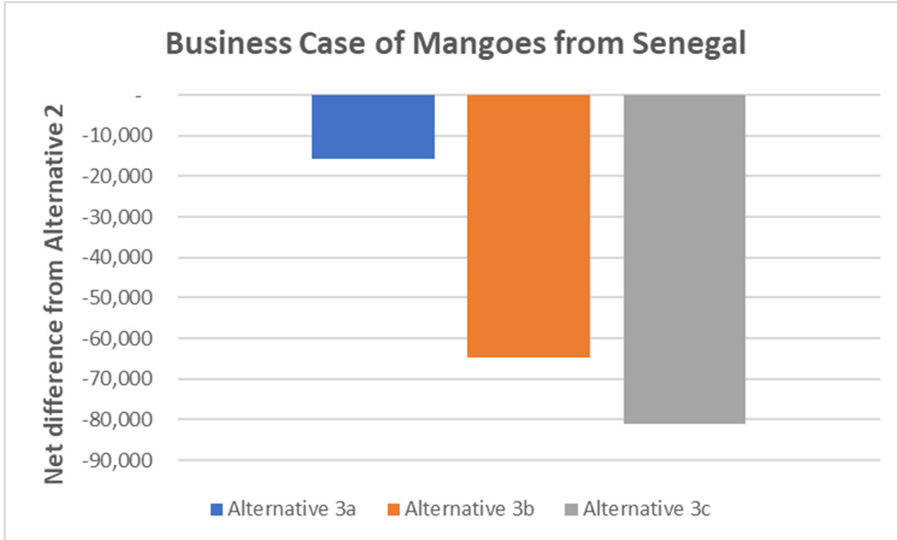


Figure 13: Net difference in revenue from Alternative 2.

As can be seen, it is not profitable to re-route the produce as it results in a loss as compared to the usual dynamic climate control alternative (Alternative 2). This goes on to say that the re-routing option, although it leads to selling the very vulnerable produce in the local market, does not cover up for the extra costs.

It can hence be concluded that the Alternative 2 (dynamic climate control scenario) seems to be the most profitable for this case study.

3.5 Sensitivity analysis

Sensitivity analysis has been applied onto one particular trade lane. Despite differences in basic assumptions, the analysis reveals the sensitivity of the model for adjustments in certain basis assumptions. We have chosen to apply the sensitivity analysis to the trade lane of Galia Melons from Senegal.

The analysis addresses sensitivity of the model outcomes to changes in:

- Sensors and sensor costs
- Product robustness
- Impact of the interventions
- Fast ripening shipment probability
- Spot prices and alternative sales channels
- Modal split
- Limited sensor application, e.g. applying the sensor technology only to the shipments with vulnerable products

The sensitivity findings are presented in the next sections.

3.5.1 *Sensors and sensor costs*

The following graph shows the sensitivity analysis for changing number of sensors and sensor costs, resulting in differences in the net revenue (y-axis). This is done to check how sensitive the model is to changing costs of sensors.

The following scenarios are checked in the analysis:

a) Reference: 1 average cost sensor of each;
b) 1 upper bound sensor of each type;
c) 1 lower bound sensor of each type;
d) 2 upper bound sensors of each type;
e) 2 average cost sensors of each type;
f) 4 upper bound sensors of each type.

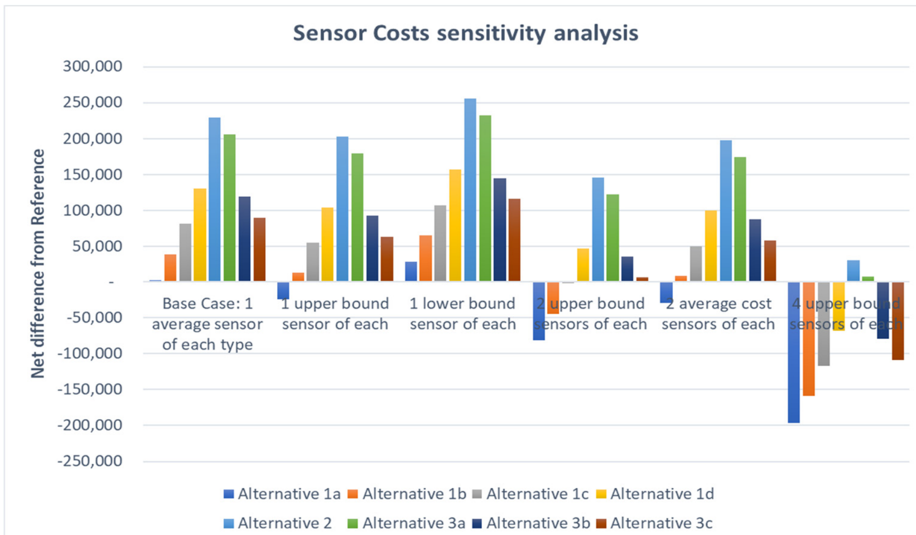


Figure 14: Sensitivity Analysis for Sensor Costs.

The figure shows the difference in the net revenue from the reference scenario. Hence the reference in the figure is at 0. It can be seen that the sensor costs have a huge impact on the total net turnover of the produce. Since the reference is without any sensors, the reference turnover remains the same for all the given scenarios. It can also be seen that even when 2 upper bound sensors of each kind are used for each shipment, the net turnover is still higher than in the reference scenario for Alternative 1d, 2, 3a, 3b and 3c. This implies that the dynamic (sensor-enabled) quality controlled logistics concept generates net value, even when the more expensive sensors are used for monitoring. Naturally, when cheaper sensors are being used, the difference in the net turnover is even higher.
The break-even point seems to be when there are 4 upper bound sensors used. In this case, all the alternatives seem to work worse or almost the same as the reference case thereby acting as the threshold. Any more expense made on the sensor technology would lead to a loss, given the cost and quality decay assumptions.

3.5.2 *Product robustness*

The following graph shows the sensitivity analysis for changing robustness to vulnerable ratio of the harvest. This is done to check how sensitive the model is to changing vulnerability of the harvest.

The following scenarios are checked in the analysis:

a) Reference: 30% vulnerable;
b) 10% vulnerable;
c) 50% vulnerable;
d) 75% vulnerable.

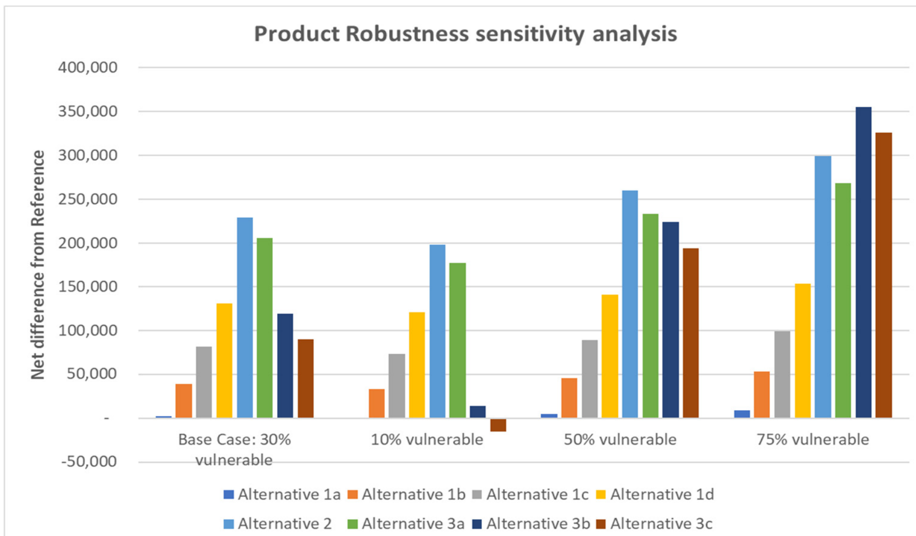


Figure 15: Sensitivity Analysis for Product Robustness.

The figure shows an interesting insight in the fact that with increasing vulnerability, Alternative 3b starts performing better than Alternative 2. Apparently, rerouting fast ripening road shipments becomes more attractive, since the net value when trucking them to Dinteloord is lower with a higher share of vulnerable melons.
The reason that the road re-routing works better than the sea re-routing is because of the fact that the road re-routing can be done faster. This is also the reason why, Alternative 3c (re-routing via sea and road) also seems to be performing better for highly vulnerable produce. Since Alternatives 3a, 3b, and 3c are all done in combination with alternative 2 i.e., they also have the dynamic climate control, the vulnerable produce has a higher chance of making it to the target location with the option of selling the extremely vulnerable produce in the local market. This seems to be the most lucrative option in that case. On the other hand, when the harvest is highly robust, the re-routing options seem to be much less profitable and almost leading to a loss. This confirms the idea that the re-routing options are only valuable when the produce is vulnerable.

3.5.3 *Impact of interventions*

The following graph shows the sensitivity analysis for the impact of interventions. This is done to check how sensitive the model is to changing robustness after harvest and the changing impact of interventions.

The following scenarios are presented in the analysis:

a) Reference, this refers to the expected impact according to the assumptions described in section 3.2.
b) Lower average quality upon arrival (and corresponding impact of interventions).
c) Higher impact of interventions on maintaining high quality.

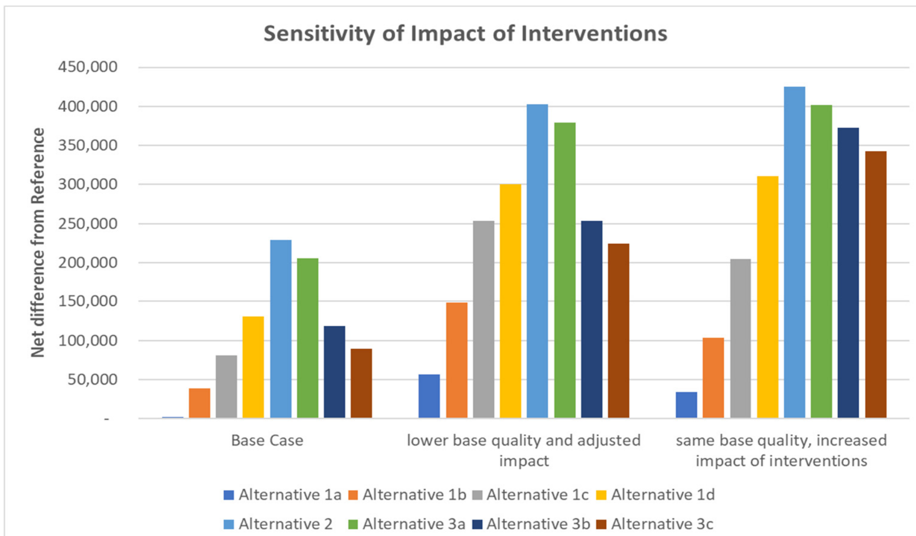


Figure 16: Sensitivity Analysis for impact of interventions.

The figure shows that when the base quality of the produce is lower (and the impact of the alternatives is adjusted accordingly), the relative impact of the interventions is bigger, it makes more sense to intervene in vulnerable products. Dynamic climate control (Alternative 2) still seems to out-perform all the other alternatives.

3.5.4 *Fast ripening shipment probability*

The following graph shows the sensitivity analysis for the rate of the ripening. This is done to check how sensitive the model is to changing ripening pace.

The following scenarios are checked in the analysis:

a) Reference: 10% of shipments;
b) 35% of shipments.

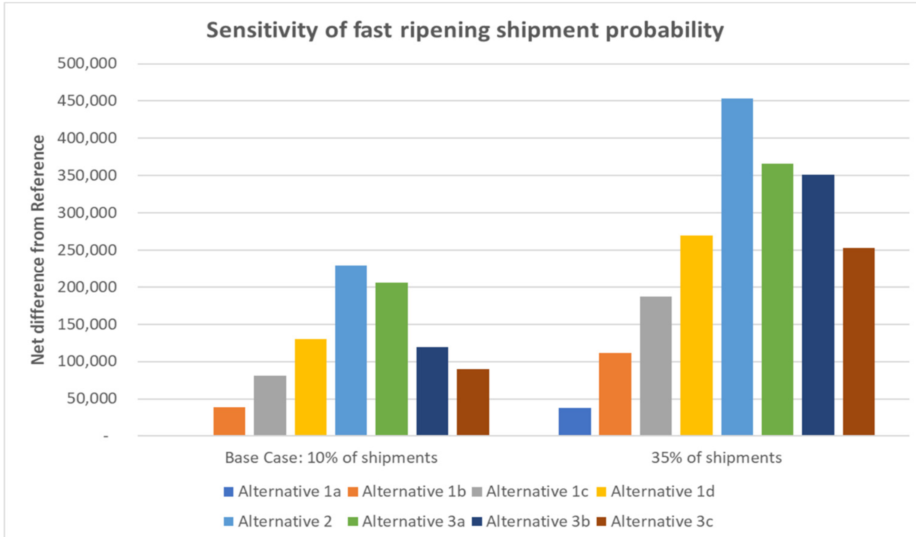


Figure 17: Sensitivity Analysis for the fast ripening probability.

The figure shows that when the shipment ripens faster than in the base case, all the other alternatives seem to gain more than the reference, implying that the interventions help in getting more profit out of the fast ripening produce. Alternative 2 (with dynamic climate control) still seems to outperform all the other alternatives. This is because of the fact that the quality of the shipment can be controlled via the control and monitoring of climate conditions. Also the alternatives with re-routing (via road or sea) also seem to be performing well. This is because of the fact that the re-routing of the vulnerable goods can help reduce waste and thereby save costs.

3.5.5 *Spot prices and alternative sales channels*

The following graph shows the sensitivity analysis of changing spot prices and the alternate sales channels.

The following scenarios are checked in the analysis:

a) Reference: Spot prices 20% mark-up on own sales prices and 30% external sourcing needed in case of outside specification deliveries. Depreciation of 40% for outside specification sales.
b) 50% sales price mark-up and 100% external sourcing.
c) Depreciation of 20% for outside specification alternative sales.

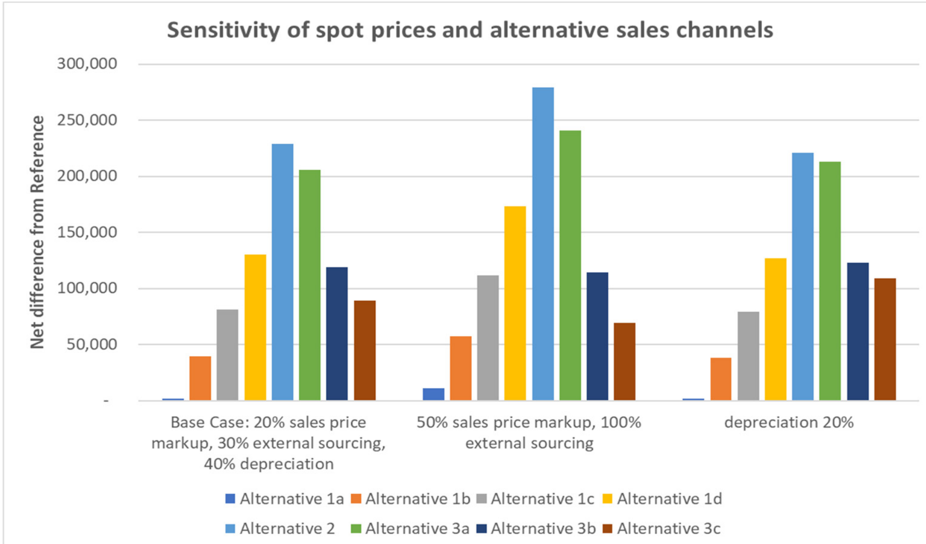


Figure 18: Sensitivity Analysis of spot prices and alternative sales channels.

When 100% of the goods needs to be sourced locally, it leads to a lot less net turnover. This is due to the fact that the spot prices for alternative sourcing are substantially higher than the usual price. Even then, the Alternative 2 seems to fare well. When the depreciation of the risky goods is less (20% instead of 40%), the net turnover goes up, as expected. It is also interesting to see that the alternative 3a also seems to be working well in this case as the vulnerable goods could be re-routed and that would give it more chance to sell it in that local market, thereby increasing the net turnover. In this 20% decreciation case, the alternative 2 and 3a seem to be doing equally good. In the other cases, alternative 2 still seems to be outperforming all the other alternatives.

3.5.6 *Applying sensor technology only to vulnerable produce*

The following graph shows the sensitivity analysis of the case when the sensor technology is applied only to the vulnerable shipments instead of all the produce. This would require a lower investment in sensor technology, concentrating on the vulnerable produce, assuming that these products have the highest chance turning into fast ripening stage, or going to waste.

This case hence compares the following:

a) Base Case: when the sensor technology is applied to all the produce;
b) Case when the sensor technology is applied to only the vulnerable produce.

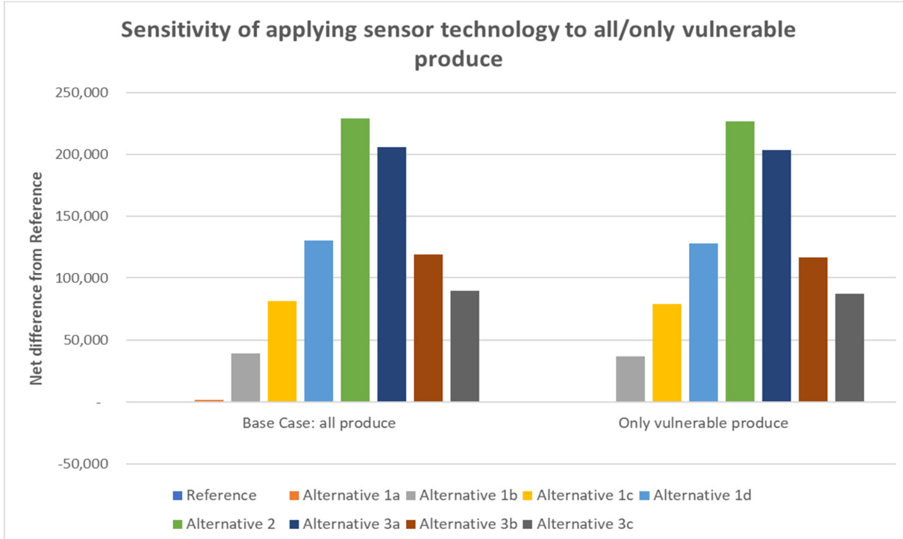


Figure 19: Sensitivity analysis of applying sensor technology to all vs. only vulnerable produce.

As can be seen in the figure, the net turnover is more or less similar in both scenarios. This is counterintuitive to the belief that using the sensor technology to only vulnerable produce would reduce total investment costs. But this is not the case since the investment per shipment becomes much higher in that case. Apparently, the model assumes substantial economies of scale in for instance the data sharing infrastructure needed.

3.6 The business case of embedded sensors

The consequence of removable sensors is the logistics of shipping the sensors to the place of loading, attaching the sensors to a shipment, removing the sensors upon arrival and reposition them for a next use. Alternatively, the sensor technology can be embedded in the logistic assets. This may be the container, the truck, a pallet, or a crate.

In this analysis we elaborate on the business case considerations of embedded crates, since the crate pool service provider is one of the project partners particularly interested in this case. This logistic asset pool provider holds an inventory of about 250 million crates.

3.6.1 The value propositions of smart sensor-embedded crates

Smart sensor embedded crates support three different value propositions:

- Supporting integrated Quality Controlled Logistics of perishables shipped internationally;
- Improve asset visibility;
- Allow for downstream application of quality controlled logistics.

The first value proposition is fully in scope in the IoT4AGRI project and is actually an alternative for removable sensors per shipment. The second value proposition obviously provides added value to the asset pool operator and requires tracking and tracing functionality from the sensors. We assume that the asset owner will invest in this sensor technology, uses it for internal asset optimization strategies and may offer corresponding services to its customers.

The value case of asset visibility has already been explored by the asset pool operator and will not be further explored in this analysis. The third value proposition is clearly relevant and requires more or less the same initial investment, but is outside the scope of this research project. The retail supply chain has its typical contextual challenges and power balance is different from the import/export logistic chain. This value proposition will also not be further explored.

3.6.2 *Assumptions for the embedded case for the integrated QCL-service*

Manufacturing costs
We assume that a small fraction of the total crate pool will be equipped with embedded tracking and tracing technology, say 1%. That would still imply a pool of 2.5 million smart T&T crates. From this smart embedded pool, a small fraction will also be equipped with additional sensors to facilitate the QCL-service to particular customers. The marginal manufacturing costs of embedding a number of additional sensors is assumed to be € 1000 per crate for five sensors. This is on top of the costs of the sensors as such. The embedded sensors are assumed to have a life span of 10 years, allowing for some periodic refurbishment or software updates during regular periodic maintenance controls.

Turnover rate
Whereas standard crates have an average turnover rate of around 5 shipments per year (both national transport and international transport), the smart QCL-sensors are expected to be applied as much as possible given the higher margin the company can gain with it. Despite the long international trade lane, we assume the smart crates can have a turnover rate of 8 times per year. That means, the investment costs can be spread over (8 times 10) 80 shipments.

Alternative sensing
Instead of adding six times five sensors per shipment, a FCL or FTL shipment could also be equipped with six smart QCL-crates, provided they are positioned in a representative way (for instance the top layer of a stacked pallet).

Opportunity costs
By applying embedded sensors, all assumed costs associated with the logistics of the sensors could be avoided. In the business case, we assumed these costs to be €55 per shipment. If we compare this with the additional costs of using 1 smart crate instead of 5 removable sensors, the additional crate costs would be € 12,50. This would make the business case for embedded crates already positive for this value proposition alone. Even when using four smart crates, this would result in lower cost than the handling costs of the removable sensors.

The interview performed for this embedded sensor business case consideration also highlighted additional complexity. A promising concept might be a hybrid combination of removable and embedded sensors. If a limited number of removable sensors would sense high ethylene values, embedded temperature sensors in smart crates could localise where the fast ripening products are situated, based on relative temperature differences between the crates. This concept will be further elaborated in the course of the project.

4 The IoT4AGRI business model

4.1 Business model variants

The value propositions are centred around the value of sensor data captured during transportation of shipments with perishables.

Basically three methods can be considered to capture sensor data:
- Disposable sensors per shipment;
- Removable sensors per shipment;
- Embedded sensors.

The latter can refer to embedded sensors on different levels
- Embedded truck / container sensors;
- Embedded pallet sensors;
- Embedded Crate/box sensors.

In the project, we concentrate on removable and/or embedded sensors. The costs of the sensors are too high to justify disposing them after one shipment. Moreover, the business case of embedded sensors appeared to rather complex and broader in scope (see section 3.6), with different customer segments and different value propositions.

Also we have to distinguish between offering sensor data during transportation and being able to dynamically control the quality of perishables during transport.

The latter requires an integration of four partial services with corresponding value propositions in order to offer the integrated service:

- Capturing and providing different type of sensor data during transportation;
- Running a sensor-enabled quality decay prediction model;
- Running a corresponding logistic intervention decision model;
- Offering the supporting data connectivity and data sharing infrastructure.

So we consider the following business model variants:

1. BMV1: An integrated dynamic Quality Controlled Logistics service allowing for dynamic interventions in the logistics chain of perishable shipments based on dynamic quality decay monitoring
2. BMV2: A removable sensor data provision service during transportation of a shipment with perishables. This is a partial service and a prerequisite for the integrated QCL service. We can distinguish sub-variants for:
   - Sensing ethylene;
   - Sensing humidity;
   - Sensing temperature;
   - Sensing CO_2 and;
   - Sensing oxygen.
3. BMV3: A quality decay prediction service, based on sensor values. This is a partial service and a prerequisite for the integrated QCL-service.

4. BMV4: A logistic decision support service that recommends logistics interventions based on quality decay predictions of the corresponding shipment. This is a partial service and a prerequisite for the integrated QCL-service.
5. BMV5: A data connectivity service that allows for an integration of the different partial services. This is a partial service and a prerequisite for the integrated QCL-service.
6. BMV6: An embedded sensor data provision service. This is a variation on business model variant 2, but then the data capture is done by embedded sensors instead of removable sensors. Subvariants here include:
   - Embedded sensors in truck of container;
   - Embedded sensors in pallet;
   - Embedded sensors in crate (BMV6a).

In order to further explore and elaborate these different business model variants, we apply Osterwalder's business model canvas. The next section describes this method in more detail.

4.2 The business model methodology

4.2.1 Business model canvas

Business Model Canvas is a strategic management template for developing new or documenting existing business models. It is a visual chart with elements describing a firm's or product's value proposition, infrastructure, customers, and finances. The nine "building blocks" of the business model design template comprise the Business Model Canvas, initially proposed in 2005 by Alexander Osterwalder[3] and based on his earlier work on business model ontology.

The building blocks include:

An ***infrastructure*** block describing:
- Key Activities: The most important activities in executing a company's value proposition. An example for Bic, the pen manufacturer, would be creating an efficient supply chain to drive down costs.
- Key Resources: The resources that are necessary to create value for the customer. They are considered assets to a company that are needed to sustain and support the business. These resources could be human, financial, physical and intellectual.
- Partner Network: In order to optimize operations and reduce risks of a business model, organizations usually cultivate buyer-supplier relationships so they can focus on their core activity. Complementary business alliances also can be considered through joint ventures or strategic alliances between competitors or non-competitors.

The ***offering*** block, including:
- Value Propositions: The collection of products and services a business offers to meet the needs of its customers. According to Osterwalder (2004), a company's value proposition is what distinguishes it from its competitors.

[3] Osterwalder, Alexander (2005-11-05). "What is a business model?". http://businessmodelalchemist.com/2005/11/what-is-business-model.html.

The value proposition provides value through various elements such as newness, performance, customization, "getting the job done", design, brand/status, price, cost reduction, risk reduction, accessibility, and convenience/usability.

A ***customers*** block, including:

- Customer Segments: To build an effective business model, a company must identify which customers it tries to serve. Various sets of customers can be segmented based on their different needs and attributes to ensure appropriate implementation of corporate strategy to meet the characteristics of selected groups of clients.
  The different types of customer segments include:
  - Mass Market: There is no specific segmentation for a company that follows the Mass Market element as the organization displays a wide view of potential clients. e.g. Car
  - Niche Market: Customer segmentation based on specialized needs and characteristics of its clients. e.g. Rolex
  - Segmented: A company applies additional segmentation within existing customer segment. In the segmented situation, the business may further distinguish its clients based on gender, age, and/or income.
  - Diversify: A business serves multiple customer segments with different needs and characteristics.
  - Multi-Sided Platform / Market: For a smooth day-to-day business operation, some companies will serve mutually dependent customer segments. A credit card company will provide services to credit card holders while simultaneously assisting merchants who accept those credit cards.
- Channels: A company can deliver its value proposition to its targeted customers through different channels. Effective channels will distribute a company's value proposition in ways that are fast, efficient and cost-effective. An organization can reach its clients through its own channels (store front), partner channels (major distributors), or a combination of both.
- Customer Relationships: To ensure the survival and success of any businesses, companies must identify the type of relationship they want to create with their customer segments. That element should address three critical steps on a customer relationship: How the business will get new customers, how the business will keep customers purchasing or using its services and how the business will grow its revenue from its current customers.
  Various forms of customer relationships include:
  - Personal Assistance: Assistance in a form of employee-customer interaction. Such assistance is performed during sales and/or after sales.
  - Dedicated Personal Assistance: The most intimate and hands-on personal assistance in which a sales representative is assigned to handle all the needs and questions of a special set of clients.
  - Self Service: The type of relationship that translates from the indirect interaction between the company and the clients. Here, an organization provides the tools needed for the customers to serve themselves easily and effectively.
  - Automated Services: A system similar to self-service but more personalized as it has the ability to identify individual customers and their preferences. An example of this would be Amazon.com making book suggestions based on the characteristics of previous book purchases.

- Communities: Creating a community allows for direct interactions among different clients and the company.
  The community platform produces a scenario where knowledge can be shared and problems are solved between different clients.
- Co-creation: A personal relationship is created through the customer's direct input to the final outcome of the company's products/services.

A ***finance*** block, including
- Cost structure; Is it cost driven or value driven, and how strong are economies of scale or economies of scope (fixed cost versus variable costs)?
- Revenue streams; The way the company makes income, think of asset sale, usage fee, subscription fee, licencing, brokerage or advertising.

4.2.2 Approach
The business model canvas has been applied in a series of workshops with the consortium members. In addition, interviews have taken place to better understand the background. Since the integrated dynamic QCL-service not yet exists, and requires integration of different partial services, the project participants found it pretty hard to elaborate already on some of the business model canvas elements. This report therefore only describes a first elaboration of the business model considerations.

In the next sections, each of the business model variants is being discussed.

4.3 The integrated dynamic Quality Controlled Logistics service (BMV1)

This integrated dynamic Quality Controlled Logistics service

The key value proposition is product quality conditioning. This service allows for dynamic interventions in the logistics chain of perishable shipments based on dynamic quality decay monitoring. In doing so, the product value can be optimised throughout the logistics chain.

Key activities include the integration of the four partial services: sensing and monitoring the product quality, predicting the quality decay and intervene accordingly.

Key resources include the sensors, the hardware, the software and the intellectual knowledge behind the quality decay model and the logistic intervention model.

The ***partner network*** includes the service providers of the partial services needed to offer the integrated service. Moreover, a freight forwarder network could strengthen the channel to bring the value proposition to the market. Int that case, these freight forwarders offering the dynamic QCL-service are partners.

The ***customer segmentation*** includes niche markets of international transport of perishable fruit and vegetables. This niche market can be further segmented into trade lanes for typical perishable products, that put different requirements to the quality decay monitoring.

The foreseen ***channel*** to deliver the value proposition could be by an own store front, but could also be offered via a partner channel of freight forwarders.

The ***customer relationship*** would first require close personal assistance, in order to configure the solution in a way that fits the typical trade lane and product characteristics. It is expected that the concept requires a number of iterations in order to offer a stable trade lane service. It may even become a co-creation service with the end user, where the direct input from the customer is needed to optimise the dynamic QCL-settings.

The ***cost structure*** is value driven, the sensor data part has economy of scale advantages in terms of sensor costs, the logistic intervention model part is less scalable.

The foreseen ***revenue stream*** is by a fee per shipment.

This is all summarised in the figure below.

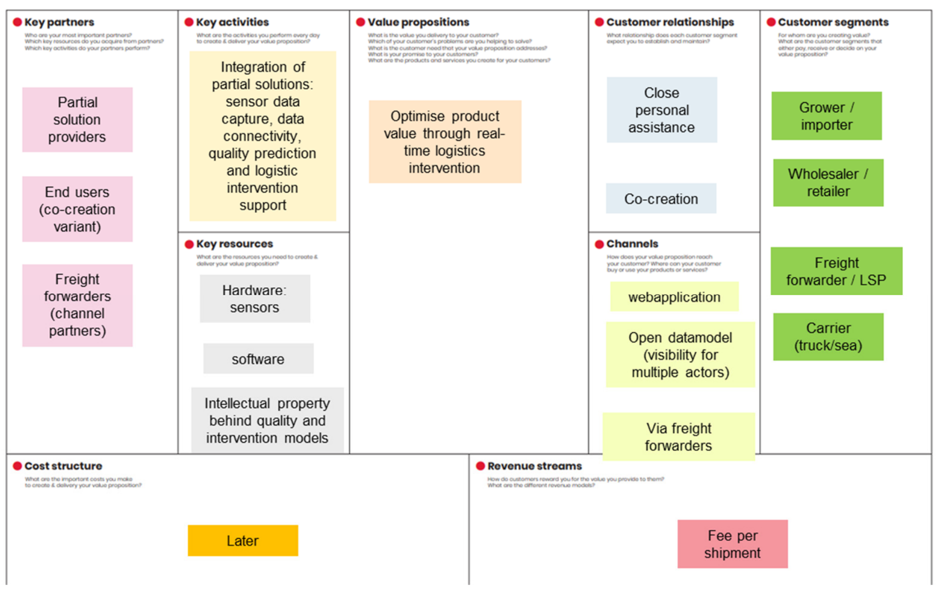


Figure 20: Business Model Canvas of integrated dynamic Quality Controlled Logistics service (BMV1).

4.4 Removable sensor data provision service (BMV2)

The ***value proposition*** of this partial business model is the provision of typical sensor data within a shipment in transit. Depending on the hardware, this could be an ethylene sensor with typical measurement specifications, a temperature sensor (with typical specs), a CO_2 sensor (with typical specs), an oxygen sensor (with typical specs) or a relative humidity sensor (with typical specs), or a combination of sensors.

Key activities include the placement of the sensors in a shipment, the data capture of the sensor data and the data provision to the user, the removal of the sensors after arrival and repositioning of the sensors for another shipment.
The whole sensor logistics could be executed by the end user or logistic operator.

Key resources include the sensors, the hardware, the software, the repositioning system and the operators that execute the ‘sensor logistics’.

The ***partner network*** includes the sensor technology providers, and the customer or logistic operator for the sensor logistics. Moreover, if this service is being used for the integrated QCL-service, this integrated QCL-service provider is part of the partner network.

The ***customer segmentation*** includes niche markets of international transport of perishable fruit and vegetables. This niche market can be further segmented into trade lanes for typical perishable products, that put different requirements to sensor specifications for quality decay monitoring. Also other niche markets could be considered, depending on the type of sensor. Think of temperature sensors for meat, dairy or pharmaceutics, humidity sensors for food, shock sensors for fragile products, and so on.

The foreseen ***channel*** to deliver the value proposition could be by an own store front.

The ***customer relationship*** could require close personal assistance during first use, eventually accompanied by a user training. In this case, the customer is managing the ‘sensor logistics’. A fee per shipment suits this model. Alternatively, the sensors are being delivered according to specifications without any after sales service. The user is responsible for the complete application. Revenue streams follow from selling the sensors.

The ***cost structure*** is more cost driven compared to the fully integrated QCL-service, there are clear economies of scale in the sensor costs. Ethylene sensor data is probably more value driven then for instance temperature sensors data.

The foreseen ***revenue stream*** could be asset sale, lease or periodic rental.
This choice also relates to the responsibility for the sensor logistics.

This is all summarised in the figure below.

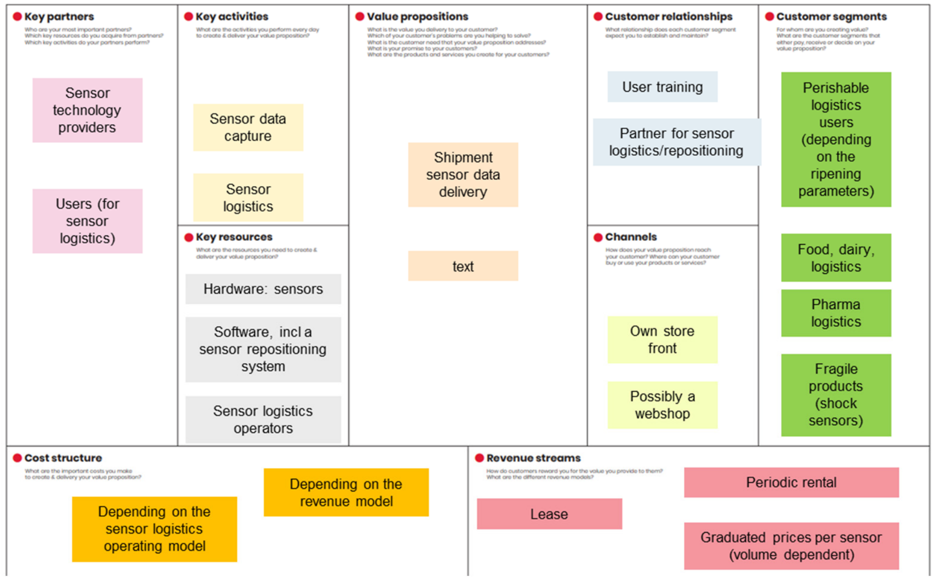


Figure 21: Business Model Canvas of removable sensor data provision service (BMV2).

4.5 The quality decay prediction service (BMV3)

The ***value proposition*** of this partial business model is the provision of quality decay predictions for perishable products in transit, based on sensor data, product characteristics and historic quality measurements (starting with post-harvest determination).

Key activities include reference quality settlement at the start of the journey, model input collection, model runs and model outcome interpretation.

Key resources include historic data, actual sensor data and intellectual property behind the prediction model.

The ***partner network*** includes an end user community for validation purposes, the logistics intervention support service provider using the (interpreted) model output and/or the integrated QCL-service provider.

The ***customer segmentation*** includes niche markets of (international) transport of perishable fruit and vegetables. This niche market can be further segmented into trade lanes for typical perishable products, that put different requirements to sensor specifications for quality decay monitoring.

The foreseen ***channel*** to deliver the value proposition could be by two web-interfaces: one for model entry data with the sensor data providers and one for (interpreted) model outcomes with the logistics intervention decision support service provider or with end users who can use it to support their own decision making.

The ***customer relationship*** may result in co-creation with the end user to refine and calibrate the model.

The ***cost structure*** is cost driven, the model is well scalable. The level of model refinements is a co-creation process with the end user and is more value driven.

The foreseen ***revenue stream*** is by a fee per shipment.

This is all summarised in the figure below.

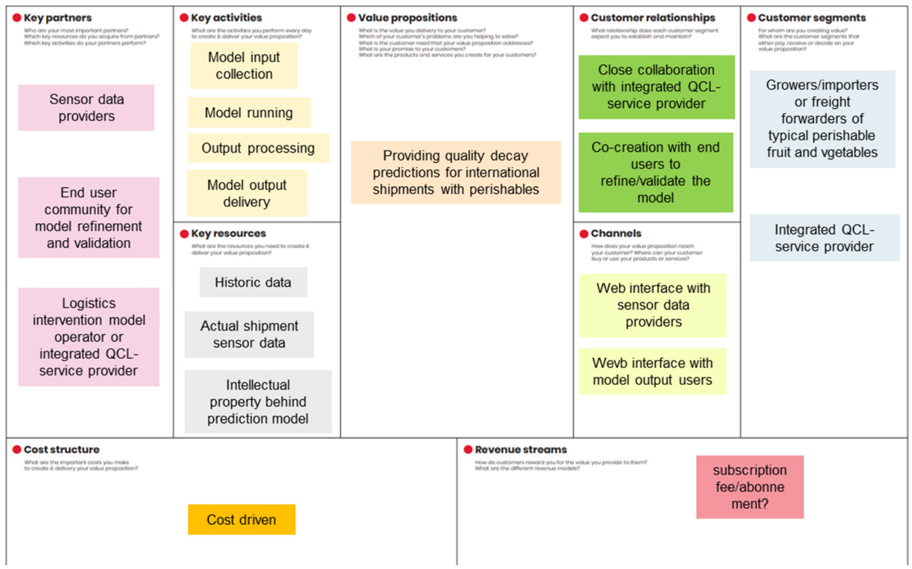


Figure 22: Business Model Canvas of quality decay prediction service (BMV3).

4.6 The logistics intervention decision support service (BMV4)

The ***value proposition*** of this partial business model is the provision of an advise to intervene in order to optimise the product value of the shipment in transit.

Key activities include basic trade lane configuration (trade lane characteristics, modal choice, reference routing and lead time), the quality decay predictions combined with a time slot and corresponding coordinates, a model run simulating the reference logistic chain and a number of alternative logistics interventions and provision of an advise for a typical intervention strategy.

Key resources include know how on the basic trade lane characteristics (to be provided by the end user), shipment decay predictions (provided by the decay model operator), and intellectual property behind the logistics intervention model.

The ***partner network*** includes the quality decay model operator, the end user and the integrated QCL-service provider.

The ***customer segmentation*** includes niche markets of international transport of perishable fruit and vegetables. This niche market can be further segmented into trade lanes for typical perishable products, that put different requirements to quality decay monitoring.

The foreseen ***channel*** to deliver the value proposition could be by three-way web-interfaces: one for trade lane configuration of basic characteristics, one for quality decay predictions as model input, and one for provision of model output / intervention advise.

The ***customer relationship*** may result in co-creation with the quality decay model operator and the end user to refine and calibrate the model.

The ***cost structure*** is cost driven, the model is well scalable. The level of model refinements is a co-creation process with the end user and is more value driven.

The foreseen ***revenue stream*** is by a fee per shipment.

This is all summarised in the figure below.

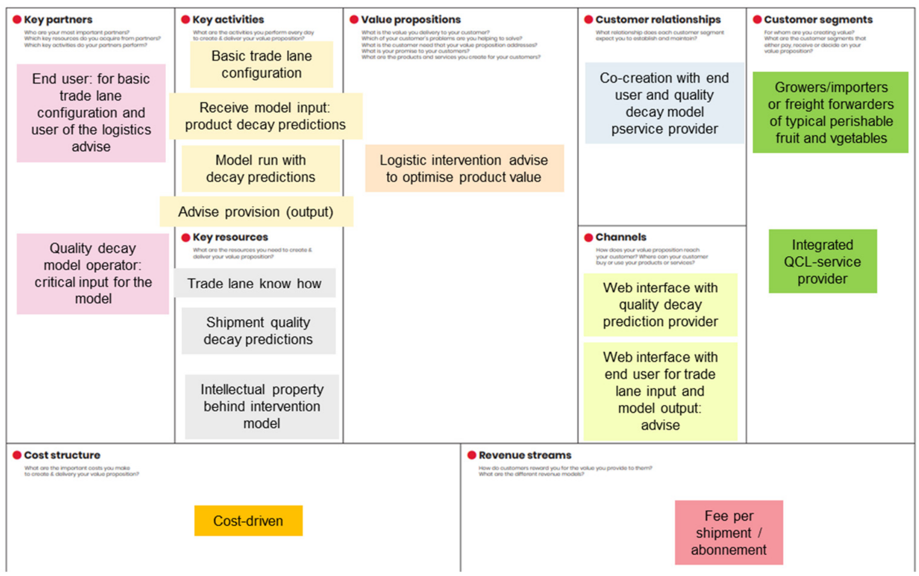


Figure 23: Business Model Canvas of logistics intervention decision support service (BMV4).

4.7 The connectivity infrastructure for integrated Quality Controlled Logistics (BMV5)

The ***value proposition*** of this partial business model is the provision of an efficient and reliable connectivity infrastructure that facilitates the required data exchanges between the different partial service providers. As such, it allows the integrated QCL-service to work against lower cost compared to a combination of stand-alone interfaces between partial service providers.

Key activities include real-time communication of sensor data along the trade lane, managing a data warehouse facility and developing and operating a number of interfaces between the partial service providers.

Key resources include the hardware and software components to provide the required data connectivity (Raspberry Pie, LoRa Gateways, The Things IoT Network configuration, the data warehouse facility, a number of standard interfaces between the partial service operators, and an end user dashboard presenting the sensor data characteristics, the quality decay predictions, and the logistics intervention advise in a comprehensive and user-friendly way.

The ***partner network*** includes the The Things Network for IoT connectivity and the partial service providers.

The ***customer segmentation*** includes all kinds of niche markets for real-time sensor data exchange, including international transport of perishable fruit and vegetables.

The foreseen ***channel*** to deliver the value proposition is by a store front, with interfaces being developed context specific.

The ***customer relationship*** is primarily with the operator of the integrated QCL-service and/or the partial QCL-service providers to configure the right interface specifications.

The ***cost structure*** is cost driven, data warehouse infrastructure has strong economies of scale, the interface configuration is less scalable.

The foreseen ***revenue stream*** is by a fee per data transactions per shipment.

This is all summarised in the figure below.

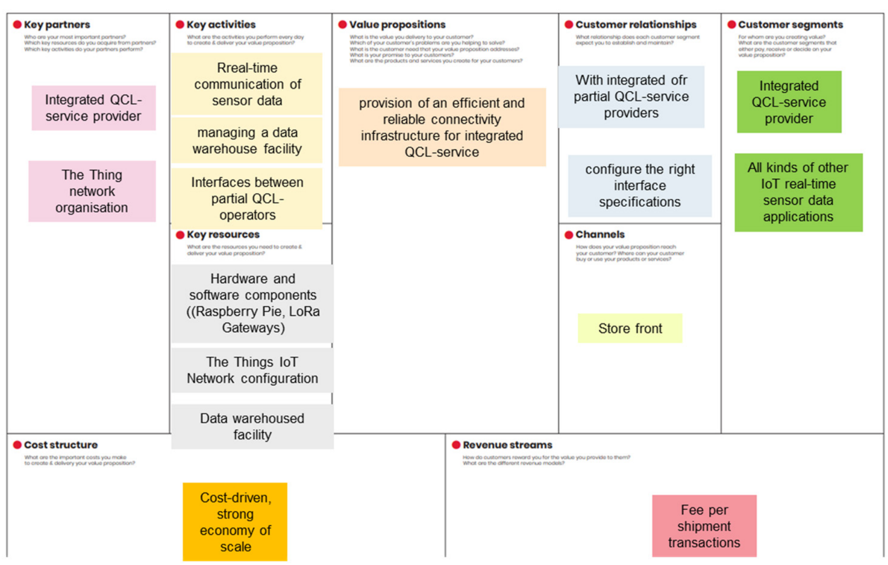


Figure 24: Business Model Canvas of data connectivity provision service (BMV5).

4.8 Business model variants for embedded crate sensors (BMV6a)

The Business Model Canvas has not been applied to embedded sensor variants. We only highlight some of the business model considerations. The business model for embedded sensors on crates and pallets is largely similar to that of removable sensor data provision. The main differences are in the value propositions and in the business case considerations. For the latter we refer to section 3.6.

Regarding the value propositions, worth noticing that it may deliver three different value propositions in an integrated way:
- Supporting the concept of integrated quality controlled logistics, similar to the removable sensor provision business model, but with other cost and revenue streams.
- Providing asset visibility to the pooling organisation.
- Ability to offer quality controlled logistics services in downstream supply chain activities (retail chain).

For embedded truck of container sensors, the value proposition is similar to the removable sensor data provision, but again the cost and revenue streams are different. Here we assume that this specific sensing technology is integrated in already existing smart sensor solutions to be used for asset tracking. In Smart container tracking, smart embedded container devises (e.g. Traxens embedded smart container devise being used by Maersk, CMA-CGM and MSC[4]) often allow for easy connecting multiple specific sensors to the smart devise. The connectivity infrastructure solution is already in place, and adding an additional data entry feed results in minimal marginal data connectivity costs. So if sensing on container level is acceptable for good quality decay predictions, the existing smart container connectivity and service infrastructure allows for connecting the typical ethylene and CO_2 sensors to such a Traxens devise and benefit from the existing business model of container carriers deploying smart container services along the container supply chain.

4.9 Competitive considerations

Some partial business solutions such as sensor data provision, quality decay prediction and providing data connectivity are good scalable, whereas other partial services such as logistic intervention decision support and development of interfaces for specific data connectivity are less scalable.

This also poses challenges to the business model of the integrated QCL-service. One of these challenges is that actually all partial solution providers might procure the other partial services and operate the integrated service. Moreover, this strategy might result in alternative competition. This may be the case when for instance the data connectivity solution provider insources low cost sensor hardware and applies advanced data analytics to the sensor data being transferred through its data warehouse. In that way he may even compete with the quality decay prediction service provider as well as with high quality sensor data providers.
This offers flexibility to deploy several business model variations, but can also raise tension among the research partners in the development stage.

[4] https://www.traxens.com/en/news/a.p.-moller-maersk-will-join-traxens

5 Conclusions

Product quality control of perishables during international transport
Product quality decay and waste occurs during transportation, particularly on international trade lanes, such as in the reference case with Van Oers United perishable lanes from West-Africa to North-West Europe. Quality monitoring by sensing the conditions of perishable products during transport clearly has value generating potential, though it is not common practise today. The business case analysis of the IoT4AGRI concept applied to trade lanes of green beans, mangoes and Galia melons from Senegal/Morocco to The Netherlands confirm this value generating potential of dynamic condition monitoring during transportation.
And the business case only includes the direct product value and associated costs of the monitoring system and costs of the interventions. Other benefits related to tracking and tracing of shipments, trade compliance benefits or downstream benefits from embedded sensors in the retail channel have been excluded from the business case analysis.

Fixed inspection and sorting processes built into perishable supply chain already contribute to product quality control and are regularly being used in today practices. This is included in the reference business case scenario.

The quality decay offers potential for en-route monitoring using advanced sensor technology and IoT technology to allow for real-time anticipatory strategies or logistic interventions. These interventions result in higher product quality and less waste upon arrival, and the harvested products destined for export deliver substantially more turnover for the producer of importer. However, this sensor-driven quality control concept comes with a price, it also increases the logistics costs of a shipment. Moreover, some interventions may result in alternative cost for sourcing good quality products on the spot market in order to deliver to promise to the key customers.

The business case findings
In the reference scenario, the trade lanes of Moroccan and Senegalese green beans, Senegalese Galia melons and Senegalese ready-to-eat mangoes are modelled, taking into consideration the modal split (sea, road) and corresponding lead times, the product robustness distribution, sales prices for the different sales channels, basic quality parameters upon arrival, and an average share of fast ripening shipments. This results in a net revenue for all trade lanes, varying from €15,7 million for the Moroccan Green Beans (12,000 tons export volume) up to €98,000 for the ready-to-eat Senegalese mangoes (155 tons export volume).

The logistics interventions considered in the business case model include reducing the transport lead time by respectively 12 hours, 24 hours, 36 hours and 48 hours, regardless of the practical (im)possibilities. Another intervention includes dynamic condition control and optimal adjustment based on the actual ripening status. Finally, a logistic intervention is to reroute a fast ripening shipment during its journey, either via sea or via road or both. The intervention options all assume the shipments to be dynamically monitored with five sensors and a data sharing infrastructure. These sensors include an ethylene sensor, an oxygen sensor, a CO_2 sensor, a temperature sensor and a relative humidity sensor.

The costs of these sensors are the average of a lower bound estimate and an upper bound cost estimate. This results in additional cost of more than €1,000 per shipment, for the set of sensors, a processing and communication unit (Raspberry Pie Zero) and a cover unit.

The lead time shortening option can result in substantial net value creation, depending on the reduction potential and the corresponding costs of the intervention. For Moroccan green beans, a lead time reduction of 12 / 24 /36 /48 hours would result in a net result of respectively -/- €313,000 (loss) / €176,000 / €1,1 million / €1,9 million. Similar results become apparent for the other trade lanes. Apparently, if lead time reduction by 36 hours or more would be possible, it would be recommended to implement this measure for all shipments under these model assumptions. Alternatively, lead time reductions by 24 hours
(or less) seem to be feasible in particular circumstances, where quality decay goes faster than anticipated.

The option to dynamically adjust the condition parameters based on the actual decay pace generates the highest net value under the model assumptions.
In case of the Moroccan Green Bean trade lane, the additional net value equals €3,5 million. For the other trade lanes the net effect is also considerable, and higher than the lead time reduction alternatives. The additional net value for Senegalese green beans would then be €2,0 million, for Senegalese Galia melons this net value would be €229,000 and for Senegalese ready-to-eat mangoes the option would generate €79,000.

The option of rerouting fast ripening shipments often does not generate any additional value, in many cases continuing the shipment route and accepting the losses in Dinteloord is more preferable then intervening and rerouting. And if It results in net value creation, the effect is minimal.

The sensitivity analysis findings
Sensitivity analysis brings additional insight in the sensitivity of the model against certain assumptions. The sensitivity analysis has been applied to the trade lane of Senegalese Galia melons, insights are expected to be also applicable to the other trade lanes. The sensitivity analyses results in the following findings.

First of all, the model appears to be rather sensitive to the number and quality level of the sensors. When using more than four sets of high cost sensors per shipment, the interventions no longer result in a positive net value. Not surprisingly, if low cost sensors would be feasible for reliable quality decay modelling, the business case becomes substantially stronger.

When assuming a bad harvest with a higher share of vulnerable products, the effect of sensing and intervening becomes more apparent. Even the rerouting option for fast ripening shipments becomes positive. We see similar effects if we adjust the base quality decay parameters upon arrival. The relative impact of the interventions and accordingly the net value generation become much stronger.

Also if the probability of fast ripening shipments increase, the effect of sensing and intervening becomes more apparent.

Moreover, we see that the net value in the reference case drops and even becomes negative in case the probability of fast ripening shipments rises from 10% to 35%. Consequentially, more volume needs to be bought on the spot market and positive net margins disappear. A similar pattern appears when the spot prices become higher.

The option to apply the sensor solution only to vulnerable shipments would result in similar net revenues. This may be counterintuitive to the belief that investment costs are substantially lower whilst the rationale for intervening would be primarily apparent among vulnerable shipments. But apparently, the model assumes strong economies of scale in the data connectivity infrastructure, resulting in substantially higher data connectivity cost per sensor-embedded shipment in case of low shipment volumes.

Finally, the business case of embedded crate sensors looks promising. When assuming a turnaround rate of 8 shipments per year for smart embedded crates, it is more attractive to deploy four smart crates per shipment instead of four sets of five removable sensors. Moreover, the embedded crate sensors also offer considerable benefits in other parts of the value chain, though these benefits have been considered out of scope. For the logistic asset pool operator when equipped with localisation sensors for tracking and tracing of the crates and it offers additional benefits in the downstream retail channel.

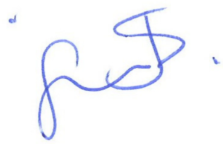
The business model analysis findings
The business model analysis highlights that the integrated Quality Controlled Logistics service actually requires a combination and integration of different partial solutions, which each have their own value proposition and corresponding business model considerations. Some partial business solutions such as sensor data provision, quality decay prediction and providing data connectivity are good scalable, whereas other partial services such as logistic intervention decision support and development of interfaces for specific data connectivity are less scalable.

This also poses challenges to the business model of the integrated QCL-service. One of these challenges is that actually all partial solution providers might procure the other partial services and operate the integrated service. Moreover, this strategy might result in alternative competition. This may be the case when for instance the data connectivity solution provider insources low cost sensor hardware and applies advanced data analytics to the sensor data being transferred through its data warehouse. In that way this actor may compete with the quality decay prediction service provider as well as with high quality sensor data providers.

6 Signature

The Hague, 15 February 2021

TNO



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Author

A Ripening parameter model assumptions

This Annex includes the ripening assumptions for the logistic interventions in the different trade lanes. They provide the basis for the business case analysis results.

Table 9: The ripening parameters of the lead time interventions on the Senegalese Green bean sea lane.

Sea Trade Lane Green Beans Senegal (1)	**Reference**		**Lead time – 24 hours**		**Lead time – 36 hours**		**Lead time -48 hours**	
Shipments following a standard ripening pattern	95%		95%		90%		90%	
Product robustness	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.
% within specs	85.0%	65.0%	87.0%	69.0%	89.0%	73.0%	90.0%	75.0%
% alternative sales channel	7.5%	17.5%	6.5%	15.5%	5.5%	13.8%	5,0%	12.5%
% waste	7.5%	17.5%	6,50%	15,50 %	5,50%	13,25 %	5,0%	12,5%
Fast ripening shipments	5%		5%		5%		5%	
% within specs	15%		20%		30%		40%	
% alternative sales channel	15%		20%		30%		40%	
% waste	70%		60%		40%		20%	

Table 10: The ripening parameters of alternative interventions on the Senegalese Green bean sea lane.

Sea Trade Lane Green Beans Senegal (2)	**Reference**		**Dynamic climate control**		**Rerouting**	
Shipments following a standard ripening pattern	95%		95%			
Product robustness	Rob.	Vuln.	Rob.	Vuln.		
% within specs	85.0%	65.0%	90,0%	75,0%		
% alternative sales channel	7.5%	17.5%	5,0%	12,5%		
% waste	7.5%	17.5%	5,0%	12,5%		
Fast ripening shipments	5%		5%		5%	
% within specs	15%		50%		0%	
% alternative sales channel	15%		40%		65%	
% waste	70%		10%		35%	

Table 11: The ripening parameters of the lead time interventions on the Senegalese Green bean road lane.

Road Trade Lane Green Beans Senegal (1)	**Reference**		**Lead time – 24 hours**		**Lead time – 36 hours**		**Lead time -48 hours**	
Shipments following a standard ripening pattern	92%		92%		92%		92%	
Product robustness	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.
% within specs	90,0%	70,0%	91,5%	74,0%	93,0%	77,0%	94,0%	80,0%
% alternative sales channel	7,5%	15,0%	4,3%	13,0%	3,5%	11,5%	3,0%	10,0%
% waste	7,5%	15,0%	4,3%	13,0%	3,5%	11,5%	3,0%	10,0%
Fast ripening shipments	8%		8%		8%		8%	
% within specs	15%		20%		30%		40%	
% alternative sales channel	15%		20%		30%		40%	
% waste	70%		60%		40%		20%	

Table 12: The ripening parameters of alternative interventions on the Senegalese Green bean road lane.

Road Trade Lane Green Beans Senegal (2)	**Reference**		**Dynamic climate control**		**Rerouting**	
Shipments following a standard ripening pattern	92%		92%			
Product robustness	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.
% within specs	90,0%	70,0%	94,0%	80%		
% alternative sales channel	7,5%	15,0%	3,00%	10%		
% waste	7,5%	15,0%	3,00%	10%		
Fast ripening shipments	8%		8%		8%	
% within specs	15%		50%		0%	
% alternative sales channel	15%		40%		80%	
% waste	70%		10%		20%	

Table 13: The ripening parameters of the lead time interventions on the Moroccan Green bean sea lane.

Sea Trade Lane Green Beans Morocco (1)	**Reference**		**Lead time – 24 hours**		**Lead time – 36 hours**		**Lead time -48 hours**	
Shipments following a standard ripening pattern	95%		95%		90%		90%	
Product robustness	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.
% within specs	90,0%	70,0%	91,5%	74,0%	93,0%	77,0%	94,0%	80,0%
% alternative sales channel	5,0%	15,0%	4,25%	13,0%	3,5%	11,5%	3,0%	10,0%
% waste	5,0%	15,0%	4,25%	13,0%	3,5%	11,5%	3,0%	10,0%
Fast ripening shipments	5%		5%		5%		5%	
% within specs	15%		20%		30%		40%	
% alternative sales channel	15%		20%		30%		40%	
% waste	70%		60%		40%		20%	

Table 14: The ripening parameters of alternative interventions on the Moroccan Green bean sea lane.

Sea Trade Lane Green Beans Morocco (2)	**Reference**		**Dynamic climate control**		**Rerouting**	
Shipments following a standard ripening pattern	95%		95%			
Product robustness	Rob.	Vuln.	Rob.	Vuln.		
% within specs	85.0%	65.0%	94,0%	80,0%		
% alternative sales channel	7.5%	17.5%	3,0%	10,0%		
% waste	7.5%	17.5%	3,0%	10,0%		
Fast ripening shipments	5%		5%		5%	
% within specs	15%		50%		0%	
% alternative sales channel	15%		40%		65%	
% waste	70%		10%		35%	

Table 15: The ripening parameters of the lead time interventions on the Moroccan Green bean road lane.

Road Trade Lane Green Beans Morocco (1)	**Reference**		**Lead time – 24 hours**		**Lead time – 36 hours**		**Lead time -48 hours**	
Shipments following a standard ripening pattern	92%		92%		92%		92%	
Product robustness	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.
% within specs	93,0%	75,0%	94,00 %	77,50 %	95,0%	80,00 %	96,0%	82,5%
% alternative sales channel	3,5%	12,5%	3,00%	11,3%	2,5%	10,00 %	2,0%	8,75%
% waste	3,5%	12,5%	3,00%	11,3%	2,5%	10,00 %	2,0%	8,75%
Fast ripening shipments	8%		8%		8%		8%	
% within specs	15%		20%		30%		40%	
% alternative sales channel	15%		20%		30%		40%	
% waste	70%		60%		40%		20%	

Table 16: The ripening parameters of the lead time interventions on the Moroccan Green bean road lane.

Road Trade Lane Green Beans Morocco	**Reference**		**Dynamic climate control**		**Rerouting**	
Shipments following a standard ripening pattern	92%		92%			
Product robustness	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.
% within specs	93,0%	75,0%	96,0%	82,50 %		
% alternative sales channel	3,5%	12,5%	2,0%	8,75%		
% waste	3,5%	12,5%	2,0%	8,75%		
Fast ripening shipments	8%		8%		8%	
% within specs	15%		50%			
% alternative sales channel	15%		40%		80%	
% waste	70%		10%		20%	

Table 17: The ripening parameters of the lead time interventions on the Senegalese Mango sea lane.

Sea Trade Lane Ready-to-eat Mango Senegal (1)	**Reference**		**Lead time – 24 hours**		**Lead time – 36 hours**		**Lead time -48 hours**	
Shipments following a standard ripening pattern	90%		90%		90%		90%	
Product robustness	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.
% within specs	70,0%	55,0%	72,0%	57,0%	73,5%	58,5%	75,0%	60,0%
% alternative sales channel	15,0%	22,5%	14,0%	21,5%	13,3%	20,8%	12,5%	20,0%
% waste	15,0%	22,5%	14,0%	21,5%	13,3%	20,8%	12,5%	20,0%
Fast ripening shipments	10%		10%		10%		10%	
% within specs	10%		20%		25%		30%	
% alternative sales channel	10%		20%		25%		30%	
% waste	80%		60%		50%		40%	

Table 18: The ripening parameters of alternative interventions on the Senegalese Mango sea lane.

Sea Trade Lane Ready-to-eat Mango Senegal (2)	**Reference**		**Dynamic climate control**		**Rerouting**	
Shipments following a standard ripening pattern	90%		90%			
Product robustness	Rob.	Vuln.	Rob.	Vuln.		
% within specs	70,0%	55,0%	75,0%	60,0%		
% alternative sales channel	15,0%	22,5%	12,5%	20,0%		
% waste	15,0%	22,5%	12,5%	20,0%		
Fast ripening shipments	10%		10%		10%	
% within specs	10%		50%		0%	
% alternative sales channel	10%		25%		67%	
% waste	80%		25%		33%	

Table 19: The ripening parameters of the lead time interventions on the Senegalese Mango road lane.

Road Trade Lane Ready-to-eat Mango Senegal (1)	**Reference**		**Lead time – 24 hours**		**Lead time – 36 hours**		**Lead time -48 hours**	
Shipments following a standard ripening pattern	90%		90%		90%		90%	
Product robustness	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.
% within specs	75,0%	60,0%	77,5%	64,00 %	80,0%	67,0%	82,5%	70,0%
% alternative sales channel	12,5%	20,0%	11,3%	18,0%	10,0%	16,5%	8,8%	15,0%
% waste	12,5%	20,0%	11,3%	18,0%	10,0%	16,5%	8,8%	15,0%
Fast ripening shipments	10%		10%		10%		10%	
% within specs	10%		20%		25%		30%	
% alternative sales channel	10%		20%		25%		30%	
% waste	80%		60%		50%		40%	

Table 20: The ripening parameters of alternative interventions on the Senegalese Mango road lane.

Road Trade Lane Ready-to-eat Mango Senegal (2)	**Reference**		**Dynamic climate control**		**Rerouting**	
Shipments following a standard ripening pattern	90%		90%			
Product robustness	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.
% within specs	75,0%	60,0%	82,5%	70%		
% alternative sales channel	12,5%	20,0%	8,8%	15%		
% waste	12,5%	20,0%	8,8%	15%		
Fast ripening shipments	10%		10%		10%	
% within specs	10%		35%		0%	
% alternative sales channel	10%		35%		80%	
% waste	80%		30%		20%	

Table 21: The ripening parameters of the lead time interventions on the Senegalese Galia Melon sea lane.

Sea Trade Lane Galia Melon Senegal (1)	**Reference**		**Lead time – 24 hours**		**Lead time – 36 hours**		**Lead time -48 hours**	
Shipments following a standard ripening pattern	90%		90%		90%		90%	
Product robustness	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.
% within specs	70,0%	55,0%	72,0%	57,0%	73,5%	58,5%	75,0%	60,0%
% alternative sales channel	15,0%	22,5%	14,0%	21,5%	13,3%	20,8%	12,5%	20,0%
% waste	15,0%	22,5%	14,0%	21,5%	13,3%	20,8%	12,5%	20,0%
Fast ripening shipments	10%		10%		10%		10%	
% within specs	10%		20%		25%		30%	
% alternative sales channel	10%		20%		25%		30%	
% waste	80%		60%		50%		40%	

Table 22: The ripening parameters of alternative interventions on the Senegalese Galia Melon sea lane.

Sea Trade Lane Galia Meloon Senegal (2)	**Reference**		**Dynamic climate control**		**Rerouting**	
Shipments following a standard ripening pattern	90%		90%			
Product robustness	Rob.	Vuln.	Rob.	Vuln.		
% within specs	70,0%	55,0%	75,0%	60,0%		
% alternative sales channel	15,0%	22,5%	12,5%	20,0%		
% waste	15,0%	22,5%	12,5%	20,0%		
Fast ripening shipments	10%		10%		10%	
% within specs	10%		50%		0%	
% alternative sales channel	10%		25%		67%	
% waste	80%		25%		33%	

Table 23: The ripening parameters of the lead time interventions on the Senegalese Galia Melon road lane.

Road Trade Lane Galia Melon Senegal (1)	**Reference**		**Lead time – 24 hours**		**Lead time – 36 hours**		**Lead time -48 hours**	
Shipments following a standard ripening pattern	90%		90%		90%		90%	
Product robustness	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.
% within specs	75,0%	60,0%	77,5%	64,00 %	80,0%	67,0%	82,5%	70,0%
% alternative sales channel	12,5%	20,0%	11,3%	18,0%	10,0%	16,5%	8,8%	15,0%
% waste	12,5%	20,0%	11,3%	18,0%	10,0%	16,5%	8,8%	15,0%
Fast ripening shipments	10%		10%		10%		10%	
% within specs	10%		20%		25%		30%	
% alternative sales channel	10%		20%		25%		30%	
% waste	80%		60%		50%		40%	

Table 24 :The ripening parameters of alternative interventions on the Senegalese Galia Melon road lane.

Road Trade Lane Galia Melon Senegal (2)	**Reference**		**Dynamic climate control**		**Rerouting**	
Shipments following a standard ripening pattern	90%		90%			
Product robustness	Rob.	Vuln.	Rob.	Vuln.	Rob.	Vuln.
% within specs	75,0%	60,0%	82,5%	70%		
% alternative sales channel	12,5%	20,0%	8,8%	15%		
% waste	12,5%	20,0%	8,8%	15%		
Fast ripening shipments	10%		10%		10%	
% within specs	10%		35%		0%	
% alternative sales channel	10%		35%		80%	
% waste	80%		30%		20%	