THE ROUTE OF CRIME

Analysing the impact of risk vs gain trade-offs on international criminal supply chains.

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The Route of Crime

Analysing the impact of risk vs gain trade-offs on international criminal supply chains

by

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Preface

As a fanatic newsreader, working on a topic for the last six months that weekly reached the headlines of Dutch papers has been a real thrill. Although I had little to do with the impressive number of criminal shipments intercepted in the ports of Rotterdam and Antwerp, I met the officers behind the Police interventions. I was also able to recognise the routing patterns of the intercepted shipments. Besides being interesting and exciting, working on a project regarding criminal supply chains was also confronting. During the interviews with members the Police, they were transparent about the excessive amount of violence going hand-in-hand with the import of illegal products. I hope this research can make the tiniest bit of positive change in the destructive world of corruption, violence, and addiction.

Without the great guidance of my external supervisors of the Dutch National Police, this thesis could not have been realised. I have immensely enjoyed our weekly meetings on Monday - which was not only insightful, but also a lot of fun. Ron van den Bosch and Prins Hans Baas, thank you so much for your support and patience during the development of this challenging project.

I would also like to thank my graduation committee from the TU Delft. Especially my daily supervisor Isabelle, who guided me through my struggles of creating an academic thesis rather than a consultancy report. Moreover, she took sufficient time on a weekly basis to brainstorm on the direction of my research. I have enjoyed our trips all over the Netherlands to visit different Police offices. Isabelle, I wish you all the best in the coming years of your PhD research. A special thanks to Alexander Verbreack, who has the beautiful ability to make students feel as if every question is a good one. I have rarely met anyone who speaks which such a high rate of interesting statements and suggestions; the speed in which I can take notes doubled up during our meetings. I want to thank Jan Kwakkel for his critical reflection of the modelling methods and suggestions to improve the scientific value of my study. I want to thank Haiko van der Voort for posing a contrary opinion during the graduation meetings; your insights helped me make this thesis more than a mathematical model.

Lastly, I would like to thank my family and friends for posing as my support system during my years of study time leading up to this moment. My parents and amazing sister for believing I can make things happen, even when I did not. Ande, my day-one friend without whom I probably would not have been able to pass beyond my first study year. My Mannen-friends from Utrecht, Robin, my friends from Stud, and all others; thank you for letting me babble and providing me candy when I lost my motivation. And finally, my EPA family consisting of Can, Esmée, and Boris. You three provided the perfect pep-talk, brainstorm, and bad joke environment to make this Covid-graduation period an overwhelmingly fun period to look back on.

To the reader, I hope you enjoy reading my report. I have tried to make the academic material less dry with the use of visuals and personal stories of Police officers. When reading an English thesis is not your piece of cake, I urge you to take a look at appendix F. This appendix contains a visual outline of my thesis in Dutch, used for explainability purposes for the Dutch National Police. A final suggestion is to look at appendix A, just because it is fun.

Roos Klaassen
30 July, 2021

Executive Summary

The interception of illegal shipments originating from South America making their way towards the Netherlands hit new records in 2020. However, despite the growing efforts of the Dutch National Police and Dutch Customs, the size of the criminal supply chains is still increasing. This increase suggests that the current criminal detection practices of the Dutch Police and Dutch Customs are not sufficient to intercept the majority of the criminal shipments. The resources used by the Dutch National Police and Customs to detect criminal shipments do not yet include information from the criminal risk vs gain trade-off point of view. This research aims to increase criminal detection by identifying criminal transport configurations with a high chance of smuggling, using the criminal risk vs gain trade-offs. Supply chains analysis based on trade-offs is a much-used practice for legitimate supply chains but has not yet been applied to criminal supply chains.

To come to a research conclusion that has an academic and societal value, the following main research question is investigated: *Which transport configurations are preferred by smugglers in criminal supply chains from South America to the Netherlands when reasoning from the criminal risk vs gain trade-off, and which factors influence this trade-off?*

This main research question translates into the five following sub-questions:

1. What are the main differences between a legitimate and a criminal supply chain?
2. What are the possible transport configurations, consisting of route and smuggling method, exploited by criminals when smuggling illegal products into Northwestern Europe?
3. How do criminals give value to risk and gain variables when considering their criminal supply chain's route and smuggling method?
4. How can the impact of the risk vs gain trade-off on the transport configurations within the criminal supply chain be modelled using a multi-objective optimisation?
5. How can the qualitative, and modelling results be reduced to characterised configurations while maintaining their validity?

This research is split into a qualitative and a modelling research part to answer the main research question and its sub-questions. The qualitative part aims to identify and quantify all variables influencing the risk and gain value of the criminal trade-off. The modelling part focuses on identifying transport configurations with a high chance of smuggling by selecting the configurations with an optimal low risk/ high gain balance.

The methodology of the qualitative part consists of literature research in combination with 25 semi-structured interviews with the Dutch National Police, Europol, Dutch Customs, and the Port of Rotterdam. These interviews give a unique opportunity to creating insight into the criminal thought process due to the recent developments in criminal detection. In the last years, six criminal crypto communication networks were hacked by international Police forces, allowing the Dutch Police access to billions of messages sent between smugglers, which can be utilised for criminal detection and criminal behaviour analysis. The modelling part of the research consists of a multi-objective optimisation model. The model generates all possible transport configurations based on four transport variables: routing, smuggling method, type of bribery, and type of piggybacking company. Subsequently, each risk and gain value for every configuration is calculated. Finally, the model selects the configurations with the optimal balance between risk and gain as the Pareto solutions. The selected solutions represent the transport configurations most likely to be used for smuggling illegal products.

The results of the qualitative part focusing on the risk vs gain trade-off are as follows: the criminal risk value is influenced by mutual criminal trust, bribed (non) officials, route risk, and smuggling risk. The route risk variable consists of loading possibilities for the illegal products in the country of origin, extraction possibilities of the illegal products in the country of arrival, and the detectability of the shipment route. The smuggling variable consists of the safety rating of the piggybacking company and the detectability of the smuggling method. The gain value of the risk vs gain trade-off is influenced by two variables: the wholesale price of the illegal products between the two shipment countries and the transport cost.

The results of the modelling part show a strong preference for shipping routes from Brazil to the Netherlands. Other common routes include Chile, Colombia, Ecuador and Argentina. Although less prominent in the solution set, countries requiring a second transit stop (such as Central America and Africa) are included in the preferred criminal routes. When transported to the Netherlands, the smuggling methods most attractive to criminals are a cover load or hidden inside the container construction. As a smuggling method within South America, the smuggling method using a semi-submersible presents a large part of the solution set. A wide range of types of bribery is present in the solution set. For the type of piggybacking company, there is a preference for the use of fruit companies. The study continues with measuring the disturbance caused within the criminal supply chain of hypothetical Dutch Customs interventions. Based on the analysis, it can be concluded that interventions strongly differ in their effect on the preferred criminal transport configurations. An intervention focused on tackling corruption within the Dutch ports reduces the illegal shipments originating from Brazil from 19% to 6%.

The results of this research have proven that a multi-objective optimisation of the criminal supply chain can effectively select preferred transport configurations based on the criminal risk vs gain trade-off. In other words, this study has the potential to enhance the criminal detection practices of the Dutch National Police. Besides the societal contribution of this study, it contributes to the academic research field of criminal risk perception and criminal supply chain analysis. This study shows a multi-objective optimisation is a suitable method for analysing a criminal supply chain and identifies the challenges of analysing criminality: modelling with data scarcity and selecting a suitable solution space for a MOO.

Finally, it is essential to note that the entire study takes place under high data uncertainty. All information gathered via literature and interviews represents the visible 5 - 20% part of the criminal supply chain. Assumptions were made in this study regarding routes, smuggling methods, transport prices, and more. Under such a level of uncertainty, it is impossible to state the exact impact this study will have on increasing the criminal detection practices of the Dutch National Police and Dutch Customs. However, whether the contribution to the currently 5 - 20% of detected shipments is 1%, 0.1% or 0.001% does not matter for the fact that every extra detected shipment counts as a contribution to a safer Dutch society.

Contents

List of Figures

List of Tables

Introduction

1

The trafficking of illegal goods has become an increasing threat to Dutch society. Despite the growing efforts of the Dutch National Police, Dutch Customs Administration, and Fiscal Information and Investigation Services (FIOD), the smuggling of drugs and illegal cigarettes into the Netherlands hit new highs in 2020 (van der Wel & Brink, 2020; Meijer, Pfeil, & van Vliet, 2019). The import of illegal products forms a threat to the Dutch government's legal trade and tax income. Besides economic influences, the increase of smuggling in the port of Rotterdam and Vlissingen has caused more excessive violence on Dutch streets (InsightCrime, 2020).

Effectively disrupting a criminal supply chain is highly complex due to the low amount of verified data on the logistic movements of smugglers (Vermeulen, van der Leest, & Dirksen, 2018). Where interventions in legitimate supply chains are optimised using optimisation models, Dutch Customs or Police cannot use this technique to plan interventions in the criminal supply chain. The high uncertainty of the acquired data sets the Dutch Police for an impossible task: how to intercept all illegal goods, while only a fraction of the criminal supply chain data is known. This research focuses on increasing the criminal detection of smugglers so that the Dutch National Police can create a safer Dutch society.

1.1 Criminal detection gap

Although the exact percentage is disputed, all scientific researchers and Dutch Police employees agree: only a tiny part of the illegal goods travelling through the ports in Northwestern Europe are detected (Caulkins, 2020; McDermott, Bargent, den Held, & Ramírez, 2021). Due to the high uncertainty of the criminal supply chain data, most scientists do not want to burn their hands on an estimation. Based on the scarce researches mentioning a percentage of detected illegal goods, the number approximates 5-20% (McDermott et al., 2021). Even though this number is highly uncertain, it can be concluded that the current method of criminal detection used by Dutch Customs is not yet sufficient.

The Dutch Customs' criminal detection practices start when a shipment is registered right before entering the Dutch ports. The Dutch Customs explained during introductory conversations for this research that their employees assess every foreign shipment entering the Netherlands on possible smuggling using a risk profile. When a risk profile ticks a certain amount of boxes, the shipment is detected and either scanned or physically checked by Customs employees with sniffer dogs. If any illegal goods are found in the shipment, the Dutch Police is brought in to handle the case further.

The risk profiles drawn up by Dutch Customs are created based upon the historic Customs' information, Police intelligence, the intelligence of foreign Customs, and open-source research. The two pie charts in fig. 1.1 show the small part of detected illegal products (left) and the current information sources used by the Dutch Customs to detect those products (right). The question mark represents the criminal detection gap: the gap of information that has to be filled to increase the percentage of detected illegal products drastically.

If Dutch Customs and Police manage to intercept more shipments in the Netherlands, the demand for illegal products in Europe will be unchanged. Criminals will move their operations to other North European ports such as Antwerp or Hamburg (Roks, Bisschop, & Staring, 2020). The illegal products will still enter the Netherlands from other European countries, but now by truck over the open border roads. More interceptions by the Dutch Police do not kill illegal trafficking; it only increases the difficulty. Sadly but true, increasing the degree of difficulty is the only thing the Dutch National Police can do. By decreasing illegal trafficking in the Netherlands and collaborating with neighbouring countries, the international police forces work together on a safer Europe.

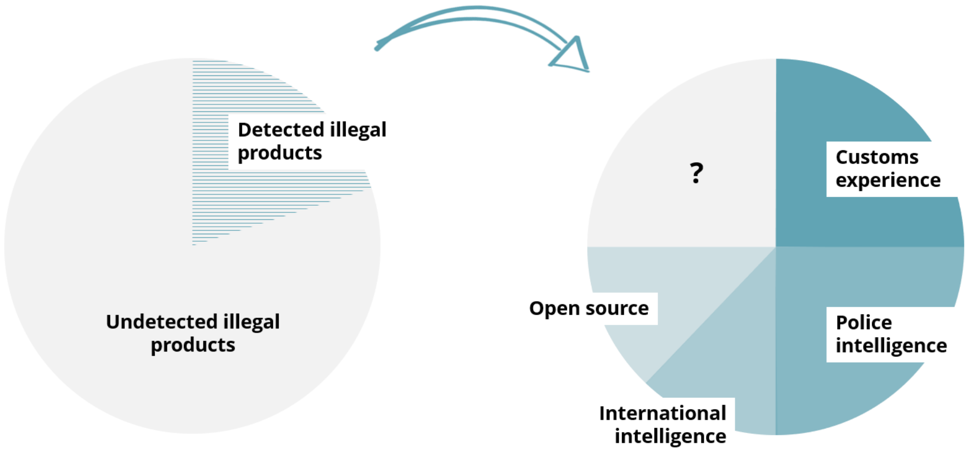

Figure 1.1: Part of illegal products detected (left) and information sources used for detection (right)

1.2 Scientific research gap

Despite the criminal nature of products such as illegal cigarettes, most characterisations of their supply chain are similar to that of legal products (New, 1997; Kilmer & Hoorens, 2010). Similar to the legitimate supply chain, a criminal supply chain consists of different stakeholders and can be divided into five phases: sourcing, manufacturing, distributing, retailing and consuming (Vermeulen et al., 2018). Because the number of studies on criminal supply chains is limited, I use the current literature on legitimate supply chains to try and fill the criminal detection gap.

1.2.1 Supply chain trade-offs

Many supply chain studies use trade-offs between a quantity or quality to assess the dynamics and effectiveness of a supply chain (Fynes, Voss, & De Búrca, 2005; Vahid Nooraie & Parast, 2016). According to the Merriam-Webster dictionary, the definition of a *trade-off* is a balancing of factors, all of which are not attainable at the same time. A well-known exemplary trade-off, currently trending for multinationals as Unilever, is the *cost efficiency* vs *sustainability* trade-off (Hong, Zhang, & Ding, 2018). When a company shifts its focus towards sustainability, this leads to the inspection and optimisation of all logistic movements to comply with the new sustainable standards. The method of using trade-offs to investigate an international supply chain has been proven to work but has not yet been used to uncover the secrets of criminal supply chains. Therefore, applying trade-off modelling to an international criminal supply chain could provide new academic insights.

1.2.2 Risk & gain trade-off

Creating insight into the influence of the criminal trade-offs on the logistical movements will make it easier for the Dutch National Police to initiate successful interventions. A crucial trade-off in the world of crime is risk vs gain (Morselli, Giguère, & Petit, 2007). Decision-makers in a criminal supply chain have to assess the probability of getting caught versus the profitability of their illegal products. The criminal's profit rises with larger shipment sizes, but so does their financial loss when Customs intercept the shipment. Criminals make logistical decisions based on their assessment of risk vs gain. When the risk or gain value of the trade-off changes, the criminal supply chain adjusts accordingly. For example, the adjusted illegal cigarettes supply chain in 1999 after re-evaluating the shipping route risk. When criminals discovered the port of Rotterdam equipped itself with a new x-ray machine, the risk of shipping via Rotterdam increased. This lead to an adjustment of the smuggling route: the standard destination Rotterdam was exchanged for ports outside of the Netherlands with lower chances of interception (Bouma, 2005).

The interplay between risk and gain within criminal decision-making has only been extensively discussed in one study as far as open resource goes. Morselli et al. (2007) describe the risk vs gain trade-off as the interplay between the need to act collectively and the need to assure trust and secrecy. However, this description is not sufficient for the trade-off made within criminal supply chains. Risk in this setting is not merely the need to assure trust, but rather the chance of getting caught by the Police. The study is insightful but does not focus on further defining and quantifying the value criminals give to risk and gain. Quantifying criminal risk and gain is necessary to measure the impact of the trade-off on the logistical movements within the supply chain.

1.2.3 Impact trade-offs on supply chain

The implications of trade-off decisions on the logistical movements within supply chains are discussed in the research field of supply chain management (SCM). This extensive research field regained the interest of the scientific community since the rise of the complex global supply chain (Manuj & Mentzer, 2008). As stated at the beginning of this chapter, the smuggling of illegal products through a criminal supply chain can be vastly compared to a legitimate international supply chain. An overview of relevant studies using different modelling techniques to represent the effect of trade-off decisions within international supply chains is shown in table 1.1.

Citation	Model approach	Type of trade-off	Main objective
(Afshin Mansouri, Gallear, & Askariazad, 2012)	Multi-objective optimisation	Cost vs due date	Improve decision-making in build-to-order supply chains.
(Elhedhli, Gzara, & Waltho, 2021)	Second order cone programming	Client loyalty vs sustainability	Improve green supply chain design with emission sensitive demand.
(Esfahbodi, Zhang, & Watson, 2016)	Multiple Regression Analysis	Environmental vs cost performance	Improving sustainable supply chain management in emerging economies.
(Fahimnia, Sarkis, & Eshragh, 2015)	Nested integrated cross-entropy	Leanness vs greenness	Tactical supply chain planning model to investigate trade-offs.
(Guillén, Mele, Bagajewicz, Espuña, & Puigjaner, 2005)	Multi-objective optimisation	Risk vs profit	Creating supply chain models under high production uncertainty.
(Hasheminia & Jiang, 2017)	Logistic regression (logit)	Vessel delay vs schedule recovery	Testing the relationship between the delay of and the scheduled operations.
(Ivanov, 2018)	Discrete event simulation	Efficiency vs resilience	Simulation-based study on supply chain resilience.
(Margolis, Sullivan, Mason, & Magagnotti, 2018)	Multi-objective optimisation	Cost vs connectivity	Designing resilient supply chain networks.
(Olivares-Aguila & El-Maraghy, 2020)	System dynamics	Cost vs service level	System dynamics framework to evaluate supply chain disruptions.
(Orjuela-Castro, Aranda-Pinilla, & Moreno-Mantilla, 2019)	Deterministic multi-objective linear programming	Environmental vs social	Optimise trade-offs in bio-diesel sector in Colombia.
(Rohmer, Gerdessen, & Claassen, 2019)	Multi-objective optimisation	Cost vs climate change	Addressing sustainability issues in context of global food system.
(Smew, Young, & Geraghty, 2013)	Gaussian process modelling	Customer service level vs work-in-process	Use of simulation to determine optimal configuration of operational parameters.
(Somjai & Jermsittiparsert, 2019)	PLS-SEM	Cost vs environmental performance	Understanding sustainable supply chain implementation and performance.
(Vahid Nooraie & Parast, 2016)	Multi-objective stochastic model	Risk vs cost	Evaluation of trade-offs in supply chain disruption.
(Wang, Lai, & Shi, 2011)	Multi-objective optimisation	Cost vs environmental influence	Modelling environmental investment decisions in the design-phase.
(Zhao, Wu, & Huang, 2018)	Multi-objective optimisation	Time vs cost	Supply chain configurations to improve clinical trial efficiency.

Table 1.1: Literature review for modelling trade-offs in supply chains

The modelling approaches shown in table 1.1 are all based on predictive modelling with as a goal defining the optimum value for the supply chain trade-off decision. Although all models have the same purpose, the techniques widely differ. Discrete event simulation and nested integrated cross-entropy are simulation-based modelling techniques used for a point-by-point match of a system (Ivanov, 2018; Fahimnia et al., 2015). A more high-over The goal of the system dynamics approach used by Olivares-Aguila (2020), is to find optimal trade-off values on the strategic decision level. Other modelling methods include Gaussian process modelling, logistic regression, second-order cone programming, multiple regression analysis, and deterministic linear programming. All methods shared the purpose of optimising a supply chain, but each is based on a different mathematical approach.

The modelling technique most frequently used for modelling trade-offs within international supply chains is the multi-objective optimisation method. Multi-objective optimisation (MOO) is used for optimisation problems, including multiple objectives which need to be fulfilled at the same time, often with a conflict between the objectives (Afshin Mansouri et al., 2012). It is used as a decision support system to facilitate better-informed decision-making. MOO is a suitable optimisation method for supply chain trade-off modelling because, in comparison with single objective methods, it is more reasonable and practical in terms of actual applications (Wang et al., 2011).

A MOO model considers multiple objectives and therefore not presents a singular solution, but a *set* of optimal solutions. Other modelling techniques such as logistic regression (logit) offer a ranking of solutions. Using a logit approach is a much-used method in container ship routing research (Hasheminia & Jiang, 2017; Halim, Kwakkel, & Tavasszy, 2016). In a 2017 study, Halim et al. (2016) presented a path-sized logit model used to rank worldwide container transport routes based on duration and cost. Important to note is the difference in data availability between the worldwide container study on legitimate transport and this study on criminal supply chains. A solution ranking offered by logit models might not be appropriate for a criminal supply chain that deals with high data uncertainty.

Based on the literature research into trade-off modelling within supply chains, I can conclude that using a multi-objective optimisation model is a suitable method to model criminal supply chains. Compared to other modelling methods, the MOO method allows me to simultaneously optimise the objectives for criminal risk and gain. Although already applied on legitimate supply chains, this study is, as far as open research goes, the first time a MOO model is build to analyse the trade-offs in a criminal supply chain.

1.3 Research goal

This research aims to increase criminal detection of illegal product import by identifying transport configurations with a high chance of smuggling, using the criminal risk vs gain trade-offs. Based on the current methods used for criminal detection and the literature study presented in section 1.2 & section 1.1 the research goal can be split into two research objectives. The first objective, shown in the blue textbox on the left, focuses on the qualitative part of this research: identifying the quantifiable factors making up the criminal risk vs gain trade-off. The second objective, shown in the blue textbox on the right, captures the modelling part of this research: the impact of the trade-offs on the logistical movements within the criminal supply chain.

1. Criminal trade-off objective

Identify and quantify all factors influencing the risk and gain value of the corresponding criminal trade-off.

2. Transport configurations objective

Identify transport configurations with high chance of smuggling by selecting the configurations with an optimal low risk & high gain balance.

1.4 Research scope

Due to the time limit of this study, a demarcation of the research field is needed to come to a relevant and challenging research question. This demarcation is two-fold: which part of the physical supply chain, and which independent actors taking part in the criminal supply chain, are to be taken into account.

1.4.1 Supply chain demarcation

This research focuses on the part of the criminal supply chain transporting illegal products from South America to the Netherlands as shown in fig. 1.2. Research by the Dutch National Police showed the criminal supply chain consists of five phases: sourcing, manufacturing, distributing, retailing & consuming (Vermeulen et al., 2018). The three source countries for illegal products are Colombia, Bolivia and Peru (Caulkins, 2020). This study focuses on the distribution part of the supply chain from the three countries to the Netherlands. This demarcation is coordinated with the Dutch National Police, who explained that arrival ports are a bottleneck in the criminal supply chain.

The Customs check at the moment of arrival in the Netherlands plays a vital role in intercepting shipments. Once the products have passed the border, they can be freely transported through the European Union. Researchers from the Dutch Police discovered the Netherlands is a transit country for most illegal products, in which only a small part remains within our borders (Vermeulen et al., 2018). Meaning the journey of illegal products is far from over when they reach the ports in Northwestern Europe.

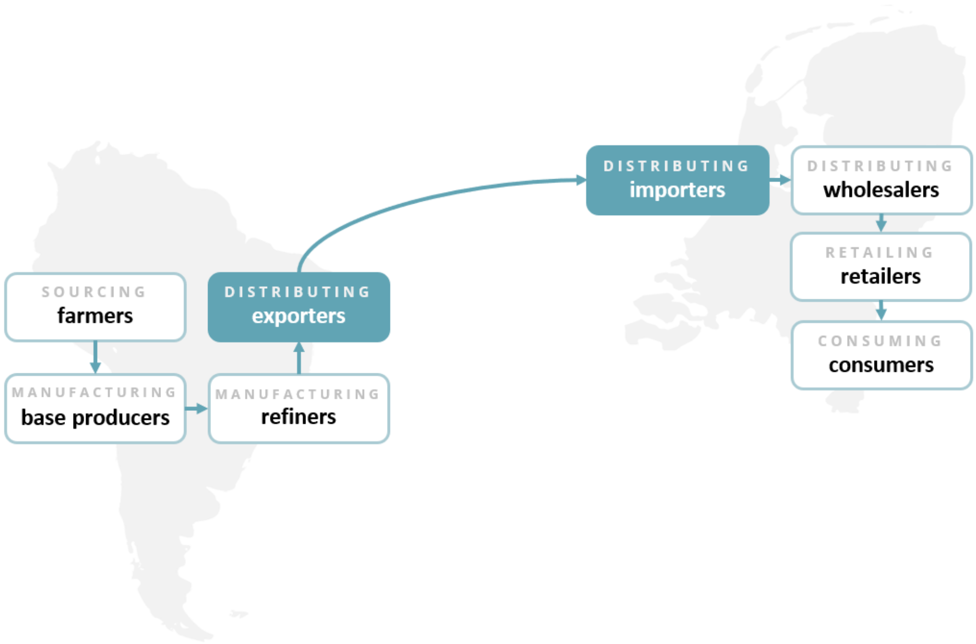

Figure 1.2: Demarcation of criminal supply chain

The criminal supply chains taken into account in this study is restricted to the container ships arriving in the Northwestern ports of Rotterdam, Vlissingen, Antwerp, and Hamburg. According to Dutch Police employees, the vast majority of illegal products enter Northwestern Europe on container ships. Although an upward trend is detected in the use of sailboats or planes, none of the modalities besides container ships offers the possibility of shipping thousands of kilos at the same time.

1.4.2 Actor demarcation

The actors involved in a supply chain are typically categorised in suppliers, manufacturers, distributors, retailers, and customers (Fiala, 2005). This study focuses on the distributors of the criminal supply chain who distribute illegal products from South America to the Netherlands. The actor field of the criminal supply chain is more complicated than its legitimate counterpart. Besides the criminals, there is an important role to play for the Dutch Customs, FIOD, the Dutch Police and legit companies used for piggybacking. This section touches shortly upon each of the five main actors.

The Dutch Customs, the Dutch Police, and the FIOD closely collaborate in the process of criminal detection. The three organisations meet weekly in an information hub to discuss intelligence they have gathered on possible arriving criminal shipments. Every Dutch port has its information hub consisting of three governmental organisations. A Police employee working at the port of Vlissingen explained the Dutch Customs can be seen as the commodities police, the FIOD as the money police and the Dutch Police as the people police. The fifth actor in the distribution of the criminal supply chain is the company that is used for piggybacking. The shipments of legitimate companies can be used for piggybacking without their knowledge when bags of illegal products are dropped inside containers and extracted before the container arrives at its destination. However, in recent years more stories have come to light of legitimate companies being extorted or threatened to participate in criminal activities (Meeus, 2021). Criminals want to make use of their legal transport by adding illegal products in the containers or demand a refund for illegal products the legitimate companies located and reported to the Dutch Police. How to handle the victimisation of legitimate companies is until now unsure. Without their consent, they play a role in the world of crime leading to extortion, physical intimidation, arson, and grenade attacks (Van Dinther, 2020; Driessen, 2021).

The criminals can play multiple roles within the distribution part of the supply chain, under which shippers, planners, organisers, commissioners, drivers, and product owners (Roks et al., 2020). In some cases, one individual takes up multiple roles. A tactical analyst of the Seaport Police of Rotterdam shared in most cases the roles are fulfilled within one organised crime group (OCG), but they have found cases in which multiple OCGs collaborate within the distribution or in which the distribution roles were taken up by individuals not connected to an OCG. The risk vs gain trade-offs are mostly in the hands of the organiser of the distribution, therefore this research focuses on the criminals in the role of organiser.

1.5 Research questions

This study aims to improve criminal detection by exploring the influence of the risk vs gain trade-off on the criminal supply chain. This is done by defining the criminal risk vs gain trade-off and using a MOO model to explore the impact of criminal risk and gain on the selected transport configuration in the criminal supply chain. The research creates a set of transport configurations that are likely to be used for smuggling. This configuration set scales down the large set of possible criminal transports monitored by the Dutch Customs and the Dutch National Police.

The main research question, based upon the research goal and research scope, is shown in the text box below.

> Main research question
>
> Which transport configurations are preferred by smugglers in criminal supply chains from South America to the Netherlands when reasoning from the criminal risk vs gain trade-off, and which factors influence this trade-off?

This main research question translates into the five following sub-questions:

1. *What are the main differences between a legitimate and a criminal supply chain?*
2. *What are the possible transport configurations exploited by criminals when smuggling illegal products into the Netherlands?*
3. *How do criminals give value to the factors risk and gain when considering the transport configurations of their criminal supply chain?*
4. *How can the impact of the risk vs gain trade-off on the transport configurations within the criminal supply chain be modelled using a multi-objective optimisation?*
5. *How can the qualitative and modelling results be reduced to characterised configurations while maintaining their validity?*

1.6 Research structure & deliverables

The research on trade-offs in criminal supply chains is structured into five phases. All research phases, including sub-questions, methods, and deliverables, are shown in the research flow diagram displayed in fig. 1.3.

Phase 1: Background

The goal of the background research phase is to find the research gap and define challenging research questions. Since this research uses three research techniques, literature study, interviews and modelling research, a separate chapter is dedicated to explaining the exact methodology. The methodology chapter is part of the background research phase.

Phase 2: Qualitative research

The objective of the second research phase is the qualitative research goal of this study: defining the factors which make up the criminal risk vs gain trade-off. The second phase consists of expert interviews and additional literature research. The expert group consists of employees of the Dutch Police, Dutch Customs, Europol, and the Port of Rotterdam. A more detailed description of the methodology of these interviews is explained in chapter 2. The quality of the information during the interviews depends on the expert group. To assess the usefulness of each interview, a summary and evaluation are written after each interview. My daily thesis supervisor checked these evaluations, who is under contract with the Dutch National Police.

Phase 3: Modelling research

The modelling research focuses on creating a multi-objective optimisation model to explore the impact of the risk vs gain trade-off on the logistical movements of criminals. The model creates a set of transport configurations using the specified criminal supply chain and the risk and gain formulas created in phase 2. Based on all possible transport configuration possibilities, the model selects the configurations with an optimal balance between minimising risk and maximising gain. These identified configurations are likely transport configurations for criminals to use in their supply chain.

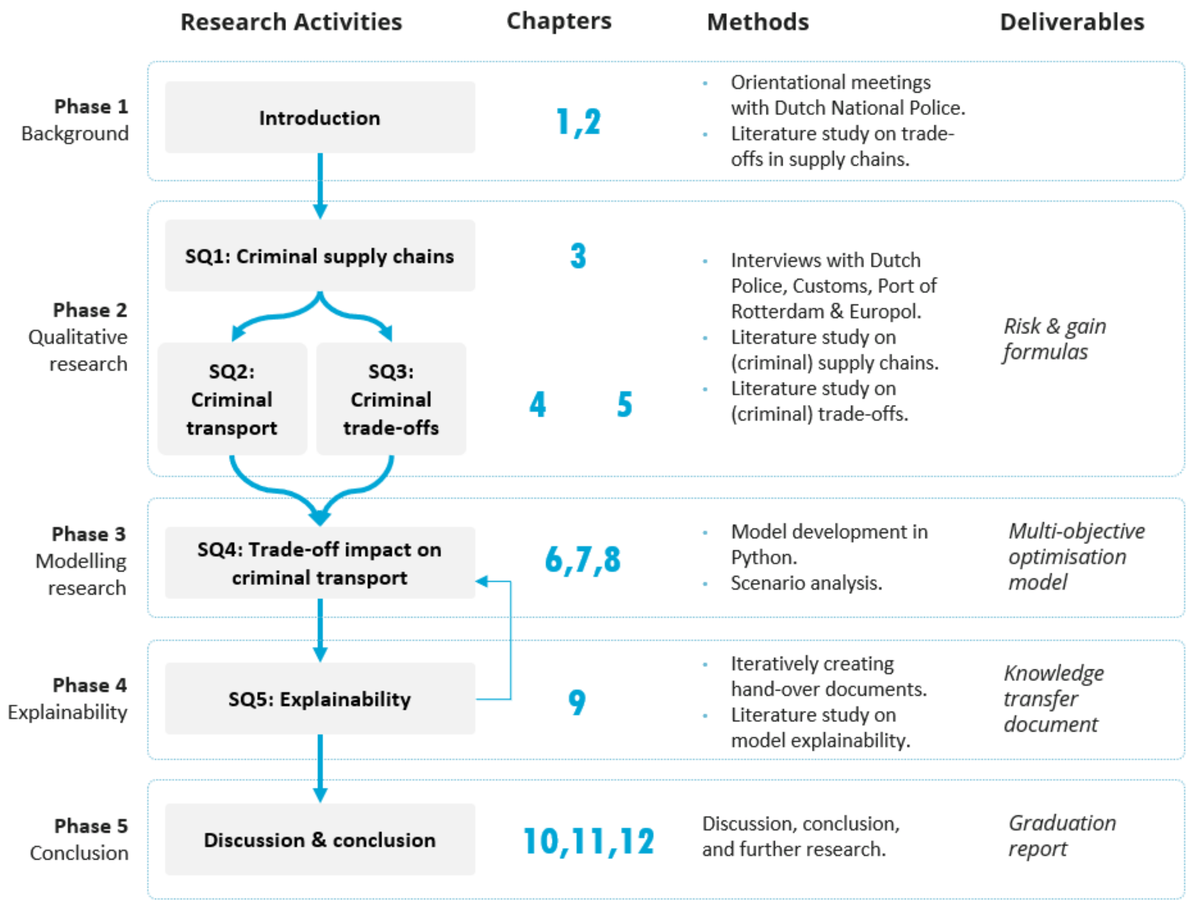

Figure 1.3: Research approach and sub-questions

Phase 4: Explainability

In close collaboration with the Dutch National Police, an information sheet is configured to hand over the results of this research. The goal is to create a smooth knowledge transfer in which Police employees of every rank understand the methods and purpose of this research. At the start of the explainability phase, I identify design principles to which the visual plan must comply. Together with the Police, I ensure the design principles align with the needs of the Port of Rotterdam & Vlissingen and the Police.

Phase 5: Conclusion

The conclusion section has a straightforward goal: answering the main research question. Besides, this phase focuses on the discussion of the results and propositions for further research.

1.6.1 Final deliverables

Each research phase described in section 1.6 has a corresponding deliverable which is stated in fig. 1.3. The value of this study lies in the deliverables of the last three phases:

1. **Multi-objective optimisation model** - modelling the logistic effects of criminal trade-off behaviour on the criminal supply chain.
2. **Knowledge hand-over document** - an explainable visual document on the usefulness of this study for the daily operations of the Dutch National Police.
3. **Graduation report** - a final report containing all scientific arguments for the choices and conclusions during the quantitative and modelling research.

2 Methodology

This study combines a qualitative and a modelling approach to meet the research goal as shown in fig. 2.1. The qualitative research into criminal risk vs gain trade-offs is executed using a literature study and a large number of interviews. The modelling research into the impact of these trade-offs on the criminal transport configurations is executed by building a multi-objective optimisation model. Because using criminal trade-offs to identify likely smuggling transport configurations is a new approach. This chapter is used to clearly explain how the two research parts are executed to create new scientific insights.

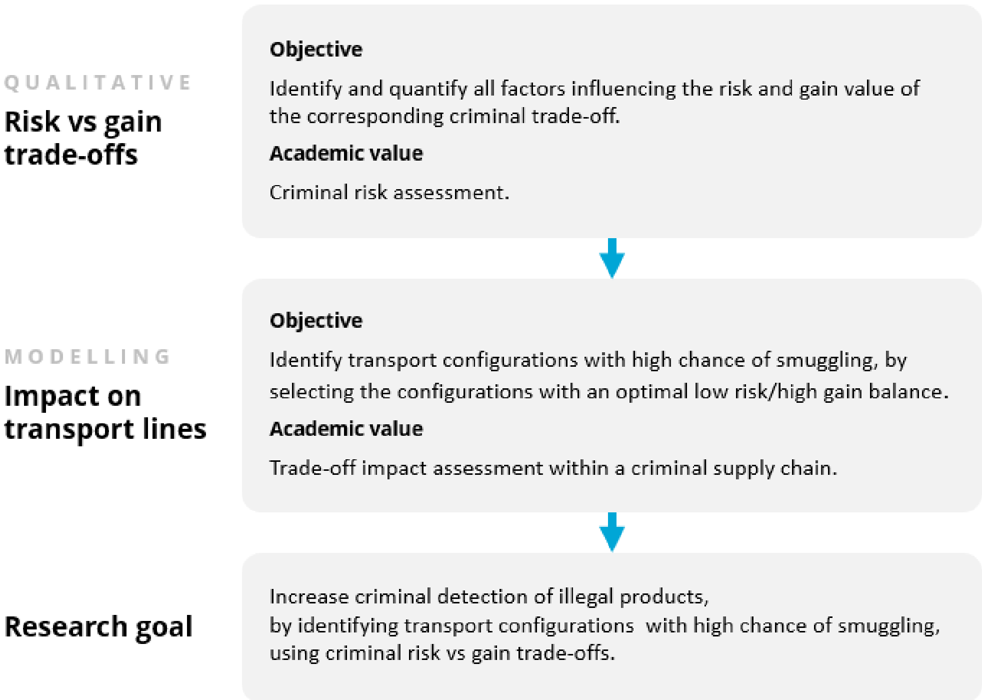

Figure 2.1: Research goal with qualitative and modelling objective

2.1 Risk vs gain trade-off

To gather information on the criminal trade-offs, I conducted interviews with 25 members of Dutch law enforcement. As described in chapter 1, the open-source information on criminal trade-offs is scarce. Besides a criminal trade-off study by Morselli, no research papers were found describing the criminal trade-off between risk and gain (Morselli et al., 2007). Although not published, all qualitative knowledge regarding the criminal risk and gain assessment already exists within different Police departments. The value of this study is to bring all the information together and create a clear overview of the factors influencing the risk vs gain trade-off. When all the trade-off information is pieced together, it can be used to determine its impact on criminal transport configurations, contributing to an increase in criminal detection.

2.1.1 Interview approach

To research the variables influencing the criminal perception of risk and gain, I conducted 25 interviews of approximately one hour long with employees of the Dutch National Police, Dutch Customs Administration, Port of Rotterdam and Europol (European Union agency for law enforcement). The majority of interviewees are employed at the Dutch Police. They occupy positions from operational coast guard employees to the highest rank strategic chief officers operating on the national level. Due to confidentiality, their names, function descriptions, and transcripts of the interviews are not be made public. The summary and evaluation of each interview isis checked by the daily thesis supervisor, who is under contract with the Dutch National Police.

Due to the exploratory nature of this study, the conducted interviews have a semi-structured character rather than a structured interview accompanied by an interview protocol. The semi-structured approach means I prepared a few questions beforehand based on the interviewee's expertise, but I tried to facilitate a free-flowing conversation during the interview.

During the interviews, I used visuals that I created representing processes within the criminal supply chain or the handling of the Police. By using graphics that visualise the complex structures of the criminal supply chain, the visual stimuli of the interviewee are triggered and used to stimulate further thoughts on the interview topic (Greenbaum, 2000). This technique of showing visuals during interviews is called a projective visual interview technique and is known to foster collaboration between the researcher and informant (Comi, Bischof, & J. Eppler, 2014). Iteratively, the visuals were improved after every interview.

2.1.2 Prime insights from interviews

Recent developments in cracking criminal communication networks by the Dutch National Police lead to prime insights for this study on criminal decision making. In 2020 the Dutch Police, in collaboration with the French, hacked the server of popular criminal communication network Encrochat (Politie, 2020b). The Police were able to read all in and outgoing communication for several weeks, without the knowledge of the criminals. Besides the live reading, 20 million previously send messages were decoded and visible to the Police forces. Jannine van den Berg, chief officer at the Dutch Police, describes it as follows: "It is as if we were sitting around the conference table with the criminals themselves" (Politie, 2020b). At the beginning of 2021, a new joint task force announced an even bigger catch: the encrypted network SKY ECC had been accessed by the Police resulting in access to 80 million criminal messages (Politie, 2021a). The latest reveal that arrived in June 2021 was of a whole new level: Europol announced a criminal encrypted network was created by Police forces and sold via undercover agents to criminals as an "uncrackable communication product" (Politie, 2021b). Since October 2019, international Police forces were able to read criminal communication in real-time. The unexpected transparency of criminal communication creates a unique insight into the minds of organised crime groups.

Around one-third of the people I interviewed is involved in projects related to the analysis of the encrypted messages. Some interviewees use the messages to analyse criminal behaviour, and others use the messages to intercepted illegal products. The millions of messages give a unique glimpse into the world of criminal decision-making. Until now, the Police and Customs had to guess how criminals organised their supply chains or assessed their risk vs gain trade-offs. The recent developments present these insights on a silver platter. These new insights provide the unique opportunity to research the influence of criminal trade-offs on the logistical movements in their supply chain.

2.2 Trade-off impact on transport

To identify the transport configurations with a high chance of smuggling, this study applies the multi-objective optimisation (MOO) method. Using the MOO method has been proven to be a suitable method for generating insight into the impact of trade-offs on a physical legitimate supply chain (Wang et al., 2011; Afshin Mansouri et al., 2012). This study researches whether the same accounts for using a MOO to research the impact of trade-offs within a criminal supply chain. This section goes into the specifics of the MOO method and the generation of solutions.

2.2.1 Multi-objective optimisation solutions

As I conclude in section 1.5 using a multi-objective optimisation (MOO) model is a suitable method for modelling trade-offs within a supply chain. The criminal risk of the trade-off needs to be minimised, and the criminal gain needs to be maximised. Multi-objective optimisation models have been widely researched for the use of a legitimate supply chain (Zhao et al., 2018; Vahid Nooraie & Parast, 2016; Rohmer et al., 2019). As far as open research goes, this study is the first application of a MOO model to a criminal supply chain, analysing the impact of criminal trade-offs.

There are two ways to solve a multi-objective optimisation: by combining the multiple-objectives into a single-objective to obtain a single solution or by simultaneously solving the two objectives and obtaining a Pareto optimal front (Gunantara, 2018). The single-objective method, which is referred to as the scalarisation method, has two disadvantages: converting two objectives with a different unit into a single-objective is currently impossible, and the insight into the trade-offs of the objectives is limited with a single solution (Schilt, 2020). Therefore, the scalarisation method is not suitable for this research.

A multi-objective optimisation that obtains a Pareto optimal front allows simultaneous optimisation of two objectives, providing the opportunity to optimise both the risk and the gain side of the trade-off. The obtained Pareto front is a set of non-dominant Pareto solutions. A non-dominant solution is a solution where objective A cannot be improved without reducing the value of objective B (Ehrgott, 2005). A MOO problem can potentially contain an infinite number of Pareto optimal solutions. The region around the Pareto solutions is referred to as the decision-makers region of interest (ROI). A visual representation of the Pareto front and the ROI is shown in fig. 2.2.

Decision-makers generally use the Pareto optimal solution set to analyse an accurate and useful representation of the possible trade-off outcomes (Fleming, Purshouse, & Lygoe, 2005). However, in this study, where trade-offs in the criminal supply chain are analysed, considering solely the Pareto optimal solutions might not be sufficient to reconstruct real-world events. A decision-maker in a legitimate supply chain will generally choose a Pareto efficient trade-off solution because there is no reason to settle for less than optimal. In reconstructing the criminal supply chain, the trade-offs are analysed under high uncertainty and with no input from the actual decision-makers (criminals). Therefore, the region of interest (ROI) should be expanded to consider optimal solutions and near-optimal solutions. The expansion of the ROI and near-optimal Pareto solutions are further elaborated upon in chapter 8.

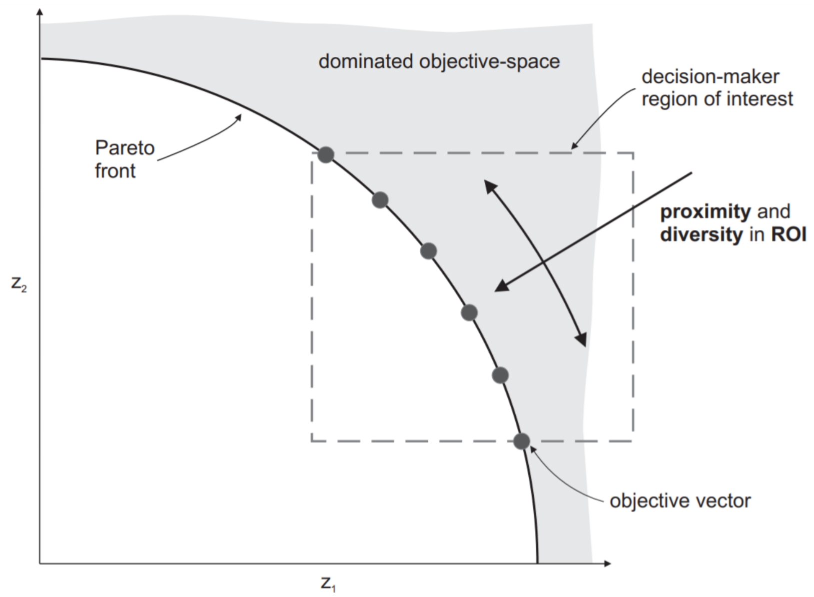

Figure 2.2: The ideal solution to a multi-objective optimisation problem (Fleming,2005)

2.2.2 Calculation of Pareto optimal

The Pareto optimal solution set of a multi-objective optimisation problem can be calculated using an evolutionary algorithm or with mathematical programming (Coello Coello, 1999). The use of evolutionary algorithms has gained increasing attention from the scientific community as it offers an attractive alternative for the computationally expensive mathematical programming method (Zitzler, Thiele, Laumanns, Fonseca, & Grunert Da Fonseca, 2003). Evolutionary algorithms are inspired by the concepts in Darwinian Evolution and use a population-based approach in which the possible solutions represent the population. Although shorter in computation time, evolutionary algorithms are complex and require a thorough understanding of their functioning and characteristics in order to apply them correctly. Therefore, an evolutionary algorithm should only be implemented if there is a sufficient computational time decrease in comparison to the mathematical programming method.

The computation time will increase as the set of possible solutions becomes larger (Margolis et al., 2018). In terms of the multi-objective optimisation build during this research, it means the size of the generated set of transport configurations will be pivotal for the choice for mathematical programming or an evolutionary algorithm. The majority of studies considering a multi-objective optimisation formulate the possible solutions by constructing constraints around the objective space (Afshin Mansouri et al., 2012; Zhao et al., 2018; Vahid Nooraie & Parast, 2016). Due to the limited set of geographical possibilities, this study generates a set of possible solutions in the form of possible transport configurations instead of constructing mathematical constraints. It can be expected that the size of the set of transport configurations is limited due to the limited scope of container transport travelling between South America and the Netherlands. The limited set of possible solutions means mathematical programming is sufficient to obtain the Pareto optimal solutions. The sufficiency of mathematical programming can be confirmed after the generation of the transport configurations, which takes place in chapter 4.

Criminal transport variables

3

The first step towards determining the impact of the risk vs gain trade-off on the transport configurations in the criminal supply chain is to create insight into the variables of the criminal transport configurations. Many studies have been published on transport within legitimate supply chains, but the research on transport in criminal supply chains is scarce. Currently, the variables influencing the criminal transport configurations are unknown, as visually demonstrated in fig. 3.1. This chapter compares the legitimate and criminal supply chain based on a literature review and interviews with the Dutch National Police. With the use of this comparison, the transport variables influencing the criminal freight transport are established.

Figure 3.1: Research assumptions and variables of criminal freight transport

This chapter first discusses the legitimate freight variables found in literature, followed by criminal freight variables obtained from interviews with the Dutch National Police. A short reflection is given on the dynamism of criminal freight transport, after which the chapter concludes by answering the first sub-question, which is presented below.

Sub-question 1
What are the main differences between legitimate and criminal freight transport?

3.1 Legitimate freight transport variables

As displayed in fig. 1.2 this research focuses on the distribution part of the supply chain ranging from the manufacturing countries until the arrival in the Netherlands. The distribution of products within a supply chain is referred to in academic literature as freight transport. In their book *Modelling Freight Transport*, Tavassy and De Jong (2013) describe four types of freight transport variables: modality, means of transport, scheduling and routing. Modality describes whether the transport goes via land, water, or air. The means of transport consists of two variables: modality type (for example, commercial or private plane) and the shipment quantity. The scheduling described the time of year/month/day the shipments sets off and arrives. The last variable type is routing, described by the geographical routing of the shipment. The five freight transport variables are displayed in fig. 3.2.

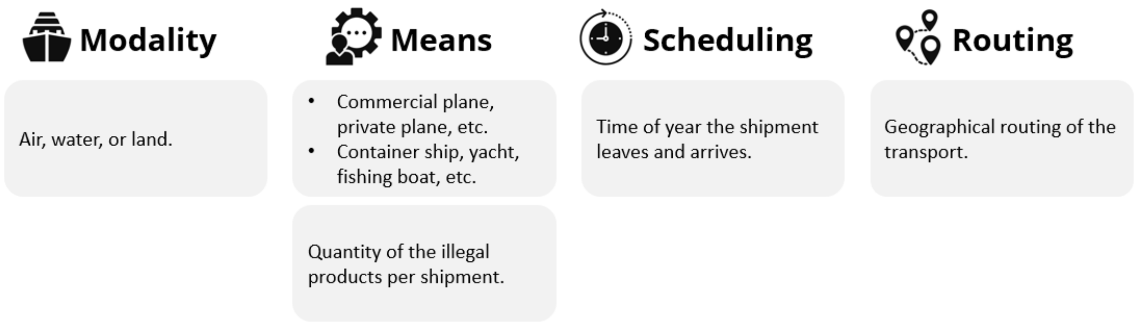

Figure 3.2: Variables of legitimate freight transport

3.2 Criminal freight transport variables

Based on interviews with transport and logistic specialists of the Dutch National Police, freight transport within a criminal supply chain is described by the same variables as legitimate freight transport with the addition of three extra variables: smuggling method, bribery, and piggybacking company. All three fall in the means of transport category as they describe a characteristic of transport independent of time and geography. The three additional freight transport variables are each discussed in this section and are visually demonstrated in fig. 3.3.

3.2.1 Smuggling method

A practice non-existent for legitimate transporters but daily business for a trafficker of illegal products is selecting a smuggling method. Every few months, new hiding techniques are discovered by port employees, Customs, and the Police. Vermeulen (2018), who is employed as a researcher at the Dutch National Police, describes four smuggling methods for transporting illegal products: cover load, concealment in structures, rip-off and drop-off. Cover load describes how legitimate products conceal illegal products. Concealment in structures means the illegal products are hidden in a double floor, wall, or hidden compartment of the vehicle. The rip-off method is less complicated and consists of packing illegal products in bags, storing them inside the vehicle and retrieving them before a possible Customs check. Lastly, drop-off describes transferring illegal products out of the vehicle before Customs (for example, into the water) to be picked up by a different group. Further specifications on the variety of options for the smuggling method are discussed in chapter 4.

3.2.2 Bribery

All interviewed Police officials agreed on the importance of bribes for the success of a criminal supply chain. Corruption also exists in legitimate supply chains, but its occurrence is not comparable to the pivotal role bribes have in the criminal supply chain. Bribery can occur in different forms and at different locations in the supply chain, making it a dynamic and influential criminal freight transport variable. More detailed information on the different types of bribery is given in chapter 4.

3.2.3 Piggybacking

A more structural difference between the criminal and legitimate supply chain is piggybacking. In its current form, the criminal supply chain would cease to exist without the concept of piggybacking, which describes the criminal misuse of legitimate supply chains and facilities to transport their illegal products. Piggybacking is used by criminals in two forms:

- **Legitimate company piggybacking -** The criminal uses the supply chain and containers of a legitimate company that imports products from South America to the Netherlands. Illegal products are hidden by criminals in the legitimate company's containers and are retrieved from the containers after arriving in the ports. Legitimate company piggybacking can occur without the knowledge of the company. For example, a truck driver can easily make an extra stop before arriving at the company's official warehouse. A second possibility is the occurrence of legitimate company piggybacking within sight of the company. For example, when criminals manage to bribe an employee. The advantage for criminals of legitimate company piggybacking is they encounter no infrastructural transport cost. A second advantage occurs when criminals manage to piggyback their products with a legitimate company known at Customs as a reliable company. When a company operates under strict rules to prevent their containers from being used by criminals, they build a clean reputation with Customs. A clean reputation means a lower chance of being selected for a smuggling check by Customs. Although the company's rules might make it harder for criminals to piggyback along, when they *do* manage to succeed, the chance Customs intercept their products is low due to the trustworthy reputation of the legitimate company.

- **Infrastructure piggybacking -** A more indirect way of piggybacking is when criminals do not use legitimate companies for transport but create their own functioning company as a cover for their illegal business. The Dutch National Police regularly dismantles suspicious fruit companies who leave their imported bananas to rot but have millions on their register due to the transported illegal goods. When a criminal creates their own criminalised company in which they have the entire supply chain in their hands, it lowers the risk during transportation. However, these criminalised companies use legitimate infrastructure such as ports, roads, and tax systems to facilitate their illegal supply chain. Instead of piggybacking directly on legitimate company transport, the criminals piggyback indirectly on the legitimate systems created for trade and transport.

Both legitimate company piggybacking and infrastructure piggybacking play an essential role in smuggling illegal products from South America to the Netherlands. Neither open literature nor employees of the Dutch National Police could give a reliable estimation of the percentage of shipments going via legitimate or criminal company piggybacking.

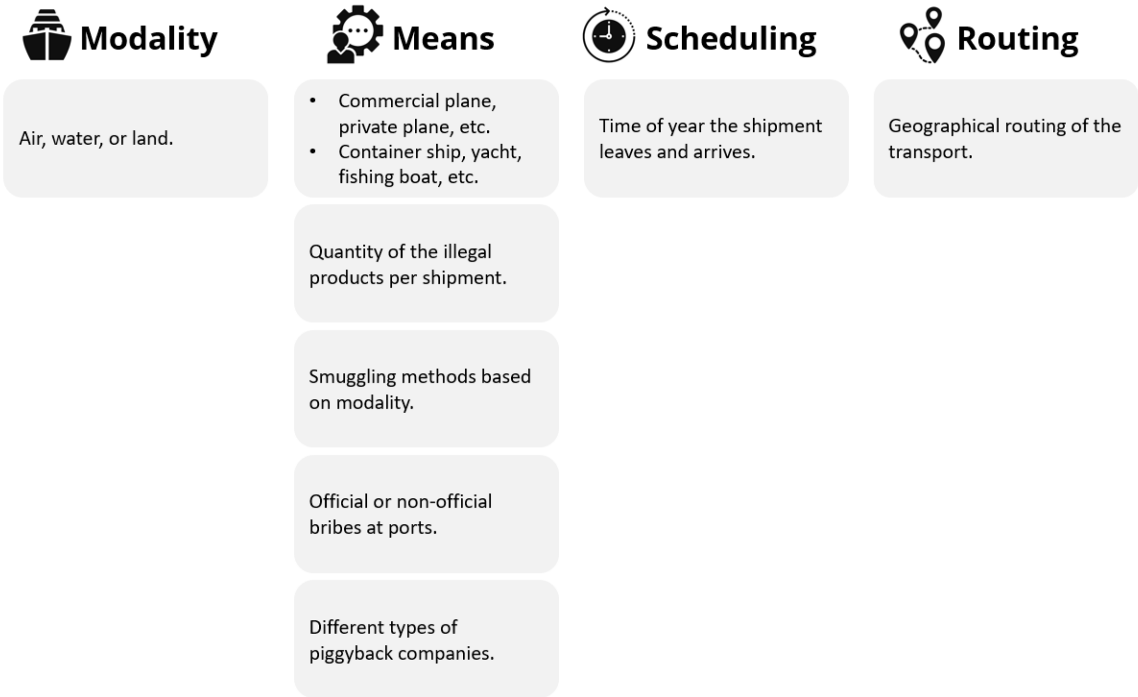

Figure 3.3: Variables of criminal freight transport

3.3 Dynamic transport configurations

Compared to the legitimate international supply chains, the criminal supply chain is highly dynamic. A legit company plans their transports weeks or even months before the shipment date. To arrange a legal shipment, the company needs to contract transport companies for in-land transport, packaging, and international transport. These sub-contracts usually last up to years to ensure a low, constant transport price. The methods, contractors, and routes of the criminal supply chain change daily. A strategic analyst in the illegal trafficking team of Rotterdam expressed their amazement at the speed with which criminals came up with a new modus operandi (MO). As soon as the current smuggling methods are discovered, new innovative methods pop up.

Besides not being stuck to contracts, criminals are highly dynamic because they have enough money to be creative. Their illegal products know an extreme turnover. A unit of illegal product can cost 80 times more in Europe than in South America (Caulkins, 2020). The most creative solution the Rotterdam analyst had encountered in their career was the creation of an illegal transport submarine built especially to transport illegal goods from South America to Europe.

3.4 Transport configuration research variables

From the eight criminal freight transport variables shown in fig. 3.3 four are selected to use as research variables: routing, smuggling method, bribery, and piggybacking company. The other variables are be assigned a value in chapter 4 and function as an assumption during this study. Not all criminal freight transport can be used as a research variable in this study due to time limitations. The four research variables are selected in conjunction with the Dutch National Police. The Police pointed out the bottlenecks in criminal supply chains are the ports where container ships arrive. A strong influence on the Customs check is the routing of the arriving ships. Therefore, *routing* was chosen as a research variable. The other three variables differ the criminal supply chain from the legitimate supply chain and are of high interest to the Police. The choice in *smuggling method*, *bribery* and *piggybacking company* provide the possibility for the criminals to act out of sight for the Police and should therefore be taken under a loop. The four selected research variables are visually demonstrated in fig. 3.4.

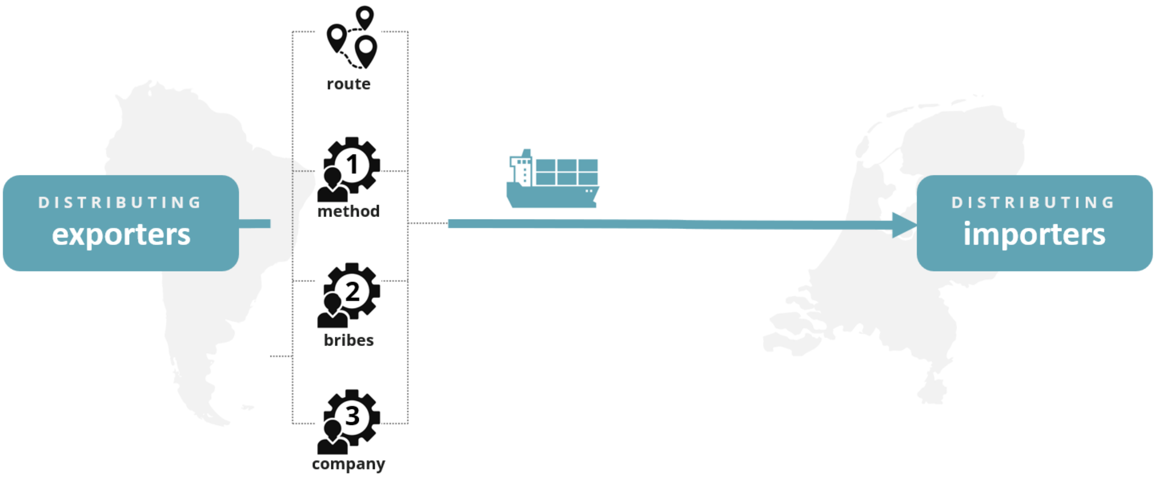

Figure 3.4: Research variables of criminal freight transport

Criminal transport configurations

4

The four criminal transport variables, routing, smuggling method, bribery, and piggybacking company, are researched in this chapter. A combination of these variables makes up a possible criminal transport configuration for smuggling illegal products from South America to the Netherlands. This chapter starts with an extensive discussion on each of the criminal transport variables, including the possible values for the variable. In doing so, this chapter answers the second sub-question, which is presented below. The chapter concludes with a remark on (non) existing patterns in criminal transport configurations.

> Sub-question 2
>
> What are the possible transport configurations exploited by criminals when smuggling illegal products into the Netherlands?

4.1 I. Transport routes

Criminals do not hesitate to use a wide range of routes to transport their illegal products from South America to the Netherlands. A 2021 report shows dozens of routes transporting illegal products to Europe via all South American countries, Central America and West Africa (McDermott et al., 2021). Criminals mainly transport their illegal products to a *transit country* before shipping their goods to Europe to minimise the chances of being picked out by Customs in Dutch ports for a security scan (Vermeulen et al., 2018; McDermott et al., 2021). A schematic overview of the known routes taken by criminals when shipping illegal products from South America is shown in fig. 4.1.

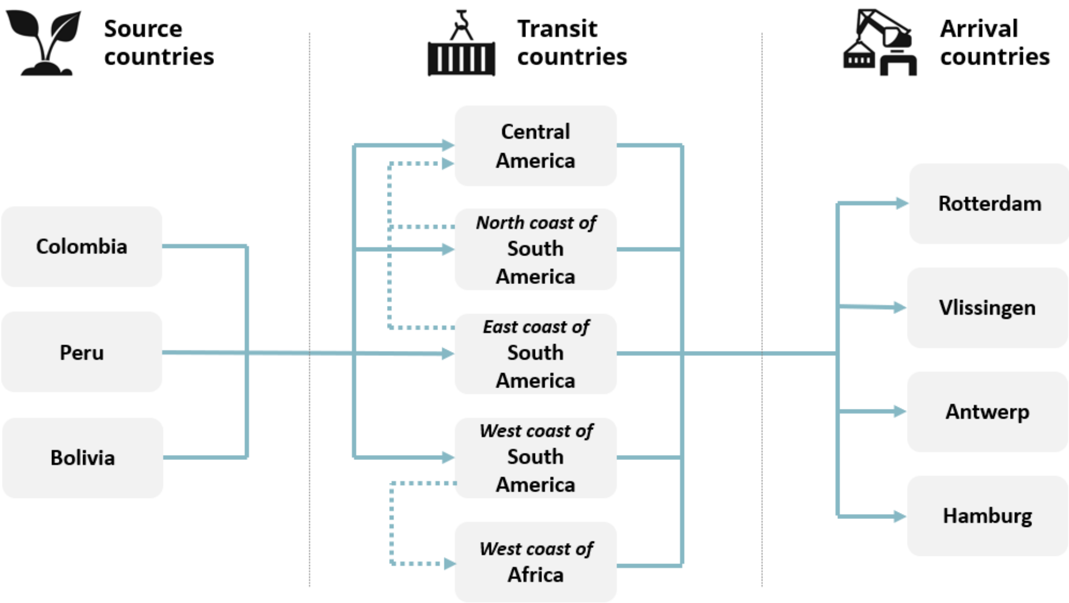

Figure 4.1: Main routes in the criminal supply chain

Due to an increase in illegal product interception in the ports of Rotterdam and Vlissingen, the Dutch National Police observe a higher flow of illegal shipments destined for the Netherlands arriving in other large European ports, after which they are transferred to the Netherlands by truck (McDermott et al., 2021). For this reason, the ports of Antwerp and Hamburg are included in fig. 4.1. After the illegal products arrive in Belgium or Germany, criminals pay little extra to have their shipments transported to warehouses in the Netherlands. A transport expert from the Dutch Police shared that criminal transport from neighbouring countries to the Netherlands over land has such a speed, it is nearly impossible to catch the shipments once they are on official EU ground.

Criminals are dynamic and flexible in the use of their routing options. The options shown in fig. 4.1 are used interchangeably, and new routes are constantly added to the set of possibilities. This study uses three source locations, 37 transit locations, and four arrival locations during the modelling research. These locations are selected based on shipments intercepted by the Police in the last five years (McDermott et al., 2021). The complete list of locations is shown in appendix D.

4.2 II. Transport smuggling methods

As shown in fig. 4.2 this research is demarcated to illegal products arriving in the port of Rotterdam, Vlissingen or Antwerp on a container ship. Although they cannot prove it due to a lack of data, the Dutch National Police interviewees expect the vast majority of illegal products to enter the Netherlands via container ships. In comparison with air transport or sailboats, it offers a container the possibility for shipping large quantities, which increases the criminal's profit. For example, to ship a thousand kilos of illegal product in a container, a criminal needs to bribe one port official. To ship the same amount in travel bags via commercial planes, the criminal would need to bribe the whole team of bag checkers. The most commonly used smuggling methods with container transport are rip-off, container construction, cover load and ship construction (Vermeulen et al., 2018). A smuggling method only recently discovered involves the chemical dissolution of illegal products in other substances (McDermott et al., 2021). The Dutch National Police got hold of multiple shipments in 2020 of illegal products which were dissolved in cardboard boxes, clothes and shampoo (Rechtspraak, 2021; Politie, 2020a). Once the illegal products arrive in the Netherlands, unique "washing stations" regenerate the illegal products to their pure form. All five smuggling methods which are used with container shipments are shortly discussed with the use of examples in appendix A.

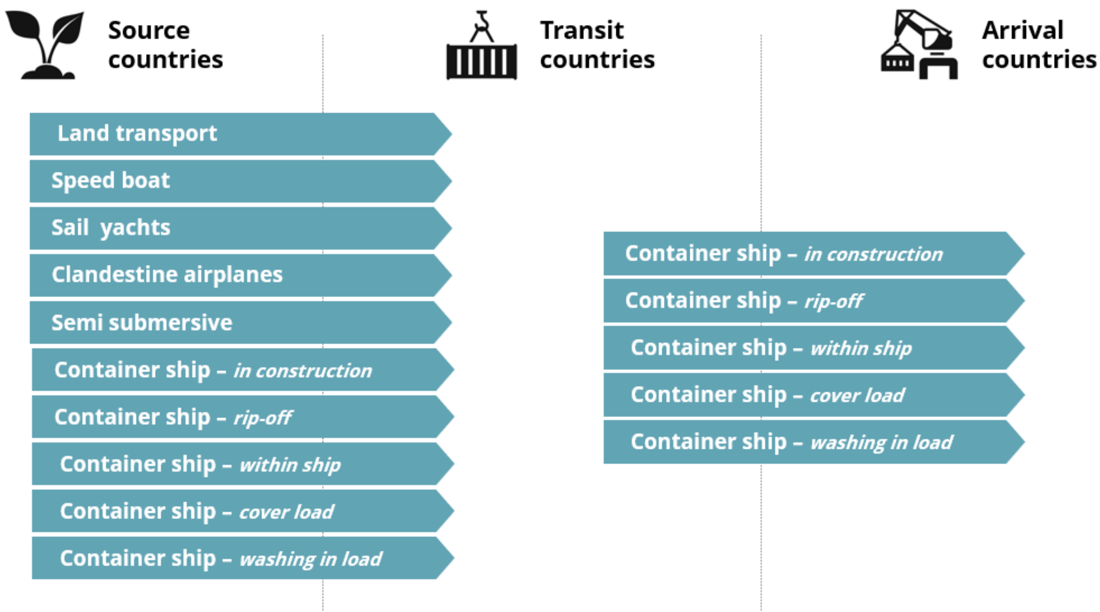

Figure 4.2: Main smuggling methods in the criminal supply chain

For the transport of illegal products from the source to the transit countries, this study uses a broader scope, as displayed in fig. 4.2. The distances between the source and the transport countries generally do not cross the ocean, which leaves a wider variety of possible smuggling methods. The 2021 research of independent journalistic platform InSight Crime describes the smuggling of illegal products within South and Central America with the use of trucks, speed boats, sail yachts, propeller planes, and submersible boats (McDermott et al., 2021). The five smuggling methods using modalities besides container ships are elaborated upon in appendix A.

4.3 III. Transport bribery

Bribery plays a vital role in the criminal supply chain and is pivotal for transporting illegal products. Criminals will try to recruit baggage handlers, cleaners, supervisors, stevedores, security guards, winch operators, truck drivers, shipping companies, port officials, and even entire ship crews (InsightCrime, 2020). In an interview with Rotterdam's Seaport Police, a senior analyst explained that the Dutch Police distinguishes bribing officials and bribing non-officials. Both types of bribery are explained below.

- **Bribery officials -** people employed by the government with an official status. For example, Police or Custom officials. Officials who are part of the transport process have a golden position to corrupt the legitimate supply chain and clear the path for criminal shipments. Bribery of officials is more common in non-western countries, where corruption is larger than in the Netherlands. An officer with experience in Latin America stated, "not one kilo of illegal product leaves Colombia without the local police's knowledge". Although less common, corruption also occurs in the Netherlands. A well-known example on the east side of the Atlantic is Dutch Customs official Gerrit Groenheide. Gerrit earned millions of euros between 2015 and 2018 by simply hitting the "no scan necessary" button for shipments arriving from Colombia (Meeus, 2019).
- **Bribery non-officials -** people involved in the transport process employed by commercial companies. Non-officials such as cleaners and winch operators are present in large numbers throughout the full legitimate supply chain. Due to the enormousness of container ports, it is easy to make a small adjustment without anyone noticing. The cost of bribes for non-officials are lower because the role of non-officials in the transport process is smaller than that of officials.

4.4 IV. Transport piggybacking company

Every criminal shipment entering the Netherlands via a container ship is transported under the name of a registered company and is therefore subject to the concept of piggybacking. Piggybacking occurs either via legal infrastructure or via a legitimate company, as explained in chapter 3. When it occurs via legal infrastructure, it means the criminal has created their own company to cover their criminal activities. When piggybacking occurs via a legitimate company, the criminal uses law-abiding citizens' legal practices. Whether it is a criminal or a legitimate company, the companies used for piggybacking can be categorised into three types:

- **Low rated fruit company -** small unknown fruit companies are an attractive option for criminals to use for their smuggling activities. Since the import of fruit from Latin America is of such a large and continuous market, new import companies pop up all year long (Meeus, 2019). The advantage of a fruit company is the proximity of banana and mango fields to the local laboratories where illegal products are manufactured. A second advantage is the relatively low price of a container filled with fruit, making it an attractive cover load for illegal products. Fruit companies without a trustworthy reputation at the Customs of the arrival country have a higher chance of being selected for a Customs check.
- **Premium fruit company -** fruit companies such as banana importer Chiquita have many rules and restrictions to prevent their supply chain from being used for smuggling. Chiquita owns and handles its containers, ships and trucks. The fewer parties involved, the smaller chance of being corrupted. Their containers also have a temperature sensor which shows when the container is opened, making it impossible for criminals to enter bags in the container without the control centre of Chiquita noticing (Balkenende, 2019). Because Chiquita is so strict on protecting their supply chain against illegal interference, they build up a reputation of a trustworthy premium company. Their premium reputation means their containers are not as often selected for a scan as regular banana import companies. A large advantage for Chiquita, because being selected for a scan means a container needs to wait for days, which messes up their supply chain schedule. However, the premium reputation makes Chiquita an even more attractive target for criminals. If criminals manage to insert their bags of illegal products in any way, the chances of their products being intercepted by Customs is very small.
- **Non-fruit company -** although the vast majority of intercepted illegal product shipments are found in containers filled with fruit, a variety of non-fruit companies has been identified on shipping illegal products. Examples of non-fruit cover loads are paper cups, wood, car parts, and plastic waste. Because the proximity of the manufacturers is less optimal than that of fruit growers, it costs the criminals more effort to arrange a non-fruit cover load. However,

once a non-fruit cover load is arranged, it offers better protection as non-fruit companies are not likely to be picked out for a Customs check.

4.5 Generated transport configurations

All physically possible configurations between the four variables were generated, leading to 839.232 unique transport configurations. The variables and assumptions used to generate the transport configurations are shown in fig. 4.3. Every transport configuration describes a unique combination of a route, smuggling method, type of bribery, and type of piggybacking company. An example of an impossible physical configuration that is left out is combining a route from Colombia to South Africa using a truck as a modality type.

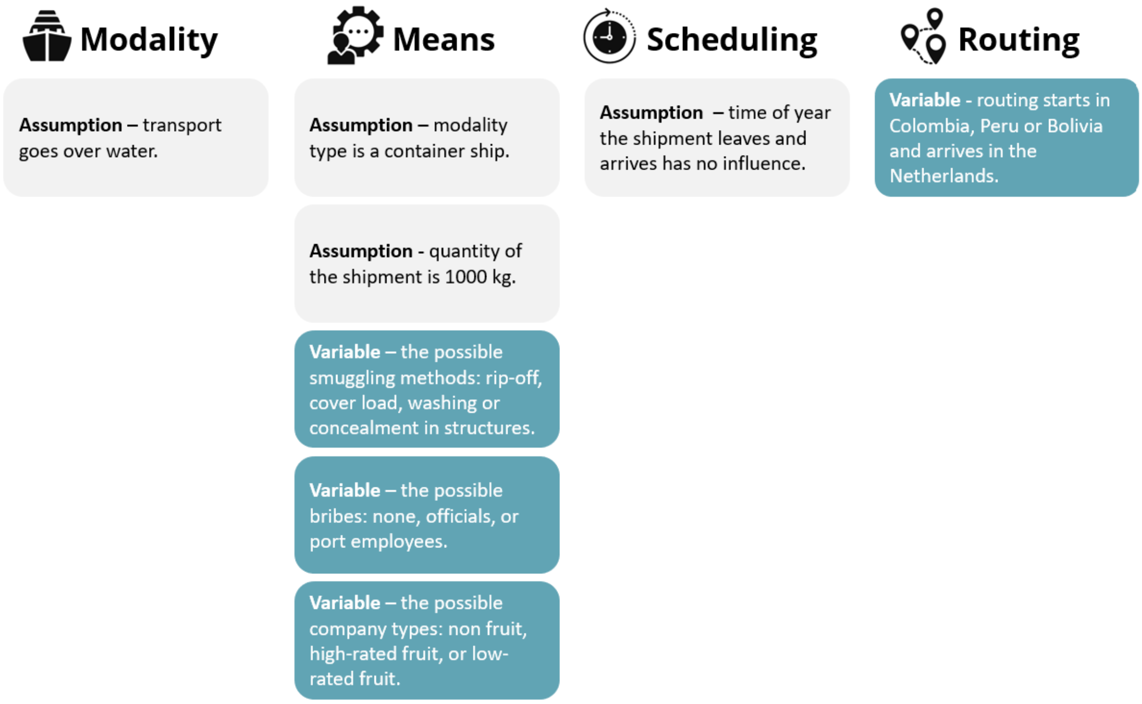

Figure 4.3: Research assumptions and variables of criminal freight transport

4.5.1 Non-existing variable patterns

Based on the content for the four transport variables presented in this chapter, I tried to look for combinations between the route, smuggling method, bribery type, and piggybacking company appearing commonly together. An example of such a pattern could be: if criminals travel via the continent of Africa, they are more likely to use the rip-off smuggle method, bribe non-officials and use a low-rated fruit company for piggybacking. Multiple Dutch Police officers were questioned on the topic, but none were aware of any existing combinations. They expect these combinations to exist but are not visible due to low criminal supply chain data.

The absence of knowledge on such transport configuration patterns is an exciting outcome of the interviews with smuggling experts within the Dutch Police. Having inside in the occurrence patterns could lead to higher efficiency in criminal detection. Research into the possible configuration patterns is included in the further research suggestions in chapter 11.

Criminal trade-offs

5

After defining the possible transport configurations in chapter 4, the next step towards modelling the impact of criminal trade-offs on their transport configurations is to define criminal risk and gain. By creating insight into how criminals value each side of the trade-off, it is possible to evaluate the transport configurations and select the most optimal ones. The value for risk and gain is constructed by identifying the variables influencing each side of the trade-off. These variables are based on interviews with the Dutch National Police and academic literature. After identifying the variables for both sides of the trade-off, the trade-off is quantified. The quantification is followed by a summation of the most critical assumptions of the quantification. In doing so, the third research question is answered, which is presented below.

Sub-question 3

How do criminals give value to risk and gain, when considering the transport configuration of their criminal supply chain?

5.1 Criminal risk value

The criminal risk during this research is defined as the likelihood of a shipment being caught by the authorities. The likelihood of being caught is in itself a binary risk: the illegal shipment gets caught (1), or it does not (0). The criminal's understanding of the likelihood of whether the Police intercept their shipment is described during this study as the *criminal risk value*. Criminal risk value is hard to quantify as it relies on subjective human emotions and experiences. Although independent variables influencing the criminal risk value can be found both in literature and conversations with the Dutch National Police, no scientifically proven formulas exist to calculate the criminal risk value (Zaitch, 2002).

Both literature and the Dutch National Police employees I interviewed agree on the crucial role of *mutual trust* between criminals when considering a value for criminal risk. Malm et al. (2017) showed how criminal networks with more missing actors perceive a higher chance of getting caught by law enforcement. Although this risk variable is identified, it is not scaled or quantified. A study by Zaitch (2002), in which 25 Colombians trafficking illegal products to Rotterdam were interviewed, describes how working with reliable partners is essential to criminal activities. According to the interviewees, it lowers risks concerning stash, cross-border transportation, and cash collection (Zaitch, 2002). Although the Oxford dictionary describes trust as the belief that somebody will not try to trick you, most people have a different emotional association with the word. In daily use, the word trust represents a warm, loving environment. In the criminal supply chain, it represents the chance someone will rat you out to the Police. Since the Dutch Police uses the word trust (NL: vertrouwen) for the criminals' commitment to one another, I copy their terminology for this thesis and leave the anthropological discussion about the deeper meaning of the word.

As the second influential variable in criminal risk, the Dutch National Police agrees on the number of *bribed (non) officials*. The more port handlers, transport company chauffeurs, and border control officials are bribed, the higher the security of the criminal transport line. The third variable influencing the risk value of a transport line is the *route risk*. An official of the Dutch National Police, working with intercepted criminal communication, described how the route risk consists of three variables: police knowledge about the route, product loading possibilities at the port of origin and extraction possibilities at the port of destination. Fourth, the criminal risk value is influenced by the *smuggling risk*. The smuggling risk is defined by the detectability of the smuggling method selected by the criminals. The detectability is twofold: the detectability of the smuggling method itself (as defined in section 4.2), and secondly, the detectability of the company used for piggybacking (as described in section 4.4).

5.1.1 Risk quantification

The variables used during the modelling phase of this study to calculate criminal risk value are displayed in table 5.1. Each included risk variable has a value ranging from 1 to 5. The indications for each risk variable per corresponding value (1 - 5) are shown in appendix B. Based on these variables, a formula is constructed, shown in eq. (B.1), to calculate the risk objective. The criminal objective is to *minimise* the risk of their transport to evade the chance of Police or Custom interception of their shipment.

A multiplication factor can be applied to the four variables due to the high uncertainty of their interconnectedness. The majority of interviewed Police officers indicated the knowledge of criminal choice behaviour was too uncertain to give value to the importance of risk variables. One highly placed Police officer who worked with smugglers for over ten years considered mutual trust and bribed (non) officials to be the variables that most influenced the criminal risk value. However, the officer was not able to state *how much more* important these two variables were in comparison with route and smuggling risk.

Important to note is the risk approach used in this study is a zero-order approach. It does not take into account the interaction between the risk variables shown in table 5.1. Therefore, using the risk formula shown in eq. (B.1) is a zero-order approach to the criminal supply chain risk, making this a linear approach to the problem.

$$R(i) = \alpha * MT(i) + \beta * BO(i) + \gamma * RR(i) + \delta * SR(i) \tag{5.1}$$

Variable	Notation	Range	Motivation
Mutual trust	MT	$1-5$	When a criminal selects a sub contractor who is willing to make an extra stop to dump the illegal shipment load, they have to trust their contacts on verbal promises.
Bribed (non) officials	BO	$1-5$	The more port handlers, transport company chauffeurs and border control officials are bribed, the higher the security of the criminal transport line.
Route risk	RR	$1-5$	Route risk consists of three variables: police knowledge about the route, product loading possibilities at the port of origin and extraction possibilities at the port of destination.
Smuggling risk	SR	$1-5$	The detectability of the smuggling risk is twofold: the detectability of the smuggling method (as defined in section 4.2) and the detectability of the company used for piggybacking
Transport configuration	i	categorical	Variable describing the specific combination of routes and smuggling methods making up a transport configuration ranging from South-America to Northwestern Europe.

Table 5.1: Quantification variables criminal risk

5.1.2 Risk assumptions

Another variable influencing the risk value is the shipment time. Interception reports of the Dutch National Police show an increase in illegal product trafficking during the Dutch winter and summer holidays. Even with a lower staff on duty, Dutch Customs interceptions of illegal products peak during the holiday. This increase in illegal activity shows transport criminals are aware of the staffing shortage during the holidays and make good use of it. The phenomenon of increased criminal activity in the ports can be compared to the increase in home invasions when people are on holiday. Criminals are aware of the absence of staff in ports during the holidays, just like they are aware of absence in family homes. Criminals use this absence to their advantage. Time-related risk is not included in the risk formula. Modelling time-sensitive shipments would require a level of modelling algorithms I can not achieve during this graduation research. The absence of time-related risk is stated as a further research possibility in chapter 11. According to the interviewed Police officials, the time-related risk has the most negligible influence on the risk value of the 4 explained risk variables in section 5.1. Therefore, I believe this study can provide additional insights, despite the absence of time risk.

Not yet taken into account in the risk formula is the criminal awareness of local sentencing. One interviewed officer ensured criminals are very aware in which country they take specific risks. A country like the Netherlands is known to hand out short sentences and house its criminals in comfortable prisons. Criminals are more afraid to be picked up in South America or be extradited to the USA.

5.2 Criminal gain value

Gain of the criminal supply chain is defined for this research in terms of financial gain. Research shows the criminal organisations which transport illegal products are mainly driven by economic incentives (Kenney, 2007; Morselli et al., 2007; Aziani, Berlusconi, & Giommoni, 2021). Profit is equal to the subtraction of cost from the product price. This section elaborates on the definition and calculation of the cost and product price, making up the criminal gain value.

The further the illegal products are transported along the supply chain, the higher the product prices. The price of a product is based on its market value, which has been surprisingly stable for illegal products. The market value of illegal products increases with the geographical distance the product has travelled. The more complex the geographical transport, the higher the price increases. The illegal products in Colombia cost 2.000 euros a kilo, 4.000 euros a kilo in Suriname and are sold for a wholesale price of around 30.000 euros a kilo in the Netherlands (Caulkins, 2020). After storage, the product is cut up and sold on the streets for a price ranging from 50.000 to 80.000 euros a kilo (50-80 euros a gram) (Santvoord, 2020).

The cost of transporting illegal products along the supply chain depends on the decisions taken by the criminals. The first decision the OCG takes once they own the illegal products is to either directly sell the product (in which transport costs are zero) or transport the product further along the supply chain and pay transport costs. If an OCG decides to transport the product, they select a route and a smuggling method, which both come at a price. In a financial crime script, Santvoord (2020) calculated an estimated price per smuggling method. These prices are used in chapter 6 to calculate the transport cost variable in the criminal gain value. An overview of the transport prices is included in appendix C.

5.2.1 Gain quantification

All variables influencing criminal gain are displayed in table 5.2. Based on these variables, a formula is constructed, shown in eq. (5.2), to calculate the gain objective. From the equation, it can be concluded that the further a criminal transports the illegal products, the more money they make. Purely from the gain perspective, the criminals should deliver the products from production in South America until the hands of the European users.

$$G(i) = MV_t(i) - TC_t(i) \tag{5.2}$$

Variable	Notation	Range	Motivation
Market value	MV_t	$\$2.000 - \$80.000$	The amount of euros per kilo of illegal product a criminal receives for selling the product at that geographical spot. For the market value variable the wholesale price of the product is used. The detailed data is shown in appendix C.
Transport cost	TC_t	$\$1.500 - \$1.500.000$	Transport cost from origin location to destination location. Transport cost include bribes, starting a malicious company, etc. For full explanation see appendix C.
Transport configuration	i	categorical	Variable describing the specific combination of routes and smuggling methods making up a transport configuration ranging from South-America to Northwestern Europe.

Table 5.2: Quantification variables criminal gain

5.2.2 Gain assumptions

The most significant assumption made in the gain formula is the transport costs. The exact prices for the transport cost have a high data uncertainty. In a conversation with a Dutch Police officer who has overseas experience with criminal supply chains, it was explained that the Police is ultimately touching in the dark when it comes to the prices criminals pay for the smuggling method of chemically washing their illegal products. Other costs, such as the bribe paid to port officials, differ strongly per case but can be roughly estimated based on closed trafficking cases. Since washing in the illegal products is a pivotal part of the criminal supply chain, the exact costs are used as bribing high officials: $350.000 per bribe in origin countries, $1.000.000 per bribe in arrival countries.

The second assumption regards the wholesale prices per kilo of illegal products. The input data for the wholesale prices of this study comes from the United Nations Office on Drugs and Crime (UNODC) (Caulkins, 2020). All countries are asked yearly to submit the wholesale prices of illegal products in their country. As presented in appendix C, the last submission year of wholesale prices strongly differs per country. The assumption is made that the last submitted wholesale price still holds until today.

Model formulation: impact of trade-offs

6

After generating the criminal transport configurations in chapter 4 and identifying the variables influencing the criminal risk vs gain trade-off in chapter 5, the next step towards finding configurations likely to be used for smuggling is to apply the quantified risk vs gain trade-off. When the risk and gain value is determined for each transport configuration, the configurations can be selected with the most optimal balance between low risk and high gain. A multi-objective optimisation (MOO) model was built to select the most optimal transport configurations. With the help of the MOO model, the fourth sub-question is answered, which is presented below.

Sub-question 4

How can the impact of the risk vs gain trade-off on the transport configurations within the criminal supply chain be modelled using a multi-objective optimisation?

The majority of multi-objective optimisation studies formulate their model in three steps: assumptions, objectives, and constraints (Afshin Mansouri et al., 2012; Zhao et al., 2018; Vahid Nooraie & Parast, 2016). The approach this research takes is slightly different and demonstrated visually in fig. 6.1. In the first phase the transport configurations are generated, which has been done in chapter 3 and chapter 4. Generally, the space in which possible solutions can take place is described by mathematical constraints. Due to the limited set of possible geographical routes, this study takes a different approach and does not describe constraints in formula form but generates a list of 839.232 transport configurations based on four transport variables and possible physical routes.

The second phase shown in fig. 6.1 describes how formulas for the risk and gain objective created in chapter 5 are applied. This phase is further elaborated upon in section 6.1. The final phase consists of applying the solution algorithm to identify the transport configurations with the optimal balance between the lowest risk and highest gain value—the details of the used algorithm are discussed in section 6.2. After discussing the model objectives and the solution algorithm, this chapter concludes with a discussion of the most important assumptions of the MOO model.

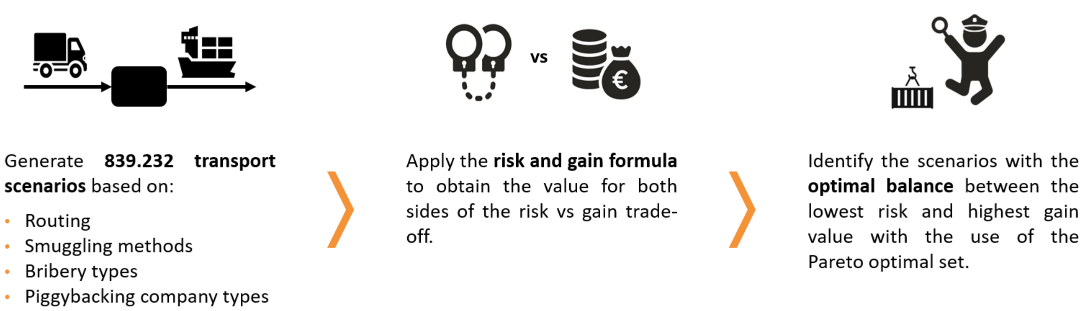

Figure 6.1: Model structure in 3 steps

6.1 Model objectives

The two objectives used in the MOO model are minimising risk and optimising gain for criminals within the international criminal supply chain. The factors influencing risk and gain have been identified in chapter 5. The objective formula for risk and gain are shown in eq. (6.3) and eq. (6.2) respectively. The risk formula calculates the risk value over transport configuration i by adding up the mutual trust (MT) between criminals, the bribed non-officials (BO), the route risk (RR), and the smuggling method risk (SR). All four factors are scaled between 1 and 5. The corresponding description for all values is given in fig. B.1. The gain formula calculates the illicit profit by subtracting the transport cost (TC) from the transport configuration from the market value of the shipment (MV).

$$R(i) = \alpha * MT(i) + \beta * BO(i) + \gamma * RR(i) + \delta * SR(i) \tag{6.1}$$

$$G(i) = MVt(i) - TCt(i) \tag{6.2}$$

6.2 Model Pareto algorithm

As described in chapter 2 the use of mathematical programming to find the Pareto front is sufficient if the set of solutions is limited. In chapter 4 the size of the set of transport configurations was determined to be equal to 839.232. According to the documentation of the Python *Paretoset* package, which uses mathematical programming to calculate the Pareto front, the computation time stays within seconds for a possible solution set up to a few million possibilities. Since the size of the transport configurations set falls within that range, the use of mathematical programming is assumed to be a suitable calculation method for the Pareto front.

The programming package *Paretoset* works based on an iteration over the possible solutions during which it selects dominant and non-dominant solutions. The algorithm returns a boolean mask indicating the Pareto set of numerical data. A boolean mask consists of a list of *True* and *False* values with the same length of the possible solution set. The Pareto solutions are indicated with the *True* label. The algorithm finds the index of the Pareto values and returns the risk and gain values of the Pareto optimal solutions.

Although using a mathematical programming approach to calculate the Pareto front is currently sufficient for the formulation of the multi-objective optimisation model, this might change when the model is further developed and the size of the possible solution set model complexity increases. When the computation time increases significantly, it might be necessary to implement an evolutionary algorithm to calculate the Pareto front. A wide range of evolutionary algorithms is suitable for use in a multi-objective optimisation (Zitzler et al., 2003). Each algorithm has its performance metrics and characterise, wherefore it is essential to select an evolutionary algorithm suitable for a MOO model describing a criminal supply chain.

6.3 Model assumptions

The assumptions made during the creation of the multi-objective optimisation model can be divided into two categories: assumptions for data scarcity reasons, assumptions with the goal of model simplification. This section presents ten assumptions divided into two categories.

6.3.1 Model simplifications

The research demarcations described in section 1.4 are used as a starting point for this section. This section continues by elaborating on the choices made to simplify the multi-objective optimisation model. Simplification of the model allows for increased model understanding (Eberlein, 1989). The model assumptions for simplification reasons are listed below.

- **Model linearity -** the multi-objective model considers one shipment of 1.000 kg being transported from South America to the Netherlands. However, most criminals use risk distribution and do not choose one transport configuration to send their full stash. They divide their illegal products over different shipments and test which transport configurations are the safest and cheapest for future shipments. The linear model does not take risk distribution into account.
- **Unilateral shipments -** the model assumes one organised crime group (OCG) is assessing the risk and gain of their shipment. In reality, most shipments are combination shipments prepared for multiple customers in the Netherlands. Alternatively, OCGs make a deal that illegal products can join the shipment in trade for illegal

products of a different type that are not available in South America. This aspect of multilateral shipments is not taken into account.

- **Farm lab production -** the assumption is made that the illegal products do no longer consist of raw materials but are fully produced when they are shipped to the Netherlands. A criminal information analyst of the National Police shared that the bulk of the shipments contains the illegal end product. However, they see an increase in the shipment of raw materials due to growing production expertise in the Netherlands.
- **Absolute handover -** an essential assumption of this study is the absolute handover of illegal products. The transfer of ownership to a new OCG does not mean the old OCG completely takes their hands of the product. Many Police cases describe how Colombians still keep an eye on delivering the product in the Netherlands, even though they sold it two the Mexicans at the beginning of the supply chain.
- **End to end transportation -** the model only considers the risk vs gain trade-off of a shipment ranging from the farm labs in South America to the arrival in the Netherlands. A different approach could have been to look at risk vs gain trade-offs of partial shipments. For instance, to analyse trade-offs from Colombia to Central America.

6.3.2 Data scarcity

As described in section 1.1, analysing criminal supply chains comes hand-in-hand with the challenge of data scarcity. Every shipment of illegal products intercepted by the Customs or Police is posted online. Although this is mainly for preventing drug wars between criminals who might blame each other for missing shipments, it gives the public an overview of how much is caught in a year. The first question that arises in news articles: how much of the shipments is *not* intercepted? (de Jonge & Haan, 2020; de Lange & Lalkens, 2020). Most researchers argue that the percentage of undetected shipments is too uncertain to prove scientifically. A rough estimation based on open literature research and expert interviews is between 5 - 20% (McDermott et al., 2021; Caulkins, 2020). It can be concluded that this research on the impact of criminal trade-offs on the criminal supply chain is based on just a fraction of the actual data. Therefore, it is essential to note the data scarcity assumptions listed below.

- **Transport costs -** the transport costs used to calculate the criminal gain are retrieved from or estimated based on information from Police interviews, trustworthy crime journalists, and scientific researches. However, the uncertainty of the transport costs is high, as explained in section 5.2.2. The available data strongly differs per criminal case, and many exact costs are missing. The assumption of transport cost is an important one as the gain value directly influences the outcome of the model.
- **10 smuggling methods towards container ports -** as a demarcation of this study, only the criminal supply chain that arrives at the container ports of Northwestern Europe is taken into account. Before the illegal products are put on the container ship heading for Europe, ten different smuggling methods are considered. These ten methods are all which are currently publicly known (McDermott et al., 2021). Undoubtedly more will exist, but the assumption is made that these 10 are a representation of the real world.
- **3 source countries -** currently, only three countries are known as the source of illegal products (Caulkins, 2020). It is an assumption that it only originates from Colombia, Peru, and Bolivia.
- **36 transit ports -** physically, the illegal products could be shipped from every port in the world. For this model, the 36 most commonly used ports are selected (McDermott et al., 2021; Caulkins, 2020).
- **Current Police data -** due to the confidentiality of the data on currently active criminal organisations and their shipments, it is not possible for this research to use the latest data in the MOO model. After the Dutch Police cases are closed, most of their data on criminal shipments are made public and shared with organisations like the UN and EU. This outdated Police data is used for this research in combination with information shared by Police employees during the interviews. The assumption is that combining these two data sources is a sufficient representation of the criminal supply chain, even when the current Police data on active cases is missing.

6.4 Model validation

To validate the multi-objective optimisation model with the available data on the real-world criminal supply chain, I tested different combinations of multiplication factors for the risk variables shown in eq. (6.3): $\alpha, \beta, \gamma, \delta$. After applying a combination of multiplication factors, I broadly inspected the routes and smuggling methods in the top left corner of a scatter plot showing all risk (x-axis) and gain (y-axis) values. The top left corner contains the trade-off configurations with the optimal risk vs gain balance. I calibrated the model until the combination of multiplication factors led to the occurrence of trade-off configurations in the top left corner of the scatter plot comparable to the real-world configurations.

Important to note is the influence of high data uncertainty on the calibration of the multi-objective optimisation model. As discussed in section 6.3 the estimation of data I base the model on is 5-20% of the real-world data. Given the unchangeable situation of the high uncertainty, the multiplication factors leading to trade-off configurations with a low risk and high gain comparable to the available data are:

- $\alpha = 1$
- $\beta = 2$
- $\gamma = 3$
- $\delta = 1$

Which leads to the following completion of the risk formula:

$$R(i) = MT(i) + 2 * BO(i) + 3 * RR(i) + SR(i) \tag{6.3}$$

Model results: optimal transport configurations

7

Subsequently to the formulation and the validation of the MOO model in chapter 6 the model results are discussed in this chapter. The chapter will start with a presentation of the Pareto optimal results, followed by the argumentation to enlarge the solution set with near-optimal solutions. The chapter concludes with research into the characteristics of the solution set.

7.1 Pareto optimal solutions

As described in section 6.2 the Pareto optimal solutions of the MOO model are created with the use of a mathematical optimisation algorithm. After the value for risk and gain is determined of all transport configurations with the use of the objective formulas, the Pareto algorithm is applied with the help of the Python software package *Paretoset*. The solution algorithm generates a set of 14 Pareto optimal solutions. The risk vs gain value for all possible transport configurations are indicated in green in fig. 7.1, the Pareto solutions are indicated in orange.

As can be observed in fig. 7.1, the transport configurations form vertical lines. This is caused by the fact the axis of the risk value is of a much smaller range than the gain value axis. A limited amount of risk values can be applied to the roughly 800.000 trade-off configurations. The final risk value is the average of the risk values calculated per transit port. For that reason, the risk values shown in fig. 7.1 lie in between the integers. Even though the final value is an average of the four risk variables, the possibilities are still minimal. The value possibilities are not limited for the value of gain, which depends on the smuggling method and routing. Though the gain value is discrete, it shows continuous behaviour due to the large number of possibilities distributed over a wide interval.

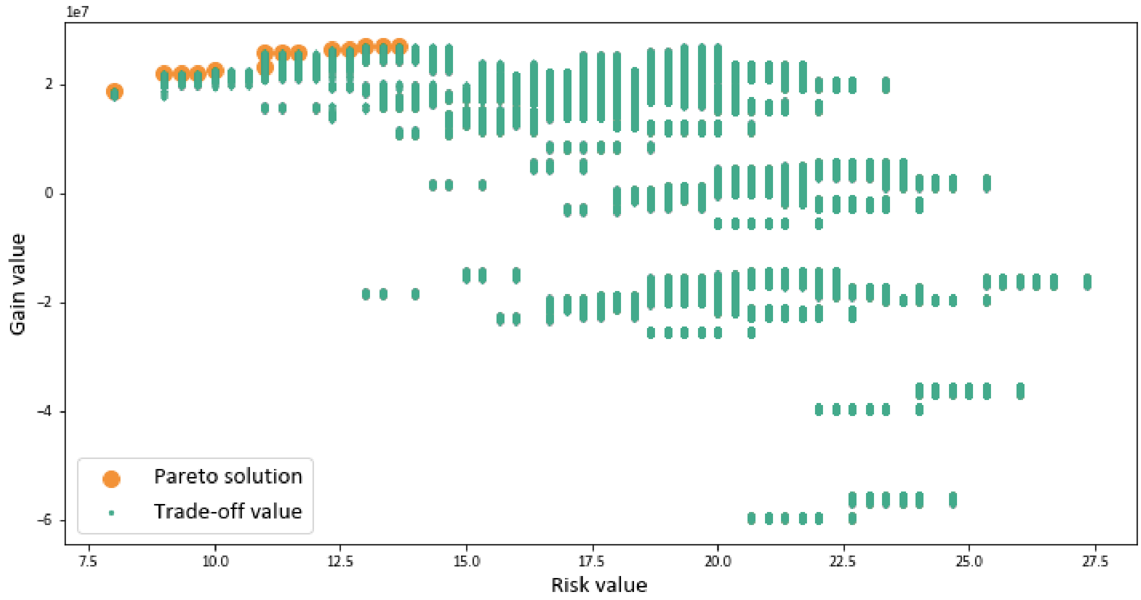

Figure 7.1: Pareto front of full route optimisation

To analyse the characteristics of the Pareto solutions, they are extracted from the data set. The transport configuration and trade-off specifications of the 14 Pareto solutions are shown in table 7.1. The routes in the Pareto set are concise, but the smuggling method, bribes, and smuggling risk differ per the Pareto solution. The conciseness of the routes indicates the route has a more significant influence on the Pareto optimal solutions than the smuggling method, bribes of smuggling risk. The importance of routing on the choice of transport configuration is in line with the observation made about the importance of route risk in section 6.4.

Risk value	Gain value	Route	Smuggling method	Bribes	Piggybacking
12.3	26,4 mill	Colombia - Paramaribo - Rotterdam	Truck - Container construction	4	2
12.7	26,4 mill	Colombia - Paramaribo - Rotterdam	Truck - Container construction	4	3
13	27,1 mill	Colombia - Paramaribo - Rotterdam	Truck - Container construction	5	2
13.3	27,1 mill	Colombia - Paramaribo - Rotterdam	Truck - Container construction	5	3
13.7	27,1 mill	Colombia - Paramaribo - Rotterdam	Truck - Container construction	5	4
11	25,8 mill	Colombia - Paramaribo - Rotterdam	Truck - Cover load	2	2
11.3	25,8 mill	Colombia - Paramaribo - Rotterdam	Truck - Cover load	2	3
11.7	25,8 mill	Colombia - Paramaribo - Rotterdam	Truck - Cover load	2	4
10.0	22,6 mill	Colombia - Paramaribo - Rotterdam	Truck - Washing	1	1
11.0	23,2 mill	Colombia - Paramaribo - Rotterdam	Submersible - Container construct	5	2
9.0	21,9 mill	Colombia - Paramaribo - Rotterdam	Submersible - Cover load	2	2
9.3	21,9 mill	Colombia - Paramaribo - Rotterdam	Submersible - Cover load	2	3
9.7	22,0 mill	Colombia - Paramaribo - Rotterdam	Submersible - Cover load	2	4
8.0	18,8 mill	Colombia - Paramaribo - Rotterdam	Submersible - Washing	1	1

Table 7.1: Pareto solutions

7.2 Near optimal solutions

The Pareto solutions listed in table 7.1 are not sufficient enough for the purpose of the MOO: being an accurate and useful representation of the possible trade-off outcomes. According to Fleming et al. (2005) an accurate and useful near-optimal solution set must comply with the following aspects: proximity, diversity, and pertinency. Each of these aspects is elaborated upon below, focusing on what each aspect means for the criminal risk vs gain near-optimal solution set.

- **Proximity -** the near-optimal set should contain solutions that are close to the true Pareto front. For the case of the risk vs gain trade-off, this means the near-optimal solution set should be formed around the orange dots in fig. 7.1 representing the Pareto solutions.
- **Diversity -** the near-optimal set should contain a good distribution of solutions that show an extent of diversity. A practical example of the usefulness of a diverse solution set is the functioning of the Google Maps route search. If you ask Google Maps to bring you from point A to point B, Google gives you a few different options. These options are relatively diverse: usage of a highway, whether the route includes a toll road or not, and so on. However, the most optimal routes might not be as diverse as the solutions presented to you (li, Aamir Cheema, Taniar, & Indrawan-Santiago, 2018). The most optimal routes are probably very similar; they differ, for instance, only whether the road goes left or right around the church in the village of point B. The diversity of the options presented by Google is the same diversity a criminal considers while choosing transport configurations. Not just a small detail at the end of the route, but a completely different option. Therefore, it is important to have a diverse near-optimal solution set for the risk vs gain trade-off.
- **Pertinency -** the near-optimal set should contain only solutions which are in the decision-makers region of interest. In the case of the gain value, the gain part of the trade-off must always be larger than zero to be of interest to the criminal. When there is no profit for a smuggler's transport configuration, the smuggler will not be interested.

The aspect of proximity is satisfied when the enlarged solution set fits around the Pareto optimal solutions and is kept as approximate as possible to the orange dots representing the Pareto solutions shown in fig. 7.1. The aspect of diversity within the solution set can be fulfilled when complete different solutions are included, which contain different routes, smuggling methods, bribery types, and piggybacking company types. This diversity is currently is not represented in the solution set shown in table 7.1: the origin, transit, and arrival location of all fourteen solutions are similar. The pertinency aspect can be satisfied when the gain value is at least above zero and the risk value is as low as possible.

Besides the fact that the solution set should be accurate and useful for the criminal, another argument to include a more extensive set of near-optimal solutions in the solution set is the factor of criminal behaviour. Solely considering the Pareto solutions also assumes the criminal trade-off decisions are purely rational. However, the criminal makes decisions based on other inputs than rationality, such as emotionality, self-control, social ties, and stress (Van Gelder & De Vries, 2012; Aziani et al., 2021). Because criminals are not entirely rational, the criminal choices in transport configurations go beyond the rational optimum of the Pareto solutions. Therefore, a more reliable approach is to select a broader range of possibilities and inspect the correlations within this set.

7.2.1 Enlarged solution set

Based on the proximity, diversity, and pertinency, the enlarged solution set, including near-optimal solutions, ranges from a gain minimum of zero dollars until the maximum possible gain value. The chosen risk range of the enlarged solution set ranges from the lowest possible risk value until the maximum risk value of the Pareto solution set. The Pareto set and the expanded solution set are shown in the risk vs gain graph in fig. 7.2. The enlarged solution set consists of 2,73% of the entire data set and contains 22.884 trade-off configurations. In other words, the best 2,73% of all possible transport configurations with the optimal risk vs gain balance are selected. From now on, this optimal 2,73% of the data is referred to as the *solution set*. The solution set contains the transport configurations that are likely to be selected by criminals to smuggle their illegal products because of the low risk combined with high gain.

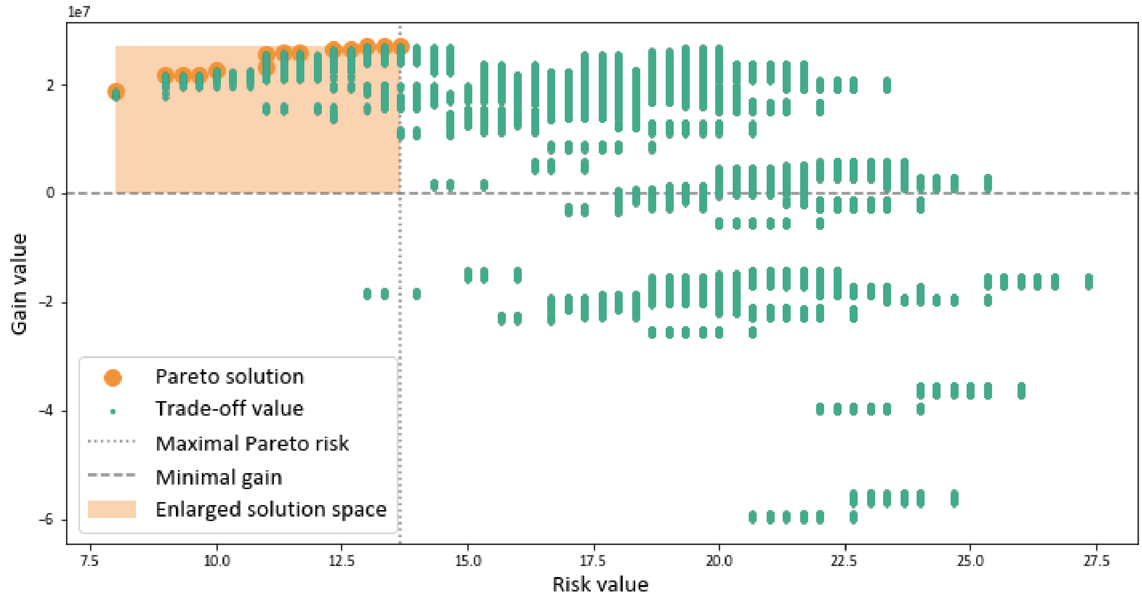

Figure 7.2: Enlarged solution space

7.3 Characterisations in solution set

This section analyses the selected solution set, indicated with orange in fig. 7.2, to find characterisations between the solutions the Dutch National Police and Customs can use to design impactful interventions. The characterisations of the solution set are compared with the characterisations of the entire data set to identify which transport configurations are lucrative for criminals. The characterisations are compared based on: number of transits in the route, usage of smuggling methods, and the frequency of port occurrence.

7.3.1 Transit distribution

The distribution of the data set over the three options for route-transits is shown in fig. 7.3. Zero transit means the illegal products are shipped directly from one of the source countries: Colombia, Peru or Bolivia. One transit represents the routes passing through one other country before arriving in one of the ports in the Northwest of Europe. Two transits entail the transfer of illegal products in two ports before arriving in Europe. The difference between the entire data set (green) and the solution space (orange) shows criminals are inclined to take 1-stop routes over 0- or 2-stop routes.

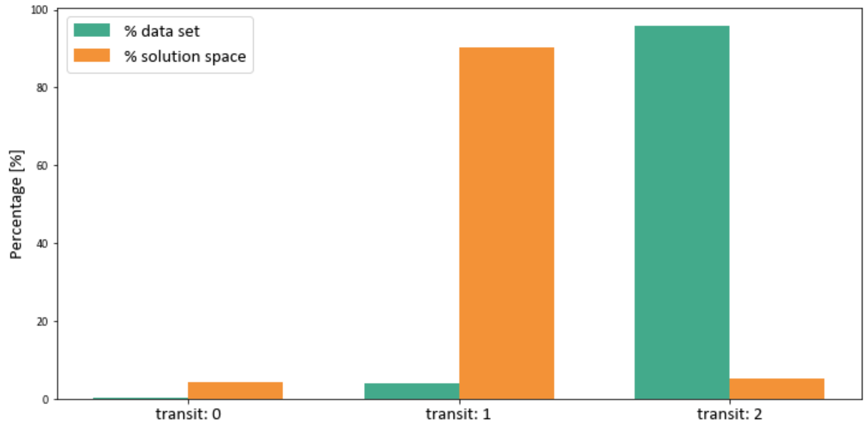

Figure 7.3: Distribution of number of transits in transport configurations

7.3.2 Smuggling method distribution

As displayed in fig. 7.4 the submersible, container construction, and cover load method are well represented within the solution set. Meaning even though there are more possible transport configurations with a rip-off or ship construction smuggling method, the optimal high gain/ low-risk routes use mostly indirect piggybacking methods such as container constructions or the use of cover loads.

Interestingly the percentage of most the submersible, container, and cover load smuggling methods in fig. 7.4 show a step from 10% to 20% when the solution set is compared to the entire data set. This jump in percentage cannot be explained by a twofold increase of either the risk value or gain value for the smuggling method. Therefore, the jump in percentage is most likely due to the linearity of the model. Meaning changes in transport configurations do not occur gradually but with significant steps. Every criminal shipment in the MOO model consists of 1.000 kg. In real life, these shipments also occur in smaller proportions, which probably results in smaller jumps than the one that can be observed in fig. 7.4.

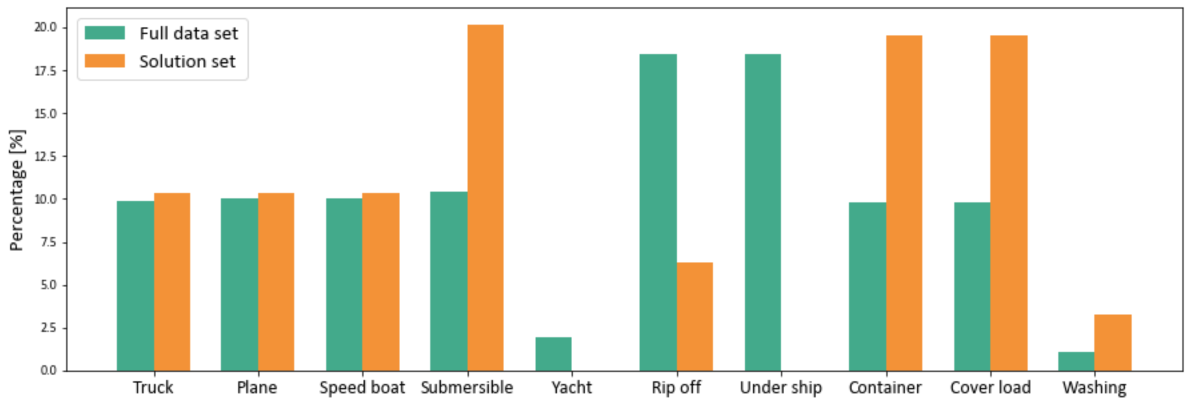

Figure 7.4: Distribution of smuggling method use in transport configurations

7.3.3 Routing distribution

The distribution of origin ports used for criminal shipments to the Netherlands is shown for the full data set in fig. 7.5 and for the solution set in fig. 7.6. The route distribution of the full data set shows a high occurrence of routes via Central America and Africa because these routes contain a second transit. If a shipment arrives from a second transit location, the number of possible routes the illegal products have travelled is longer. In the distribution of origin ports of the solution set in fig. 7.6 the top countries are the ones who do *not* include a second transit. The top country is Brazil, which can be traced back to Brazil having the most container ports, creating the most possibilities for shipment routes.

From the distribution graphs of smuggling methods and origin ports, it can be observed that the complete set of transport configurations and the solution shown a more substantial distinction for the routing variable than for the smuggling method variable. A clear shift between the complete data set and the solution set can be observed in the bar graph representing the smuggling methods in fig. 7.4. However, this shift is not as fundamental as the shift between the two Sankey graphs visualising the shipment's origin in fig. 7.5 and fig. 7.6. The fact that the change in origin port is more significant than the change of smuggling method considering the solution set part of the data over the complete data set indicates the routing is pivotal for criminals in selecting a transport configuration. The route of the transport configuration has more impact on their final choice than the smuggling method. In other words, the route has a more extensive influence on the optimal transport configuration than the smuggling method.

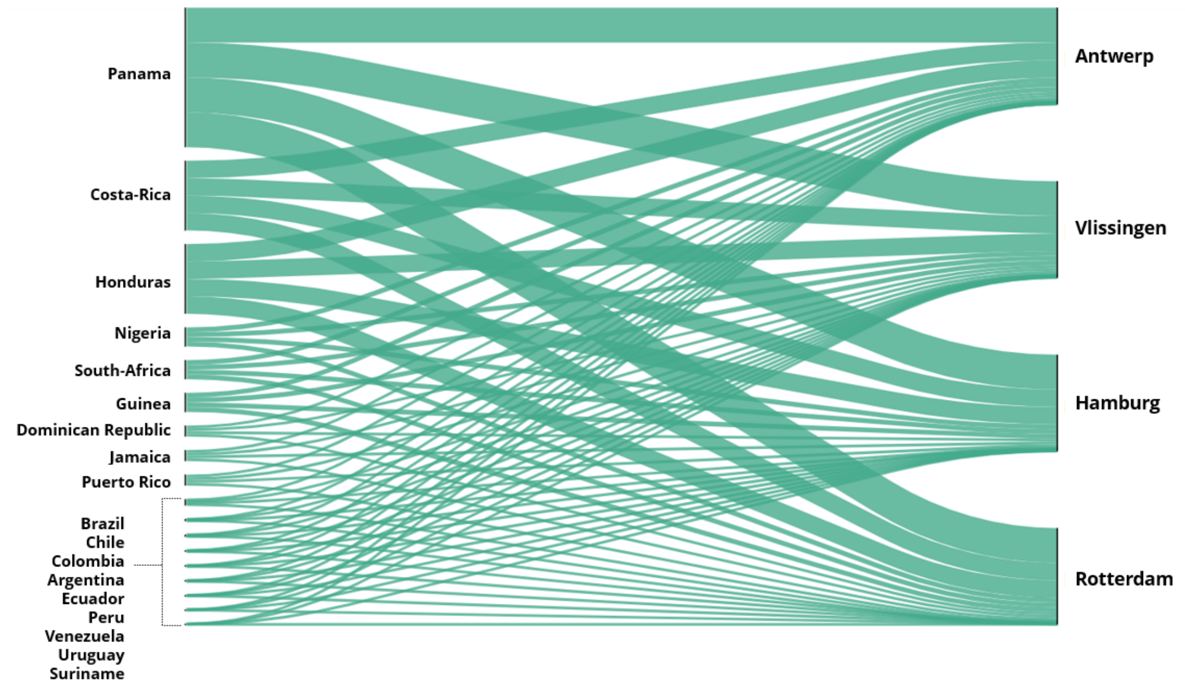

Figure 7.5: Distribution of origin ports in full set of transport configurations

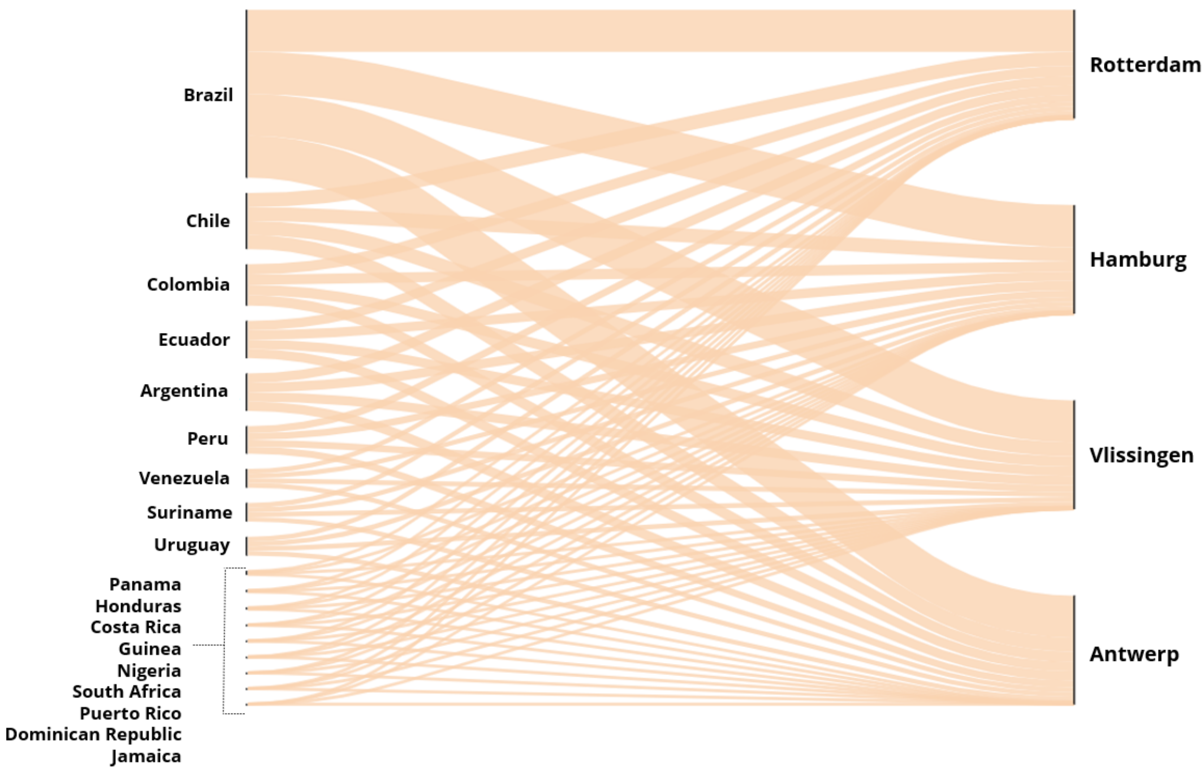

Figure 7.6: Distribution of origin ports in solution set of transport configurations

Model exploitation: intervention analysis

8

The formulation of the multi-objective optimisation model in chapter 6 describes the impact of criminal risk vs gain trade-offs on the criminal supply chain in three phases: generating transport configurations, combining the configurations with risk and values to create trade-off configurations, and finally identifying the optimal configurations of the solution set. The results of the model presented in chapter 7 show that clear correlations exist within the solution set, meaning targeted Police interventions could have a significant impact on the criminal supply chain. This chapter uses the model presented in chapter 6 and the results presented in chapter 7 to explore the impact of hypothetical interventions by the Dutch Police and search for the tipping points of the effectiveness of the interventions. The chapter concludes with a section on the implication of the results for the criminal detection activities of the Dutch Customs and Police.

Important to state is the fact this form of modelling is purely exploratory. I will not be able to calculate the exact number of officers needed during inspections leading to a tipping point of intervention effectiveness. I focus on exploring the dynamics of the criminal risk vs gain trade-off and estimate the impact of different interventions undertaken by the Dutch Customs and Police.

8.1 Hypothetical interventions

By varying the risk values in the multi-object optimisation model, a Dutch Police or Customs intervention can be simulated. By executing hypothetical interventions, I can observe how the solution set changes and which are the new likely transport configurations to be used by criminals. In other words, the model simulates the waterbed effect of the criminal supply chain. In all the interviews I conducted, the officers confirmed the size of the import of illegal products does not reduce when new transport configurations are identified by the Police, or more criminals are taken off the street. The criminal supply chain is highly dynamic and, despite efforts of the international Police forces, only increases in size (Caulkins, 2020). For this reason, the criminal supply chain can be compared to a waterbed; if you push on one side, the water moves to the other side. The only thing the Police forces can do is push at the right places on the criminal supply chain/waterbed to create large replacements and stand ready to catch to blow at the other side.

To demonstrate the waterbed effect caused by different types of interventions, I have worked out two examples: Dutch Customs interventions in the port of Rotterdam and Vlissingen focused on shipments with Brazil as origin, and Dutch Customs interventions in the port of Rotterdam and Vlissingen focused on indirect piggybacking via fruit shipments. Both examples are elaborated upon in this section.

8.1.1 Method of intervention implementation

The interventions are executed by altering one of the risk or gain variables for a specific set of transport configurations. After the alteration, the optimal transport configurations with the lowest risk and highest gain are recalculated. An example of such an alteration is increasing the route risk variable for all shipments originating in Brazil. As shown in appendix B the majority of the smuggling methods has multiple possibilities for the route risk value based on bribery and piggybacking company type. After the alteration, the transport configurations with the lowest route risk value displayed in the risk matrices in appendix B are excluded from the entire data set. The size of the entire data set slightly decreases because the transportation configurations originating in Brazil with the lowest route risk per smuggling method have been omitted.

8.1.2 Dutch interventions for Brazil

The country from which by far the most illegal product shipments originate is Brazil, as is shown in fig. 7.2. Almost three times more illegal shipments leave the ports of Brazil in comparison to the runner up Chile. Of the shipments arriving in the Dutch ports, 19% originates from Brazilian ports. Taking shipments from Brazil seems a logical starting point for the search for an impactful intervention. I implement three different types of interventions: increasing checks on all shipments originating from Brazil, increasing checks on unknown fruit shipments originating from Brazil, and increasing corruptions checks on all port employees and government officials handling shipments originating from Brazil.

All three interventions created a disturbance in the criminal supply chain. Meaning, the solution set of transport configurations that are most likely to be used by criminals was disturbed by the intervention. Due to the intervention, a smaller part of the most optimal routes for criminals goes via Brazil. The solution set before each intervention consisted of 19% out of shipments via Brazil; after intervention 1 to 3 and a recalculation of the solution set, these percentages went down to 17, 15 and 6% respectively. The interventions were executed individually; the decreasing percentages are not a summation. As shown in fig. 8.1 the intervention concerning corruption creates the largest disturbance in the supply chain.

After the interventions, the solution set and the characteristics change. The graphs presented in section 7.3 are regenerated after the application of the third intervention, which had the most impact on the solution set. The new graphs are displayed and shortly discussed in appendix E.

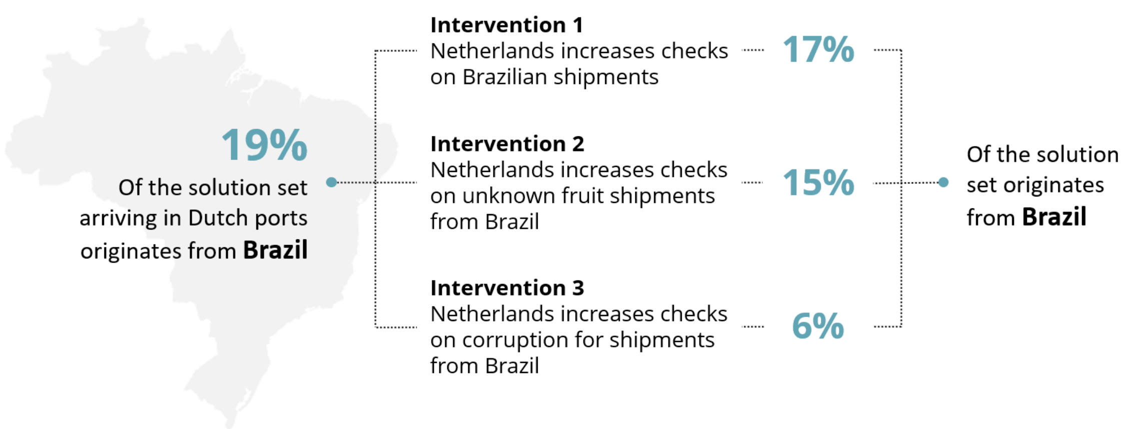

Figure 8.1: Impact of different constraints on the percentage of shipments via Brazil

8.1.3 Dutch interventions for indirect piggybacking

The two most commonly used smuggling methods, as observed from fig. 7.4, are inside the container construction or with the use of a cover load. Both of these methods are indirect piggyback methods, as explained in chapter 3. The smugglers do not make use of the transport of legitimate companies but create their own companies importing goods from South America. The washing smuggling method also includes criminals creating their own company, but this method requires a different (chemical) checking method by Dutch Customs. Because the washing method makes up only a small part of the solution set, and it requires a much more intensive Customs inspections method, it is not included in the indirect piggybacking interventions.

The shipments using a cover load or container construction method make up 40% of the solution set arriving in the Dutch ports. Four different interventions by the Dutch Customs in Rotterdam and Vlissingen are applied to the data set: increasing checks for all countries on low rated fruit companies, increasing checks for all countries on all triple-A-rated fruit companies, increasing check for all countries on all fruit companies and increasing checks for all countries on non-fruit companies. The effect the interventions have on the solution set is displayed in fig. 8.2. The third intervention, increasing checks for all countries on all fruit companies, creates the largest disturbance. The part of the solution set using an indirect piggybacking smuggling method is cut in half: from 40% to 20%.

After the interventions, the solution set and the characteristics change. The graphs presented in section 7.3 are regenerated after the application of the third intervention, which had the most impact on the solution set. The new graphs are displayed and shortly discussed in appendix E.

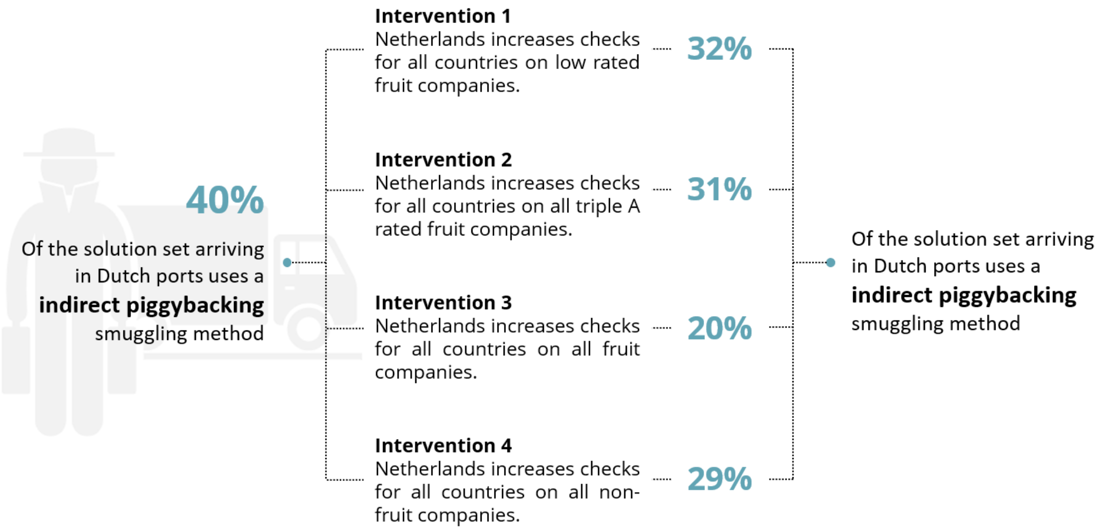

Figure 8.2: Impact of different constraints on the percentage of shipments via Brazil

8.2 Intervention tipping points

The hypothetical interventions suggested in section 8.1 are quite rigorous; completely banning corruption or the use of a smuggling method requires a lot of time, manpower, and money. To research whether there is a more effective way to achieve a large disturbance in the criminal supply chain, I try to find tipping points within the application of interventions. Executing interventions in the real world is not binary. The Dutch Customs can not ban all corruption from one day to the other. It is interesting to observe how much effort is needed to achieve the wanted effect. This section searches for a tipping point in the solution sets of the examples introduced in section 8.1.

8.2.1 Tipping point shipments Brazil

The intervention on Brazilian shipments in which increasing checks for low rated fruit companies are executed is used to discover the tipping point. In 20 steps moving from 0% intervention execution to 100% intervention execution, the percentage is analysed of shipments originating from Brazil within the newly calculated solution set. In other words, the disturbance on the criminal supply chain is determined. The results are shown in fig. 8.3. The change of the solution set differs from 0.5% to 1% and is, in general linear. There is no clear tipping point that can be observed.

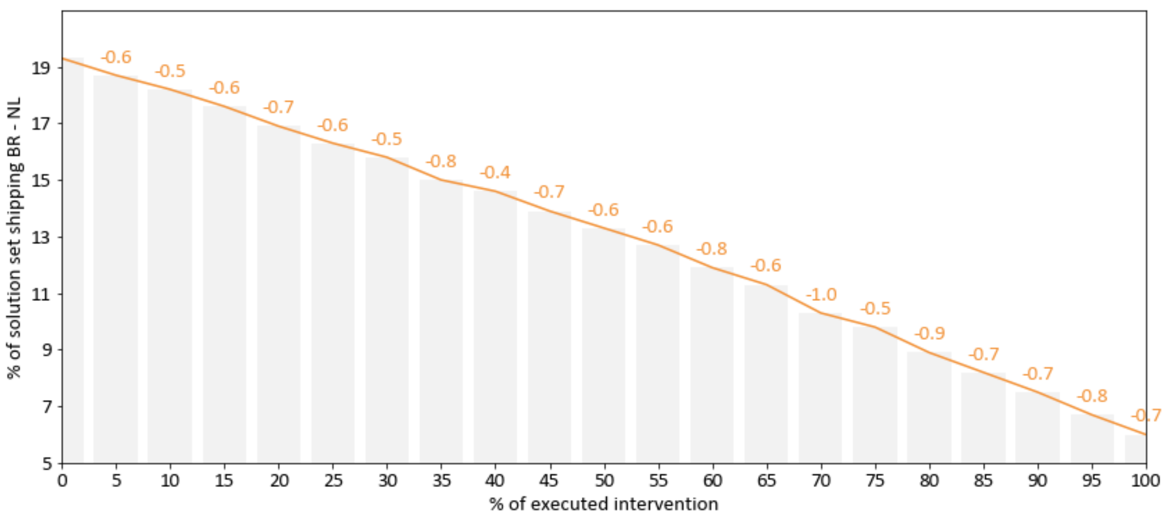

Figure 8.3: Impact of increasing interventions on shipments Brazil

8.2.2 Tipping point indirect piggybacking shipments

The intervention increasing checks on fruit companies for illegal products hidden under a cover load or inside a container construction is used to discover the tipping point. Similarly to the previous example, I use 20 steps between 0% and 100% of the intervention execution. The results are shown in fig. 8.4.

The graph shows an increasing change between 70 and 80% and between 85 and 100 %. Still, there is no clear tipping point that can be observed. The graph shows largely linear behaviour.

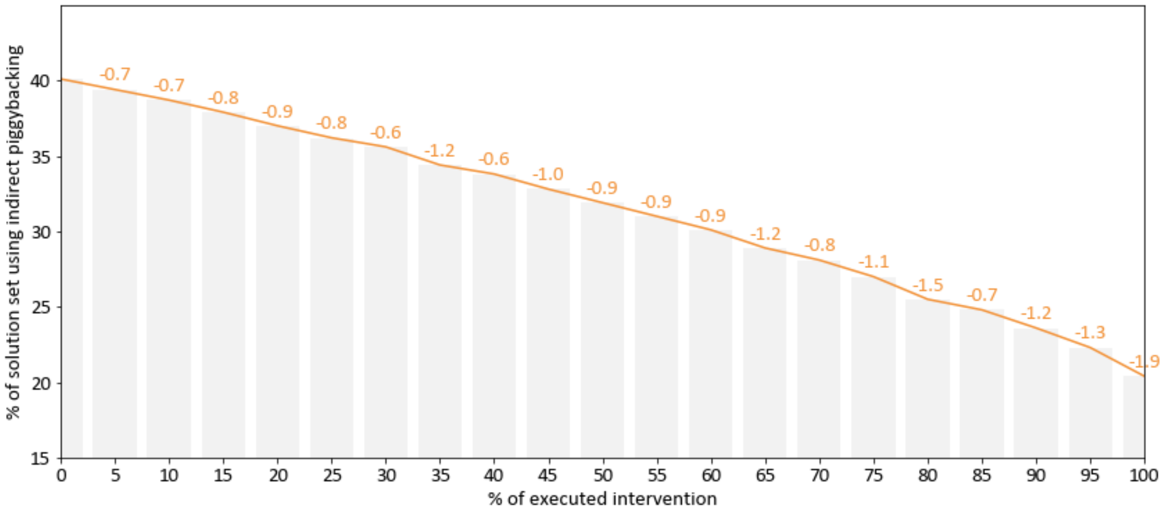

Figure 8.4: Impact of increasing interventions on indirect piggybacking methods

8.3 Implication of results

The result of the hypothetical intervention analysis is two-fold: the focus of the intervention has a large effect on the magnitude of the criminal supply chain disturbance, but within the specific intervention, no effective tipping point can be found. This result has an impact on the operational perspective of the Dutch National Police and Dutch Customs. Although the gut instinct of the officers might have already indicated it, the results of the multi-objective optimisation model scientifically prove interventions have a wide-ranging effect on the criminal supply chain. The criminal trade-off model allows Police officers to test their ideas and observe the impact on the criminal supply chain.

Not only can the Police officers observe the impact of the intervention, but also the waterbed effect is demonstrated. As shown in appendix E, the characteristics of the solution set undergo a drastic change after the application of an impactful intervention. Both the intervention for corruption on Brazilian shipments as the intervention on indirect piggybacking shipments show a disturbance in the recalculated solution set. In other words, the Police are now able to simulate how the criminal supply chain changes after a Police intervention. This allows the Police to be ready for the next move before the criminal has even made it. The "ready before they are" - approach has been used before by the international Police forces. In 2021 international Police Forces created a crypto communication network before criminals had discovered the Police had hacked their largest existing network. When criminals made the switch from the old to the new network, the Police forces were already waiting for them (Politie, 2021b).

Unfortunately, no tipping points within the execution of the interventions could be identified as displayed in fig. 8.3 and fig. 8.4. This linear behaviour means the model acts as if there does not exist a low input/ high output effect when it comes to the use of money or workforce within the execution possibilities of a specific intervention. However, it is possible that the model behaviour not represents the real-world situation. Phenomenons in real-world situations rarely show linear behaviour. More likely is the explanation that the tipping points exist in the real world, but they cannot be found due to the linearity of the MOO model constructed during this research. The linear model describes the most optimal transport configurations for a single criminal shipment of 1.000 kg. However, the Dutch Police is aware that criminals first send smaller test shipments of a few dozen kilos before the larger size shipments are sent via the same transport configuration. This shipment distribution is a form of criminal shipment risk distribution. Suppose a specific route is checked more often by Customs due to a strategic intervention. In that case, it can be expected that criminals stop using the transport configuration after their smaller test shipments are intercepted. The reactive behaviour of criminals based on risk distribution is not visible in the model due to the model's linearity. It is expected that the tipping points in the interventions can not be identified for the same reason.

Model explainability

9

This chapter addresses the explainability of this study towards the Dutch National Police, building upon the presentation of the multi-objective optimisation (MOO) results in chapter 7 and chapter 8. Since the model provides additional insight into the criminal detection practices of the Dutch Customs and Dutch Police, it is of high importance that the qualitative and modelling results of this study are simplified. In a 2019 collaborative study between the Dutch Police, the University of Leiden, and the Delft University of Technology, the importance of explainable Artificial Intelligence (AI) is emphasised. The researchers argue the explainability and interpretability of AI is crucial for implementing AI models within the criminal detection practices Dutch Police (Dechesne, Dignum, Zardiashvili, & Bieger, 2019). Although the MOO model built in this study does not qualify as an AI system because it does not use an evolutionary algorithm, the perceived complexity and non-transparency of the MOO model from the perspective of the Dutch National Police is similar to that of an AI system. Therefore, this chapter uses literature on explainable AI to construct an explainable representation of this study for the Dutch National Police.

This chapter starts with a short literature study on the explainability of Artificial Intelligence systems. Subsequently, the role of explainable AI within the Dutch National Police is discussed. The chapter concludes by applying the explainable AI theories to the results of the MOO model built for this research. In doing so, the fifth sub-question is answered, which is presented below.

Sub-question 5

How can the qualitative and modelling results be reduced to characterised configurations for the purpose of explainability, while they maintain their validity?

9.1 Literature on explainable AI

Due to the high complexity of artificial intelligence (AI) systems, they are treated as a black box, which is not desirable as AI systems are increasingly used in real-world applications (Xu et al., 2019). Explainability and explainable AI have gained the increased interest of researchers, presenting us currently with a broad range of studies on the subject (Samek, Wiegand, & Müller, 2017; Samek, Montavon, Vedaldi, Hansen, & Müller, 2019; Xu et al., 2019). Samek et al. (2019) divide an explanation into three facets: the recipient, the information content, and the role. They explain that different recipients may require explanations with a different level of detail and with different explanation techniques. Within the Dutch Police, three types of employees focused on the criminal supply chain: operational level, tactical level and strategic level.

The information content facet describes how based on the recipient's intent, four types of explanations can be used: explaining learned representations, explaining individual predictions, explaining model behaviour, and explaining with representative examples. The explanation of the MOO model to the Police is twofold: establish trust in the predictions of the model and spark curiosity for the computer model to increase data science used by the Police force. For the establishment of trust, the suitable explaining model behaviour type is most suitable. A black box's perception is degenerated by explaining the model behaviour and pointing out how the computer model generates specific outcomes. For the second part of the explainability intent, spark curiosity to increase the use of data science by the Police, the most suitable explanation type is explaining with representative examples. As Samek (2019) describes, the explanation method using representative examples can increase the commitment of users and potentially help to make models more effective and robust.

Samek et al. (2019) conclude by describing how the role of the explanation, or its purpose, distinguishes two aspects: what question does the explanation answer and for what do we want to use the explanation. The explanation of this study is to describe to the Dutch National Police how the results of the model were generated to establish the trustworthiness of the model and spark the curiosity of Police officers for the use of data science in criminal detection.

9.2 Explaining AI within the Dutch Police

Although explainable Artificial Intelligence is widely published, the research into explainable AI within Police forces is scarce. The Dutch National Police increasing makes use of Artificial Intelligence. However, more operational Police officers are hesitant to use these advanced systems due to the low transparency of their functioning (Dechesne et al., 2019). Desirable is developing an explainability method for Police computer models perceived as a black-box by operational officers. This section focuses on developing such a method.

Because the scientific literature on explainable AI within the Police force is insufficient to develop an explainability method, I conducted interviews, organised design sessions, and created a panel group to generate input from operational Police officers. The most insightful was the panel group which took place at the Customs office in Vlissingen. This afternoon was attended by eight officers who focus daily on the dynamics and detection of criminal supply chains. The officers are deployed by three different governmental organisations: the Dutch National Police, the Dutch Customs Administration, and the Royal Military Police (NL: Koninklijke Marechaussee). The eight participants received an explainability document of three pages of the functioning of the MOO model created during this study. Based on the document, they were asked to write down questions and ambiguities. The afternoon continued with a presentation on the impact of trade-offs on supply chains, which contained the same information as the explainability document but described more extensively. After the presentation, the panel group discussed which pieces of information of the presentation answered their written down questions and which questions were left unanswered. Based on the information pieces which were pivotal to facilitate understanding of the presented research, the panel group agreed on three crucial factors for understanding complex computer models: visual approach, Police terminology, and Police function specific. These three factors are not only applicable to the research presented in this study but are meant as a handle for all further complex computer models which need to be explained to the Police force. The three factors crucial for effective explainability can be described as follows:

- **Visual approach -** a visual representation of a problem showed during the design sessions to facilitate a faster comprehension of the problem's structure and its internal causal relations. As one of the Police officers working in the port of Vlissingen phrased: "I work on the streets because my attention span of looking at a piece of text is too short to spend my days behind a computer". The officer explained that a visual or picture immoderately drew their attention because it triggered curiosity.
- **Police terminology -** many panel group discussions centred around the exact definition of words as illegal, intervention, and transit. Although these words all have a dictionary definition, some words might have a different meaning in the organisation of the Dutch Police. The misuse of jargon caused a stealthy confusion in the explainability process as it was hard to pinpoint where the misunderstanding originated.
- **Police function-specific -** during the panel group session, different fronts formed within the group during the discussions on explainability aspects. The fronts were not based on governmental organisations but the functions of the officers within these organisations. On-the-ground working officers from the Dutch Police and Customs differed in explainability needs from their tactical or strategic level colleagues.

The three factors are largely in line with the literature on explainable AI, which does not specifically focus on explainability within a Police force. The use of visuals, drawings, and graphs to explain computer models is argued to be crucial for understanding in the book of explainable Wojciech Samek (2017) who is head of the Department of Artificial Intelligence and the Explainable AI Group at Fraunhofer Heinrich Hertz Institute in Berlin. Samek also pleads for an explanation tailored to the receiver, as earlier described in section 9.1. The crucial role of jargon and exact terminology is not yet represented in the literature on explainable AI. However, it is strongly recommended to include police-based terminology in explainability considerations based on the design sessions and panel group executed during this study.

9.3 Explainability of results

Based on the literature study on explainable AI presented in section 9.1 and three factors for effective explainability presented in section 9.2, the hand-over documents for the Dutch National Police were prepared. As pointed out in section 9.1 the Police officers working with the criminal supply chain can be categorised in operational, tactical and strategic. As described in section 9.2 each type of officer must receive an explanation that is in line with their function.

In collaboration with the panel group, the decision was made to distinguish between the operational officers and the tactical/strategic officers. How the two types of documents were created is explained in the coming two sections.

The *operational* Police officers focus in their daily work on the physical operations of the Police work taking place in the ports and on the street. They execute orders coming from the tactical officers. The operational level hand-over document consists of three pages: a header page with an introduction and two pages with visualisations and short text explanations on the model's functioning. The full three-page hand-over document can be found in appendix F.

The *tactical* Police officers focus on the planning of interventions based on the received information. They primarily work from the office to analyse the information about possible criminal activities and decide whether or not to intercept a shipment. They receive a high-over intervention strategy from the strategy level officers. The *strategic* level officers create a high over strategy for the Police force to tackle the problem of criminal supply chains. They use (international) intelligence to plan and try to out-smart the criminals. This study, its demarcations, and methodology discussions will all be of use for the daily job of the tactical and strategic level Police officers. A document similar to the thesis report is prepared for the tactical and strategic officers. This hand-over document contains Police jargon instead of scientific jargon and has a recommendations page focused on possible Police projects instead of scientific suggestions for further work. The document for the tactical and strategic officers also includes confidential information from Police interviews which could not be shared in this public version of the thesis report.

10 Discussion

This chapter critically reflects on the methodology and limitations of the research presented in the previous chapters of this study. The reflection and limitations of the research are built around four topics: Police perspective, model linearity, data scarcity, and criminal waterbed. The Police perspective topic mainly considers the methodology of the qualitative part of this research. The model linearity topic focuses on the methodology of the modelling part of the research. The topics data scarcity and criminal waterbed are a high-over analysis of the chosen perspective for this study and its implication on the results presented throughout the research.

This chapter continues by outlining the academic contribution and the societal contribution of this study, based on the answers to the sub-questions throughout the report and the presented research reflection and limitations. The structure of this chapter is visually demonstrated in fig. 10.1.

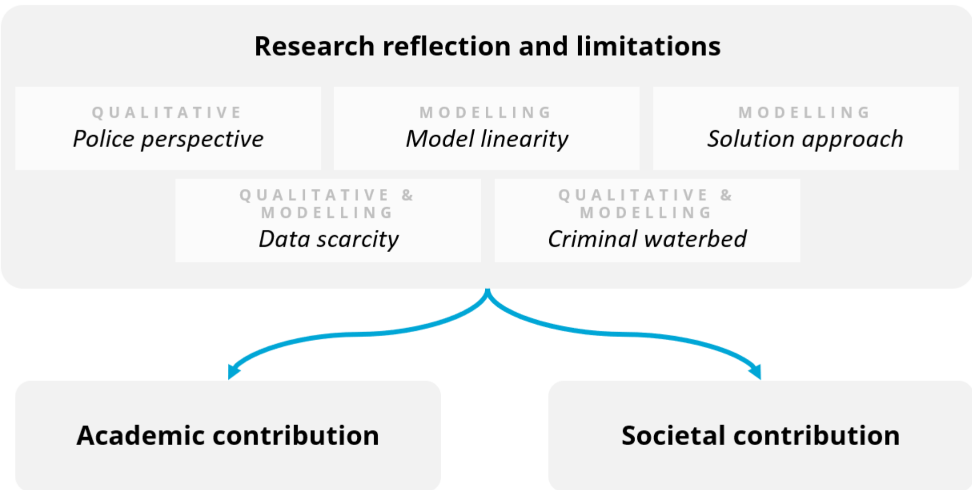

Figure 10.1: Structure of research discussion

10.1 Police perspective

In the qualitative part of this study, the variables influencing the risk vs gain trade-off were identified based on interviews with the Dutch National Police. The critical reflection of the qualitative part of this research consists of a reflection on the interview methodology and a reflection on the one-sidedness of the Police interview approach.

10.1.1 Police interviews

The information used to identify and quantify the variables influencing the criminal risk and gain variables was gathered by executing 25 semi-structured interviews with Dutch police force members. Eight of the 25 interviews had to take place in an online environment due to the Covid-19 restrictions. There was a notable discrepancy in the quality of the interviews executed online when considered an employee who was not talkative. As an example, take Police officer A and officer B. Both worked as tactical analysts for the Rotterdam region and were relatively quiet at the beginning of the interview, making it hard to have a free-flowing conversation. Officer A, I spoke to in the office in Rotterdam; after around 10 minutes of small talk, the officer loosened up and provided me with important insights about the importance of illegal product extraction possibilities in the arrival ports. With officer B the conversation never transformed into a free-flowing conversation, and the answers continued to be brief.

The interviews were semi-structured, meaning I prepared a few questions, but part of the interview always consisted of a free-flowing conversation. The most helpful information was usually shared during the free conversation part of the interview. This contribution was mostly caused by the impossibility of knowing which exact questions to ask due to the lack of openly available information on criminal supply chains. From the success of the free-flowing conversation parts of the interviews, I can conclude that executing structured interviews would not have been suitable for this research. A third possibility would have been unstructured interviews. However, I am confident this would have led to (unnecessary) extended interviews.

During the interviews, a projective technique towards visuals was used to foster collaboration with the interviewees. The presentation and explanation of the visuals was a clear tipping point when Police officers went from vague general answers towards information-dense responses. The theory of Greenbaum (Greenbaum, 2000) was confirmed that the triggered visual stimuli allow for a better understanding of complex structures and stimulate further thoughts on the interview topic. The visual use in interviews could have been an even more significant success when the projective visual technique is combined with another visual interview technique: the facilitation visual technique (Comi et al., 2014). With the facilitation technique, the interviewer uses visual templates, which are progressively filled out throughout the interview. The visual facilitation brings analytical advantages because the templates provide a framework for analysing the data (Comi et al., 2014). When I started the interviews, I was not aware of the facilitation technique. I believe it could have been helpful during the interviews with Police analysts working with the large data sets of encrypted criminal messages.

Concluding, besides the handicap of some online interviews, the semi-structured interview approach worked adequately. Although a combined projective/facilitation technique might have worked even better, the projective visual interview technique worked as expected.

10.1.2 One-sided perspective

Most of the interviews executed for this study were executed with the Dutch National Police employees, meaning the variables influencing the risk and gain value are constructed from their perspective. The one-sided perspective of the problem became apparent during the panel group, where both Police and Customs employees were present. The two organisations had different opinions about criminal behaviour and the dynamics of the criminal supply chain. A higher level of employment diversity would have been a contribution to the neutrality of this study.

Besides the inclusion of more Customs, FIOD, and Royal Military Police employees, the group of interviewees could have included (ex) criminals. The inclusion of criminals would have given a more reliable perspective on the criminal trade-off. Besides, including the criminal perspective would allow research on forming the trade-off from a psychological point of view. For example, criminal choice behaviour differs from typical choice behaviour and influences the risk vs gain trade-off.

Besides homogeneity in employment, the group of interviewees is also geographically homogeneous. Everyone interviewed for this study currently works for a Dutch organisation or company. Two of the interviewees have experience abroad in the field of criminal detection of smuggling. These officers provided valuable insights into the criminal risk differences and gained value between Dutch criminals and foreign criminals. If more Dutch officers with experience abroad were interviewed, or officers from foreign Police forces were approached, the results from the qualitative research part would have had more ground.

To conclude, the 25 interviewees work close to the heat of the criminal supply chain, so was able to provide sufficient insights for the MOO model. However, a more diverse group of nationalities and types of employments would have strengthened the research.

10.2 Model linearity

An important limitation of the current modelling approach is the linearity of the model. The multi-objective model considers one shipment of 1.000 kg being transported from South America to the Netherlands. However, most criminals use risk distribution and do not choose one transport configuration to use for all of their shipments. Criminals divide their stash of illegal products over different shipments and test themselves which transport configurations are the safest. Police officers shared how criminals use small trial shipments to test the safety of a transport configuration. After the trial shipments have arrived at their destination without any trouble, the larger shipments up to 10.000 kilos are prepared. Due to linearity, this was not taken into account.

Due to the linearity of the model, the influence of shipment time could not be taken into account. As explained in chapter 5 criminals are aware of the staff shortages in the Dutch ports during the summer and winter holidays and use this opportunity to increase their shipments. Including the shipments, time was not possible in the simplified linear model but could significantly influence the total amount of illegal products shipped per year. Leaving out the timing in the model also means disregarding the criminal's reactive handling in their supply chain. Suppose a criminal sends three shipments from South America via three different ports in Northwest Europe. The first is intercepted due to a wrong extraction risk estimation in the first port. In that case, the criminal prepares a different extraction strategy for the two shipments that are still on their way. Calculating the risk vs gain trade-offs for trial-shipments, reactive handling and risk distribution is impossible with the linear approach used in this study.

A grand limitation due to the linear behaviour of the model is the impossibility to calculate whether the Police interventions presented in chapter 8 have a tipping point. The graphs presented in fig. 8.3 fig. 8.4 are not likely to be a valid representation of the real world. Mainly because the real world rarely shows linear behaviour. Whether the linear behaviour of the intervention execution is due to the linearity of the model itself or for a different reason should be inspected in further research.

10.3 Solution approach

The solution of a multi-objective optimisation can be calculated via a scalarisation of the multiple objectives or a Pareto optimal solution set; the approach of this study was the latter. The approach of a Pareto optimal solution set allows for the optimisation of two objectives simultaneously. Due to the different units of risk and gain, this is the preferred solution approach, as it would have been impossible to combine the objectives. This section will discuss the functioning of the Pareto algorithm and the selection of the near-optimal solution set.

10.3.1 Pareto algorithm

This study uses a mathematical programming approach to find the Pareto optimal solutions instead of using a metaheuristic evolutionary algorithm. Evolutionary algorithms are more complex than mathematical programming, but they offer a significantly faster computation time. Currently, the calculation of the Pareto front for a transport configuration set of 839.232 configurations with the use of mathematical programming lasts only a few seconds. The model in its current form is of purpose to Police analysts who work on designing strategic interventions in the criminal supply chain. For this purpose, a run time of a couple of seconds should not be a problem.

When the MOO model is further developed or the transport configuration set is significantly enlarged, the run time might go up to hours or even days. For intervention prediction, a run time of hours is too long. If a piece of intelligence comes in to alert Police analysts of a criminal shipment, they must act fast. There is no time to test multiple interventions if every run takes multiple hours. To conclude, the current run time of the MOO model is sufficient for the model's purpose, but if the model becomes more complex, switching to a metaheuristic algorithm to reduce run time should be considered.

10.3.2 Near-optimal solution set

During the first Pareto optimal results discussion, I chose to include near-optimal solutions in the solution set to create a more useful and accurate representation of the real-world situation. In enlarging the solution set, it grew from 14 optimal Pareto solutions to roughly 22.000 near-optimal solutions. The question arises where the optimal point lies for the solution set size. The solution set size was chosen based on three aspects found in literature: proximity, diversity, and pertinency. However, even within the range of these three aspects, the solution set size can differ. The size of the trade-off solution set is a trade-off in itself: to which extent should a researcher be prepared to deviate from the Pareto optimal solution set (proximity) to achieve a real-world representation in the solution set (diversity & pertinency). How this trade-off is approached should differ per study. For the risk vs gain trade-off within transport configurations, the choice was to focus more on diversity and pertinency rather than proximity. For this reason, the solution set significantly grew in size.

Besides focusing on the size of the solution set, the shape can also be an interesting discussion point. In this study, the solution space is shaped like a rectangle based on Pareto literature which includes squared or rectangle shapes of the discussed decision-makers region of interest (ROI). Another approach could be to use a bandwidth beneath the Pareto solutions as a selected shape for the enlarged solution set, of which an example is visually demonstrated in fig. 10.2. With a Pareto curve-shaped solution space, the proximity of the near-optimal solutions is kept high, but the solution set can be enlarged and therefore diversified.

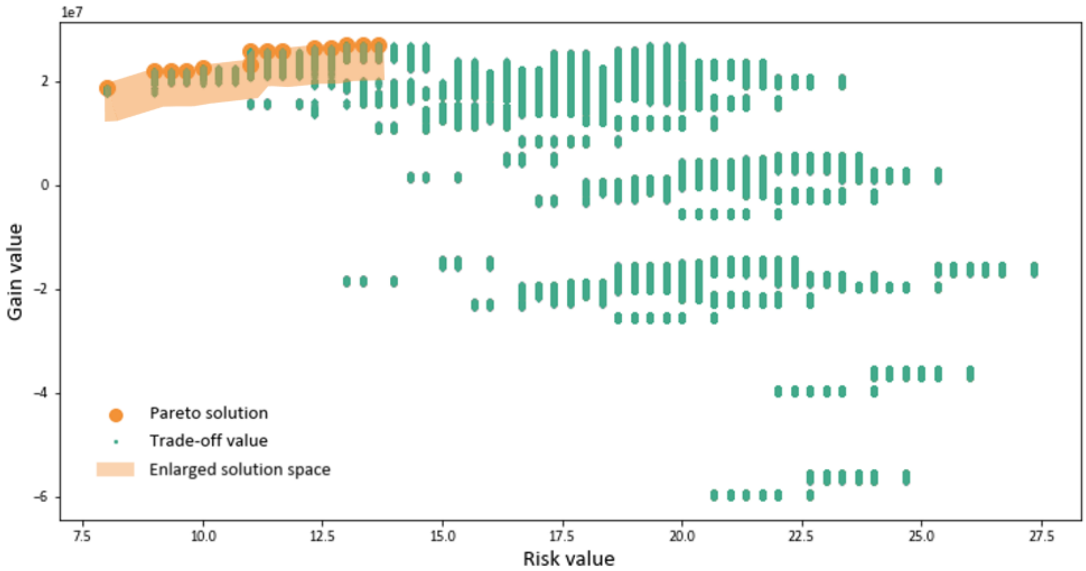

Figure 10.2: Enlarged solution space by using a Pareto band width

Another approach to the discussion of near Pareto optimal solutions is to questions the use of Pareto in itself when considering a criminal supply chain. The concept of Pareto is beneficial for calculating optimal trade-offs for a legitimate supply chain in which the decision-maker itself is handling the outcome of the multi-objective optimisation. However, in the case of the criminal supply chain, using a multi-objective optimisation model by the Police to simulate transport choices of criminals can be seen as a serious game technique. This different model use requires a different solution approach than the standard use of Pareto for multi-objective optimisation of a legitimate situation. That selecting near Pareto optimal solutions is unusual is confirmed by the scarce literature on the topic. Many studies have been published on near-optimal solutions in mathematical computer models, but barely any studies focus on near-optimal solutions in combination with a Pareto front. Which type of solution space is most suitable for multi-objective optimisation of a criminal supply chain is yet to be determined.

10.4 Data scarcity

Although most scientists do not want to burn their hands on an estimation, chances are the criminal supply chain analyses made in this research are based on only 20% of the real-world data. Meaning both the qualitative and the modelling part of this research are executed with a high level of data scarcity. This section discusses the data scarcity present for the Dutch Police, followed by the extra data scarcity. This study was built upon due to the confidentiality of Police data. The section concludes with a discussion on the impact of data scarcity on the overall research.

10.4.1 Police data gaps

The criminal shipments detected by the Dutch Police are probably between 5 and 20% of all existing criminal shipments. To use the words of many Dutch Police officers: "we do not know what we do not see" (NL: we weten niet wat we niet zien). Starting from the construction of transport configurations in chapter 3, the high data scarcity of the criminal supply chain starts to play a significant role in the limitations of the research. All following chapters assume the available data on criminal supply chains are presentable for all existing criminal supply chains. However, this is most likely not the case.

The construction of the transport configurations in chapter 3 and chapter 4 is done based on interviews with the Dutch National Police, reports of the United Nations, publications of research journalistic platform Insight Crime (regularly publishing commissioned by the Dutch government) and scientific papers. This methodology comes with the limitation that the model's input data is based on previously discovered shipments instead of all geographical possibilities. One measure to solve this limitation would require expanding the model from the ports used for smuggling known by the

Police to all ports in South America. This model expansion would provide a complete picture of the situation, but the data gathering and the model building take a significant amount of time.

The construction of the formulas for risk and gain in chapter 5 is based on interviews with the Dutch National Police. Also, in these interviews, data scarcity plays an important role. The Police share information based on the criminal shipments they have intercepted. Based on this incomplete criminal shipment data, the variables were determined to influence criminal risk and gain. However, the factors would likely differ if the Police knew the complete criminal supply chain.

10.4.2 Confidential data

Besides the incomplete information available at the Dutch Police, this study has a second data scarcity reason: it is based on second-hand information shared by Police officials and outdated criminal shipment data published in reports and papers. The actual Police data on organised crime groups and details of recent criminal shipments are confidential. I did not receive a level of screening sufficient enough to get access to actual criminal files.

Data on organised crime groups (OCGs) is crucial for the inclusion of the mutual-trust risk factor, discussed in chapter 5. However, the information on active OCGs is highly confidential. Therefore, the mutual trust factor is currently absent from the calculation of risk per transport configuration. The factor was first included with a different value for every transport configuration. However, results showed every trade-off configuration occurring five times in the results, exactly five times adjoining on the same horizontal axis. Since the addition of the mutual trust factor did not deliver extra insights but enlarged the transport configuration set significantly, all transport configurations were given the same mutual trust risk factor. It would be interesting to observe how the solution set would shift if part of the transport configurations had a higher mutual trust than others.

A second limitation due to information confidentiality is the calibration of the MOO model based on actual available criminal shipment data at the Dutch Police and Dutch Customs. Although the model could not be fully calibrated, its results can be confirmed by other means. The MOO showed a crucial role for bribery in the multi-objective optimisation, which has a clear correlation with the results of a recent report on corruption in the Dutch Customs. On the first of July 2021, the Dutch Customs stated: "Criminals are constantly adapting their ways of working at lightning speed, while Customs is not yet sufficiently equipped for this. That is why strengthening and broadening Customs' anti-corruption approach is necessary and urgent." (Rijksoverheid, 2021). The press release was a reaction to the 58-page destructive advisory report of consultant KPMG executed commissioned by the Dutch Customs (Lak, 2021). The report concludes the Dutch Customs are essential for the import of illegal products.

10.4.3 Impact of data uncertainty

The exact impact of data scarcity on the results of this thesis is difficult to estimate. The two types of data scarcity described above both have their own impact on the results. If all data on actual criminal shipments at the Dutch National Police would have been available to use for this research, the MOO model would have been a representation of the 5-20% of the criminal supply chain. In a perfect situation all data on criminal supply chains would be available, which would allow for the creation of a MOO model representing 100% of the criminal supply chain data. In other words, the availability of more data would not increase the number of optimal transport configurations presented by this study, but it would increase the validity of the configurations present in the solution set.

An approach this study could have taken to estimate the impact of data uncertainty on the research results is to execute a deep uncertainty analysis. A deep certainty analysis on all input variables of the multi-objective optimisation model gives insight into the impact of uncertainty of the data. Due to the time scarcity of this thesis research, such an analysis was not included. Kwakkel and Pruyt (2013) argue that by using models differently, the challenges of deep uncertainty can largely be overcome. A possible research methodology for handling deep uncertainty is using the exploratory modelling and analysis (EMA) developed by the RAND Corporation. EMA uses computational experiments to analyse complex and uncertain systems. It would be interesting to analyse how the results of this study change if the EMA method is applied to the highly uncertain input variables of this study.

10.5 Criminal waterbed

The introduction of this study described how a higher interception rate of criminal shipments would not lead to lower demand for illegal products. The supply chain does not decrease by removing illegal products from the criminal supply chain; it just moves to a different place. The Police officers refer to this phenomenon as the *waterbed effect*. The Police can push on the part of the criminal supply chain, but the amount of criminality does not decrease; it just moves to a different place. Interviews with the Dutch National Police revealed that the criminal supply chain is highly dynamic and moves faster than the Police can keep up with. The MOO model in this study shows criminals are more flexible to interchange their routing than their means of transport. Although the created MOO model might assist the Police in planning more efficient and effective interventions, it does not have the means to derail the criminal supply chain. During the interviews, Police officers expressed a desire for more strategic interventions to undermine the criminal supply chain rather than sweeping in large criminal shipments. However, even if the Police can create structural holes in the criminal supply chain, the demand for illegal products in the Netherlands will not change. The waterbed effect ensures the illegal products will still enter the Netherlands; they will only use a different route.

During the interviews, some Police officers raised the topic of a sustainable solution for importing illegal products, which quickly turned into a philosophical conversation due to the enormousness of policy and culture change needed for a significant decline in criminal smuggling activities. These conversations mainly arrived at the question of how to influence the consumer of illegal products. Due to the extremely high turnover of illegal products as described in chapter 5, criminals will always keep trying to find a way to work around Police forces who are protecting the rule of law. The difficulty of appealing to the feeling of responsibility of consumers is a dilemma shared with other societal challenges such as climate change. The CEO of oil company Shell Ben van Beurden phrased one of the solutions for climate change in 2018 as follows: "It is consumers that must change their consumption behaviour" (Mommers, 2018). In other words, as long as there is an oil demand, Shell will provide it. The same goes for criminals; as long as the demand for illegal products exists, they will find a way to transport the products to the Netherlands. Until now, no problem-shifting solution has effectively appealed to consumers on their responsibility to behave carbon-neutral or stop using illegal products. When such a solution presents itself, the Police will stand in front of the line to implement it and, in doing so, structurally undermine the criminal supply chain.

10.6 Academic contribution

The academic contribution of this study is twofold: the qualitative contribution of the construction of the criminal risk and gain value and the modelling contribution of modelling trade-offs within a criminal supply chain. Both will be discussed in this section.

Based on 25 interviews conducted with the Dutch National Police, Europol, Dutch Customs and the port of Rotterdam, the variables influencing the criminal risk vs gain trade-off were identified and quantified. The identification of these variables contributes to the field of criminal choice behaviour. As far as open research goes, no similar study into the variables influencing the criminal risk vs gain trade-off within a criminal supply chain. Although plenty of researches exist on the variables influencing the decision of whether a person is going to commit a crime or not, the research on decision making within the criminal supply chain is highly scarce (Paternoster & Pogarsky, 2009; Lynam & Miller, 2004).

Identifying and quantifying the variables influencing criminal risk is more innovative than the similar process for the criminal gain value because the elements influencing the gain value are more forward. The fact that gain is equal to the difference in product price minus transport cost is easy to construct based on basic economic theories. The scientific contribution of the gain quantification lies in the transport cost data presented in fig. C.1 and fig. C.2. Although the figures are listed in this study under high uncertainty, the figures have not yet been openly published. Identifying the variables of the risk formula was less straightforward and took many iterations during Police interviews before they were constructed in their current form. In current literature, the risk assessment of criminals within the criminal supply chain is mentioned, but always briefly and never broken down into multiple variables (Zaitch, 2002; Magliocca et al., 2019; Malm et al., 2017). Identifying all variables influencing the risk value is an academic contribution. I could not identify the correct value of the multipliers of the risk formula, due to the data scarcity of the criminal supply chain.

The academic contribution of the modelling part of this study is the fact that this study applies a multi-objective optimisation model to model trade-offs within a *criminal* supply chain. The method of using multi-objective optimisation for creating insight into the impact of trade-offs on a supply chain has been executed many times before, but always with for a legitimate supply chain. The results presented in this study show that a multi-objective optimisation can provide insightful results when applied to a criminal supply chain accompanied by a high level of data uncertainty. These insights that the multi-objective optimisation modelling technique can also be applied to model trade-offs in different supply chains coping with high data uncertainty. Besides providing a proof of concept, this study opens the debate on finding a solutions space suitable for a MOO model of a criminal supply chain and argues the Pareto optimal front should not bind such a solution space.

10.7 Societal contribution

The societal contribution of this study is its contribution to the criminal detection methods of the Dutch Customs and Dutch Police. Using the criminal risk vs gain trade-off to analyse the possible movements of criminal supply chains is a new point of view, which can be added to the information sources contributing to criminal detection practices. To return to the logic of the visual shown in the introduction of this research: the criminal risk vs gain trade-off can fill part of the gap in the criminal detection practices to increase the percentage of detected illegal products. The new version of this visual, which includes the criminal risk vs gain trade-off, is shown in fig. 10.3.

The criminal risk vs gain trade-off only fills part of the gap of unknown resources needed to achieve a 100% criminal detection. Although it will contribute to criminal detection, it is impossible to put a number to the increase of detection it will cause. Currently, the model is linear and works on many assumptions. However, whether the contribution to the currently 5 - 20% of detected shipments is 1%, 0.1% or 0.001% does not matter for the fact that every extra detected shipment counts as a contribution to a safer Dutch society.

Figure 10.3: Impact of increasing interventions on indirect piggybacking methods

10.8 Link EPA program

The study program of Engineering and Policy Analysis (EPA) at the Delft University of Technology focuses on solving complex problems within the two themes of policy & politics and analytics, modelling & simulation. This thesis touches both of those themes, mostly on the topics of policy and modelling. The complex problem outlined in this thesis is the need for an increased criminal detection within the import of illegal products. I first took a policy approach focusing on the current resources used for criminal detection. A missing component in the analysis by the Dutch Customs whether a transport configuration is likely to be used for smuggling is the criminal risk vs gain trade-off. I continued with a modelling approach using interviews and literature as qualitative input data for the multi-objective optimisation model I created.

EPA motivates their students to take an interdisciplinary approach in their studies. Executing this research at the Dutch National Police and interviewing employees from different ranks, disciplines and governmental bodies lets me conclude that this research coincides with the interdisciplinary task.

Conclusion

11

The growing import of illegal products in the Netherlands via container ships causes increased violence, addiction, and tax evasion in the Dutch society. With the current criminal detection practices the Dutch National Police and Dutch Customs do not manage to intercept the majority of the illegal shipments. The resources used by the Dutch Police and Customs for criminal detection do not yet entail information from the criminal risk vs gain trade-off point of view. Therefore, this study set out to research the impact of the criminal risk vs gain trade-off on the international criminal supply chains. This chapter presents the conclusion of this study by answering the five sub-questions, followed by an answer to the main research question, which is presented below.

Main research question

Which transport configurations are preferred by smugglers in criminal supply chains from South America to the Netherlands when reasoning from the criminal risk vs gain trade-off, and of which variables does this trade-off consist?

This main research question is answered with the use of the following five sub-questions:

1. *What are the main differences between a legitimate and a criminal supply chain?*
2. *What are the possible transport configurations exploited by criminals when smuggling illegal products into the Netherlands?*
3. *How do criminals give value to the factors risk and gain when considering the transport configurations of their criminal supply chain?*
4. *How can the impact of the risk vs gain trade-off on the transport configurations within the criminal supply chain be modelled using a multi-objective optimisation?*
5. *How can the qualitative and modelling results be reduced to characterised configurations while maintaining their validity?*

The first sub-question describes the difference between a legitimate and a criminal supply chain which can be describes based on the variables influencing the supply chain. This study focuses on the transport between South America and the Netherlands. A legitimate supply chain is described by the following variables: modality, type of vehicle, shipment size, shipment time, and routing. To describe the transport of illegal products in a criminal supply chain, three variables are added to this list: smuggling method, use of bribery, and type of piggybacking company. Each of these added variables describes a distinction between the legitimate and the criminal supply chain. There is no question of how many and what type of employees receive bribes in a legitimate supply, and only criminals use the concept of piggybacking. Besides these three variables of the criminal supply chain, two other important distinctions can be made between the legitimate and the criminal supply chain. First, the criminal supply chain is highly dynamic. Criminals can shift between transport configurations with speed impossible to follow by the Dutch Police and Customs. Second, the criminal supply chain is built on mutual criminal trust. Trusting your criminal companions has shown to be pivotal in the functioning of a criminal supply chain.

The second sub-question is answered by generating all physically possible transport configurations based on four research variables of this study describing criminal transport: routing, smuggling method, bribery type, and type of piggybacking company. A set of 839.232 transport configurations is generated, each describing a unique combination between the four research variables. As described in the discussion of this research, the transport configurations are based on the Dutch Police's current knowledge about criminal shipments. The estimation is made that the Police only knows about 5 - 20%

of the actual criminal shipments arriving in the Netherlands. It is essential to keep in mind that this lack of data skews the results.

Third, the variables influencing the criminal risk and gain value are identified. Four variables influence the criminal risk value: mutual criminal trust, bribed (non) officials, route risk, and smuggling risk. The route risk variable consists of three sub-variables: loading possibilities for the illegal products in the country of origin, extraction possibilities of the illegal products in the country of arrival, and the detectability of the shipment route. The smuggling variable consists of the safety rating of the piggybacking company and the detectability of the smuggling method. The gain value of the criminal trade-off is influenced by two variables: the wholesale price of the illegal products between the two shipment countries and the transport cost.

To answer the fourth sub-question, a multi-objective optimisation model is built using the transport configurations and the criminal risk and gain formulas. The solution set calculated by the model is dominated by routes travelling from Brazil to the Netherlands. Other much-used routes travel via Chile, Colombia, Ecuador, and Argentina. Although less prominent in the solution set, also countries in Central America and Africa cover part of the preferred criminal routes. When arriving in Northwest Europe, the smuggling methods most attractive to criminals are a cover load or hidden inside the container construction. As a smuggling method within South America or travelling from South America towards Central America or Africa, the smuggling method using a semi-submersible presents a large part of the solution set. Even though the cost of this method is high, the risk of detection by the Police is significantly low. The multi-objective optimisation model provides insight into the logical transportation preferences of criminals. However, due to the model's linearity, it has a few significant limitations: the model does not take criminal risk distribution into account, the model is not time-based, so it does not include shipment time, and possible tipping points within simulated Police interventions are impossible to locate. Besides the model linearity, the factor of data scarcity played a role in the model's validity. Due to the confidentiality of Police data on actual criminal activities, the model could only be partially calibrated. However, the model's conclusion on the essential role of corruption is in line with a report on the role of corruption in the port of Rotterdam send to the second Chamber send on the first of July 2021 by the Dutch State Secretary for Finance.

Fifth, the qualitative and modelling results can be accurately and effectively explained to the Dutch National Police using three explainability factors: taking a visual approach, focusing on correct Police terminology, and creating explainability documents for specific Police functions. These three factors are based on the literature on explainable Artificial Intelligence and design discussions and a panel group with operational officers of the Dutch National Police. A similar set of factors pivotal for effective explainability of computer models within a Police force has not yet been published as far as open research goes.

To conclude, the main research question can be answered by the following: criminals prefer to use transport configurations with one transit port such as Brazil, a cover load or container construction smuggling method, piggybacking with the use of a fruit company, and the bribery of either officials or non-officials. The simulation of exemplary Police interventions influencing the criminal risk value shows the criminal preference of transport configurations is highly dynamic when considering routing but more rigid considering smuggling method, type of piggybacking company, and bribery. The trade-off variables identified in order to come to this conclusion are for the risk value: mutual trust, bribery, route risk, and smuggling risk. The variables are the difference in the illegal product price and transport costs for the gain part of the trade-off. This conclusion shows that trade-offs on the criminal supply chain can be insightful for increasing criminal detection and can be used to plan effective Police interventions. In other words, the use of the criminal risk vs gain trade-off is an effective addition to the criminal detection resources used by the Dutch Police and Customs. The effectiveness of the model is in line with the main research goal stated at the beginning of this research: increase criminal detection of illegal products by identifying transport configurations with a high chance of smuggling, using criminal risk vs gain trade-offs.

Recommendations

12

Based on the discussion presented in chapter 10 and the conclusions in chapter 11, this chapter presents step-by-step recommendations for further research. The structure of the research presented is based on the five discussion topics introduced in chapter 10: Police perspective, model linearity, solution approach, data scarcity, and criminal waterbed effect. The recommendations for further

The first step to improving the current multi-objective optimisation (MOO) model focuses on the assumptions made due to data scarcity. With the three suggestions for further research presented below, the trustworthiness of the results produced by the MOO model can be significantly improved.

- **Effect of data scarcity -** the validity of this research, but also of all other criminal supply chain studies, would go up drastically if the effect of the data scarcity on multi-objective optimisation modelling is determined. When the effect of data scarcity is known, it is possible to anticipate it. Solving the deep uncertainty due to data scarcity can be done with the use of a deep uncertainty analysis, as discussed in chapter 10.
- **Validate MOO model -** with the use of actual Police data on recent criminal shipments, the results of the MOO model can be validated. Although a validated MOO model still represents the visible part of the criminal supply chain, it is up to date with the most actual developments in criminality. The data on actual criminal shipments is available at the Dutch Police and Customs, but I could not access it due to the data confidentiality.
- **Add OCG data -** due to the confidentiality of data on organised crime groups (OCGs), this study was not able to research the effect on mutual trust between criminals. It would be interesting to add the data on OCGs gathered from the hacked crypto communication networks to analyse the effect of mutual trust on the criminal risk value and the optimal transport configurations.
- **Transport configuration patterns -** as concluded in section 4.5 the Dutch Police is not aware of occurrence patterns existing between the transport routes, smuggling methods, type of bribery, and type of piggybacking company. The possible patterns could not be researched in this study due to the confidentiality of Police dossiers on criminal shipments. It would be interesting to do an analytical search for occurrence patterns within Police documents on intercepted criminal shipments.

Secondly, it is advised to enhance the model and the approach to the solution set by regarding the further research recommendations presented below. The complexity of the MOO model can be enhanced by creating a non-linear MOO model. The solution set generated by the model can also be enhanced with further research into a suitable near-optimal solution set for MOO models regarding a criminal supply chain.

- **Risk distribution -** currently, the model acts linearly and analyses the possible transport configurations on risk and gain for one criminal shipment. The linear model is not a fully sufficient representation of the real world, in which criminals use risk distribution to lower their chances of full investment loss. A significant step towards simulating the real-life situation would be to include portfolio analysis into the model, meaning the model calculates the risk and gain for a set of shipments that can be distributed via different transport configurations.
- **Time related risk -** in the study, the risk formula limits itself to four risk variables. A risk variable not included is a time-related risk, which is not possible in the current model due to the model's linearity. Further research into the influence of time-related risk would expand the MOO model and increase its validity.
- **Reactive handling -** due to the linearity of the model, the criminal's reactive handling is disregarded. Reactive handling describes how criminals change their chosen transport configuration details if new information arises after the transport is set in motion. For example, suppose a criminal sends three shipments using the same transport configuration, and the first shipment that arrives a week early is intercepted. In that case, the criminal

tries to react by changing the routing of the remaining two shipments. Changing the linear model to a time-based model would allow observing how reactive handling affects the criminal supply chain when a Police intervention is executed.

- **Near optimal solutions -** as discussed in chapter 10 the Pareto front is not a useful and effective representation of solution for the use of modelling trade-offs in a criminal supply chain. Separate research into the possible shapes and sizes of selecting a solution space for a MOO model for a criminal supply chain can enhance the validity of the selected results.

Third, further research can focus on broadening the perspective of the Dutch National Police, which is used during this study. As discussed in chapter 10 this study acts on a one-sided perspective of information mainly provided by the Dutch National Police. Although employees from cooperating governmental organisations have been interviewed, and open literature is used to construct the criminal risk vs gain trade-off and the MOO model, a wider range of interviewees could have been selected. The recommendations for further research regarding widening the perspective of this research are presented below.

- **Criminal perspective -** in this study, the input is used from governmental officials as information for the criminal risk vs gain trade-off. Interesting would be to compare the outcomes if similar interviews were conducted with (ex) criminals. Interviews with criminals would substantiate the results of the qualitative part of this study regarding the variables influencing the criminal risk and gain value.
- **Criminal behaviour -** this study argues that criminal behaviour is not entirely rational and selects a more extensive solution set in order to cover the uncertainty of criminal behaviour. It would be interesting to interview criminal psychologists and behavioural specialists to dive into criminal behaviour, which is fundamental for decision-making in the criminal supply chain.

Fourth, an interesting piece of further research should focus on the structural change of illegal product use in the Netherlands. The MOO model in this study researches the waterbed effect of the criminal supply chain. However, as long as consumer demand exists in Europe, the criminal supply chain will not cease to exist. The European governments have failed to design policies with a structural impact on the consumer demand for illegal products. As discussed in chapter 10 the criminal supply chain cannot be taken down if the demand for illegal products remains unchangeable. Robust policy-making research should be executed to solve the cause of illegal product import. Such a study must occur in collaboration between researchers, policy-makers, the Dutch Police, and, preferably, consumers. The results of such a study would be innovative, interesting, and of enormous value to the National Police.

Finally, a list of research scope recommendations is summed up below. The recommendations are mainly based on suggestions from interviewees from the Dutch Police and Dutch Customs. Due to the time limit of this research, a clear demarcation was made on which parts of the criminal supply chain were included. Broadening the scope beyond criminal transport configurations gives the potential for many more exciting and innovative pieces of research.

- **Expanding beyond transport -** this study analyses the criminal supply chain until the point of container arrival in the Netherlands. However, it would be interesting to know what happens after. The Netherlands is known to be a transit hub for illegal product criminals. An extended version of the model from this study could be used to research the effect of trade-offs on the criminal supply chain within the Netherlands.
- **Partial OCG involvement -** the MOO model presented in this research assumes one OCG is in charge of the criminal shipment from South America to the Netherlands. Researching the dynamics of a criminal supply chain that involves multiple OCGs would be an interesting addition to the research presented in this report.
- **Illegal product diversity -** research including different types of illegal products offers the opportunity to compare different criminal supply chains. There is a chance the supply chains of different illegal products join somewhere, similarly to a distribution centre of a supermarket which imports different types of food. If this is the case, the Police can plan more efficient interventions, as joint illegal product supply chains give them the ability to derail multiple supply chains with one Police intervention.

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A Smuggling methods

This appendix gives a short explanation of the ten smuggling methods used in this study. The appendix is divided into two parts, one part describing the smuggling method which are used on container ships, and the second part describing the smuggling methods which are used on different vehicle types. The majority of the descriptions is supported by the use of pictorial examples. The pictures are collected from international news papers.

A.1 Container smuggling methods

This section describes the container smuggling methods used within this report: container construction, cover load, rip-off, ship construction and washing.

A.1.1 Container construction

The container construction smuggling method describes the criminals hiding the illegal products in the metal construction of the shipping container. This can either be on the ceiling or the cooling element, as shown in fig. A.1, but can also be in the bottom of the container or in the walls. This smuggling method is used when criminals are involved with the company who ordered the shipment, as they need access to the inside of the container.

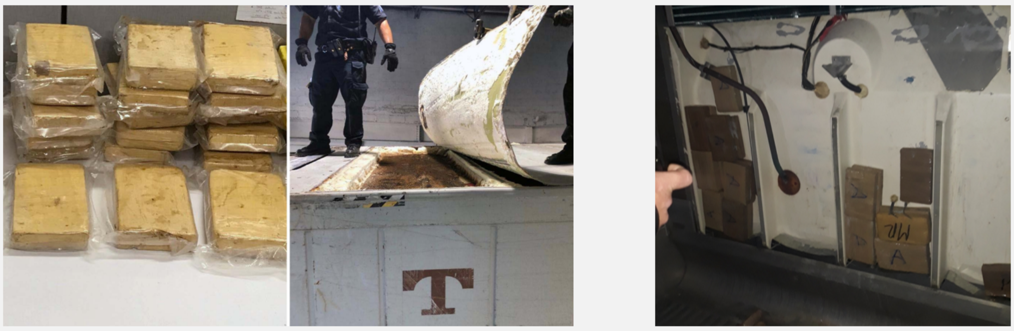


Figure A.1: Examples container construction smuggling method

A.1.2 Cover load

With the cover load smuggling method criminals use their own malicious companies to smuggle the illegal products towards the Netherlands. Criminals are innovative and creative when it comes to hiding the illegal products in between the purchased cover loads. An example of a fake banana and the use of paint buckets is shown in fig. A.2. This smuggling method, similarly to the container construction method, is used when criminals are involved with the company who ordered the shipment. They need access to the inside of the container to be able to spread the illegal products in between the cover load.

Figure A.2: Examples cover load smuggling method

A.1.3 Rip-off

When using the rip-off smuggling method criminals put their illegal products in (sport) bags and drop the bags inside containers. Examples are shown in fig. A.3. Rip-off usually takes place without knowledge of the company which is used for piggybacking. The bags are extracted in the arrival port before the containers arrive at the warehouse of the company owning the container. A criminal disadvantage posed by the use of this smuggling method is it can only ship small amounts of illegal products per container.

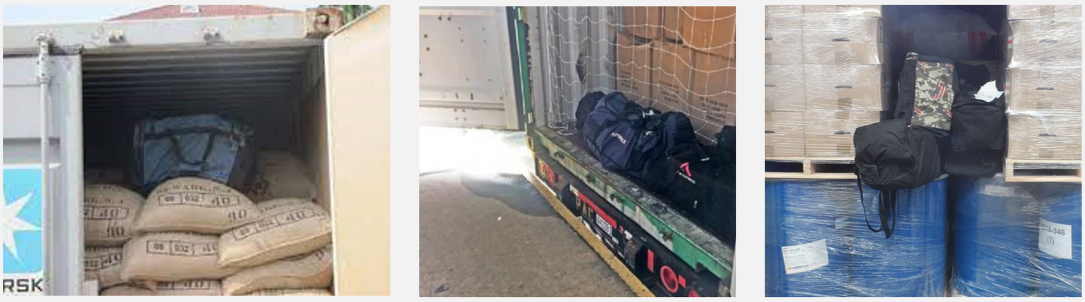


Figure A.3: Examples rip-off smuggling method

A.1.4 Ship construction

With the ship construction smuggling method criminals attach the illegal with the use of a construction at the outside of the container ship. A construction can for instance be the creation of a metal torpedo attached at the ship's propeller or the attachments of a metal box to the ship with the use of magnets. Examples of the ship construction method are shown in fig. A.4.

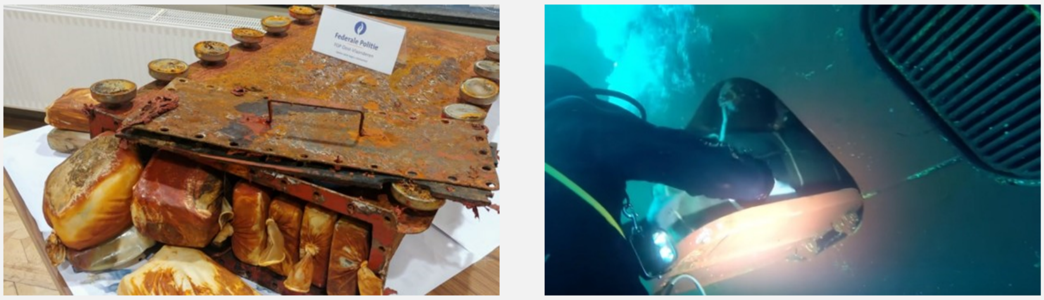


Figure A.4: Examples ship construction smuggling method

A.1.5 Washing

The chemical dissolution, or *washing*, of illegal products in other substances is a relatively new smuggling method (McDermott et al., 2021). The Dutch National Police got hold of multiple shipments in 2020 of illegal products which were dissolved in cardboard boxes, clothes and shampoo (Rechtspraak,2021; Politie, 2020a). Once the illegal products arrive in the Netherlands special *washing stations* regenerate the illegal products to their pure form. Examples of a washing station found in the Netherlands in 2020 are shown in fig. A.5. The washing smuggling method is expensive, because chemist have to be flown in from South America to the Netherlands, and the chemical retrieval process only retrieves around 80% of the original amount of illegal product.

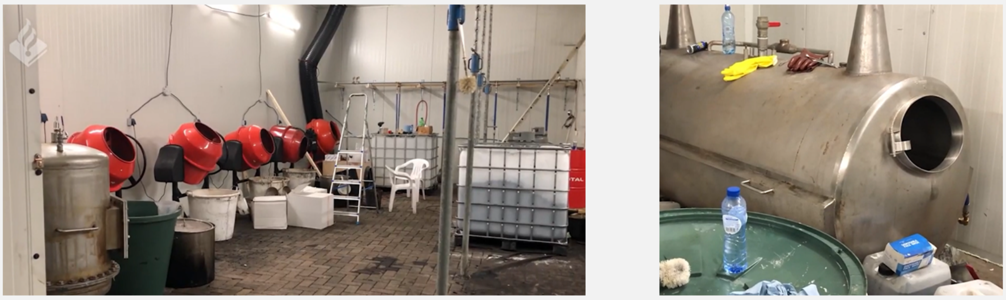


Figure A.5: Examples washing smuggling method

A.2 Other modality smuggling methods

Criminals use small standard transport modalities to transport their illegal products within South America or from South America to Central America, the Caribbean or Africa. The propeller planes, speed boats, trucks and sailing yachts are standard models bought up by criminals and used for small transportation. The submersibles however are produced by the criminals themselves. They construct (semi) submersibles to transport illegal products through the many available rivers in South America without being detected by local Police forces. The submersibles found in the recent year were built to contain 100 - 500 kg of illegal products. Two examples of submersibles intercepted by the Colombian Police forces are displayed in fig. A.6.

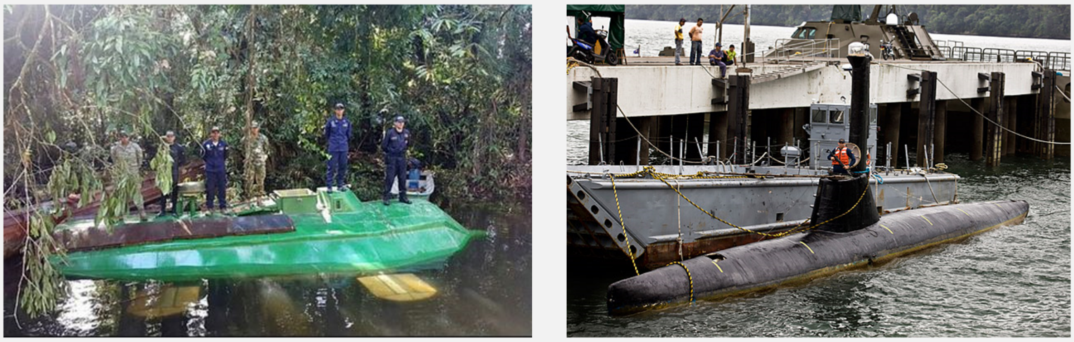


Figure A.6: Examples submersible smuggling method

B Risk quantification

This appendix describes the input data for the risk formula, shown in eq. (C.1). The specification of the variables is given in table 5.1. The four risk factors which are taken into account in this study are mutual trust, bribed (non) officials, route risk and smuggling risk. Every risk variable scales from 1 to 5. The indications describing the situation per risk variable are shown in fig. B.1. These indicators will be used when criminal supply chain scenarios will be implemented in the multi-objective optimisation model created in chapter 6.

$$R(i) = 2 * MT(i) + 2 * BO(i) + RR(i) + SR(i) \tag{B.1}$$

	Mutual trust	Bribes	Route risk	Smuggling risk
1	Working with direct family or 10+ years friends.	No need for bribing officials.	• Non checked routing: Africa, Asia. • No loading or extraction needed.	• Undetectable method: washing in substance unknown to police. • Shipping with non-fruit company.
2	Working with direct trustees of family or 10+ years friends.	Officials bribed in all ports.	• Checked routing: South or Central America. • No loading/ extraction needed.	• (Easy) detectable method: cover load, rip-off, ship/ container construction. • Shipping with non-fruit company OR no company needed.
3	Working with regular contacts, known for years.	Road bribes of (non) officials.	• Non checked routing routing: South or Central America. • Easy extraction: pin code fraud.	• (Easy) detectable method: cover load or container construction. • Shipping with triple A rated fruit company.
4	Working with contacts who proved themselves to be trustworthy.	Non-officials bribed in in all ports.	• Checked routing: South or Central America. • Easy extraction: pin code fraud.	• Detectable method: cover load or container construction. • Low rated fruit company.
5	Working for the first time with new barely known contacts.	No (non) officials bribed in ports on the transport line.	• Difficult loading or extraction.	• Easy detectable method: rip-off & ship-construct. • Low rated fruit company.

Figure B.1: Indications for the risk factor values

B.1 Risk matrices container-ship methods

This sections presents the risk matrices for the five different smuggling methods used during container ship transports.

	Mutual trust	Bribes	Route risk	Smuggling risk
1	Working with direct family or 10+ years friends.		• Non checked routing: Africa, Asia. • No loading or extraction needed.	
2	Working with direct trustees of family or 10+ years friends.	Officials bribed in all ports.	• Checked routing: South or Central America. • No loading/ extraction needed.	• (Easy) detectable method: cover load, rip-off, ship/ container construction. • Shipping with non-fruit company OR no company needed.
3	Working with regular contacts, known for years.	Non-officials bribed in in all ports.		• (Easy) detectable method: cover load or container construction. • Shipping with triple A rated fruit company.
4	Working with contacts who proved themselves to be trustworthy.			• Detectable method: cover load or container construction. • Low rated fruit company.
5	Working for the first time with new barely known contacts.	No (non) officials bribed in ports on the transport line.		

Figure B.2: Risk matrix for cover load method

	Mutual trust	Bribes	Route risk	Smuggling risk
1	Working with direct family or 10+ years friends.		• Non checked routing: Africa, Asia. • No loading or extraction needed.	
2	Working with direct trustees of family or 10+ years friends.	Officials bribed in all ports.	• Checked routing: South or Central America. • No loading/ extraction needed.	• (Easy) detectable method: cover load, rip-off, ship/ container construction. • Shipping with non-fruit company OR no company needed.
3	Working with regular contacts, known for years.	Non-officials bribed in in all ports.		• (Easy) detectable method: cover load or container construction. • Shipping with triple A rated fruit company.
4	Working with contacts who proved themselves to be trustworthy.			• Detectable method: cover load or container construction. • Low rated fruit company.
5	Working for the first time with new barely known contacts.	No (non) officials bribed in ports on the transport line.		

Figure B.3: Risk matrix for container construction method

	Mutual trust	Bribes	Route risk	Smuggling risk
1	Working with direct family or 10+ years friends.			
2	Working with direct trustees of family or 10+ years friends.	Officials bribed in all ports.		• (Easy) detectable method: cover load, rip-off, ship/ container construction. • Shipping with non-fruit company OR no company needed.
3	Working with regular contacts, known for years.		• Non checked routing routing: South or Central America. • Easy extraction: pin code fraud.	• (Easy) detectable method: cover load or container construction. • Shipping with triple A rated fruit company.
4	Working with contacts who proved themselves to be trustworthy.	Non-officials bribed in in all ports.	• Checked routing: South or Central America. • Easy extraction: pin code fraud.	
5	Working for the first time with new barely known contacts.			• Easy detectable method: rip-off & ship-construct. • Low rated fruit company.

Figure B.4: Risk matrix for rip-off method

	Mutual trust	Bribes	Route risk	Smuggling risk
1	Working with direct family or 10+ years friends.			
2	Working with direct trustees of family or 10+ years friends.	Officials bribed in all ports.		• (Easy) detectable method: cover load, rip-off, ship/ container construction. • Shipping with non-fruit company OR no company needed.
3	Working with regular contacts, known for years.			• (Easy) detectable method: cover load or container construction. • Shipping with triple A rated fruit company.
4	Working with contacts who proved themselves to be trustworthy.	Non-officials bribed in in all ports.		
5	Working for the first time with new barely known contacts.		• Difficult loading or extraction.	• Easy detectable method: rip-off & ship-construct. • Low rated fruit company.

Figure B.5: Risk matrix for ship construction method

	Mutual trust	Bribes	Route risk	Smuggling risk
1	Working with direct family or 10+ years friends.	No need for bribing officials.	• Non checked routing: Africa, Asia. • No loading or extraction needed.	• Undetectable method: washing in substance unknown to police. • Shipping with non-fruit company.
2	Working with direct trustees of family or 10+ years friends.		• Checked routing: South or Central America. • No loading/ extraction needed.	
3	Working with regular contacts, known for years.			
4	Working with contacts who proved themselves to be trustworthy.			
5	Working for the first time with new barely known contacts.			

Figure B.6: Risk matrix for washing method

B.2 Risk matrices other modality methods

This sections presents the risk matrices for the five different smuggling methods used during transport with different modalities than container ships.

	Mutual trust	Bribes	Route risk	Smuggling risk
1	Working with direct family or 10+ years friends.			
2	Working with direct trustees of family or 10+ years friends.			• (Easy) detectable method: cover load, rip-off, ship/ container construction. • Shipping with non-fruit company OR no company needed.
3	Working with regular contacts, known for years.	Road bribes of (non) officials.	• Non checked routing routing: South or Central America. • Easy extraction: pin code fraud.	
4	Working with contacts who proved themselves to be trustworthy.		• Checked routing: South or Central America. • Easy extraction: pin code fraud.	
5	Working for the first time with new barely known contacts.			

Figure B.7: Risk matrix for truck method

	Mutual trust	Bribes	Route risk	Smuggling risk
1	Working with direct family or 10+ years friends.			
2	Working with direct trustees of family or 10+ years friends.			• (Easy) detectable method: cover load, rip-off, ship/ container construction. • Shipping with non-fruit company OR no company needed.
3	Working with regular contacts, known for years.	Road bribes of (non) officials.	• Non checked routing routing: South or Central America. • Easy extraction: pin code fraud.	
4	Working with contacts who proved themselves to be trustworthy.		• Checked routing: South or Central America. • Easy extraction: pin code fraud.	
5	Working for the first time with new barely known contacts.			

Figure B.8: Risk matrix for propeller plane method

	Mutual trust	Bribes	Route risk	Smuggling risk
1	Working with direct family or 10+ years friends.		• Non checked routing: Africa, Asia. • No loading or extraction needed.	
2	Working with direct trustees of family or 10+ years friends.		• Checked routing: South or Central America. • No loading/ extraction needed.	• (Easy) detectable method: cover load, rip-off, ship/ container construction. • Shipping with non-fruit company OR no company needed.
3	Working with regular contacts, known for years.	Road bribes of (non) officials.		
4	Working with contacts who proved themselves to be trustworthy.			
5	Working for the first time with new barely known contacts.			

Figure B.9: Risk matrix for submersible method

	Mutual trust	Bribes	Route risk	Smuggling risk
1	Working with direct family or 10+ years friends.			
2	Working with direct trustees of family or 10+ years friends.			• (Easy) detectable method: cover load, rip-off, ship/ container construction. • Shipping with non-fruit company OR no company needed.
3	Working with regular contacts, known for years.	Road bribes of (non) officials.	• Non checked routing routing: South or Central America. • Easy extraction: pin code fraud.	
4	Working with contacts who proved themselves to be trustworthy.		• Checked routing: South or Central America. • Easy extraction: pin code fraud.	
5	Working for the first time with new barely known contacts.			

Figure B.10: Risk matrix for speed boat method

	Mutual trust	Bribes	Route risk	Smuggling risk
1	Working with direct family or 10+ years friends.			
2	Working with direct trustees of family or 10+ years friends.			• (Easy) detectable method: cover load, rip-off, ship/ container construction. • Shipping with non-fruit company OR no company needed.
3	Working with regular contacts, known for years.	Road bribes of (non) officials.	• Non checked routing routing: South or Central America. • Easy extraction: pin code fraud.	
4	Working with contacts who proved themselves to be trustworthy.		• Checked routing: South or Central America. • Easy extraction: pin code fraud.	
5	Working for the first time with new barely known contacts.			

Figure B.11: Risk matrix for sailing yacht method

Gain quantification

C

This appendix describes the input data for the gain formula, shown in eq. (C.1). The specification of the variables is given in table 5.2. First the transport cost is discussed, followed by a short explanation of the used wholesale price per kilo of illegal products provided by the United Nations Office on Drugs and Crime (UNOCD).

$$G(i) = MV_t(i) - TC_t(i) \tag{C.1}$$

C.1 Transport cost per scenario

Different modalities transport cost

The estimated costs for sending one shipment of illegal products via methods other than a container ship are displayed in fig. C.1. These costs have a high uncertainty. The employee costs are based upon conversations with the Police. The modality costs are my own rough estimation.

	Total cost	Modality cost	Employment cost	Other
Land (truck) (200 kg)	**$125.000**	Buy truck - $5.000	Drivers [2p] - $20.000	Bribe at border - $20.000
Speed boat (100 kg)	**$90.000**	Buy speed boat - $50.000	Drivers [2p] - $40.000	Bribe at harbour - $20.000
Sail yacht (300 kg)	**$440.000**	Rent sail yacht - $20.000	Sailors [4p] - $400.000	Bribe renting company- $20.000
Clandestine airplane (200 kg)	**$190.000**	Rent airplane - $20.000	Pilot [1p] - $150.000	Bribe renting company- $20.000
Semi submersible (400 kg)	**$4.600.000**	Build semi submersible - $1.000.000	• Builders [4p] - $400.000 • Crew [2p] - $200.000	Bribe at harbour - $20.000

Figure C.1: Estimated cost per shipment via different modalities

Container-ship transport cost

The estimated cost for sending one shipment of illegal products per container are shown in fig. C.2. Although the overall uncertainty of the displayed costs is high, some are more uncertain then others. The costs for the washing smuggling method are barely known at the Police.

Besides the costs shared with me during my conversations with the Dutch National Police it is relatively hard to find reliable numbers. A useful paper was published in 2020 by Erasmus student Richard Santvoord. He wrote a financial crime script on different types of smuggling methods used by criminals between South America and the Netherlands (Santvoord, 2020). A second useful source is the book written by NRC Handelsblad journalist Jan Meeus about the corrupt Dutch Custom officer Gerrit Groenheide (Meeus, Jan, 2019). In different conversations Police officers have told me the information provided to the public in the newspapers is from the same quality as their own intelligence. Therefore, the book by Jan Meeus can be used as a reliable source of information.

	Total cost	Cost before shipping	Cost at origin port	Cost at destination Port
Direct piggybacking, *50 – 500 kg*				
Rip-off (250 kg)	**$1.790.000**		• Loading [4p] - $40.000 • Bribe official - $350.000	• Extraction [4p] - $400.000 • Bribe official - $1.000.000
	$ 1.240.000		• Loading [4p] - $40.000 • Bribe non official [2p] - $100.000	• Extraction [4p] - $400.000 • Bribe non official [2p] - $300.000
Under/ in ship (50 kg)	**$755.000**	• Create torpedo - $5.000	• Loading [2 divers] - $100.000 • Bribe official - $350.000	• Extraction [1 fisher boat] - $300.000
	$605.000	• Create torpedo - $5.000	• Loading [2 divers] - $100.000 • Bribe non official [2p] - $100.000	• Extraction [1 fisher boat] - $300.000
Indirect piggybacking, *250 – 7.500 kg*				
Cover (1.000 kg)	**$1.373.800**	• Take-over company - $7.800 • Buy cover load - $10.000 • Transport cost 1 container - $6.000	• Bribe official - $350.000	• Bribe official - $1.000.000
	$823.800	• Take-over company - $7.800 • Buy cover load - $10.000 • Transport cost 1 container - $6.000	• Bribe non official [2p] - $200.000	• Bribe non official [2p] - $600.000
Washing (1.000 kg)	**$10.373.800**	• Take-over company - $7.800 • Buy cover load - $10.000 • Transport cost 1 container - $6.000 • Washing [3p] - $1.050.000		• Wash out products, washing loss around 20% – $6.300.000 (for 1000kg shipment) • Washing [3p] - $3.000.000
Container construct (500 kg)	**$1.373.800**	• Take-over company - $7.800 • Buy cover load - $10.000 • Transport cost 1 container - $6.000	• Bribe official - $350.000	• Bribe official - $1.000.000
	$823.800	• Take-over company - $7.800 • Buy cover load - $10.000 • Transport cost 1 container - $6.000	• Bribe non official [2p] - $200.000	• Bribe non official [2p] - $600.000

Figure C.2: Estimated cost per container ship shipment

C.2 Wholesale price per country

The wholesale price in US dollars of illegal products per kilo is retrieved from the database from the United Nations Office on Drugs and Crime (UNODC) (Caulkins, 2020). All countries are asked yearly to submit the wholesale prices of illegal products in their country. As presented infig. C.3, the last submission year of wholesale prices strongly differs per country. This is noted as an assumption in chapter 5. A PhD researcher at the Dutch National Police shared the submission of wholesale prices is a politic game between countries.

Country	Wholesale price [per kg]	Publish year
Argentina	$ 4800	2004
Belgium	$ 31609	2018
Bolivia	$ 2500	2018
Brasil	$ 8963	2011
Chile	$ 7980	2017
Colombia	$ 1654	2018
Costa Rica	$ 7300	2014
Dominican Republic	$ 8000	2017
Ecuador	$ 1800	2017
Germany	$ 50989	2018
Guinea	$ 20000	2006
Honduras	$ 15000	2018
Jamaica	$ 10211	2012
Netherlands	$ 29000	2021
Nigeria	$ 41465	2016
Panama	$ 4500	2018
Peru	$ 2000	2018
Puerto Rico	$ 11000	1997
South Africa	$ 20884	2018
Suriname	$ 4000	2002
Uruguay	$ 8000	2018
Venezuela	$ 4190	2006

Figure C.3: Wholesale kilo price of illegal products per country

D Model input data

The source countries, transit ports and arrival ports used in this study are retrieved from studies by, among others, the United Nations Office on Drugs (UNODC) and Insight Crime, an independent journalistic platform commissioned by the Dutch government to execute a research on the criminal supply chain from Latin America to the Netherlands (Caulkins, 2020; InsightCrime, 2020). The origin countries in South America are shown in table D.1, the arrival ports via which the illegal products enter Northwestern Europe in table D.2, and the transit ports via which the illegal products are shipped in table D.3.

Country	**Location name**	**Location type**	**Region**
Bolivia	farms_bolivia	farm_labs	South America
Colombia	farms_colombia	farm_labs	South America
Peru	farms_peru	farm_labs	South America

Table D.1: Origin locations of illegal products used in the MOO model

Country	**Location name**	**Location type**	**Region**
Belgium	port_of_antwerp	arrival_port	Northwest Europe
Germany	port_of_hamburg	arrival_port	Northwest Europe
Netherlands	port_of_rotterdam	arrival_port	Northwest Europe
Netherlands	port_of_vlissingen	arrival_port	Northwest Europe

Table D.2: Arrival ports used in the MOO model

Country	Location name	Location type	Region
Argentina	port_of_bahia	transit_port	South America
Argentina	port_of_buenos_aires	transit_port	South America
Brasil	port_of_belem	transit_port	South America
Brasil	port_of_fortaleza	transit_port	South America
Brasil	port_of_natal	transit_port	South America
Brasil	port_of_santos	transit_port	South America
Brasil	port_of_paraguana	transit_port	South America
Brasil	port_of_itajai	transit_port	South America
Brasil	port_of_rio_de_janeiro	transit_port	South America
Brasil	port_of_salvador	transit_port	South America
Brasil	port_of_recife	transit_port	South America
Chile	port_of_arica	transit_port	South America
Chile	port_of_antonio	transit_port	South America
Chile	port_of_coronel	transit_port	South America
Colombia	port_of_santa_marta	transit_port	South America
Colombia	port_of_buenaventura	transit_port	South America
Colombia	port_of_turbo	transit_port	South America
Costa Rica	port_of_limon	transit_port	Central America
Dominican Republic	port_of_caucedo	transit_port	Caribbean
Ecuador	port_of_manta	transit_port	South America
Ecuador	port_of_posorja	transit_port	South America
Guinea	port_of_conakry	transit_port	Africa
Honduras	port_of_cortes	transit_port	Central America
Jamaica	port_of_kingston	transit_port	Caribbean
Nigeria	port_of_lekki	transit_port	Africa
Panama	port_of_colon	transit_port	Central America
Panama	port_of_balboa	transit_port	Central America
Peru	port_of_callao	transit_port	South America
Peru	port_of_paita	transit_port	South America
Peurto Rico	port_of_san_juan	transit_port	Caribbean
South Africa	port_of_durban	transit_port	Africa
Suriname	port_of_paramaribo	transit_port	South America
Uruguay	port_of_montevideo	transit_port	South America
Venezuela	port_of_cabello	transit_port	South America

Table D.3: Transit ports used in the MOO model

Updated solution graphs

E

After the interventions tested in chapter 8 a recalculation took place of the solution set of the trade-off scenarios. The graphs representing the characteristics of the recalculated solution sets are shown in this appendix.

E.1 Updated solutions after Brazil-constraint

The graph representing transit distribution between the full data set and the recalculated solution set is displayed in fig. E.1. The graph representing the recalculated distribution of the smuggling methods is shown in fig. E.2. The smuggling method distribution has barely changed after the imposed intervention on shipments of Brazil and is largely similar to the smuggling distribution shown in fig. 7.4.

The route distribution after the Brazil intervention is executed in the Dutch ports is shown in fig. E.3. As can be expected the routing options with the most optimal balance between low risk and high gain have changed significantly in comparison with the solution set before the Brazil intervention. Also the use of the arrival ports has changed, more illegal products are shipped via Antwerp and Hamburg before transported to the Netherlands.

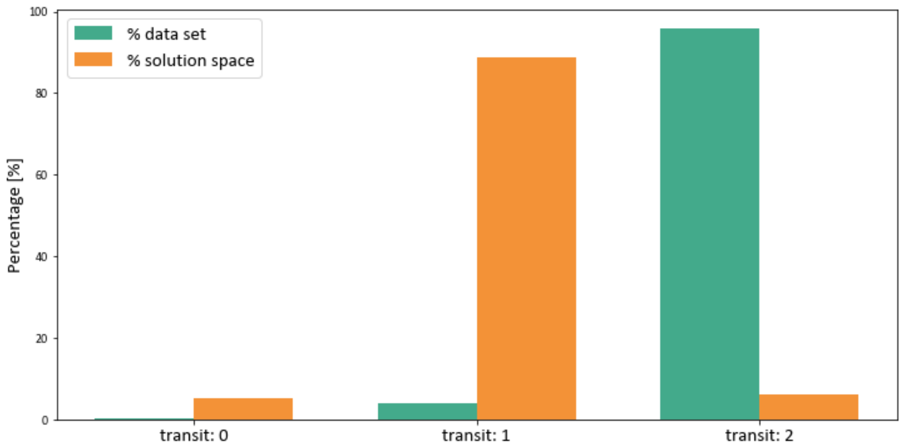


Figure E.1: Distribution of transits after Brazil focused intervention

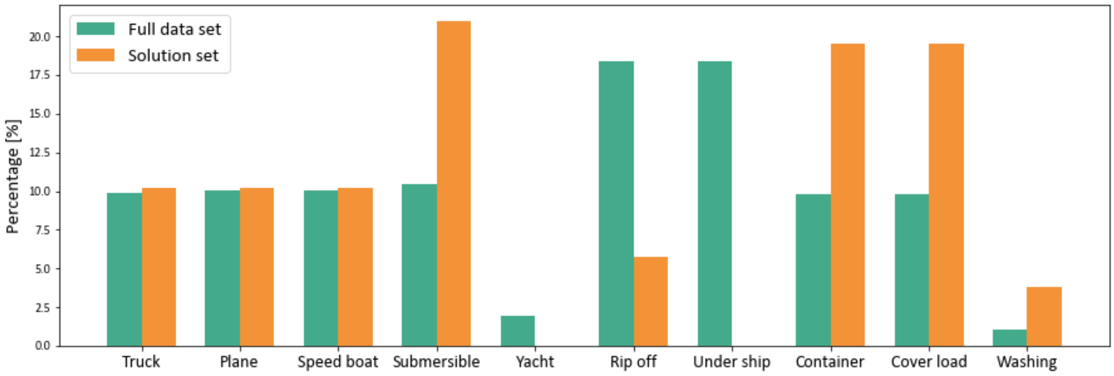


Figure E.2: Distribution of smuggling methods after Brazil focused intervention

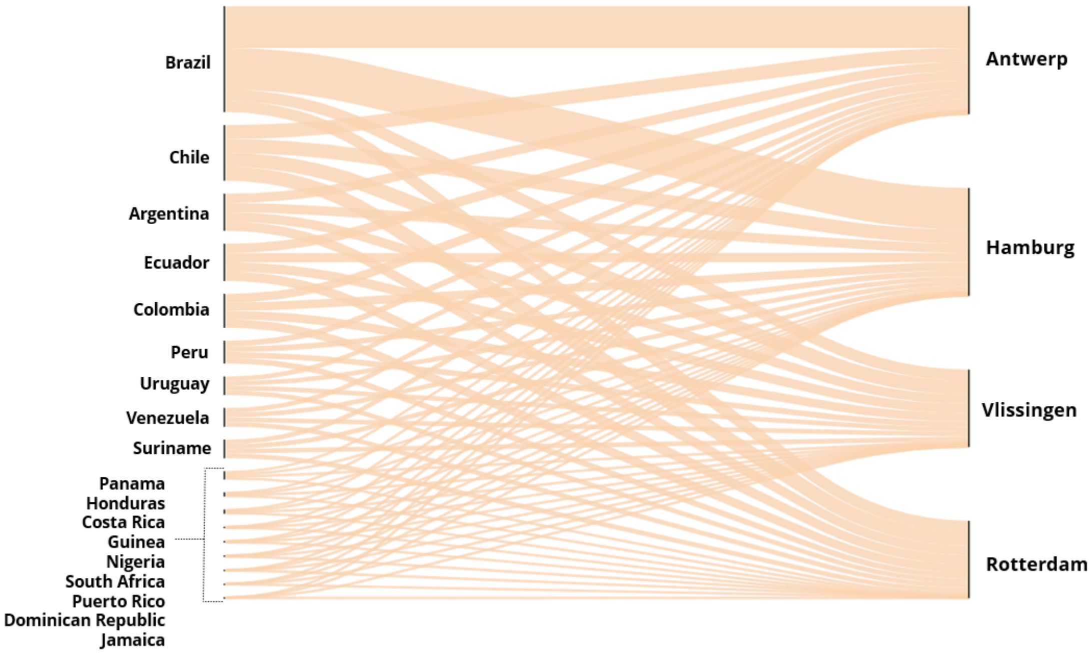


Figure E.3: Routing after Brazil focused intervention

E.2 Updated solutions after piggybacking-constraint

The graph representing transit distribution between the full data set and the recalculated solution set is displayed in fig. E.4. The graph representing the recalculated distribution of the smuggling methods is shown in fig. E.5. Although the smuggling methods entering the Netherlands via Rotterdam and Vlissingen have changed significantly from 40% indirect piggybacking to 20% indirect piggybacking, the percentage of the full solution set using indirect piggybacking has only changed sligtly. This is caused by the fact more shipments arrive in Hamburg and Antwerp, shown in fig. E.6, before the illegal products are transported to the Netherlands. The intervention focused on indirect piggybacking is only imposed in the Dutch ports. The waterbed effect flows towards other ports rather than other smuggling methods.

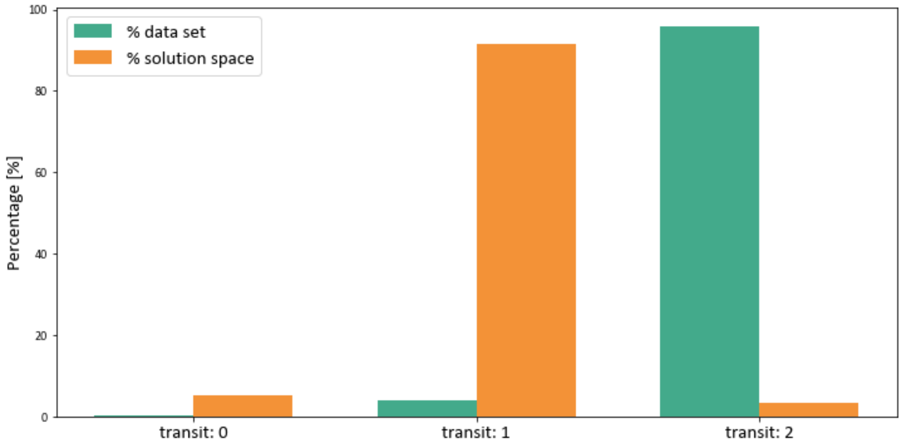


Figure E.4: Distribution of transits after indirect piggybacking focused intervention

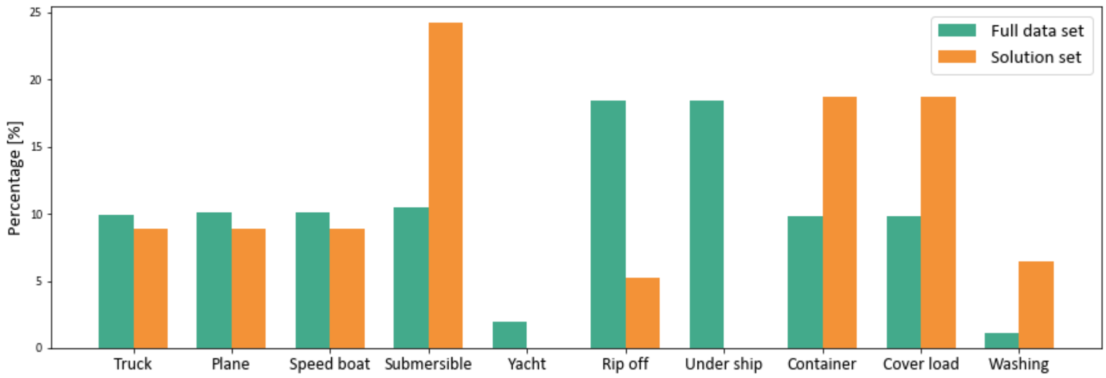


Figure E.5: Distribution of transits after indirect piggybacking focused intervention

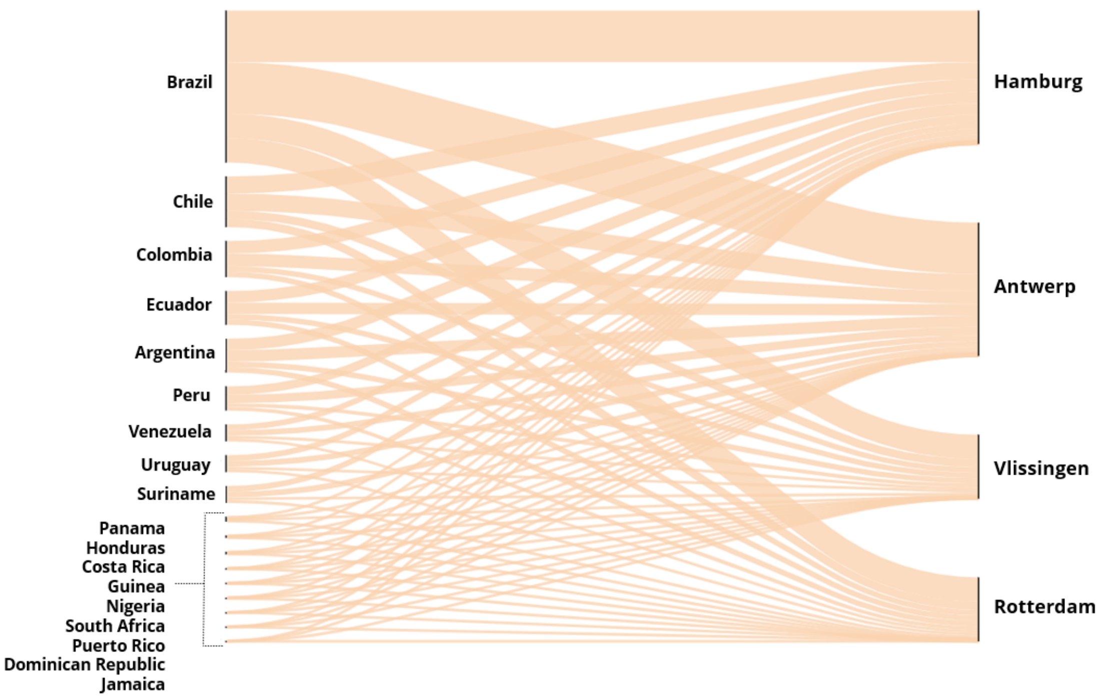
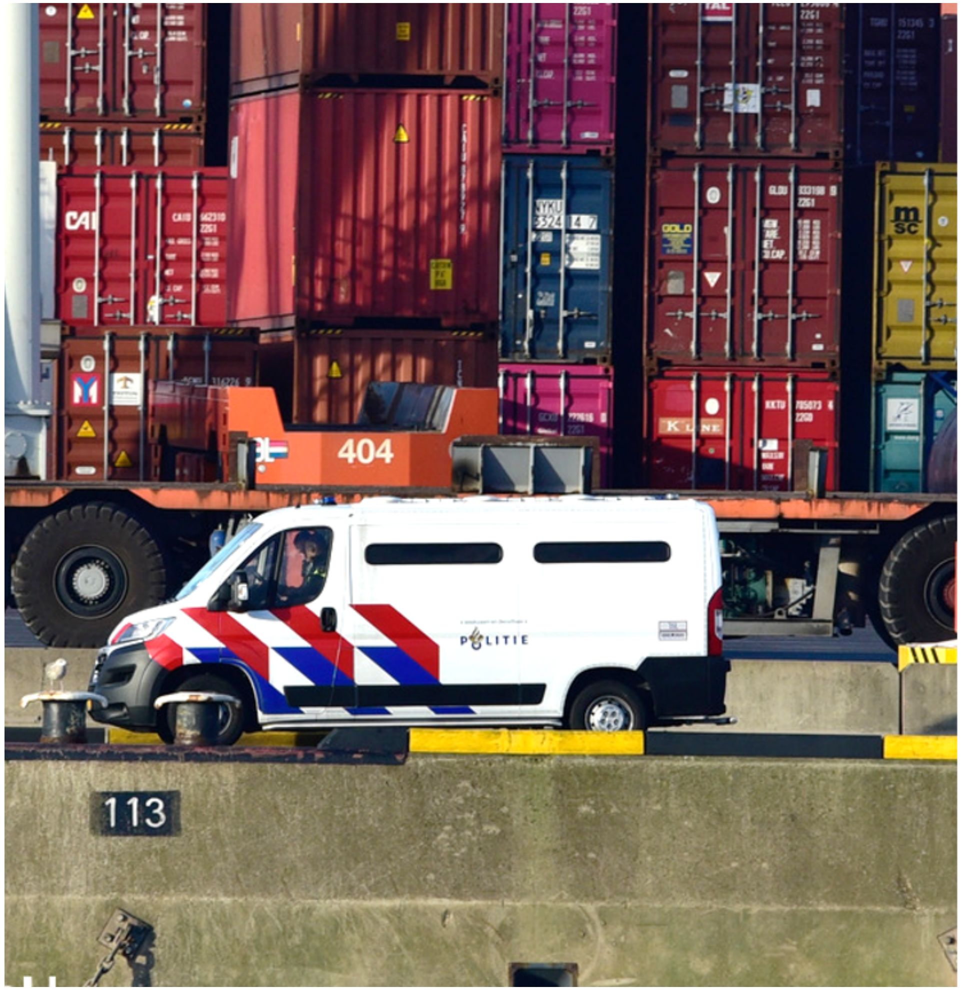


Figure E.6: Routing after indirect piggybacking focused intervention

F Explainability

The three sheets shown in fig. F.1, fig. F.2 and fig. F.3 display the 3-page handover document created for the operational officers of the Dutch National Police. A separate handover document is created for the tactical and strategic officers of the Police, which is similar to this thesis document. The second handover document uses Police specific terminology and contains confidential information. For this reason it is not included in the explainability appendix.



Criminele detectie van verdovende middelen

In samenwerking met het ICH (haven Rotterdam) en SOZ (haven Vlissingen) is door de TU Delft een computermodel gebouwd dat op basis van crimineel gedrag de transportlijnen identificeert met een vergrote kans op smokkel van verdovende middelen.

Bijdrage aan opsporing van illegale transporten

- Nieuwe invalshoek voor het opstellen van Douane risico profielen: het criminele gedrag.
- Van tevoren testen van de impact van interventies, waardoor de kleinste interventies met de grootse verstoringen worden bepaald.
- Visualiseren van waterbed-effect: waar naartoe verplaatsen de illegale transporten zich na een bepaalde interventie.

Informatieverzameling

11 interviews met analisten & officieren Landelijke Eenheid

2 interviews met voormalig foreign liason officers

9 Interviews met medewerkers regio Rotterdam & Zee-WBra

3 interviews met douane medewerkers

41 wetenschappelijke onderzoeken als literatuur

Figure F.1: Operational knowledge transfer document - 1

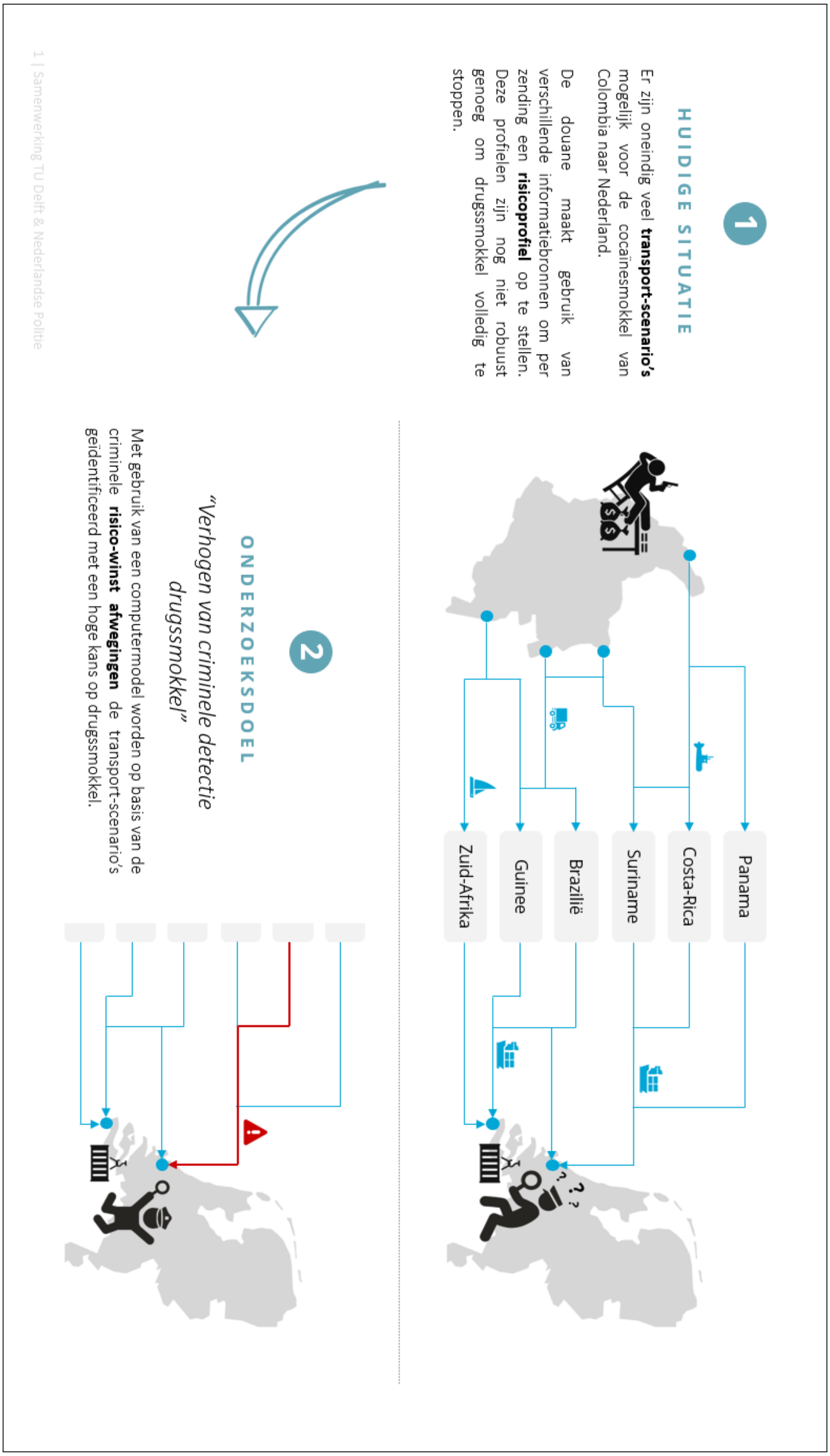
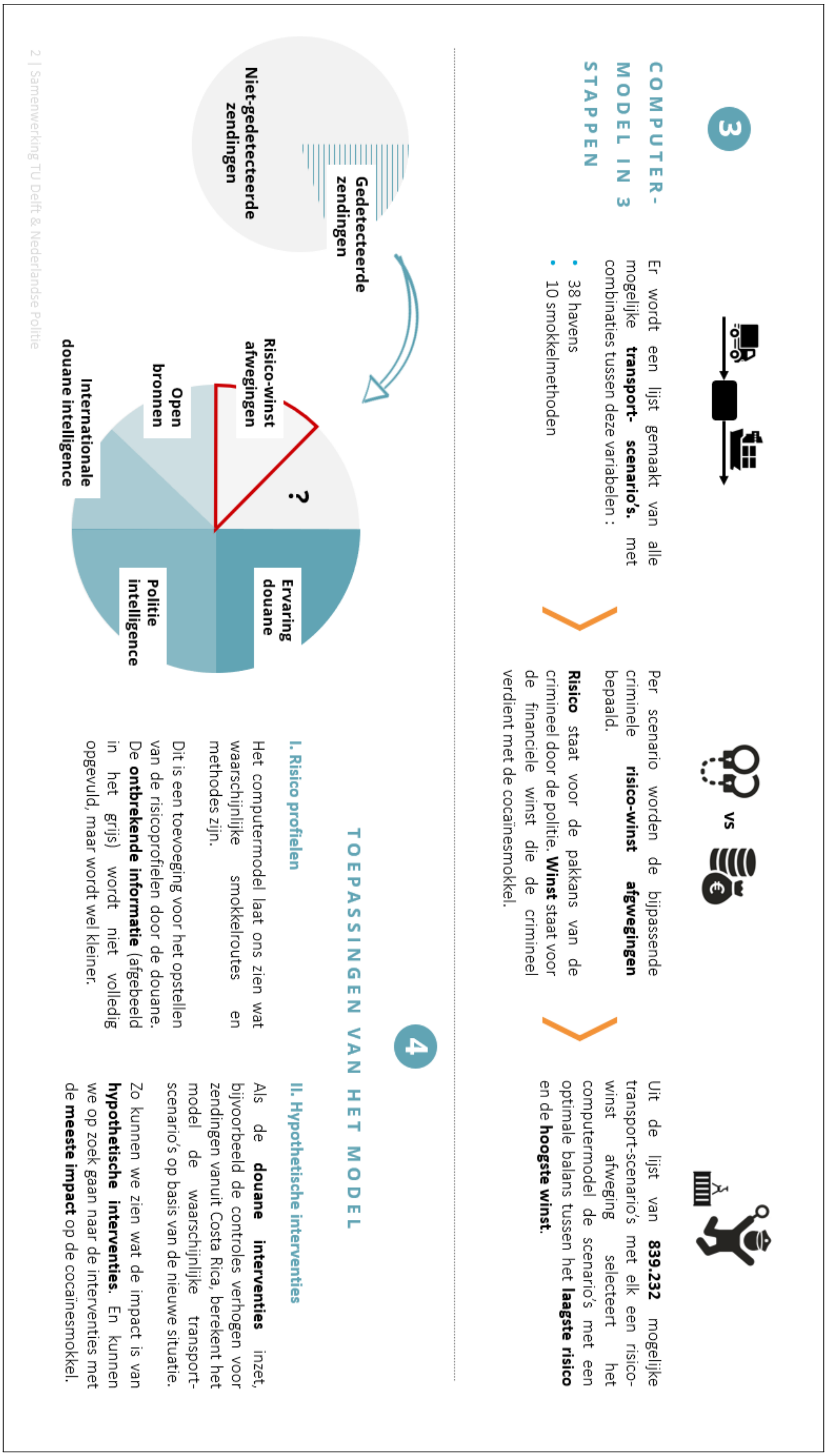


Figure F.2: Operational knowledge transfer document - 2



3

COMPUTER-MODEL IN 3 STAPPEN

Er wordt een lijst gemaakt van alle mogelijke **transport- scenario's.** met combinaties tussen deze variabelen :

- 38 havens
- 10 smokkelmethoden

Per scenario worden de bijpassende criminele **risico-winst afwegingen** bepaald.

Risico staat voor de pakkans van de crimineel door de politie. **Winst** staat voor de financiele winst die de crimineel verdient met de cocaïnesmokkel.

Uit de lijst van **839.232** mogelijke transport-scenario's met elk een risico-winst afweging selecteert het computermodel de scenario's met een optimale balans tussen het **laagste risico** en de **hoogste winst**.

4

TOEPASSINGEN VAN HET MODEL

I. Risico profielen

Het computermodel laat ons zien wat waarschijnlijke smokkelroutes en methodes zijn.

Dit is een toevoeging voor het opstellen van de risicoprofielen door de douane. De **ontbrekende informatie** (afgebeeld in het grijs) wordt niet volledig opgevuld, maar wordt wel kleiner.

II. Hypothetische interventies

Als de **douane interventies** inzet, bijvoorbeeld de controles verhogen voor zendingen vanuit Costa Rica, berekent het model de waarschijnlijke transport-scenario's op basis van de nieuwe situatie.

Zo kunnen we zien wat de impact is van **hypothetische interventies**. En kunnen we op zoek gaan naar de interventies met de **meeste impact** op de cocaïnesmokkel.

2 | Samenwerking TU Delft & Nederlandse Politie

Figure F.3: Operational knowledge transfer document - 3