Cocaine trafficking supply chain ODD

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1 Simulation ODD

This section shows the conceptual design of an agent-based simulation which models the cocaine supply chain. The conceptual model is written in Overview, Design Concepts and Details format (ODD) (Grimm et al. [3]). The model extends on a legal supply chain implementation Jalbut and Sichman [4] by modeling it within the domain of illegal cocaine trafficking in Europe. Small changes have been made in the decision making and information sharing within the agents. The model can show differences between a legal and an illegal supply chain.

1.1 Purpose

The purpose of this model is to give answers to the research question: *What is the difference between a legal and illegal supply chain?* The legal SC is the standard model. We create the illegal SC model by making two adjustments to the standard model. One adjustment is bade on trust relations, the other based on risk as these are both prominent factors in an illegal SC. A comparison of the results of both models will be used to answer the question.

1.2 Entities, state variables, and scales

The entities in the simulations are agents, countries, orders and shipments (Figure 1). They are divided in 5 levels in the SC: producers (P), internationals (I) , wholesalers (W), retailers (R) and consumers (C), based on Jalbut and Sigman [4]. *Producers* are their own suppliers and can decide their own production rate. The quality is fixed for a producer, either 40 or

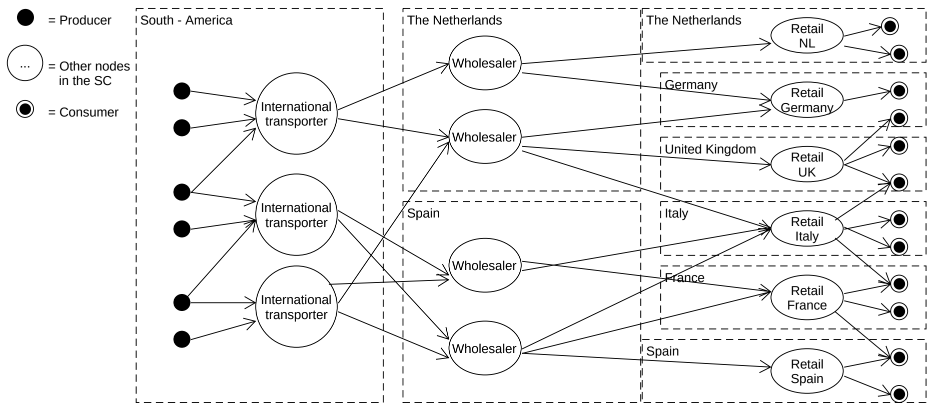

Figure 1: Simulation overview: showing the layout of the entities. Each arrow shows the direction of transport of the contraband.

60. The quality is dependent on cutting, according to Brosus et al. [2] this mainly happens at either the production stage or just after import in destination countries. The higher quality is sold for 20% more money. They have the lowest price per unit of the good. There is a maximum of producers, this prevents and overflow of the market. An overflow in the market makes it to easy to supply consumers. *Internationals* have the highest shipment quantities as they send their shipments overseas. *Wholesalers* have the option to convert high quality to low quality, for each high quality they have they get 1.5 low quality. Quality is purity and as an example 2 kg of 60 purity, would leave 3 kg of 40 purity. *Retailers* shipment quantity is the lowest as they send to the consumers. *Consumers* do not have clients as they consume the goods themselves. They have a fixed quality and consumption rate per tick. The consumers income is 1500 each tick. They are removed from the simulation when they cannot consume for a fixed amount of ticks. All the other agents are removed when they are bankrupt. The moment a node is removed all of its outgoing and incoming orders and shipments are removed.

Each of these agents contains the state variables given in Table 1. There are variables that need some extra explanation: each agent has a country of operation, the ScType indicates the type of agent. The Relation contains the concepts of a relation between supplier and client, it is a HashMap with the ID of the supplier or client and a Relation Class (C). The stock is represented as a HashMap that contains a Byte (B) indicating the quality of the good and a Double (D) indicating the quantity of the good. The *security*

State variable	Type
ID	Integer
Country	Class
ScType	Enum
RelationsS	HashMap<ID,C>
RelationsC	HashMap<ID,C>
Name	name
Sell price	Double
Min package size	Integer
Max package size	Integer
Security mult.	Double
Stock	HashMap<B,D>
Money	Double
Client cooldown	Integer
Supplier cooldown	Integer
Possible Suppliers	HashMap<ID>
Possible Clients	HashMap<ID>

Parameter	Value
Order step	3
Order learn rate	0.05
Shipment step	3
Late shipment penalty	0.5
Spawn rate	0.015
Produce amount	15
Consumer ticks remove	10
Living cost multiplier	5
Consumption min	0.5
Consumption max	5
Max number of suppliers	10
Max number of clients	10
Prob possible new min	0.1
Prob possible new mult	0.5
Quality minimum	40
Quality maximum	60
Quality extra cost	1.2

Table 1: Overview of state variables and parameters.

mult. influences the preferred stock with the expected demand. It acts as a multiplier, e.g. if the expected demand is 10 kg with quality 90 and the *security multiplier* is 2. Then the preferred stock is 20 kg with quality 90.

Table 2 shows the different agent types for each layer in the supply chain. The minimum and maximum sending sizes are roughly based on the schematic figure in Vermeulen et al. [5] (page 30). The different maximum package sizes are necessary for the supply chain to prevent a bottleneck at the wholesaler level. When there is an equal maximum shipment size (e.g. 10kg) a wholesaler with 2 suppliers (income of max 20kg per step) would not be able to provide for 3 or more retailers (they require 30kg per step). The minimum package size is 5% of the maximum package size, to prevent extremely small amounts of goods to be send which could not be realistic. Dealers who usually sell around 50kg would not bother sending 2 grams to a client or this would be a rare exception. The minimum sending size is 5% of the maximum percentage.

Layer (ScType)	Min shipment	Max shipment
0. Producer → itself	5	100
1. Producer → international	5	100
2. International → wholesale	25	500
3. Wholesale → retail	5	100
4. Retail → consumer	1	20
5. Consumer	-	-

Table 2: Default state variable for each agent in different layers

Money

The selling prices are based on table 1 in Basu [1]. For simplicity the prices are abstracted with selling price of cocaine bricks at 1 money unit per kilogram. Table 3 shows the price of Basu [1] and the simplified price, divided by 2,147. These lower numbers make it easier and more maintainable to experiment with the parameters in the simulation.

Supply chain stage	Price per kg	Price in simulation per kg
Production & refining	$ 800	≈ 0.35
Import (Mexico)	$ 2,147	1
Export	$ 34,700	≈ 16
Wholesale & retail (U.S.)	$ 120,000	Wholesale: ≈ 47 ($ 100,000)
		Retail: ≈ 53 ($ 120,000)

Table 3: Cocaine price at different layers in the supply chain.

The starting money is defined by the *sell price* $*$ *max package size* $*$ 5. Existing, costs money for the agents, or else the agents would be able to survive without participating in the network. The formula for per tick costs is: 0.01$*$ *max package size* + 0.01$*$ *goods quantity* $*$ *sell price*. Agents further to consumer level have to pay more for storage costs, since the European countries are more expensive than the originating countries.

Goods, Orders & Shipments

The goods are the things that are produced, transported through the supply chain and finally consumed. They are represented by a HashMap¡Byte, Double¿ in which the Byte represents the quality and the Double represents the quantity. The client sends an order, this will arrive *shipment step* ticks later at the supplier. The supplier retrieves the order and decides how much to send to the client, the supplier creates a shipment containing the goods. The shipment arrives after *shipment step* ticks and is accepted by the client who will pay the supplier (Table 4).

State variable	Type
Client	Class
Supplier	Class
Goods	HashMap<Byte,Double>
Steps left	Integer
Price	*Double*

Parameter	Value
Order step	3
Shipment step	3

Table 4: Parameters for orders and shipments, *italic* state variables are only for shipments

Countries

Countries are modeled to allow for matching data of cocaine prices and quality, differing levels of seizures and also to differentiate between transit countries (e.g. the Netherlands) and consumer countries (United Kingdom). The chain starts in Colombia, Bolivia and Peru which are the *producing countries*. From here *export countries* export the goods to the Netherlands and Spain which are transit countries for Europe (Vermeulen et al. [5]). From here the goods are transported to other European countries for consumption. Table 5 shows the countries. The retail price is based on data from the

Name	Layers	Purity
Producing	P	-
Export	I	-
NL	W, R, C	57.92
Spain	W, R, C	47,43
UK	R, C	41.44
Germany	R, C	42.76
France	R, C	50.81
Italy	R, C	52,89

Table 5: Default countries, with corresponding supply chain layers and purity based on EMCDDA data.

EMCDDA `http://www.emcdda.europa.eu/data/stats2018_en`. There is a difference in quality (or purity) found across countries in Europe. This difference is based on data by the EMCDDA[1] by taking the mean of the mean per year. This is represented in the table for each European country.

For simplicity the quality in the simulation is either 40 or 60, the probability of a consumer graving a certain quality is based on the mean of that country. Lower mean quality means a higher chance of graving 40, and vise versa. This is represented by the following formula where $quality_i$ is the quality for agent $i \in I$, $quality_c$ is the mean quality for the given country $c \in C$, p is a random number with $0 \leq p \leq 1$.

$$quality_i = \begin{cases} 40 & \text{if } p \leq (\frac{max(quality_{c \in C}) - min(quality_{c \in C})}{quality_c - min(quality_{c \in C})}) \\ 60 & \text{else} \end{cases}$$

Legal vs illegal

Trust

The clandestine nature of illegal trafficking makes clients and suppliers not openly visible. While legal suppliers and clients can usually be found through the internet or open commercials. The illegal SC members try to be as discrete as possible. The illegal SC model takes this into account by limiting the visible clients and suppliers. According to the vertical position of the agent y_i and a client or supplier y_j. Where *minimum probability* $\alpha = 0.1$, *probability multiplier* $\beta = 0.5$ and grid height $h = 50$. There is always one random supplier and one random client assigned to the agents possible clients and suppliers. The rest of the suppliers and clients are determined by the probability ρ, Equation 1.

$$\rho = max(\alpha, (1 - min(1, \frac{abs(y_j - y_i)}{h * \beta}))) \tag{1}$$

[1] `http://www.emcdda.europa.eu/data/stats2018/ppp` - Potency/Purity - Cocaine - Cocaine - Arithmetic Mean

Risk

One difference between the legal and illegal SC is the possible risk of getting caught by police. This is the case for participants in the illegal SC. Criminals have to wait for the right moment, where they have the right transportation available and when they can evade the police. They cannot send shipments all the time, even when they have enough stock. Therefore a shipment interrupt probability is introduced. It is set at 0.4, this means that there is a 40 percent chance in the illegal SC that an agent can send a shipment. If the agent cannot send a shipment the corresponding order is delayed and added to other delayed orders. The agent sends a shipment when there is no interruption and when there is a new order, this shipment will take all the delayed orders and the new order into account. The client will receive this shipment and compares this with the matching order (6 ticks back). The excessive quantity will be added to the received shipments with a penalty of 0.5.

Model scales

The spatial scale is international, agents reside in a specific country. The y-distance to other countries decides the possible suppliers and clients they can find, a higher probability for closer other agents. The temporal scale states that each tick is roughly a week.

1.3 Process overview and scheduling

The basic process in the model is based on the supply chain in Jalbut and Sichman [4]. The process is given in pseudocode in Algorithm 1.

1.4 Scheduling

The scheduling of the model is described by pseudocode in Algorithm 1.

Choose new suppliers and clients When an agent has more than the security stock for every quality and the *client cooldown* variable is 0, it will search for an additional client. This makes a client that gets sufficient supply search for a new client to be able to sell more.

Algorithm 1: Model schedule, based on [4]

foreach *tick* **do**
- *Agent:* Pay living cost & removal of bankrupt nodes
- *Country:* Spawning of new agents
- *Shipments:* Move one step further
- *Orders:* Move one step further
- *Agent (consumer):* Receive income
- *Agent:* Choose new suppliers and clients
- *Suppliers:* Receive orders **AND** send shipment to client
  Consumer: Consumes
- *Clients:* Send order to supplier
  Producer: Create a shipment for himself

end

Searching for a new supplier happens when one of the goods quantities is below the *minimum package size*.

Sending shipment The orders are analyzed and shipments are send according to the order. If a client asks for another quality, the supplier will start to order this other quality. The responsibility of sending is on the supplier side. The supplier makes the cost for sending, when the client receives it the client pays. The payment is done instantly, the client just pays the supplier the full amount, even if his balance is below zero.

Send order The sending of orders happens in the clients. The client calculates the required goods, by making a summation of the security stock and the previously ordered goods (by his clients). This summation is decreased by its current stock which leaves the final required goods. The clients then starts to send an order to its mostly trusted supplier. For sending orders the following function is applied.

$$\varphi_t = min(max\_ps, max(min\_ps, \lambda \cdot \psi_t + (1 - \lambda) \cdot \varphi_{t-1})) \tag{2}$$

Where φ_t is the required goods for time tick t, ψ_t is the required order amount, $0 \leq \lambda \leq 1$ is the learning rate and min_ps and max_ps are the *min package size* and *max package size* of the supplier. The formula represents the smoothing of orders, which smooths out the shipments over the supply chain. Client only request orders that are within the ranges of the package size of the suppliers.

1.5 Design concepts

Basic principles

The purpose of this model is to gain insight in cocaine trafficking supply chains, by comparing legal and illegal supply chains. The model combines a sociological model, economical model and criminal model into one.

Emergence

The agents in the supply chain find suppliers and clients to make revenue and survive. This micro level behavior should form a full working supply chain that supplies from producer to consumer. Dependent on the settings different types of networks could be formed, one could imagine a more clustered type of network when agents know fewer clients and suppliers.

Adaptation

The agents can change their suppliers when the suppliers do not deliver enough. This is based on the trust factor which is calculated from the history of interactions between the supplier and client. They can also find new clients when they have enough to send.

Objectives

The objective for the agents is to get the highest amount of payment through being able to supply the clients adequately while keeping stock low.

Learning

Trust is adapted over time by dealing with suppliers, this way the agents will learn which suppliers are reliable. The orders are influenced by a learning function that smooths the order quantity.

Prediction

The agents estimate the shipments needed based on the recent orders from their clients.

Sensing

The agents sense the incoming orders and shipments. They also know their possible clients and suppliers.

Interaction

The interactions between agents in neighboring layers are sending or receiving shipments.

Stochasticity

The consumption of cocaine, the possible clients and suppliers, and the spawning of agents is stochastically determined.

Collectives

A supply chain within the simulation could be seen as a collective.

Observation

The amount of cocaine that is transferred and the amount that has been consumed will be shown in graphs. The agents are shown and saved to data files as well, saving their coordinates, money, stock and connections.

It is more interesting to see the cumulative cocaine that has been imported in the country. Since a good supply chain does not keep much cocaine on stock, but rather processes the cocaine as quick as possible. Cumulative stock is only to be added when it gets into a different country, now it is added when it enters the Netherlands, then when it enters the retail and again when it enters the consumers which triples the amount of cocaine in the Netherlands.

1.6 Initialization

The initial state of the world is based on the parameters in table 1 and those in the simulation on GitHub. In the initialization phase the agents start with no stock (to get the supply chain going), a large amount of money, spawning is not allowed yet

1.7 Input data

The model does not use input data to represent time-varying processes.

1.8 Submodels

Trust

The trust in a supplier is modeled by comparing the ordered quantity with the received quantity. It is based on the trust implementation of Jalbut and Sichman [4]. The supplier, upon receiving an order, sends a shipment if he has enough stock. This shipment arrives a few steps later and is received by the client. The trust in the supplier is defined by the historical ratio between the orders placed and the shipment received (Eq. 3). In the formula i is the client, j the supplier, the current simulation step is denoted with n, S_{ji} is the shipment received and O_{ji} is the order send. The formula takes into account the time it takes to receive the shipment after sending an order, by mapping the shipments 6 ticks later.

$$Trust_{ij}(n) = \sum_{r=6}^{n} S_{ji}(r) / \sum_{r=1}^{n-6} O_{ij}(r) \tag{3}$$

Bigger shipments are compensations for previous missed orders, everything that is more than the ordered quantity will be penalized by the amount of *late shipment penalize*. When a client has two separate orders of 10 kg each, and he receives one order later but containing both, then it will be counted as 10 kg + 10 $*$ *late shipment penalize* kg. This will form 15 kg and gives a trust of 0.75.

When the agents in the simulation search for new suppliers and clients, they will choose suppliers with the highest trustworthiness.

The trust from supplier to client is defined as the time between the first order and now, thus the time they know each other. This trust will be $0 \leq Trust_{ij}(n) \leq 1$.

References

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