

A network model of the egg supply chain in Germany implemented as a FSKX compliant object

Petra Ganas[‡], Marcel Fuhrmann[‡], Matthias Filter[‡]

[‡] German Federal Institute for Risk Assessment (BfR), Berlin, Germany

Corresponding author: Petra Ganas (petra.ganas@bfr.bund.de)

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Abstract

In our days, food supply chains are becoming more and more complex, generating global networks involving production, processing, distribution and sale of food products. To follow the "farm to fork" paradigm when assessing risks from various hazards linked to food products, supply chain network models are useful and versatile tools.

The objective of the present "egg supply chain network model" is to allow users to predict and visualise the spatial commodity flow within the German egg supply chain. The network model provides for the user the option to select values for the input parameter "actor" in order to allow simulation of estimates for different supply chain scenarios. It generates a data frame as output regarding the estimates of food flows for the product "chicken eggs" in Germany on NUTS-3 level according to the selected parameter and a choropleth map for illustrating the distribution of product quantities.

The network model and all required resources are provided as a fully annotated file compliant to the community standard Food Safety Knowledge Exchange (FSKX) and can be executed online or with the desktop FSK-Lab software.

Keywords

Food supply chain network, Chicken eggs, network model, FSKX, FSK-Lab

Introduction

As food supply chain networks become global and increasingly complex, mathematical models and model-based simulations are getting more and more relevant for scientific research in general as well as for food safety risk assessments. Modelling of and on supply chains is therefore a domain of active research (Baranyi and Buss da Silva 2017, Horn and

Friedrich 2019, Jozwiak et al. 2016, Kaufman et al. 2014, Levi et al. 2019, Schlaich et al. 2020).

In this research food flow network models are useful tools to increase the transparency of food supply systems and are capable to reveal spatial linkages within the supply chain networks (Lin et al. 2019, Balster and Friedrich 2019). Moreover, visual analytics enables researchers to explore, interpret and communicate data more rapidly and effectively. Visualisation of food flow networks can provide important insights into the structure and dynamics of supply chains (Weiser et al. 2016).

This article describes a data-driven network model for chicken eggs in Germany ("egg supply chain network model") created to be easily applicable in supply chain visualisation and commodity flow prediction tasks.

To facilitate the easy application by end users, we generated a dedicated "egg supply chain network model" with only one input parameter "actor". Depending on the user-based selection for this input, the distribution of eggs handled by the defined actor will be calculated and integrated into an output data frame as well as displayed as a choropleth map (Torguson et al. 2008) by colouring the pre-defined areas in Germany on NUTS-3 level in proportion to the predicted product quantities within each region.

To allow efficient information sharing, this "egg supply chain network model" was designed such that it conforms to the Food Safety Knowledge Exchange (FSKX) format (Filter et al. 2019). This standardised file format was developed by the German Federal Institute for Risk Assessment to support harmonised annotation, encoding, application and sharing of models (German Federal Institute for Risk Assessment 2017). All data and metadata are stored in a FSKX compliant file allowing transparent and efficient access to the model as well as reproducibility of simulations and visualisations. The model file was generated with the software FSK-Lab (de Alba Aparicio et al. 2018, German Federal Institute for Risk Assessment 2020) and is available for download (Suppl. material 1). FSK-Lab is an open-source extension to the Konstanz Information Miner (Berthold et al. 2008) developed by the German Federal Institute for Risk Assessment. It enables KNIME users to work with FSKX models within KNIME.

Material and methods

Network Model

The described "egg supply chain network model" for Germany uses data derived from an a-priori generated "supply chain network data cube" that is provided as an integrated resource in the "egg supply chain network model". The "supply chain network data cube" was created at the German Federal Institute of Risk Assessment (unpublished). The present work doesn't focus on the implementation of the "supply chain network data cube", therefore only a brief description will be provided. Geodata for Germany are sourced from Eurostat (Europäische Kommission and Eurostat 2013).

The "supply chain network data cube" is an excerpt and reimplement of the dynamic freight flow model described by Balster and Friedrich (2019). Because it covers only the supply chain for the product "chicken eggs", the best fitting distribution for this product matching to the German federal transport infrastructure plan (FTIP) used to generate the network data cube refers to the published data of Balster (2019). This "supply chain network data cube" is represented as a directed graph with nodes and edges. Nodes have the following attributes: 1) actor: "Producer", "Wholesale", "Warehouse_brand", "Store_brand", "Consumer"; 2) product: "Eggs"; 3) location: names of urban and rural districts in Germany on NUTS-3 level with corresponding location ID (AGS, Amtlicher Gemeindeschlüssel). The 28 discrete brands for warehouses and stores are incorporated as separate actors. The edges contain the attribute for the quantities of eggs which are handled by the actors. Multi-regional input-output analyses as well as optimisation and gravity models implemented in Python (Van Rossum and Drake 2009) were used to estimate the quantities assigned to the nodes and edges for the multi-level egg supply network for Germany on NUTS-3 level (402 urban and rural districts).

The "supply chain network data cube" is based on the same data sources as the dynamic freight flow model described by Balster and Friedrich (2019) and therefore refers also to data from the year 2012. Details on the data sources can be reviewed in the original publications (Balster 2019, Balster and Friedrich 2019).

The "egg supply chain network model" compiles from the "supply chain network data cube" resource two data frames - "node data frame" and "edge data frame" - with its appendant information about actor, product, location and transported quantities of eggs.

In general, the model estimates and visualises the quantity of the product "Eggs" in tons per year per district in Germany on NUTS-3 level handled by the selected actor. Therefore, the two input parameters "product" and "actor" were defined within the model (Table 1). Because the underlying "supply chain network data cube" includes only the product "Eggs" the corresponding model parameter "product" is classified as "Constant". Regarding the parameter "actor" the end users can choose between the following options: "Producers", "Wholesale", "Warehouses", "Stores", "Consumers", "Consumers Wholesale", "Consumers Directsale", "Consumers Store" (Fig. 1).

By choosing "Producers" the model will estimate and visualise the production of eggs per district in Germany. For "Wholesale", "Warehouses" and "Stores" the quantities of eggs handled by each of these actors will be calculated and illustrated. With respect to "Warehouses" and "Stores", the corresponding 28 discrete brands, which are separate actors in the "supply chain network data cube", were aggregated in the "egg supply chain network model". In order to estimate and visualise the quantities of eggs handled by each individual brand, the user can select for the parameter "actor" values regarding warehouses and stores which are listed in Table 2.

The actor "Consumers" provides estimates and illustration of the total consumption of tons of eggs per year per district in Germany. In case it is of interest to assess and visualise the

egg consumption via specific sales channels, the user can select "Consumers Wholesale", "Consumers Directsale" and "Consumers Store".

The data frame generated by the "egg supply chain network model" code for the user-defined actor is merged by the model with the geodata data frame in order to allow visualisation with the integrated Python visualisation script. The result for the calculated distributions of eggs handled by the defined actor will be integrated into an output data frame defined by the output parameter "outputTable" (Table 1).

Simulations

FSKX compliant models allow to create and execute different simulation scenarios based on the defined input parameters. The model parameters are presented in Table 1. The simulation values of these parameters take account of product and actor involved in the food supply chains (Table 3). The default simulation is generated using the initial values provided for the input parameters. The values of the variable input parameters which are classified as "INPUT", like the parameter "actor", can be adjusted in order to create additional simulation scenarios. Values of parameters which are classified as "CONSTANT", like the parameter "product", cannot be modified.

Executable model

To be able to execute a model, you need to have an account registered with <https://data.d4science.org/>.

Read more [here](#).

In order to execute the model, please register at the [virtual research environment](#) and follow the steps described [here](#).

Execute with default simulation parameters: [execute](#)

Create a personalised simulation scenario: [execute](#)

The execution of the model with a personalised simulation scenario requires the Firefox Browser version 78 or higher.

Results

The "egg supply chain network model" provides tabulation and illustration of how the quantities of chicken eggs handled by a specified actor varies across the geographic areas in Germany on NUTS-3 level.

The primary outcome of the "egg supply chain network model" is a data frame with information about product, actor, location and calculated product quantities which geographically characterise the food flows in Germany.

In this regard, the model generates a CSV file (outputTable.csv) with the corresponding data, which is saved. When using FSK-Lab for model execution, this CSV file is automatically stored within the FSKX file after writing it out into a new FSKX file. Furthermore, the online execution of the model in the virtual research environment generates a FSKX file of the model available for download which also contains the CSV file. A second output of the described model is a choropleth map with a single-hue progression to depict the predicted egg quantities. The darkest hue represents the greatest value in the data frame and the lightest shade represents the least value. For the default simulation with the parameter actor "Consumers" the estimates of the "egg supply chain network model" show the highest amount of eggs consumed in the district Berlin, followed by other densely populated areas like Hamburg, Munich, Hanover, Cologne and Frankfurt on the Main (Fig. 2).

The simulation with selecting "Producers" as actor results in a map illustrating the regions with high egg production capacities, like district Vechta, followed by Osnabrück and Emsland, all located in the federal state Lower Saxony (Fig. 3).

Conclusion

The described "egg supply chain network model" allows calculation and illustration of the spatial resolution of the egg supply chain network in Germany on NUTS-3 level with regard to the different actors involved in this supply chain. Therefore, the model provides insights into the structure within the egg supply chain network as well as reveals spatial linkages between the corresponding actors. The model can be adapted to different end user needs by changing the parameter value for "actor". Because the underlying modelled "supply chain network data cube" is designed as an example network, the product "Eggs" is defined as a CONSTANT parameter right now. Provided that further products will be incorporated into the "supply chain network data cube", the food flows of these products can be analysed in future versions of this supply chain network model as well. Furthermore, if data sources will be used to generate the "supply chain network data cube" which refer to other time periods besides the year 2012, these updated data can be also analysed by the described network model. A restriction of the model is the fact, that the distribution of eggs per district in Germany can be estimated and visualised for only one actor per simulation setting. In order to perform calculations for several actors, different simulation scenarios can be created. Moreover, the network model conforms to the FSKX file format, storing all data and metadata in one file, which allows user-friendly re-execution and simulations in different software tools supporting the FSKX information exchange standard.

Author contributions

Petra Ganas - author and creator, Marcel Fuhrmann - author, Matthias Filter - author

Conflicts of interest

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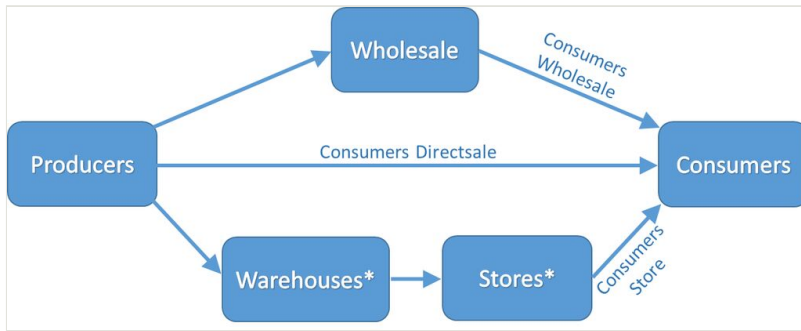


Figure 1.

Simplified schematic representation of the food supply chain network in Germany illustrating actors (indicated by boxes) and transport processes (indicated by arrows) according to the dynamic freight flow model from Balster and Friedrich (2019). *Regarding Warehouses and Stores: the respective 28 brands are implemented as aggregated and as individual actors in the "egg supply chain network model".

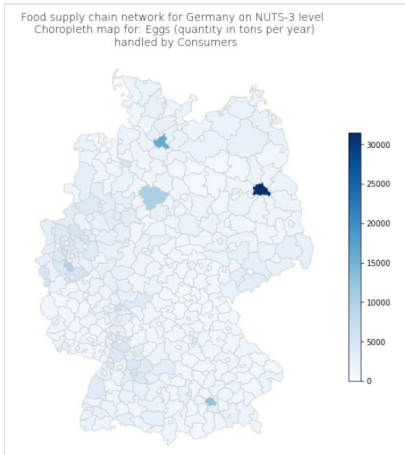


Figure 2.

Choropleth map for total consumption of the product "Eggs" (quantity in tons per year) in Germany on NUTS-3 level created by the visualisation script of the FSKX model .

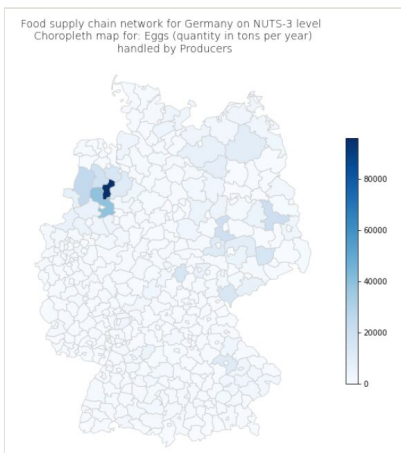


Figure 3.

Choropleth map for production of the product "Eggs" (quantity in tons per year) in Germany on NUTS-3 level created by the visualisation script of the FSKX model.

Table 1.

Model parameters defined within the "egg supply chain network model".

Id	product
Classification	CONSTANT
Name	product
Description	product defined in modelled supply chain network data cube
Unit	[]
Data Type	STRING
Source	Data
Value	"Eggs"
Id	actor
Classification	INPUT
Name	actor
Description	actors defined in the supply chain network data cube, which handle the product within the supply chains in Germany
Unit	[]
Data Type	STRING
Source	Data
Value	"Consumers", "Consumers Store", "Consumers Directsale", "Consumers Wholesale", "Stores", "Warehouses", "Who and stores (see Table 2)
Id	outputTable
Classification	OUTPUT
Name	outputTable
Description	data frame with data of product, actor, location name (districts in Germany on NUTS-3 level), AGS and calculated pr
Unit	[]
Data Type	MATRIX
Source	Model result
Id	outputTableFile

Classification	OUTPUT
Name	outputTableFile
Description	CSV file with data of product, actor, location name (districts in Germany on NUTS-3 level), AGS and calculated prod
Unit	[]
Data Type	FILE
Source	Model result

Table 2.

List of values for the parameter "actor" regarding the 28 individual brands of warehouses and stores. *Aggregation of the 7 regional subsidiaries of the Edeka Group to one actor.

Brands of warehouses	Brands of stores
"Warehouses Aldi Nord"	"Stores Aldi Nord"
"Warehouses Aldi Sued"	"Stores Aldi Sued"
"Warehouses Alnatura"	"Stores Alnatura"
"Warehouses Bartels-Langness"	"Stores Bartels-Langness"
"Warehouses Buenting"	"Stores Buenting"
"Warehouses Coop"	"Stores Coop"
"Warehouses Dennree"	"Stores Dennree"
"Warehouses Edeka Hessenring"	"Stores Edeka Hessenring"
"Warehouses Edeka Minden-Hannover"	"Stores Edeka Minden-Hannover"
"Warehouses Edeka Nord"	"Stores Edeka Nord"
"Warehouses Edeka Nordbayern-Sachsen-Thueringen"	"Stores Edeka Nordbayern-Sachsen-Thueringen"
"Warehouses Edeka Rhein-Ruhr"	"Stores Edeka Rhein-Ruhr"
"Warehouses Edeka Suedbayern"	"Stores Edeka Suedbayern"
"Warehouses Edeka Suedwest"	"Stores Edeka Suedwest"
"Warehouses Edeka" *	"Stores Edeka" *
"Warehouses Globus"	"Stores Globus"
"Warehouses Kaes"	"Stores Kaes"
"Warehouses Kaisers Tengelmann"	"Stores Kaisers Tengelmann"
"Warehouses Kaufland"	"Stores Kaufland"
"Warehouses Klaas & Kock"	"Stores Klaas & Kock"
"Warehouses Lidl"	"Stores Lidl"
"Warehouses Netto"	"Stores Netto"
"Warehouses Netto Nord"	"Stores Netto Nord"
"Warehouses Norma"	"Stores Norma"
"Warehouses Penny"	"Stores Penny"
"Warehouses Real"	"Stores Real"

"Warehouses Rewe Hit"	"Stores Rewe Hit"
"Warehouses Tegut"	"Stores Tegut"
"Warehouses Wasgau"	"Stores Wasgau"

Table 3.
Simulation settings based on the defined input parameters for the different simulation scenarios.

defaultSimulation	
product	"Eggs"
actor	"Consumers"
Simulation_Producer	
product	"Eggs"
actor	"Producers"

Supplementary material

Suppl. material 1: ChickenEgg-SCNM

Authors: Ganas, Petra

Data type: fsx model

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