DYNAMIC FREIGHT FLOW MODELLING FOR RISK EVALUATION IN FOOD SUPPLY

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ABSTRACT

The research presented in the paper defines a new dynamic model of food supply. The model includes 51 food categories including four different temperature ranges. It differentiates between the different actors in a supply chain: food producers, food retailers, wholesalers, logistics service providers, and the consumer. It works on an aggregate level of 402 regions within Germany as well as the most important trading nations. In the model, inventories for every food category, every group of actors, and every region are recorded in a single data cube. This data cube is recalculated incrementally every day, considering the production, relocation of food products, and consumption. Gravity models calibrated with data of the Federal Transport Plan generate the aggregate commodity flows between the regions. A detailed sectorial input output model for food is calculated for the year 2012 based on data from public authorities, food-related associations, and professional data providers.

Keywords: risk evaluation, simulation, German food supply, freight transport modelling

1. INTRODUCTION

This paper introduces a new concept of modelling dynamic commodity flows in supply networks. Where supply relations exist, commodities flow between locations from production via processing and distribution to the points of sale. These commodity flows are modelled for all supply relations of all companies of one specific sector on a national level. The dynamic aspect of the commodity flows is realized by modelling changeable relations between the different locations as well as by modelling the chronological sequence of production and transportation.

The modelling of dynamic commodity flows is necessary for the risk assessment of supply networks because in supply networks processing depends on the availability of preliminary products. If a supplying location fails or a connection gets disrupted, the affected actors in the supply network have to react in order to keep their production running. For example, commodity flows have to be rerouted, new connections have to be established, or safety stocks have to be used. The better a supply network can react to disruptions the more agile it is, lowering the risk of a supply shortfall.

The measurement of risk and agility is of growing importance because increasingly widespread supply networks are prone to specific kinds of risks. In addition, principles like lean, where amongst others safety stocks are reduced, are intensifying this need.

The concept of modelling dynamic commodity flows presented in this paper has the ability to meet this claim by mapping the agile supply network and its evasive reactions to disruptions on a detailed level. In the following sections, the concept is explained with a test case and first results are shown. The food supply sector in Germany is chosen as the test case. It is one of the most important sectors because it is the foundation for the life of the population. Since food supply shortfalls could endanger the lives of many people, risks have to be identified correctly and possible reactions have to be planed accordingly.

2. METHODOLOGY

The model consists of four tiers representing the supply chain: agricultural production, processing, warehousing, and consumption. It covers the German land area divided into 402 NUTS3-regions. In these 402 regions the most important stakeholders are aggregated. These are food producers, food retailers and wholesalers as well as logistics service providers. For the tiers agricultural production and processing, the relevant supplying regions are considered as well. The foods are categorised into 51 groups including four different temperature ranges, which represent the majority of the German food supply network from agricultural raw products like crops or raw milk to consumable foods like bread and pastries or cheese.

Since production, processing, warehousing, and consumption of food products are not taking place in the very same regions, the food products have to be transported between the regions while passing all four tiers. Transport within the tiers processing and warehousing is possible too, in case some foods are processed more than one time or the supply chain of a retailer has a hierarchic warehouse structure. The decision which region is supplying which region will be modelled with a gravity model for each food category.

In the model, inventories for every food category, every group of actors, and every region are recorded in a single data cube. This data cube is recalculated incrementally every day, considering the production, relocation of food products, and consumption (see Figures 1 and 2).

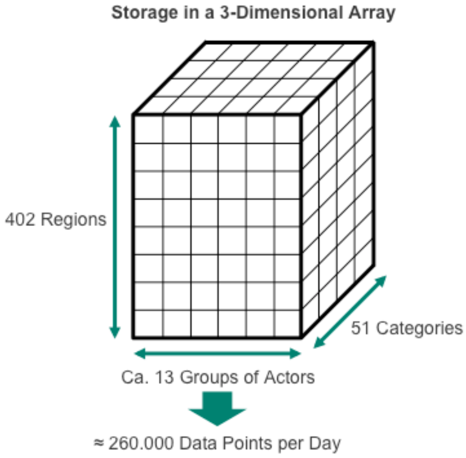

Figure 1: Dimensions of the Data Cube

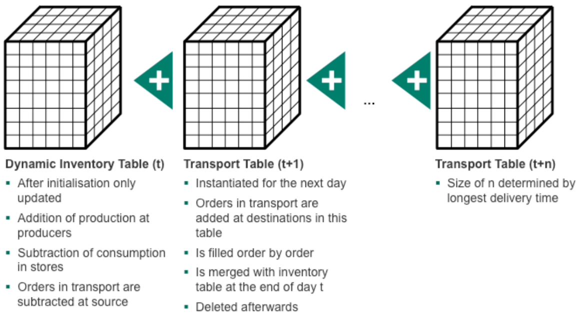

Figure 2: Interactions of Data Cubes for Inventories and Transports

The required data is collected for the year 2012 from the Federal Statistical Office, the Federal Ministry of Food and Agriculture, the Federal Ministry of Transport and Digital Infrastructure, food-related associations, and professional data providers. The gathered data and modelled processes are verified by interviews with experts from the production, logistics, and retailing sector. A model with more recent data will be possible, but it is important to consider only data from the same time period to get a consistent overall picture. Lots of data could be collected for the years 2013 and 2014, but especially national accounts are updating slowly and are still only available for 2012.

3. FINDINGS

So far, the data sources have been consolidated and aggregated to match 51 food categories. For each category the amount of metric tons produced, imported, and exported has been determined on a national level. In addition, the usage of the resulting amounts for consumption, other food products and other productions has been identified. The result is a detailed input-output-table for the German food sector.

In a second step, the consumption and production has been split from the national level to the 402 regions. While the consumption has been split up relative to the distribution of population, production has been split up by data from the Federal Ministry of Food and Agriculture as well as employment data.

Using the detailed regional production data and the results of the gravity model as well as an optimal interaction distribution the two average distances from the Federal Transport Plan for agricultural products and processed products could be detailed to all 51 food categories.

Combining all this with the data concerning the dates of harvest, processing and consumption, the level of stocks over time are calculated allowing statements regarding times of minimal stock and necessary minimum stock levels.

4. RESEARCH LIMITATIONS

The amount of data used in the model is a problem for different reasons. The gathering of data is complex and time consuming. Other issues are restrictions due to excessive time necessary for computing such big data, making model generation and visualisation with software tools difficult.

5. PRACTICAL IMPLICATIONS

The dynamic simulation of supply networks of single companies should be interesting for all supply chain managers. The dynamic simulation of a whole sector offers new insights to companies as a kind of market analysis. The main application of such dynamic sector model will be the national emergency preparedness. In this case, the public authorities will use the model to identify weaknesses in the food supply and take measures to improve the security and reliability of the food supply in Germany.

This is done using different scenarios, which can be integrated into the normal scenario of 2012. This enables predictions about stock levels in regions affected by disruptions. In addition, different measures taken by public authorities could be tested for their effects on stock levels and freight transport demand.

6. ORIGINALITY

A model is proposed, which uses system dynamics and operations research methods to show commodity flows in multi-level supply networks dynamically developing over time. It improves market and risk analyses and makes the assessment of agile networks possible.