ENVIRONMENTAL IMPACT OF GOODS TRANSPORT

WITH SPECIAL EMPHASIS ON AGRICULTURAL AND RELATED PRODUCTS;

Part 1: A Simulation Model for Goods Transport and Environmental Research, MODTRANS

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Content

Abstract

The current paper presents the assessment made on the environmental impact of goods transport with a special emphasis on agricultural and related products. The methods used were based on the concepts of system analysis and resource re-cycling. After conducting inventory assessments, a simulation model, MODTRANS, was developed to describe the transport system (both for collections and distributions of goods) and to predict emissions emanated from the vehicles used in the system.

1. Introduction

During the last decades, the relation between agriculture and population settlement obtained a new dimension in Sweden. The number of small scale farmers has been decreased rapidly and people moved to urban areas in searching for alternative jobs and today the farming community is about 4% of the Swedish population. The decrease in the number of farmers has not resulted in a decrease of agricultural production, on the contrary, agricultural production was increased significantly. Small scale farmings are transferred to large scale, specialized and centralized farms. In most of the farming communities, animal husbandry and crop productions are separated and far-away thereby minimizing the benefits that both sectors may have from each other if they could have been integrated. The crop production sector uses much more commercial fertilizer than animal manure. Today, in Sweden, the integrated farming (where crop production and animal husbandry are combined) is about 8% (Fig. 1) of the total system (SCB, 1995).

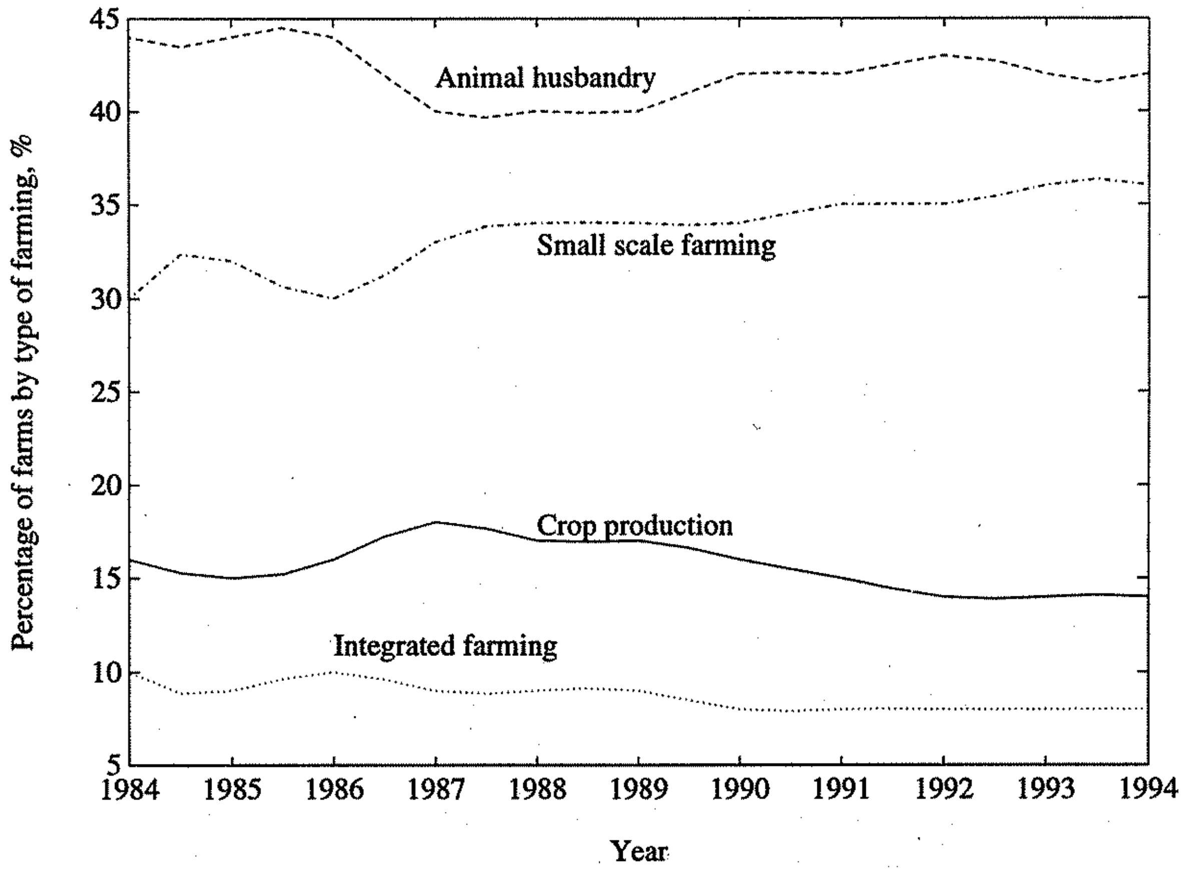

Fig. 1. Distribution of farms by type of production

The number of small scale farms is about 35%, while farms of animal husbandry and crop production are 43% and 14% respectively. Though the number of small scale farms is higher than that of the crop production farms, it's production is very low. Small scale farm is defined here as a farm that requires less than 400 standard working hours per year.

Material flows between the above mentioned production sectors are illustrated briefly in Figure 2. Fodder is transported both from industries (mainly located in urban areas) and crop production areas to the animal husbandry sectors. Processed foods including milk products, fertilizers, seeds, etc are transported from industries to crop production sector.

Millions of animals are transported from farms to farms and from farms to abattoirs. However, the portion of by-products from townships and manure from animal husbandry transported to be used as a fertilizer is very low. Most of them are remained as leakages causing negative effects on the environment.

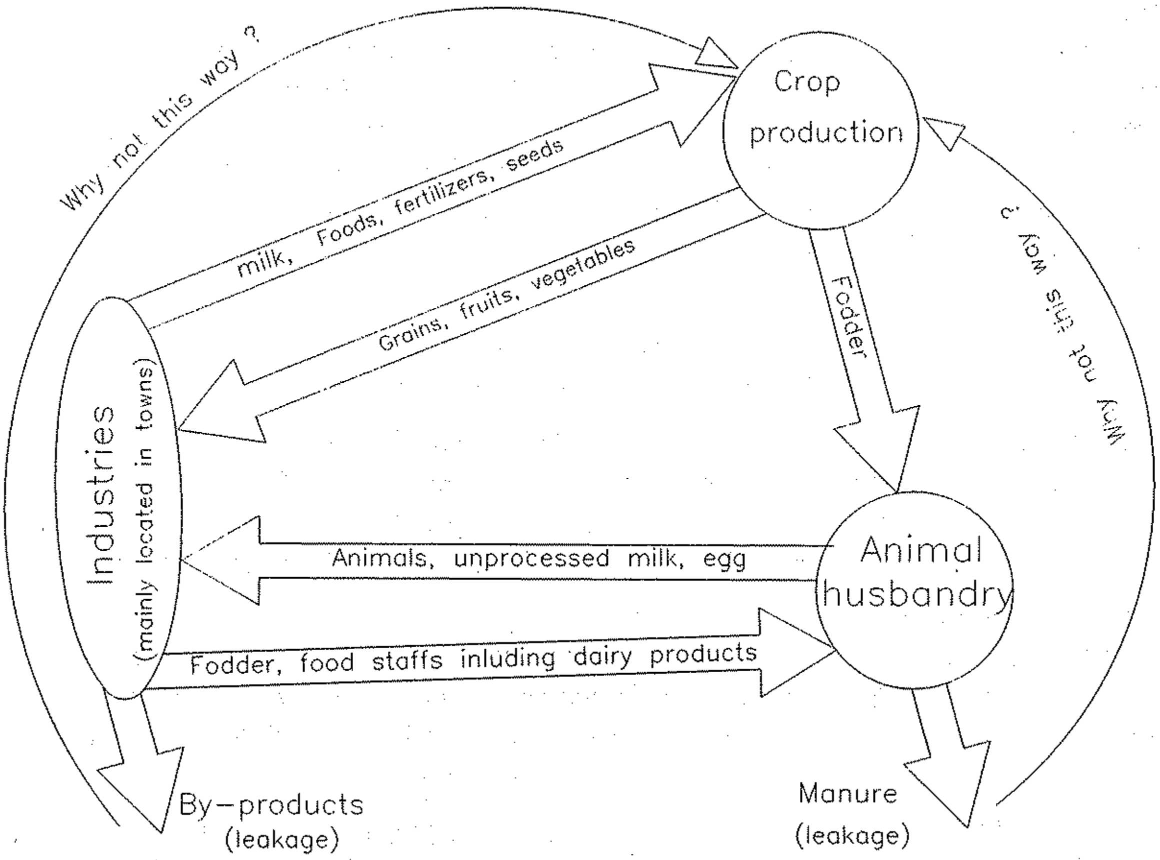

Fig. 2. The current situation of material flow, where resource re-cycling is minimized. The arrows represent transport and material flow

The current tendency of:

a) urbanization,
b) separation of crop productions from animal husbandry,
c) specialization of agriculture into large units,
d) far-away productions from consumers,
e) adequate infrastructure,
f) globalization of manufacture and trade and
g) relatively cheap fossil fuel

are associated with cheap and long range transportations, and thus transportation is substituting local production. Today, transportation of foods, agricultural products and fertilizer comprises about 15% of the total goods transport in Sweden (SCB, 1995).

An increase of transportation work has both negative and positive sides. Transportation is required to stimulate an economical development on one side and it brings negative consequences on a societal sustainability in terms of its contribution to the cause of environmental degradation on the other side. High emission levels from transportation causes unbalance in the ecosystem and are the major negative effects of the above structure.

Many researchers recommended that the problem associated with logistic systems may be tackled by optimizing the transport work, increasing the loading capacity of vehicles or increase the utilization level of the maximum capacity of vehicles and co-ordination of distribution system within the context of the existing and growing economic structure. There are also researchers who suggest that the transport dependency may be diminished through ruralization, i.e., closure integration of settlement with productions and at the same time integrate crop and animal productions. This may also enhance material re-cycling process and thereby promote societal sustainability.

2. Transport, economy and environment

Transportation is considered to be among the key stimulating factors of economic growth. Transport of goods (measured in tonne-kilometers) increased parallelling with an increase of gross domestic products (GDP) in many of the European countries (Fig. 3). It has been estimated that about 15% of GDP generated by business and industries is spent on transport of goods.

Though transport is an essential for the development of the economy of any country, it has been noted that the growth of transport should not be regarded as a simple and necessary consequence of economic growth (Commission, 1995). In some of the most industrialized countries, flow of materials through pipelines and the quick development and utilization of information technology is making the links between economic growth and transport of materials by vehicles more loosen.

However, in all less developed countries and in many industrialized countries, improvement of transport systems has a significant contribution to the growth of the economy. But, it also, at the same time, imposes pressure on the environment and society in general. Therefore, the proper balance between the transportation requirements to serve the economic development and to decrease the negative effects of transportation on our environment should be established to promote sustainable development. It may be worth to mention the emphases made by the World Commission on Environment and Development (1987) where it formulated the definition of a sustainable development. It stated that the current development should be designed to meet the needs of the present without compromising the ability of future generation to meet their own needs. This suggests that comprehensive studies should be carried out to search for a sustainable transport policy.

Comprehensive research works have been conducted on the traffic network systems and effect of transportation intensity on the environment as a whole. Though transportations of cereal grains, milk and animal from farms to industries, and distribution of foods, fertilizers, seed and fodder from industries to farming communities are about 20% of the goods flow in recent years, less attention has been paid to this sector. Limited studies were made at the end of 1970s and at the beginning of 1980 (Ottsson et al, 1976; Ottsso and Nilhag, 1981; Ottsson and Svensson, 1982) on the material flow to and from the agricultural sectors.

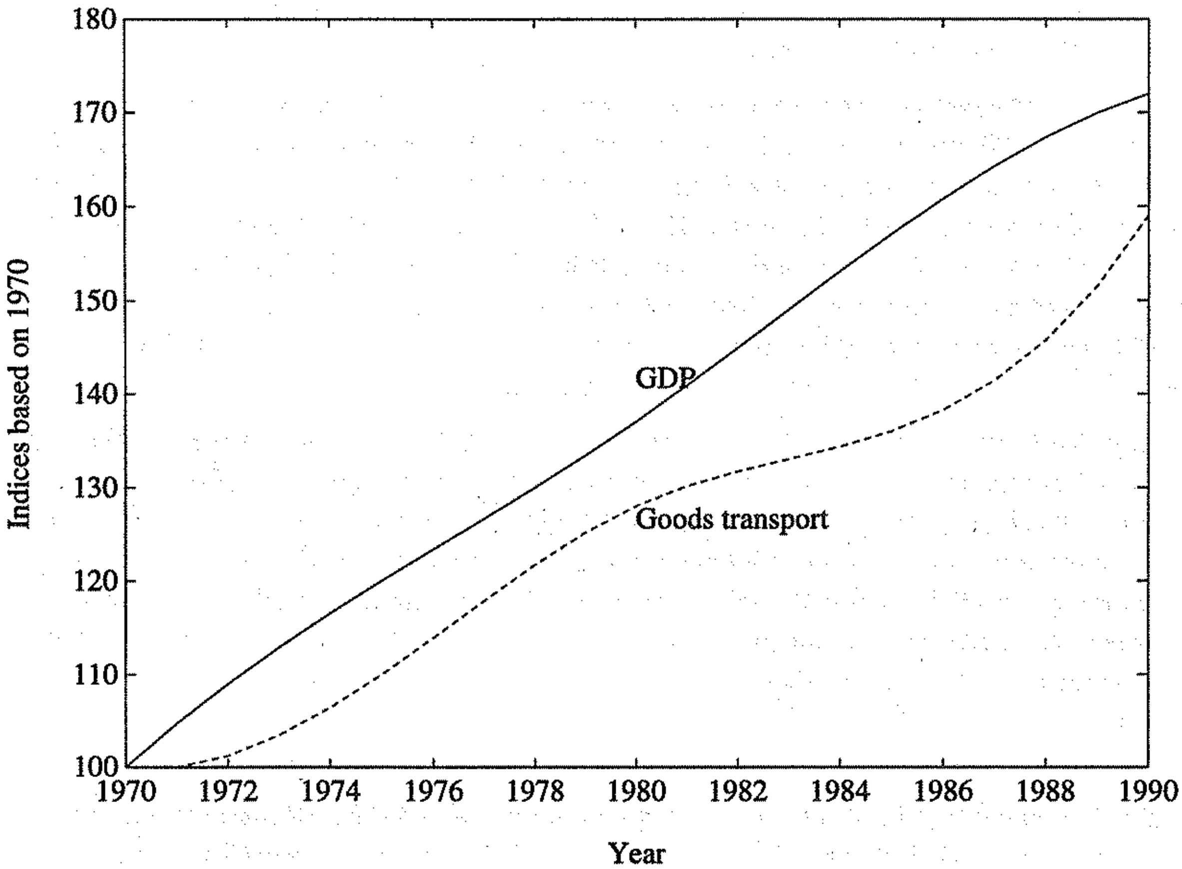

Fig. 3. Growth of goods transport in relation to gross domestic product (GDP)

Detailed studies and investigations are required to be conducted on the continuous functions of the distribution systems for the above mentioned goods in order to optimize the transportation system and design strategies to minimize its negative effect on the environment. The role of transportation in the entire system from field to table and back to the field should be considered. By optimizing transportation work and promoting material re-cycling processes, a societal sustainability may be strengthen.

3. Transport and pollution

Gaseous pollutants, such as oxides of carbon, sulphur and nitrogen (CO, SO_2, NO and NO_2), emanated from fossil fuels enter the atmosphere as a result of human activities including transport. About one to hundred million tonnes of these gases are emitted to the atmosphere every year (Manahan, 1993). These oxides are toxic gases and affect human health in several ways. The primary effects of air pollutants include toxic poisoning, causing cancer, birth defects, eye-irritations, irritation of the respiratory system, an increased susceptibility to viral infections, causing pneumonia and bronchitis, an increased susceptibility to heart disease and aggravation of chronic diseases (Botkin and Keller, 1995). Moreover, these pollutants induce disorder on plants by damaging leaves' tissues, fruits, reducing growth rate; and disrupting of reproductive process. They also pollute soil and worsen water quality.

Today, the atmospheric concentration of carbon monoxide is about 0.1 ppm. If this figure increases to 100 ppm (which is the case in urban areas) it may cause headache and dizziness. Loss of consciousness occurs at 250 ppm and further increase of concentration to 1000 ppm results in immediate death (Manahan, 1993). Since internal combustion engines are the main source of carbon monoxide emissions, attempts have been made in the last decades to decrease emissions of carbon monoxide by using catalytic exhaust reactors in such a way that CO oxides to CO_2. However, in developing countries, most of the vehicles are old and the number of vehicles equipped with catalytic reactors is extremely marginal.

In contrast to the pollutants mentioned above, carbon dioxide is among the constituents and essential components of the atmosphere because of its requirement for plants to carry out photosynthesis. However, carbon dioxide is considered to be a greenhouse gas and its increase in the atmosphere can devastate global warming. Carbon dioxides and other greenhouse gases, such as methane (CH_4) allow the solar radiant energy to penetrate to the Earth surface and also absorb infrared radiation emanating from it. CO_2 is responsible for about half of the atmospheric heat retained by trace gases (Manahan, 1993). Contributions of these gases to the enhanced greenhouse effect is given in Table 1.

Table 1. Concentration of the principal greenhouse gases in the atmosphere and their relative contributions to the global greenhouse effect (Source: Commission, 1995)

Gases	*Atmospheric concentration during 1750 - 1800*	*Atmospheric concentration 1990*	*Annual rate of change %*	*Contribution to greenhouse effect, %*
Carbon dioxide	280 ppm	353 ppm	0.5	65
Methane	0.8 ppm	1.72 ppm	0.9	20
Nitrous oxide	288 ppb	310 ppb	0.25	7
Tropospheric ozone	17 - 23 ppb	30 - 34 ppb	1 - 2	5 - 10

Manahan (1993) noted that an increase of CO_2 is associated with an increase of burning of fossil fuels on one side and deforestation (grass lands and forests converted to agriculture) on the other side, and therefore all CO_2 produced by industries and transport sectors can not be absorbed by plants. This resulted in an increase of CO_2 concentration in the atmosphere by 1 ppm per year.

It is estimated that if the production of CO_2 continues in the same rate, the concentration of CO_2 in the atmosphere may increase from today's 350 ppm to 600 ppm in the middle of the next century, and global warming may increase at the same rate, causing serious drought.

In many of the member countries of the European Union, about 20-25% of carbon dioxide emissions come from surface transport. It has been reported that only in the UK, emissions of carbon dioxide from road transport was almost doubled between 1970 to 1990, from 16 million tonnes to 30 million tonnes of carbon.

To estimate the contribution from the agriculture transport sector, it may be worth to look into the amount of agricultural products in relation to other goods. The statistics from each EU member country (CBI, 1992) indicate that 11% to 30% of the goods transported by road transports are agricultural products, foodstuffs, animals, fertilizer and fodder (Table 2).

Table 2. Percentage of transported agricultural products, foodstuffs, animals, fodder and fertilizer (natural and commercial) in relation to total goods transported per year using different modes of transport in some of the EU countries

Country	*Mode of transport, %*			
	Road	*Rail*	*Inland waterways*	*Total*
Belgium	22.9	3.7	18.7	17.2
Denmark	29.3	21.2	-	29.1
France	23.6	21.3	19.1	23.2
Germany	11.9	7.5	11.1	11.3
Greece	14.5	22.8	-	14.7
Irland	30.8	20.5	-	30.4
Italy	n/a	13.6	-	13.6
Luxembourg	10.6	4.2	20	10.5
Sweden	18.3	4.4	n/a	15.7
The Netherlands	31.5	14.8	14.8	24.3

4. Transport of animals

Transportation of animals in Sweden is increasing at a high rate. During transportation, the animals are subjected to vibration, noise, handling during loading and unloading process, transport length, moisture and temperature variations. They also feel discomfort due to change of a social group and density of the animals to be transported (Fig. 4) . All the fore-mentioned unpleasant factors cause severe stress on animals, resulting in compromising of animal welfare, substantial decrease of meat quality in terms of DFD or PSE (DFD is dark, firm and dry meat and PSE is pale, soft, exudative meat) and death of animals during transportation. The estimated total economic loss due to the mentioned consequences is about 40-60 million Swedish crowns per year and out of this 6-10 million is due to mortality (Olsson, 1986).

The other important point to mention is the problem associated with emissions. The current transport system is powered mostly by combustion of fossil fuels. Wide ranges of assessments were made on the significance of emission from the transport for human and the environment. There is a clear awareness to reduce air emission from road vehicle using various methods, such as reducing fuel consumption or improving fuel efficiency, searching for alternative fuels, and optimizing transport systems.

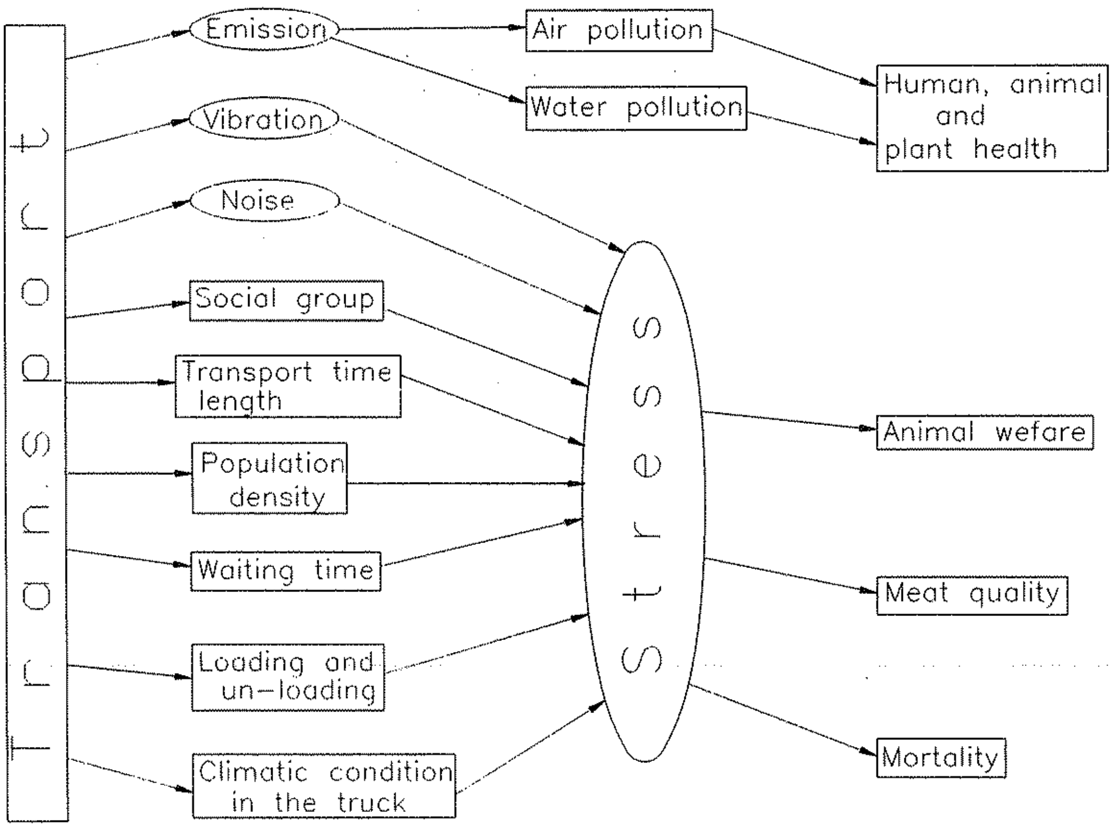

Fig. 4. Effects of transport on animal welfare, meat quality, human and plant health

In Sweden, due to the significant increase of transport work in the course of collecting animals from several farms and delivering to the abattoirs, emissions from the vehicles became one of the current central concerns of the Swedish society. However, less attention has been paid to the assessment on the contribution of goods and animal transportation to and from the agricultural sector. This necessitates to conduct research to study the system in detail and optimize the transport works of agricultural products with aim of reducing emissions, to reduce stress on the animal and thereby improving animal welfare, increase meat quality and decease mortality of the animals.

5. Responsibility of a transport sector and the current demands of the society

Nowadays, the environmental issues related to transport systems are receiving awareness from societies as a whole and particularly from environmental related peoples' movements, research institutions and other governmental organs. The arguments for why transport should be reduced are as follows.

a) Limited amount of fossil fuel and the rate of exploitation is very high;
b) Rates of increase of emissions from vehicles are very high and this may devastate our environment;
c) Negative effect of adequate and relatively cheap transport on the recycling processes of natural resources by promoting large, specialized and centralized production rather than small scale local production;
d) Life-hazards caused by transportation;
e) Long range transportation decreases quality of the transported foods.

The current general demands from our societies are to:

- increase life quality,
- resource conservation,
- environmental oriented or environmentally adapted transportation system,
- promotion of re-using system,
- promotion of small scale production system,
- decrease transportation work,
- decrease emissions and energy consumption,
- develop alternative means of transportation,
- alternative energy sources for transportation,
- structural changes in relation to: planning of production and distribution of goods, and
- increase the awareness and knowledge on the environment.

The basic requirements from the goods transport sector are:

(a) transporting of goods/products to the required destination in time;
(b) maintain quality of products;
(c) minimum damage to the environment.

6. Objectives

The objective of the present work is to study the transportation system of agricultural products, foods, animals and other agricultural related goods, such as commercial fertilizers and fodder in relation to energy requirement and environmental impact. The specific objectives are to determine emissions and transport works for each type of goods when moving from field to table and back to field. The ultimate goal of the study is to contribute to the:

a) promotion of resource re-cycling processes,
b) optimization of transport work, and thereby
c) increase societal sustainability.

7. Methods

The method of the present work is based on the concept of system analysis and resource re-cycling. After deciding the system boundaries, the work commences with various pilot projects to conduct inventory investigations (study visits, literature study, data collections). The inventory assessments allowed to developed a conceptual model. Based on the assessment made and the conceptual model, the computer based simulation model, MODTRANS, of the transportation system of food and agricultural products in relation to energy and environment. The simulated experiments were evaluated in terms of:

a) environment,
b) food quality,
c) safety,
d) energy,
e) economy, and
f) time.

8. Model development

8.1. Inventory assessment and conceptual models

Inventory assessments have been made by visiting various farms, relevant companies (transport companies, abattoirs, wholesale dealers) and by conducting a literature review. During the inventory assessments, the following points were taken into consideration.

a) Transportation routes (transports and distances between farms and industries).
b) Quantity of goods (cereal grains, vegetables, fruits, milk, fertilizers, fodder, seeds, etc) to be transported per day, per month, and per year.
d) Number of trucks used per commodity per unit time.
e) Amount of loads per truck in relation to the maximum loading capacity.
f) Cost per unit distributed load per truck from source to destination.
g) Cost per unit distributed load per truck in relation to

the total price of the unit
h) Transportation time between source and destination and speeds of vehicles.
i) Energy consumption and its relation to the energy required to manufacturing, processing, packing, etc
j) Air emissions per truck, per trip (and emission per unit commodity).

The inventory assessment included also the handling activities, such as:
a) loading and unloading processes at the industries,
b) loading and unloading processes at farms,
c) distribution processes,
d) storing and processing possibilities of each farm.

Based on the findings of the inventory assessments and literature review, conceptual models were developed to depict the material flow between various sectors (Fig. 5).

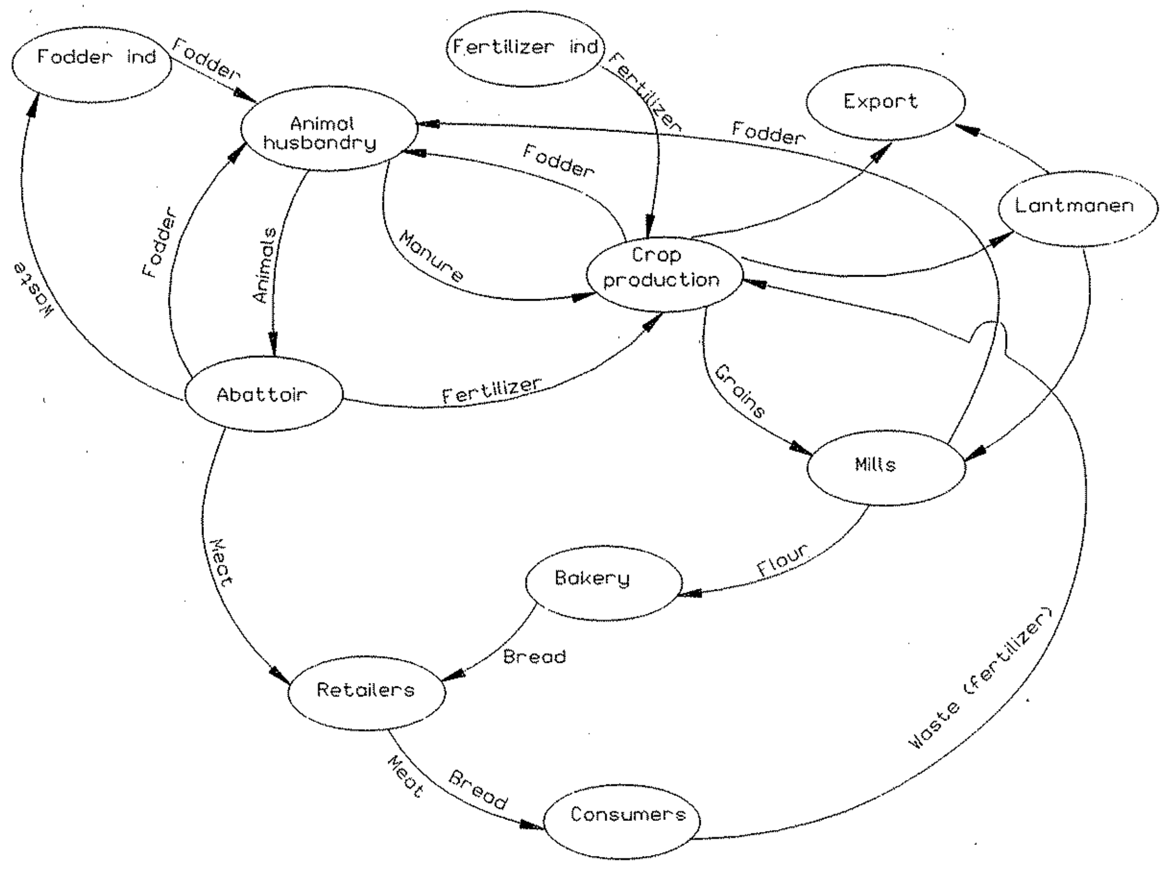

Fig. 5. Material flow between various sub-sectors and re-cycling process

8.2. Simulation model, MODTRANS

The simulation model, MODTRANS, has been developed based on the principles of system analysis and resource re-cycling concepts, using the Matlab/Simulink (MatWorks, 1991) software programme to study and evaluate the environmental impact of goods transport in the agricultural sector.

Simulink is an extension to the Matlab programme which can be used to simulate dynamic systems. It has a library of various blocks with specific functions and these block are used when developing a specific model by choosing the required blocks and connecting them by drawing lines between the blocks. The internal parameters of the blocks can easily be changed to the desired parameters or expressions (for detailed information see Simulink guide manual, 1992).

Using the Simulink/Matlab software, an hierarchic model structure was constructed (Fig. 6). Figure 6 shows the different levels of the model where each level contains more detailed information than the preceding level. The highest level depicts general information, showing the main transportation flows and different actors in the system. The lowest level contain the most detailed information and the actual computations are carried out at this level. Once the model is built, the number of levels can easily be changed at any time, making it possible to expand the model. It is possible to simulate any single sub-model without interference from the other model components.

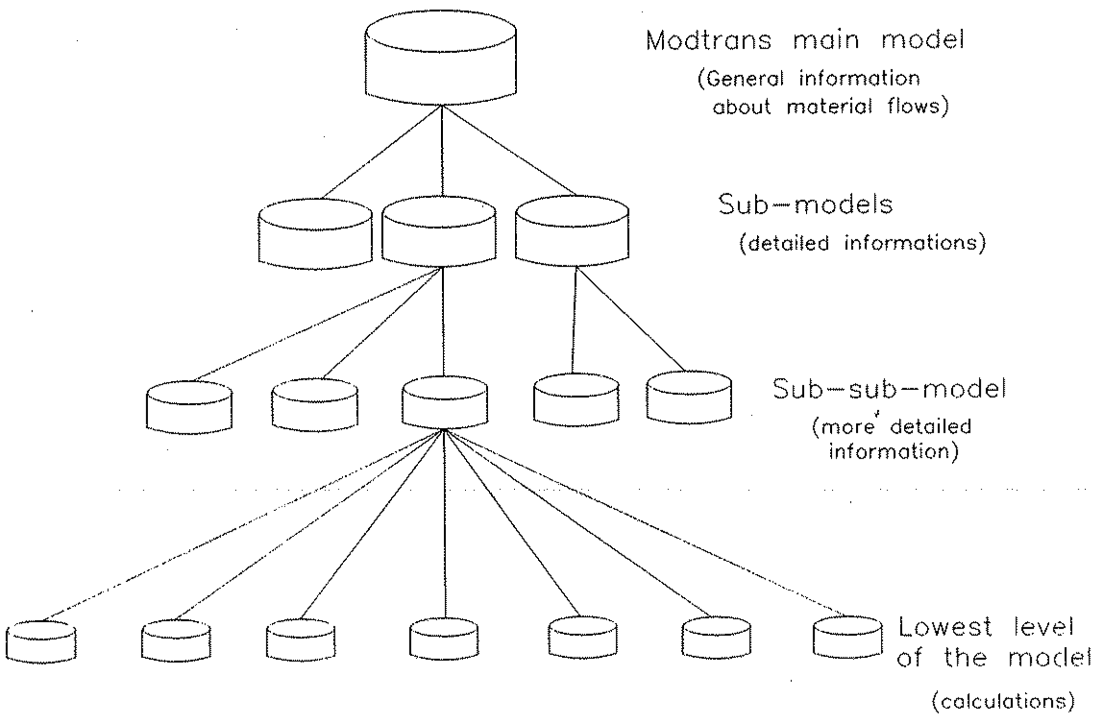

Fig. 6. Schematic presentation of the hierarchic model structure

The developed model describes the material flow (both collection and distribution systems) in the agricultural sector as a whole and sub-systems by farming types (crop production, animal husbandry and integrated) using the conceptual models and results of the inventory assessments and literature review. The model was used to study the environmental impact of goods transport system in the above sector by predicting emissions from the vehicles used in the system and to determine transport works and route systems. These informations are useful to effectively use the vehicles and develop a sustainable mobility. In the materials flow, beside the farming types, industries and firms such as abattoirs, mills, dairy, wholesale dealers, warehouses and retailers, fodder and fertilizer industries, transport companies and households are included in the model (Fig. 7).

The main model is composed of several sub-models for each types of farming. Figures 8 - 12 illustrate the Simulink sub-models for the collection and distributions of the sub-systems. Each sub-model was further divided into sub-sub-models and classifying into collection and distribution. Figure 13 shows the truck model and emission computation. Trucks used for various commodities modelled differently depending on the methods used for collection and distribution.

Variables which may describe emissions from the transport system were determined during the development of the conceptual model. For all sub-models, variables such as load, speed, road conditions, slopes and age of a truck were used considering them as the most important variables influencing the amount of emissions. There are few studies made on the relationship between the above variables and emissions from lorries. Demker et al (1994) reported the works of Backman (1984) and Scania (1989) about the effect of load on energy consumption (Fig. 14). In both cases, the energy consumption increases linearly with an increase of load. The graph (Fig. 15) showing the effect of vehicles speed on fuel consumption (of a diesel engine) has a parabolic shape (Commission, 1995). Investigations made by Lenner (1995) also showed similar results.

For animal transport, additional variables (vibration, noise, temperature, moisture variation, ventilation, social group and population density) which may have negative impact on animal welfare, meat quality and mortality were defined and Figure 4 illustrates impacts of transport on animals, human and plants.

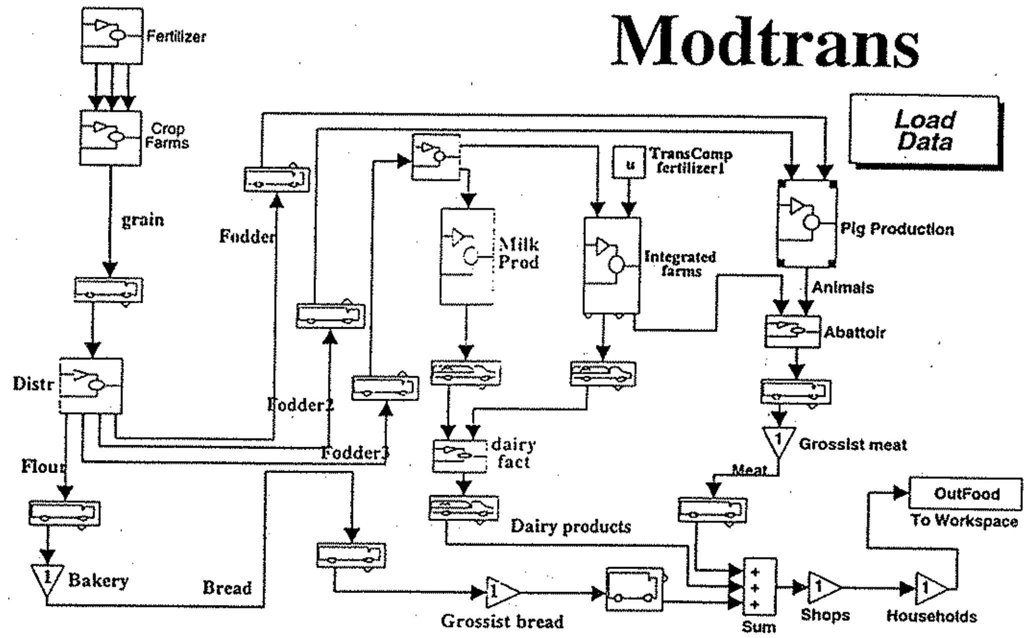

Fig. 7. MODTRANS, simulation model for transport system of agricultural and related products, developed using Matlab/Simulink software

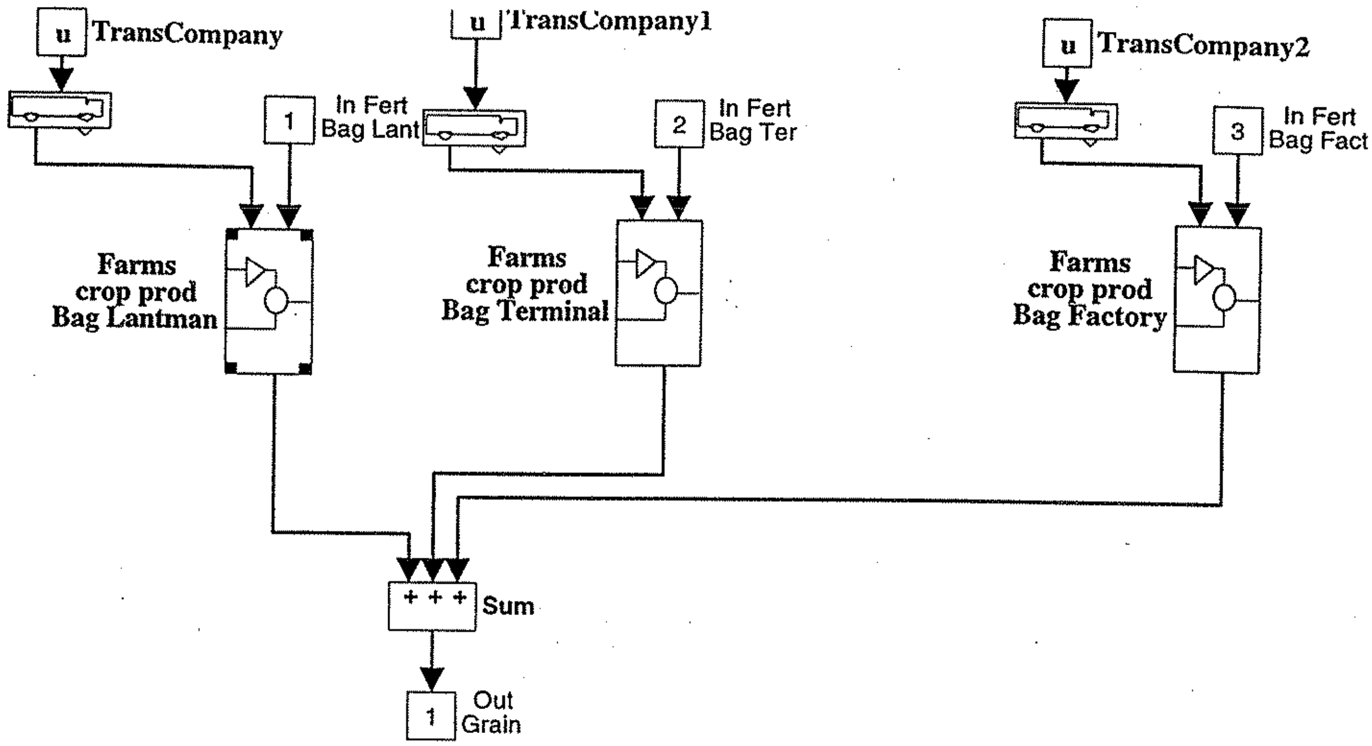

Fig. 8. Sub-model of transport system for crop production sector

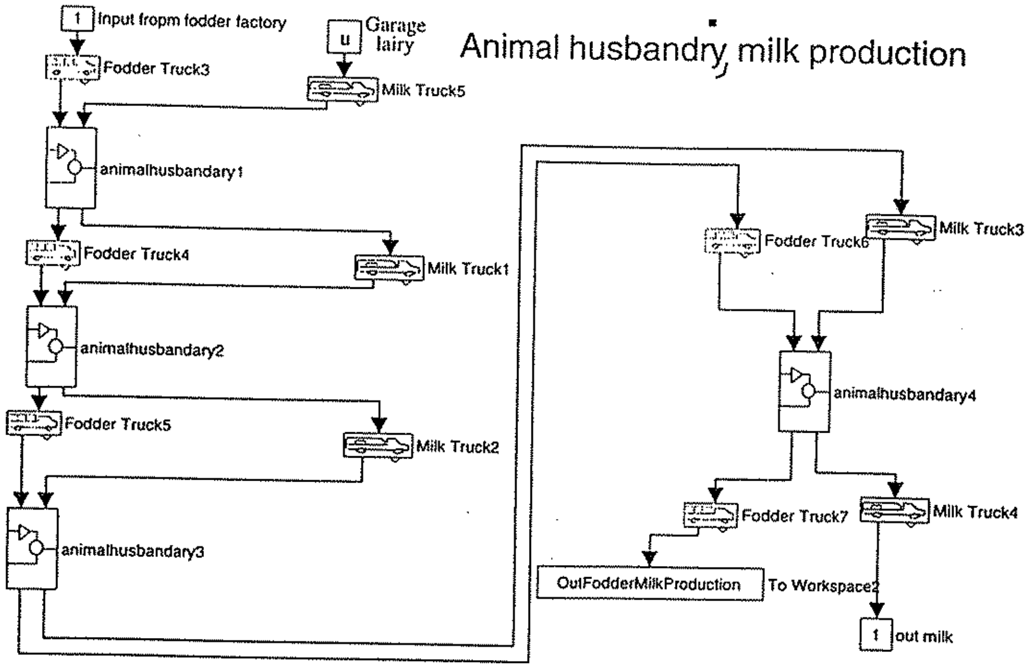

Fig. 9. Sub-model of transport system for milk production animal husbandry sector

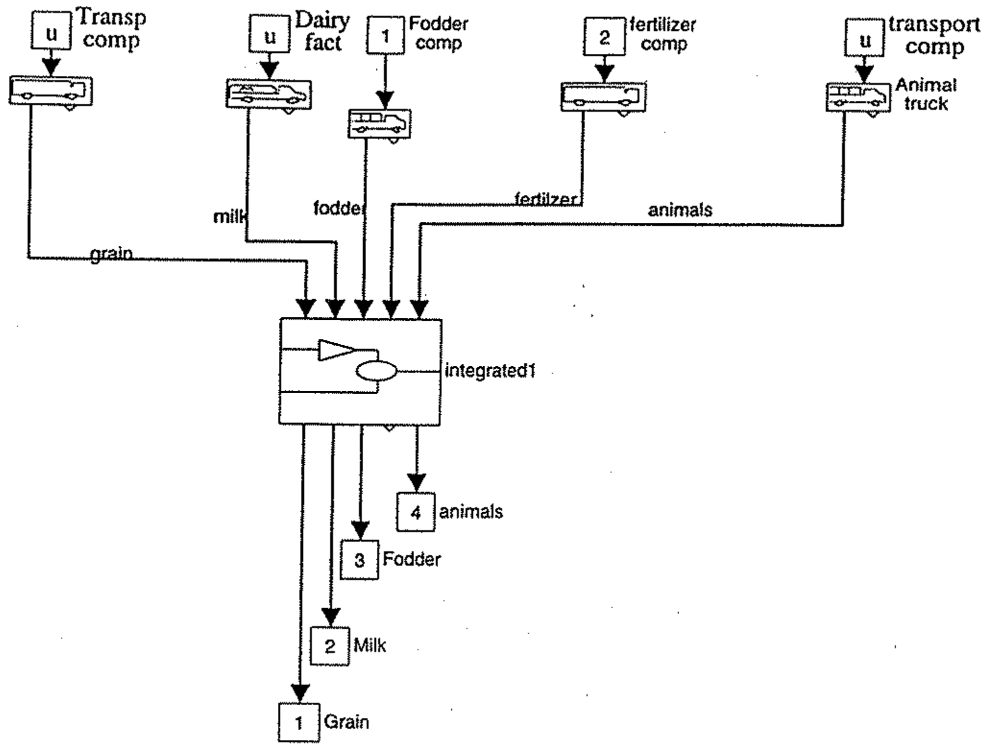

Fig. 10. The integrated farming sub-model

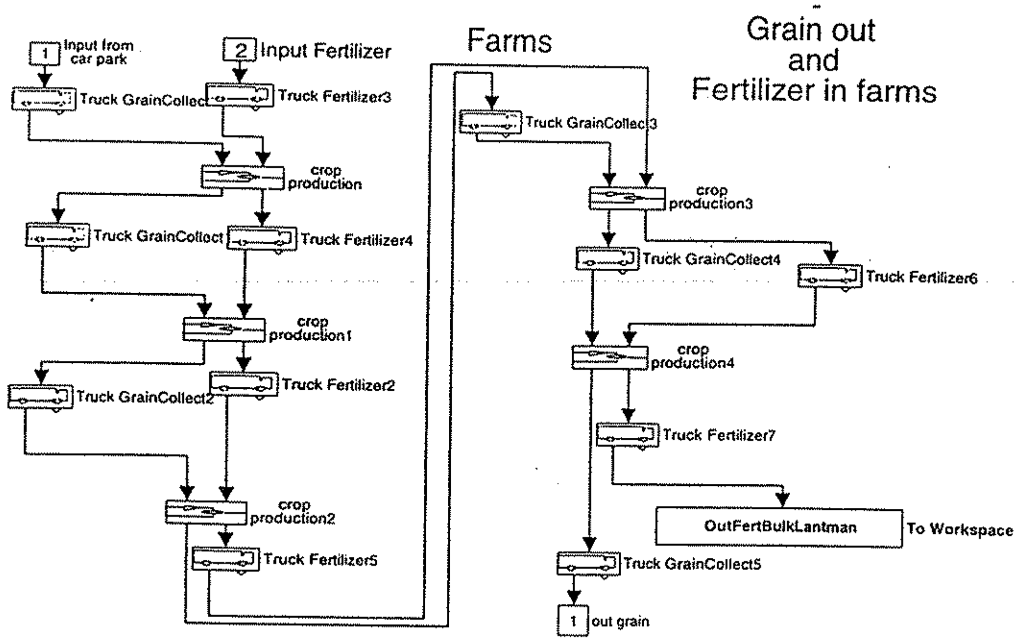

Fig. 11. Fertilizer distribution and grain collection sub-model

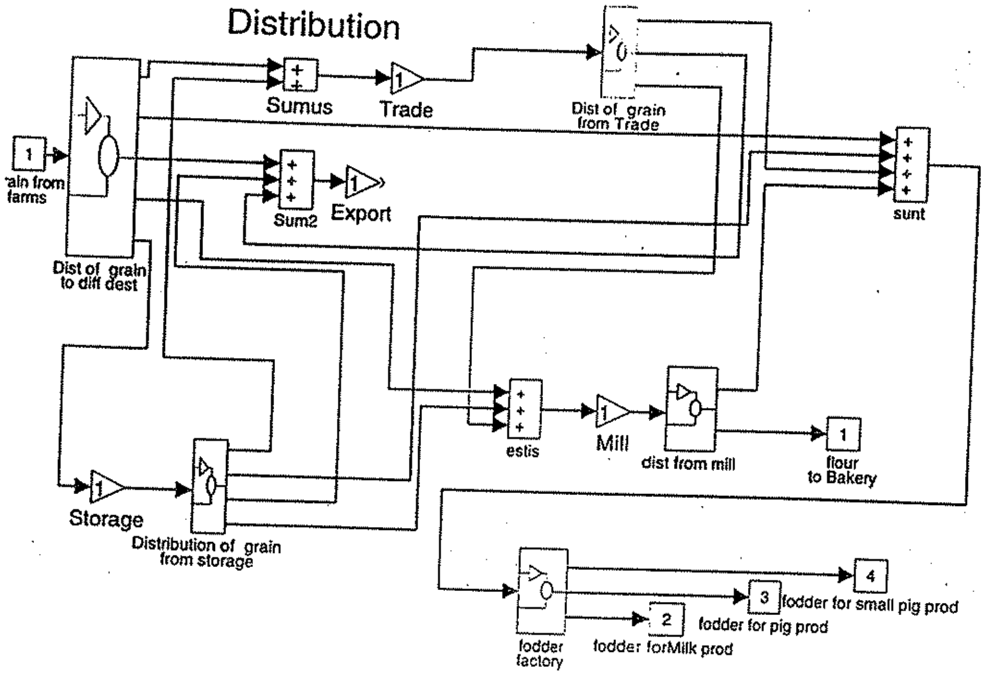

Fig. 12. Grain distribution sub-model

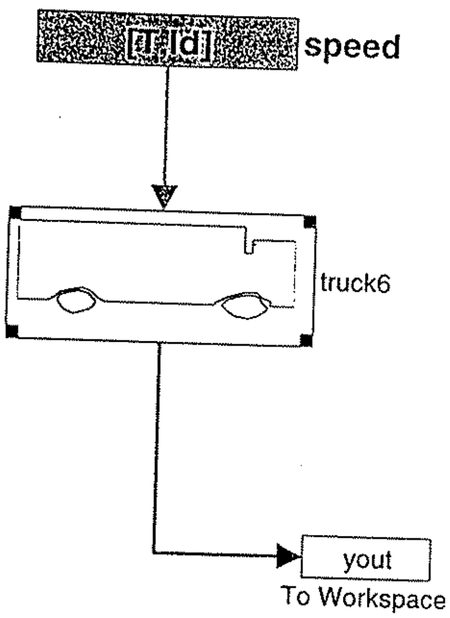

Fig. 13(a). Truck model

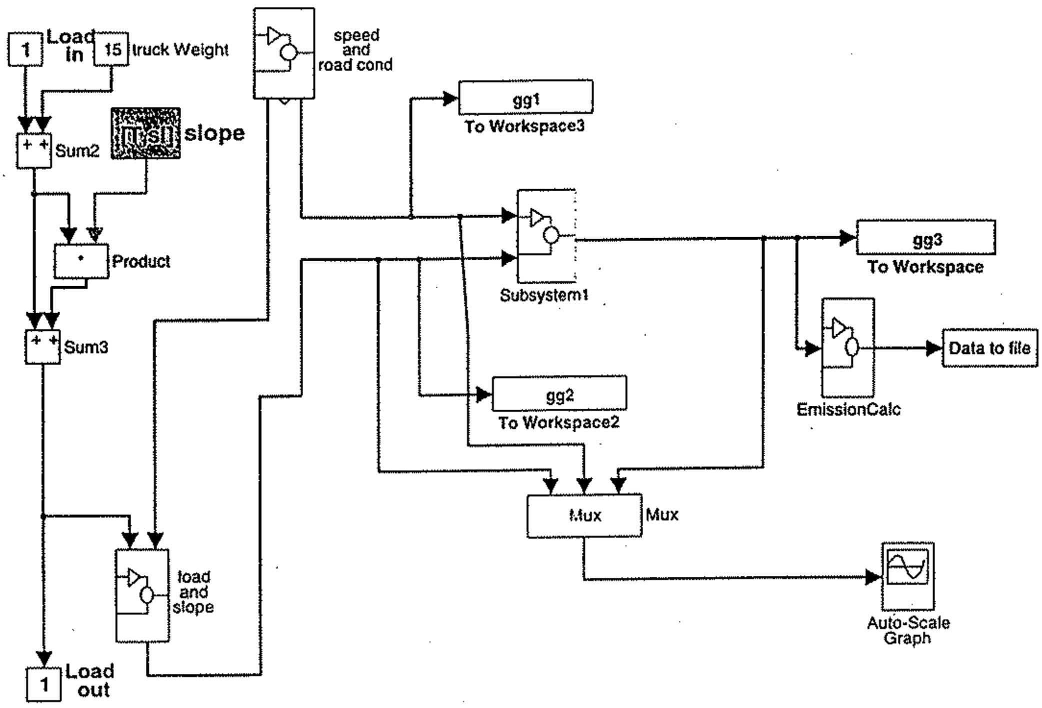

Fig. 13(b). Truck and emission computation sub-model

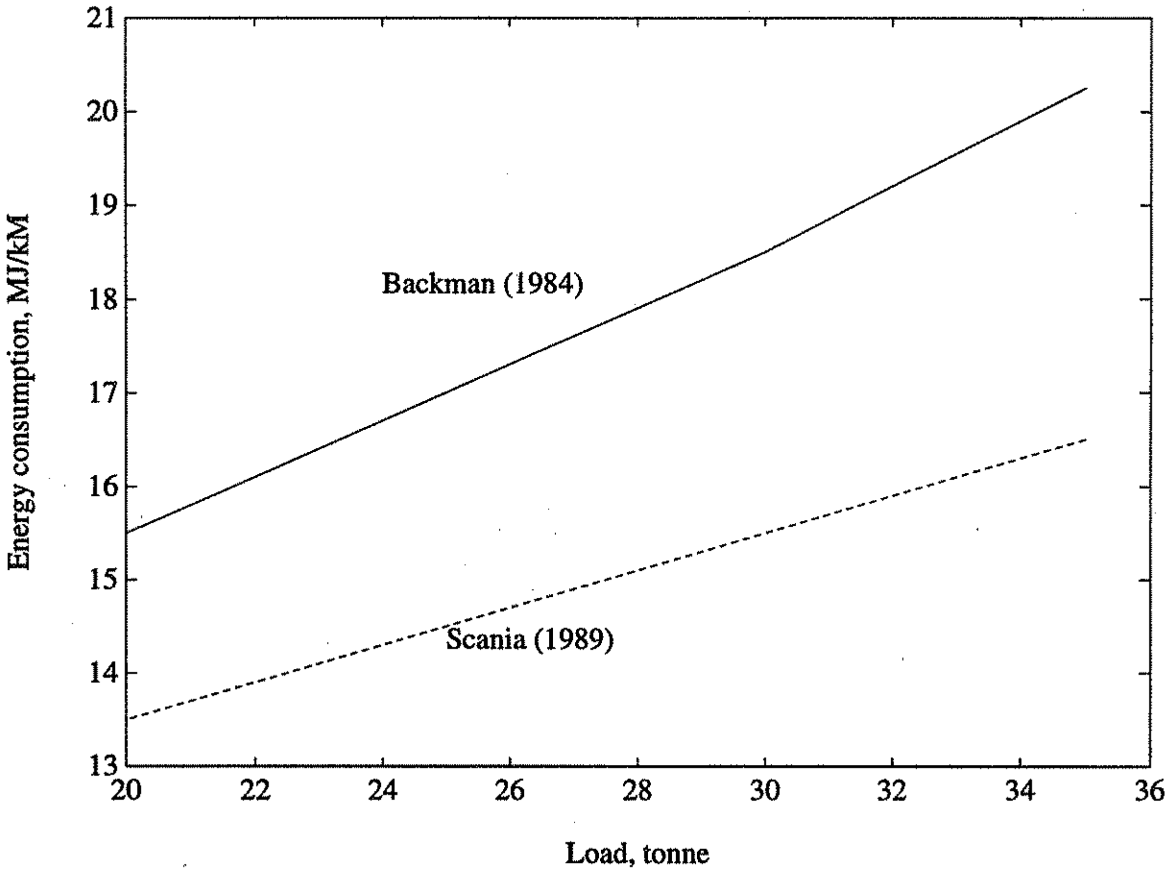

Fig. 14. Effect of load on energy consumption (KFB rapport 1994:4)

8.3. Model output

The model calculates emissions in relation to the input variables, such as load, distance, speed, road conditions and slopes (uphill or downhill). The simulation results can be presented either in a table form or in a graphic form. For instance the speed profile and the predicted emissions of hydro carbon and carbon monoxide for a truck driven for 300 minutes are depicted in Figures 16, 17 and 18 respectively. The variations of both hydro carbon and carbon monoxide emissions depend on the vehicle's speeds. The truck was first driven from the transport company for 60 km and then collected pigs from two farms. After loading the animals the vehicle continued to the nearest abattoir, and thereafter driven back to the transport company.

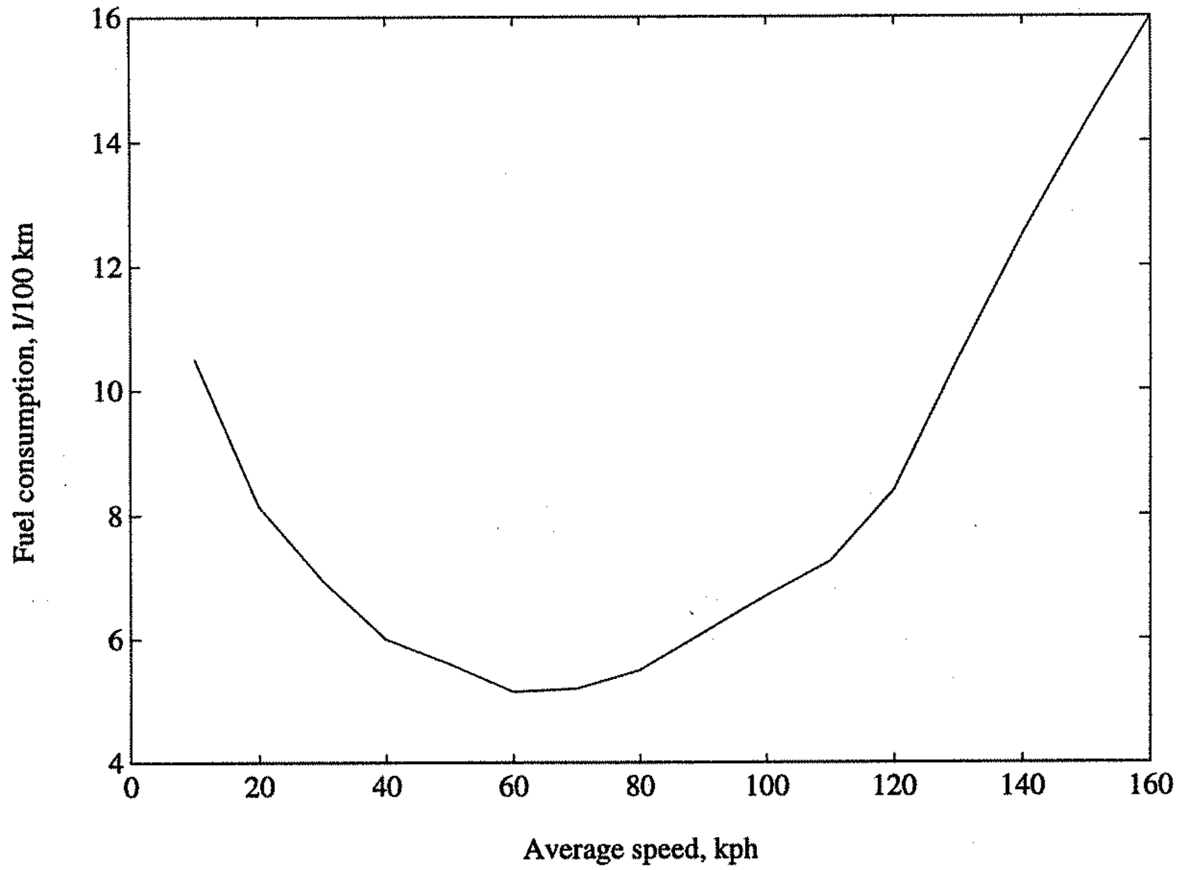

Fig. 15. Effect of speed on fuel consumption of diesel engine (Commission, 1995)

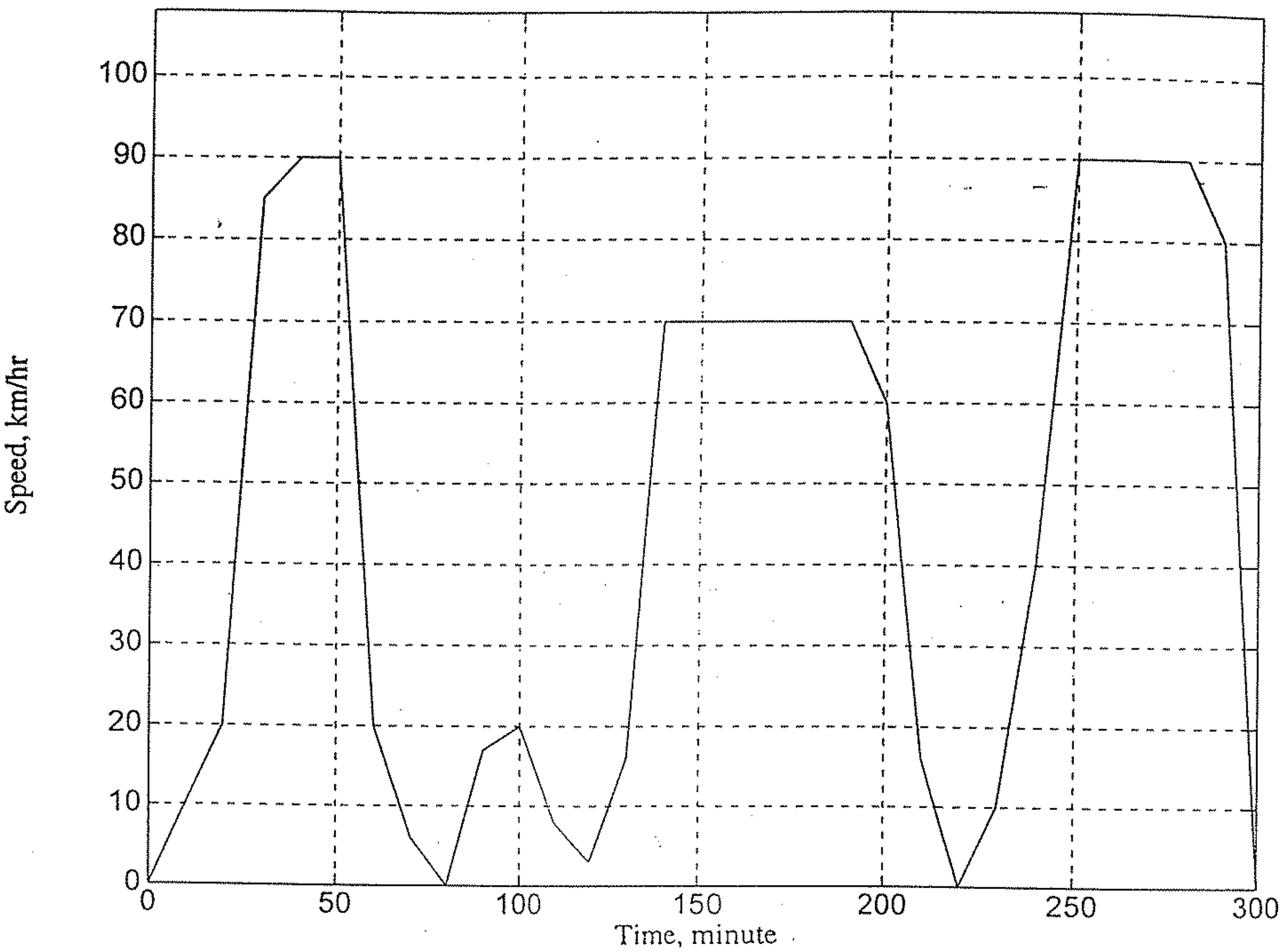

Fig. 16. Speed profile of the truck used for the simulation. The truck was driven from the transport company to two farms, and from farms to abattoir, thereafter back to the transport company

9. Conclusion

The goods transport systems for both collection and distribution have been assessed and a simulating model, MODTRANS, was developed using the Matlab/Simulink software. It was found that the model describes sufficiently the material flow to and from agricultural sector. The model enables to determine emissions and transport works.

Some of the strategies attempted to be used to decrease emissions were:
a) utilization of the maximum loading capacity of the vehicles,
b) improving of coordination and establish network between different sectors (to be able to use the same vehicle for various good groups, and also the same vehicles can be used both for collection and distribution). By doing that, the number of vehicles moving without load or 'partially-loaded' may be decreased substantially, thereby decreasing emissions and thus diminishing environmental impact.

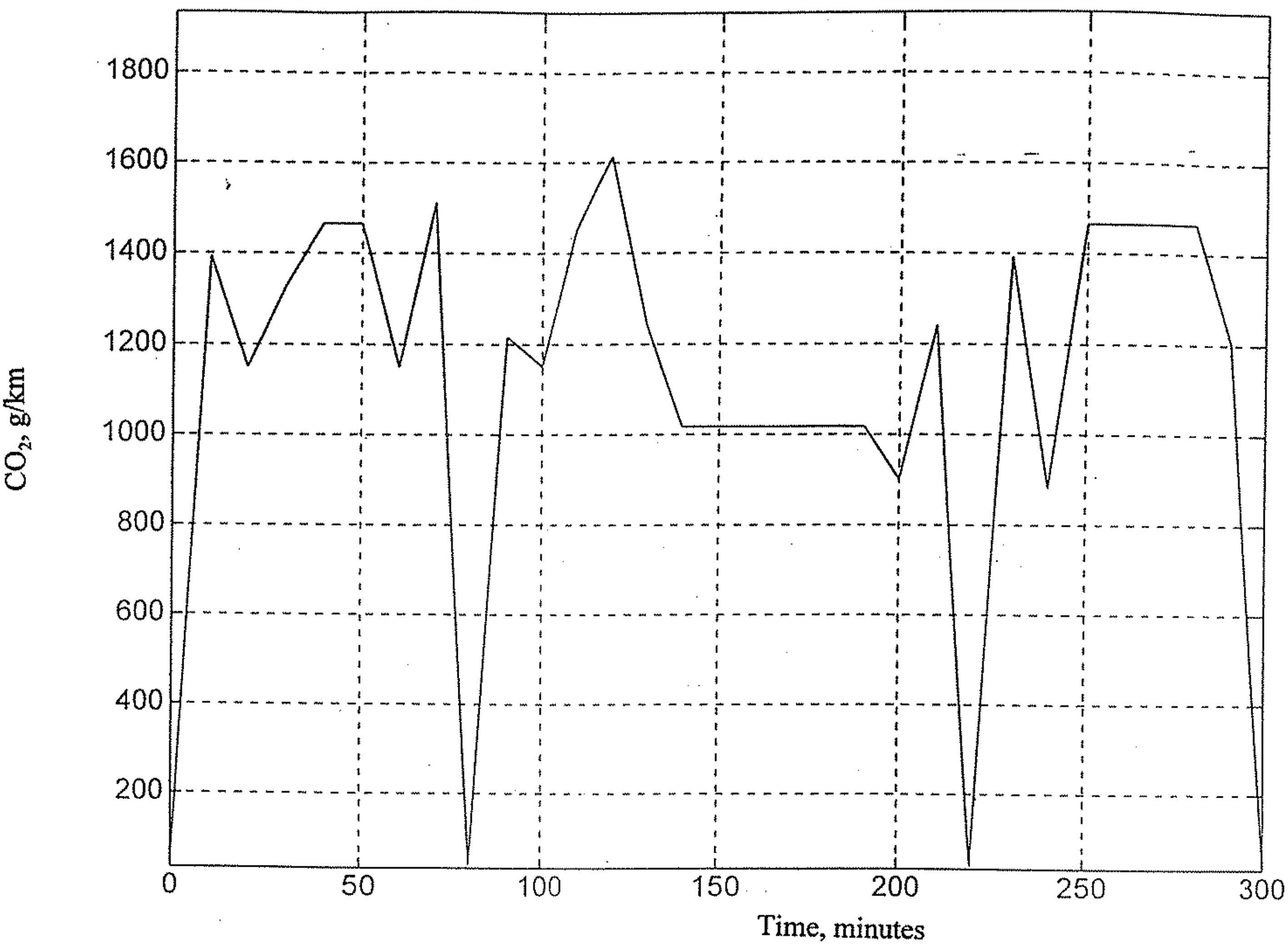

Figure 17. Emissions of carbondioxide from a vehicle driven for 300 minutes

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