Distribution and Intensity of Agricultural Traffic for Sustainable Development

Annet HOSPERS, Marije LOUWSMA, Ron VAN LAMMEREN, Paul Peter KUIPER, The Netherlands

Key words: GIS, agriculture, traffic intensity, land fragmentation, sustainability

SUMMARY

Land from many holdings is dispersed, which compels farmers to use public roads to access distant parcels. Agricultural traffic is different from other traffic with its large and heavy vehicles. When agricultural traffic mixes with other traffic, safety issues may arise. Another issue of agricultural traffic is its environmental impact. Dispersed land, also called internal land fragmentation, generates extra traffic compared to a situation where all land is located around the farmstead. Despite the relevance of the topic, little research has been conducted on agricultural traffic in relation to a holdings' land allocation. That is, how agricultural traffic is distributed over the road network and how intense traffic is. The aim of this research is to develop a GIS model that shows the spatial distribution and intensity of agricultural traffic for a specific area.

First, the route from homestead to distant parcels was determined for all holdings in the region. Then, the number of rides over each route was calculated. Finally, all rides over each road segment were summed up and mapped. Four factors that influence the number of rides (crop type, soil type, parcel size, and dump truck size) have been distinguished based on available literature. An initial run of the model produced a map with expected distribution and intensity of agricultural traffic for two different areas. The model was validated in two ways: by local experts and by traffic counting. For one area, a group of local farmers validated the results for that area. For the other area, the results were compared to available traffic measurements. Based on both validations, the model has been adapted.

Distribution and Intensity of Agricultural Traffic for Sustainable Development

Annet HOSPERS, Marije LOUWSMA, Ron VAN LAMMEREN, Paul Peter KUIPER, The Netherlands

1. INTRODUCTION

Land from many holdings is dispersed, which compels farmers to use public roads to access distant parcels. Agricultural traffic is different from other traffic with its large and heavy vehicles. When agricultural traffic mixes with other traffic, safety issues may arise (Jaarsma et al., 2013). Another issue of agricultural traffic is its environmental impact. Dispersed land, also called internal land fragmentation (Van Dijk, 2003; Demetriou et al., 2011), generates extra traffic compared to a situation where all land is located around the farmstead. Several developments may result in an increase of agricultural traffic intensity (Jaarsma & Hoofwijk, 2013). First, there is a broadening of activities at farms which may generate extra traffic to and from farms (Jaarsma & Hoofwijk, 2013; Rienks et al., 2009). Second, the average size of agricultural holdings continues to increase. Land needed for enlargement is not always available near the holding. Distant land results in longer rides over public roads (Jaarsma & Hoofwijk, 2013). Third, farmers that specialize in a specific crop need a crop rotation system that stimulates short term use of distant land.
Apart from these developments, agricultural vehicles have become larger, heavier and faster over time. In addition to an increase of agricultural traffic, recreational traffic has increased as well (Rienks et al., 2009). As a result, concerns about traffic safety arise. The number of accidents involving agricultural vehicles has been stable over the years, while overall traffic accidents in rural areas decreased (Jaarsma & Hoofwijk, 2013).
Despite the relevance of the topic, little research has been conducted on agricultural traffic in relation to a holdings' land allocation. That is, how agricultural traffic is distributed over the road network and how intense traffic is. Hence the aim of this research is to develop a GIS model that shows the spatial distribution and intensity of agricultural traffic for a specific area and for specific seasons (spring, summer, autumn, winter). Insight in the intensity and spatial distribution of agricultural traffic can be used to locate potentially unsafe situations. The information can be used to improve road design, to steer and separate different modes of traffic to minimize the number of risky encounters, or to take measures to reduce the intensity of agricultural traffic e.g. by means of land consolidation.

2. METHODS AND DATA

2.1 Methods

The spatial distribution and intensity of agricultural traffic was modelled in a geographical information system (GIS). The modelling consisted of three steps. First, the route from homestead to distant parcels was determined for all holdings in the region. Then, the number of rides over each route was calculated. Finally, all rides over each road segment were summarized and mapped.

From literature research, four factors were selected that influence the number of rides: crop type, soil type, parcel size, and dump truck size (Gónzalez et al., 2007; Jaarsma, 2010; Rienks et al., 2009). Crop type and soil type resulted in a fixed number of rides, whereas parcel size and dump truck size led to a variable number of rides. All four factors were included in the model. An initial run of the model produced a map with the expected distribution and intensity of agricultural traffic for the two case study areas: the municipality Noordoostpolder (450 km^2) and the province Zeeland (1800 km^2). Using the initial run, the model was validated in two ways: by local experts and by traffic counting. For the case study Noordoostpolder, nine local farmers were interviewed to validate the results for that area. The semi-structured interviews were conducted with farmers from different holding sizes. For the case study Zeeland, the results were compared to available traffic measurements of the area. Additionally, two employees from the province of Zeeland were interviewed to discuss the results. The model was adapted based on the validation in both areas.

2.2 Geographical data

The model used as datasets four key registries from the national spatial data infrastructure: Top10NL, BRP, BAG and BRK. Top10NL is the topographic data set, of which the road network was used. BRP provided information on land use (crops, grassland) and land users (holding). BAG provided information on buildings, and BRK on land owners. Analyses have been conducted for agricultural holdings based on owned land and agricultural holdings based on a combination of owned land and leased land. For the latter, information on land owners and users was combined to determine holdings and the location of their parcels. Information on buildings were used to locate the farmstead from which the routes to distant parcels started.

3. RESULTS

3.1 Number of rides

Four factors influence the number of rides with agricultural vehicles: soil type, crop type, parcel size, and kipper size. Figure 1 shows how these factors are related to the total number of rides. This number depends on the activities that farmers carry out on their parcels. Some rides are related to the size of the harvest and the kipper that transports the harvest. Other rides are related to the crop that is grown and the soil type. Crops need spraying insecticides and applying fertilizer. The frequency of these activities, and consequently the number of rides, depends on crop type and varies from crop to crop. Both types of rides, fixed and bulk, determine the total number of rides.

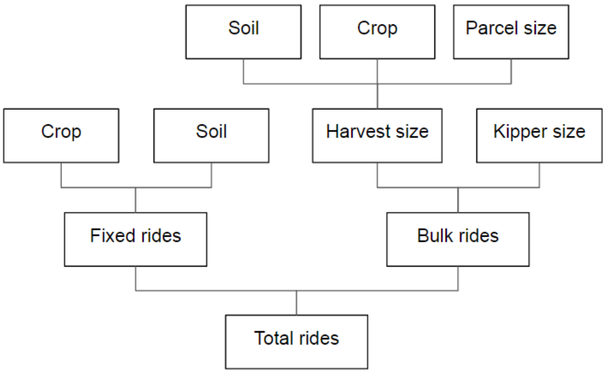

Figure 1 Factors that influence the number of rides

The “Kwalitatieve Informatie” (KWIN) publications (PAGV, 1995; PPO, 2009; PPO, 2012; WUR, 2013) provided most information on activities that influence the number of rides. However, because some information dates from 1980, figures have been updated with expert knowledge from farmers about current activities and machinery size. Farmers were also asked to indicate if the number of rides varies over the seasons. Four seasons were distinguished: spring (March - May), summer (June - August), autumn (September - November), and winter (December - February). Appendix I gives a detailed overview of the validated number of fixed rides per crop per season (Table 1) and the number of bulk rides, which are based on the harvest size per crop (Table 2) and the kipper size (Table 3). These figures are used in the model to determine the total number of rides to distant parcels.

3.2 Spatial distribution of traffic intensity

The route between homestead and distant parcel is calculated with the shortest path algorithm (Dijkstra, 1959). Figure 2 shows how these routes were modelled in GIS (Louwsma and Kuiper, 2013). The total number of rides was calculated for each road segment, based on the summed number of rides over distinguished routes. Figure 3 shows how traffic intensity was calculated in GIS. After having determined the routes from homestead to distant parcels, the model calculates the number of rides per roadsegment and per route based on the four determined factors (soil, crop, parcel size, kipper size). First, the data sets with soil types and crop types were reclassified to reduce the amount of variables. The factors soil and crop were combined into one spatial dataset to which owner and user information was added. The size of each parcel[1] with the same combination of owner, crop and soil, was determined and combined with the kipper size to calculate the number of bulk rides. Combining the seasonal number of rides, based on crop-bound (fixed) activities and production-bound (bulk) rides, resulted in a seasonal number of rides. Then, the number of rides per route were attached to each road segment of that route. For each road segment , all rides of all routes were summed up to get the number of rides per road segment, i.e. traffic intensity.

[1] A parcel may consist of one or multiple adjacent cadastral parcels.

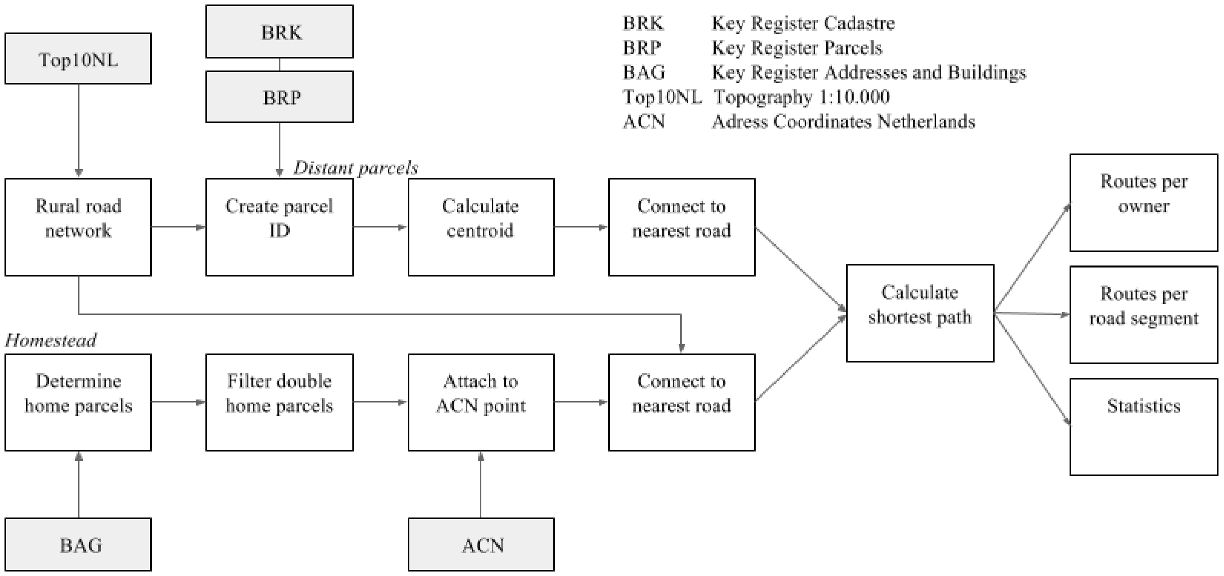

Figure 2 Calculation of routes from homestead to distant parcels (Louwsma and Kuiper, 2013)

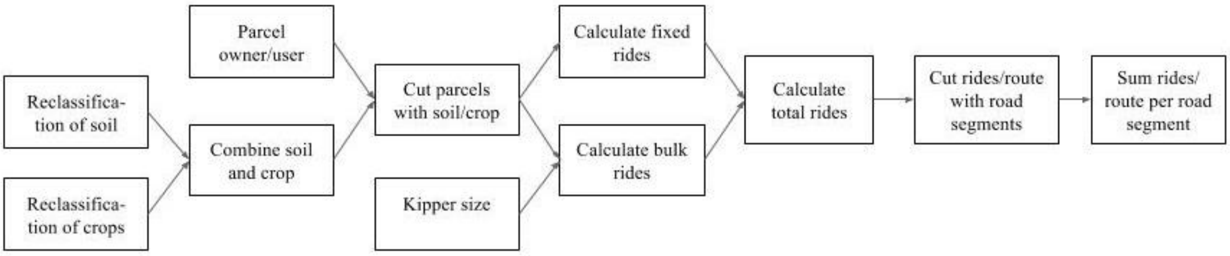

Figure 3 Calculation of traffic intensity

3.3 Case studies

The model was applied in two case studies: the municipality Noordoostpolder and the province Zeeland. Figures 4 (land owners) and 5 (land owners and users) display the spatial distribution of agricultural traffic in the Noordoostpolder on a yearly basis for 2014 (December 2013 – November 2014).

Traffic intensity is based on the land use of holdings located in the area, which includes leased land and owned land. Since about 40% of the land is leased in the Netherlands (CBS, 2008), traffic intensity cannot be sufficiently analysed by using ownership data alone. However, the data on leased land is based on farmers' input for the yearly census, which means that quality standards of this data are looser than the data on owned land, which are part of a national key register. To check the added value of including data on leased land, we ran the model twice for both case studies: one run based on ownership, and one run based on ownership and leased land. Comparing the results showed that combining ownership and leased land produced richer and more detailed information on traffic intensity. This was especially true for the Noordoostpolder where land has been reclaimed by the government. This reclamation has historically caused a larger amount of land to be leased as compared to areas without reclamation. Additionally, this case study showed that traffic related to bulb cultivation, which is major in this region, appeared in the results when data on leased land was included. Bulb cultivation requires crop rotation, because of specific soil requirements. Consequently, this cultivation increases a farmer's need for leased land, and additionally leads to more traffic.

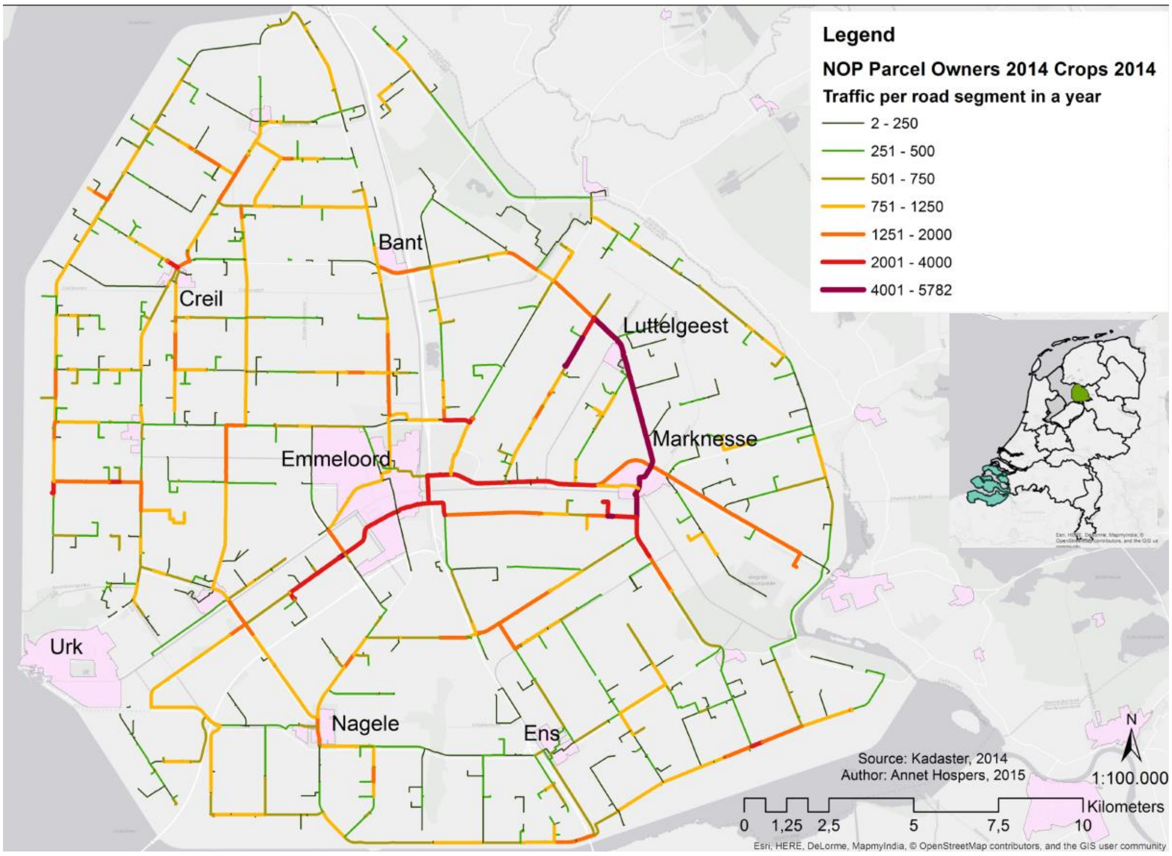

Figure 4 Traffic intensity in municipality Noordoostpolder, based on land owners and crops grown (2014)

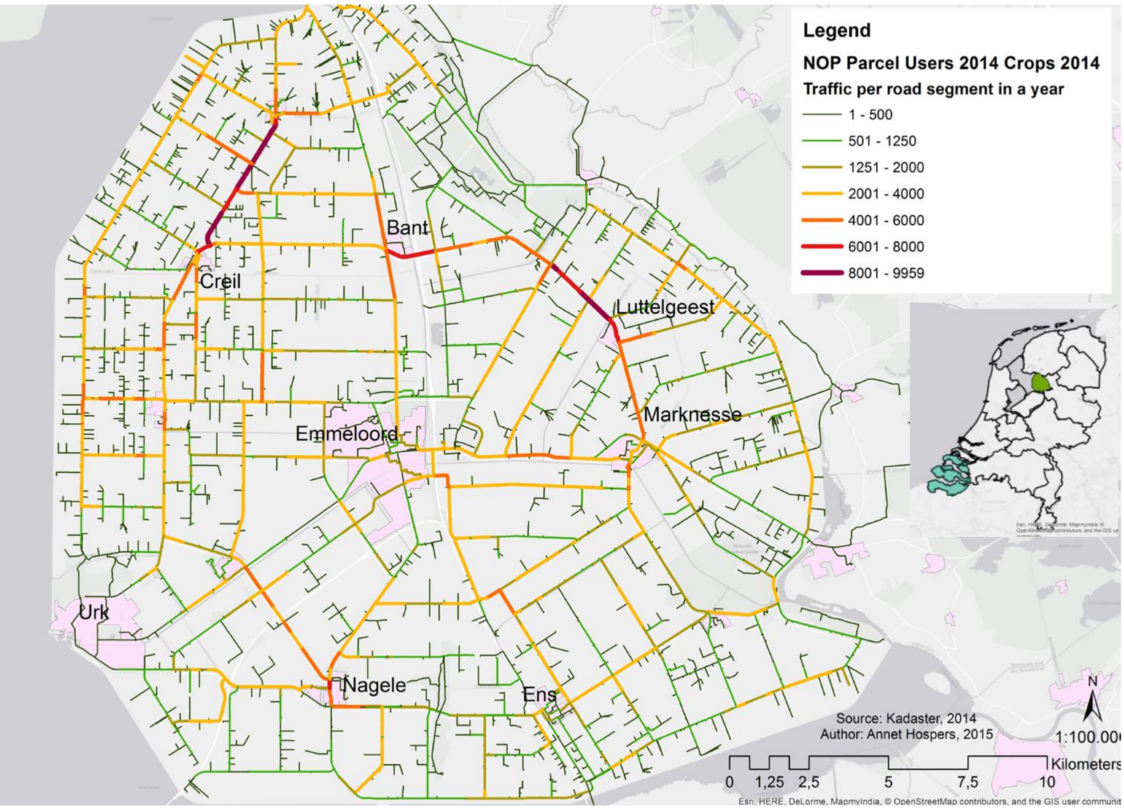

Figure 5 Traffic intensity in municipality Noordoostpolder, based on land users (2014) and crops grown (2014)

3.4 Validation

The model was validated for both case studies, though validation methods between the case studies varied. In the Noordoostpolder, nine farmers were interviewed. Three aspects were specifically discussed: the activities and harvest per crop (see Appendix I), the routes of their holding from homestead to distant parcels, and the overall results in terms of traffic intensity on the roads. Farmers noted that some activities are crop independent, such as clearing of ditches. These activities were not included in our model. They also mentioned that in practice activities are often combined. In our model we calculated all activities separately, which leads to overestimated traffic intensity. The shortest path algorithm was used to calculate the routes from homestead to distant parcels. With respect to this, farmers concluded that the calculated routes for their holding as well as calculated traffic intensity for the area generally matched their experience. Some farmers indicated to take a detour every now and then to avoid busy city centres, crossroads or roundabouts.

In Zeeland, the results of the model were compared with available traffic countings. Agricultural traffic was counted at eight locations to estimate traffic intensity on public roads in the province (Oosthoek & Pouwer, 2014). Estimated traffic intensity based on the countings was overall higher than the calculated traffic intensity by our model. This might be explained by the type of agricultural traffic taken into account. Our model only includes traffic that directly relates to farming activities on distant parcels, whereas the countings include all agricultural traffic such as trucks used to transport the harvest to factories.

4. DISCUSSION

The major finding of this research is that the developed model clearly shows the spatial distribution and intensity of agricultural traffic on the rural road network. Contrary to traffic countings, the model can be easily applied to any area as long as data on the holdings' land allocation and the area's road network is available. Moreover, the model facilitates a wide array of applications. With the information on distance and frequency of travelled routes, governments can investigate possibilities to improve land allocation to reduce agricultural traffic, to map road segments with different modes of traffic (safety issues), or to estimate emissions from agricultural traffic.

The results also show that traffic intensity fluctuates over the seasons, with summer and autumn as the busiest. These fluctuations are directly related to cultivation: grassland leads to evenly distributed traffic over the growing seasons, and crops lead to traffic mostly in the harvesting season. These findings correspond with literature on agricultural traffic (Jaarsma and De Vries, 2014; Panschin and Vitikainen, 2010). Analyzing traffic intensity also poses the question which indicator is most appropriate to measure traffic intensity: the busiest day of the year, the average intensity a day a year, or the total yearly traffic? Selecting an appropriate indicator depends on the phenomenon studied. CO2 emissions for instance are best measured based on the total yearly traffic, while safety issues are best measured based on traffic intensity in the period when different traffic modes mix. In the Netherlands, safety issues mainly occur when non-motorized traffic (cyclists) and agricultural traffic use the same roads in the same period (Jaarsma and De Vries, 2014). Both traffic modes peak in late spring, summer and early autumn. Therefore these measurements are normally based on traffic intensity on a regular weekday and a regular weekend day in all three seasons.

The limitations of this research are threefold. First, this study shows that results are more complete using a combination of ownership and use rights. However, available information on leased land in the Netherlands is difficult to acquire because it is not publicly available. Farmers report this information for financial purposes (tax and subsidy payments), which are confidential. Thus the data on leased land in the Netherlands is aggregated when it is published. Second, at the boundaries of the area, traffic intensity in reality is less than modelled, because traffic to distant land from holdings outside the area is not incorporated in the model. This implies that the model functions best for areas of considerable size and with natural or artificial topographical boundaries, such as big rivers or highways. Additionally, the study area can be extended outward to create a buffer, which then is not considered in the analysis. Third, the model does not take into account all agricultural traffic. For example, holdings that outsource work to contractors is not included. Depending on where machinery is located, contractors use different routes than farmers. Because no information is available on outsourced work, and because the amount of outsourced work fluctuates from holding to holding, the model incorporates only agricultural traffic as if the holdings carry out all the work themselves. Fourth, the analysis would be more complete taking into account the physical design of the roads and traffic regulations. Due to data issues, this could not be included in our analysis.

Furthermore, we recommend that, like all network analyses, the topological quality of the road network has to be checked before performing the analysis as disconnected roads can trouble the results.

5. CONCLUSION

Agricultural traffic was studied in relation to a holdings' land allocation to determine spatial distribution and intensity of agricultural traffic for a specific area. Based on the validations we may conclude that our GIS model gives a good impression of the intensity and spatial distribution of agricultural traffic for an area. Better results were obtained with data on ownership and use rights than with data on ownership rights alone. This is of course context dependent; in a situation where ownership rights prevail and use rights are non-existent an analysis based on ownership rights alone will suffice, and vice versa. The model has been validated with the best available means, however we recommend to extend validation preferably with countings of agricultural traffic in the field like has been done in Finland (Panschin and Vitikainen, 2010).

The results of the model, i.e. information on the spatial distribution and intensity of agricultural traffic, can be used for different applications. The results can be combined with other data, for example to locate potentially unsafe situations. When agricultural traffic mixes with other modes of transport, safety issues may arise. In the Netherlands this applies particularly for cyclists. Cyclists use rural roads for recreational, for work and for school-related purposes. Combining these information may reveal possibly dangerous locations where different modes of traffic use the same road or cross each other's route.

Other applications of the results can be found in sustainable development, for example to analyse CO2 emissions. Governments can use the information as input for policy-making and for decision-making, for example on measures to reduce agricultural traffic and related safety issues.

Future developments may have farmers using GPS tracking systems in agricultural vehicles which enables spatio-temporal analyses. For now, such systems are not yet commonplace, and therefore do not provide sufficient information for an analysis of agricultural traffic on a regional scale.

Appendix I
Table 1 Fixed number of rides per crop and per season

	Spring	Summer	Autumn	Winter	Total rides
Agricultural crops	4	8	2	3	17
Cereals	5	7	5	2	19
Flower bulbs	15	18	2	0	35
Grassland	2	23	1	1	27
Green fodder plants (on clay)	4	2	2	1.5	9.5
Green fodder plants (on sand)	4.5	3.5	1.5	0	9.5
Green fodder plants (on peat)	6	0	2	0	8
Onions	5	11	2	0	18
Potatoes, consumption	9	14	3	0	26
Potatoes, plant	8	14	3	0	25
Potatoes, starch	9	11	2	1	23
Sugar beets (on clay)	6.5	5.5	3	0	15
Sugar beets (on peat)	6	6	3	0	13
Sugar beets (on sand)	5.5	6.5	3	0	15
Fallow land	1.5	0.5	1	0	3

Table 2 Harvest (kg/ha) of crops

	Clay, IJsselmeer	Clay, other	Sand	Peat	Average
Agricultural crops	15000	15000	15000	-	15000
Cereals	9300	8600	7600	-	8500
Flower bulbs	-	-	-	-	65000
Grassland*	60000	60000	65000**	55000	60000
Green fodder plants	45000	45000	44000	-	45000
Onions	63000	50000	57000	-	57000
Potatoes, consumption	55000	47500	56000	-	53000
Potatoes, plant	40000	34000	33000	-	36000
Potatoes, starch	43000	43000	43000	-	43000
Sugar beets	83000	73000	70000	-	75500

* *Based on five times mowing per year*

** *Average of wet and dry sand*

Table 3 Kipper size used for crops

Kipper size	**Crop**
11 ton	Grassland Green fodder plants
18 ton	Agricultural crops Cereals Onions Potatoes, consumption Potatoes, seed Potatoes, starch Sugar beets

REFERENCES

Demetriou, D., J. Stillwell & L. See (2011), Land consolidation in Cyprus: why is an integrated planning, and decision support system required? Land use policy 29 (2012), pp. 131-142.

Dijkstra, E.W. (1959), A note on two problems in connexxion with graphs. Numerische Mathematik 1, pp. 269-271.

Louwsma, M. & P.P. Kuiper (2013), Ruimtelijke effecten van herverkaveling op landbouwverkeer. Verkeerskunde 5 (2013). http://www.verkeerskunde.nl/internetartikelen/ internetartikelen ruimtelijke-effecten-van-herverkavelingop.33744.lynkx [Accessed: 24-08-2014].

Gónzalez, X.P., M.F. Marey & C.J. Álvarez (2007), Evaluation of productive rural land patterns with joint regard to the size, shape, and dispersion of plots. Agricultural System 92 (2007), pp. 52-62.

Jaarsma, R. (2010), Precieze achtergrondinformatie en handvatten op maat voor de tractorproblematiek: De tractor en de openbare weg. Verkeerskunde 61 (6), pp. 38-43.

Jaarsma, R. & H. Hoofwijk (2013), Landbouwverkeer, lastig maar noodzakelijk! ROM: maandblad voor ruimtelijke ontwikkeling 31 (3), pp. 34-35.

Jaarsma, R., H. Hoofwijk & J. de Vries (2013), Trendbreuken in het landbouwverkeer. Verkeerskunde 01 (13), p. 42.

Jaarsma, R., & J. de Vries (2014), Verkeersveiligheid landbouwvoertuigen 1987 – 2012.

PAGV [Proefstation voor de Akkerbouw en de Groenteteelt in de Vollegrond] (1995), Kwantitatieve informatie voor de akkerbouw en de groente in de vollegrond. 22nd editie. Lelystad: drukkerij Belser.

Panschin, S. & A. Vitikainen, (2010), Land consolidation and agricultural traffic – instrument for calculating the traffic volume. FIG Congress 2010, Facing the Challenges – Building the Capacity, Sydney, Australia, 11-16 April 2010.

PPO [Wageningen, Praktijkonderzoek Plant & Omgeving] (2009), Kwantitatieve Informatie: akkerbouw en vollegrondsgroenteteelt. 27ste edition, Wageningen: Praktijkonderzoek Plant & Omgeving.
PPO [Wageningen, Praktijkonderzoek Plant & Omgeving] (2012), Kwantitatieve Informatie: akkerbouw en vollegrondsgroenteteelt. 28ste editie, Wageningen: Praktijkonderzoek Plant & Omgeving.
Oosthoek & Pouwer (2014), Logistieke landbouwroutes Zeeland: resultaten tellingen landbouwverkeer 2013.
Rienks, W.A., P. Galama, C.M.L. Hermans & C.F. Jaarsma (2009), Opschaling van melkveehouderij heeft ruimtelijke effecten: Kan extra belasting van plattelandswegen worden ondervangen? Spil 257-260 (2/3), pp. 31-35.
Van Dijk, T. (2003), Dealing with Central European land fragmentation – A critical assessment on the use of Western European instruments. Eburon, Delft, The Netherlands
WUR [Wageningen UR Livestock Research] (2013), KWIN Kwantitatieve informatie Veehouderij 2013-2014. Lelystad: Wageningen UR Livestock Research.

BIOGRAPHICAL NOTES

Annet Hospers is working as GIS specialist at Grontmij Netherlands, part of Sweco. Her work focuses on supporting (engineering) projects by analyzing and managing spatial information, for example via a webGIS application as GeoWeb. She has a Master's degree in geographical information management and applications from Utrecht University. During her MSc she has done research at the Netherland's Cadastre to the distribution and intensity of agricultural traffic.

Marije Louwsma is senior advisor in the department of spatial planning at the Netherlands' Cadastre, Land Registry and Mapping Agency. She has a Master's degree in spatial planning from Wageningen University and a Master's degree in geo-information management and applications from Utrecht University. Currently, she works on product and process innovations in the domain of land management and spatial planning. She also conducts PhD research which concentrates on the role of e-government services with spatial data in interactive planning processes.

Ron van Lammeren is associate professor of Geo-Information Science at the Laboratory of Geo-Information science and Remote Sensing of Wageningen University, The Netherlands. In his research and education he pays attention to the role of geo-information in planning and design of landscape and environment. Especially the nature and impact of visual representations of locational data ensembles in participatory planning and design processes are focal points of his interest. He holds an MSc and a PhD degree from Wageningen University and is Dutch State registered landscape architect.

Paul Peter Kuiper is working at the Netherlands' Cadastre, Land Registry and Mapping Agency. As an advisor in the application of spatial data, he mainly focusses on the combination of different spatial datasets for new purposes. He has a Master's degree in socio spatial analysis from Wageningen University**.**

CONTACTS

Annet Hospers, MSc
Grontmij Nederland B.V. (part of Sweco)
PO Box 203
3730 AE De Bilt
THE NETHERLANDS
Tel. +31 88 811 66 00
Email: annet.hospers@grontmij.nl
Web site: www.grontmij.nl

Ir. Marije Louwsma
Cadastre, Land Registry and Mapping Agency
PO Box 9046
7300 GH Apeldoorn
THE NETHERLANDS
Tel. +31 88 183 44 63
Email: marije.louwsma@kadaster.nl
Web site: www.kadaster.nl

Dr. ir. Ron van Lammeren
Wageningen University
Laboratory of Geo-Information Science and Remote Sensing
PO Box 47
6700 AA WAGENINGEN
THE NETHERLANDS
Tel. +31 317 48 15 53
Email: ron.vanlammeren@wur.nl
Web site: www.wur.nl

Ir. Paul Peter Kuiper
Cadastre, Land Registry and Mapping Agency
PO Box 9046
7300 GH Apeldoorn
THE NETHERLANDS
Tel. +31 88 183 63 52 19
Email: paulpeter.kuiper@kadaster.nl
Web site: www.kadaster.nl