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Hertfordshire AL4 8AN, UK
www.ufaw.org.uk

Animal Welfare 2016, 25: 255-263
ISSN 0962-7286
doi: 10.7120/09627286.25.2.255

Improvement of animal welfare by strategic analysis and logistic optimisation of animal slaughter transportation

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Abstract

The transportation of animals to slaughterhouses is a major welfare concern. The number of slaughterhouses has decreased over time in Europe due to centralisation. This is expected to increase transport time for animals and as a consequence negatively affect animal welfare. We propose an optimisation model based on a facility location model to perform strategic analysis to improve transportation logistics. The model is tested on the Swedish slaughter transport system. We show that, by strategic planning and redirection of transports while keeping the slaughterhouse capacities as of the original data, the potential exists to reduce transport distance by 25% for pigs and 40% for cattle. Furthermore, we demonstrated that approximately 50% of Swedish slaughterhouses can be shut down with a minimal effect on total transport distances. This implies that in terms of the overall welfare picture, the decision of which animals to send where plays a far more significant role than the number of slaughterhouses. In addition, by changing relative weights on distances in the optimisation function the amount of individual transports with long journey times can be decreased. We also show results from altered slaughterhouse capacity and geographical location of slaughterhouses. This is the first time an entire country has been analysed in great detail with respect to the location, capacity and number of slaughterhouses. The focus is mainly on the analysis of unique and detailed information of actual animal transports in Sweden and a demonstration of the potential impact redirection of the transports and/or altering of slaughterhouses can have on animal welfare.

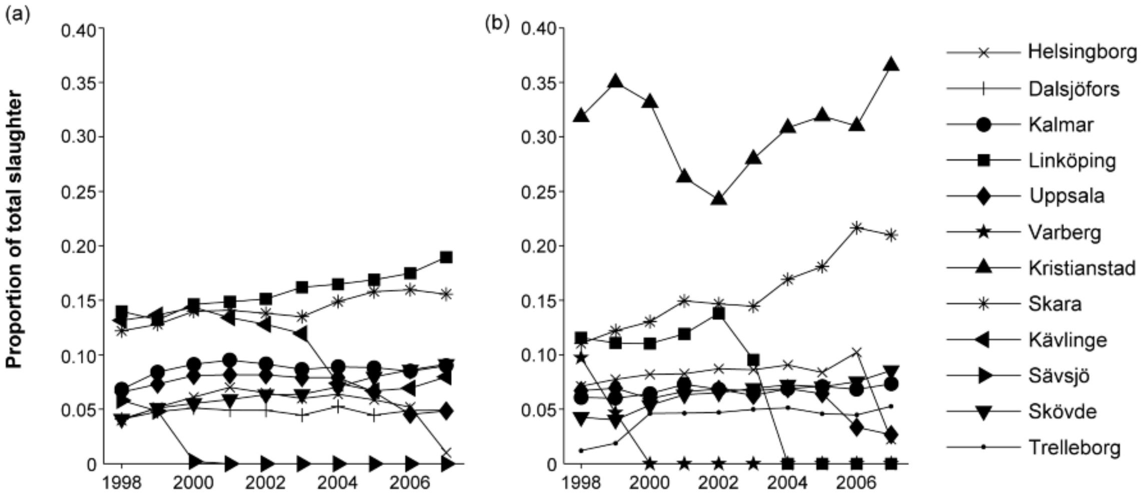
Keywords: *animal welfare, cattle, pig, slaughterhouse capacity, slaughter transports, transportation logistics*

Introduction

The transportation of animals from farms to slaughterhouses is a major welfare concern, both from the perspective of transport time and quality (Kristoffersson 2004; Gebresenbet *et al* 2005; Malena *et al* 2007). The welfare of animals in transport to slaughter systems depends on several elements. During loading and transport animals are exposed to a variety of potential stressors. Studies have shown that long journeys affect the mortality of pigs and cattle (Kristoffersson 2004; Malena *et al* 2007) and that transport time significantly influences other stress parameters (Gebresenbet *et al* 2005). Transport time may thus represent a major concern for animal welfare. Additional important questions include road quality, waiting time at the slaughterhouse, quality and design of equipment, and the behaviour and strategies of various key individuals. Hence, the overall animal welfare quality for animal journeys includes everything from loading conditions, vehicle design, driving strategies, to the structuring of the system. In this paper we focus on transport time.

Factors related to the transport to slaughter process resulting in stressed animals may, in addition to impinging on animal welfare, cause lowered meat quality through an increased risk of DFD (dark, firm and dry meat) and PSE (pale, soft and exudative meat) (Manteca & Vilanova 2007). Short animal transports, which could potentially affect animal welfare less, may therefore be another important goal of producers. Moreover, consumers are willing to pay extra for regionally produced and slaughtered meat, which implies short transport times (Anderson *et al* 2004; Carlsson *et al* 2007). However, in the meat industry the trend today is towards most animals being slaughtered at larger and fewer slaughterhouses. Between 1985 and 2004, the number of slaughterhouses in Sweden, representing more than 90% of the slaughtered animals, was reduced by 50% (Kaspersson & Gullstrand 2004). Figure 1 shows slaughter frequencies at the largest slaughterhouses in Sweden. Centralisation results in increased travel distances and travel time for animals unless animal production is also moved closer to the slaughterhouses (Kaspersson & Gullstrand 2004).

Figure 1



Trends in slaughterhouse contributions to the total number of (a) cattle and (b) pigs slaughtered in Sweden.

The location and capacities of farms and slaughterhouses are the basic parameters that govern transport time. Animal welfare may be improved by altering these. There have been several other studies exploring the area of strategic analysis of the number and location of slaughterhouses. Sigurd and Pisinger (2004), considered transportation of pigs in Denmark and studied the problem of establishing operational routes. The routes were designed to avoid the spread of disease and the study included up to 580 farms within the road network. Another study into the problems of slaughterhouse location (in Bavaria, Germany) (Freund 1997) revealed that the number of slaughterhouses can be decreased dramatically. Oppen *et al* (2010) used the method of column generation to solve the routing problem for a single slaughterhouse. In Norway, a two-stage stochastic programming model has been tested to locate single-animal product facilities (Schutz *et al* 2008).

To show the possibilities for potential improvement of animal welfare through strategic planning of slaughter transportation we have used Sweden as a case system. The animal industry in Sweden is based around 25,000 farms spread throughout the country where cattle and pigs are the main animals. Once the animals have matured they are transported to one of approximately 100 slaughterhouses (according to the Swedish Board of Agriculture 2008). From January 2006, it became permissible to slaughter cattle and pigs at mobile slaughterhouses in Sweden. Governmental subsidies also exist for the establishment of small-scale slaughterhouses. We have analysed the effect of geographical location of farms and slaughterhouses and transport logistics in combination with slaughterhouse capacities on transport time for animals. We found a significant increase in welfare to be achievable through reorganisation of existing journeys and the transport-to-slaughter system. The main focus of this paper is analysis of unique and detailed information concerning actual animal transportations in Sweden and demonstration of the potential impact of redirecting these, either through maintaining capacities as per existing records or altering slaughterhouse capacities. Other factors to explore are consideration of a reduction in the number of slaughterhouses and a move towards introducing small-scale slaughterhouses (a maximum of 106 kg slaughtered per year) or mobile slaughterhouses (which have been developed and are being slowly implemented). This is the first time an entire country has been analysed in such detail as regards the location, capacity and number of slaughterhouses. All registered transports carried out during 2008 are included. We use a model closely related to a facility location model. For more information on facility location problems, see for example, Lundgren *et al* (2010). The method presented here is readily applicable in all countries with existing corresponding databases, ie most EU-countries where such databases exist.

Materials and methods

Scenarios

No overall national strategic planning of animal transportation to slaughter exists in Sweden and the same appears to be the case elsewhere. The largest meat company in Sweden, ScanHK, report their transportation planning (K Svensson, personal communication 2010) by initially contacting the transport companies with preliminary plans that take into account slaughterhouse capacities. Farms form strong connections with specific transport companies but it is ScanHK that makes the operational planning and distribution of transports throughout all the transport companies. Also, animals might not be sent to the same or nearest slaughterhouse every time as ScanHK operates several slaughterhouses. Once the specific transport company has all the information it requires, detailed routing plans are formulated manually and implemented. Farmers report which week they require their animals to be collected

https://doi.org/10.7120/09627286.25.2.255 Published online by Cambridge University Press

and transportation is carried out during a two-week window, ie the specified, previous or following week.

Actual transportations with the manual logistic solutions carried out during 2008 have been compared with several different scenarios of optimised solutions of routes for animal transport to slaughter in Sweden. In the different scenarios we have tested: i) the effects of reduction of existing slaughterhouses; ii) weighing of animal transport time in such a way that longer journey times have a greater degree of influence over animal welfare than shorter trips; iii) potential locations for small-scale or mobile slaughterhouses as an adjunct to existing slaughterhouses; and iv) altering the capacity of existing slaughterhouses to cater for where there is the greatest need, thereby shortening animal transportation.

Transport, co-ordinates and road databases

Data of animal movements (the transport database) were obtained from the Swedish board of Agriculture. The extracted data contained 1.76 million reports of 0.88 million cattle transported to slaughter during the period from January 2007 to December 2008. For cattle, facility reports were both sent and received, with two reports recorded per animal. We amended or excluded incorrect reports and combined the animal reports into transportations. This resulted in 103,110 cattle transports to slaughter (429,000 animals) during 2008. Pig journeys are not reported individually, instead recorded in terms of group transportations and 45,191 transports to slaughter were noted (3.1 million pigs) during 2008 (Appendix, section A, see supplementary material to papers published in *Animal Welfare* on the UFAW website: http://www.ufaw.org.uk/the-ufaw-journal/supplementary-material for more details on the transport data).

In addition to transportation data we used geographical information of farms and slaughterhouses (the holding database) obtained from the Swedish board of Agriculture. The holding database contains co-ordinates, postal codes and production types of all farms and slaughterhouses in Sweden. There were 23,372 active farms that sent cattle to slaughter during the period (2007–2008), 2,619 farms that sent pigs and 832 farms that handled both pigs and cattle (those farms were treated as two farms but in the same location). Farms without co-ordinates in the database were randomly assigned the same co-ordinates as one of the other farms in the county (for more details on geographical data see the Appendix, section B in the supplementary material to papers published in *Animal Welfare* on the UFAW website: http://www.ufaw.org.uk/the-ufaw-journal/supplementary-material).

We have used the Swedish Forestry National Road database (SNVDB) and the system 'Krönt Vägval' (in English, Calibrated Route Finder) to estimate distances and transport times between farms and slaughterhouses (Flisberg *et al* 2010). The SNVDB is based on the Swedish National Road Database (NVDB; www.nvdb.se) which contains detailed digital information regarding all Swedish roads: the state road network, the municipal road and street network, and private road networks together with particular forest industry-related information regarding, for example, turning possibilities, special routes to industrial facilities and through or around cities. We did not use the shortest distance between facilities because that is not the distance that truck drivers prefer. Instead, drivers prefer high quality roads and the difference between shortest and preferred and driven distance can be as large as 7.4% (Flisberg *et al* 2010). The 'Krönt Vägval' system takes this into account and also makes it possible to set extra limitations as to which roads can be used. The limitations used here are a minimum height (bridges) of 4.4 m, minimum permissable vehicle weight of 60 metric tons and a minimum road width of 2.5 m, (for more details on SNVDB see the Appendix, section C in the supplementary material to papers published in *Animal Welfare* on the UFAW website: http://www.ufaw.org.uk/the-ufaw-journal/supplementary-material).

The model

The strategic planning of transports to slaughter was investigated as a location problem using a facility location model (Nagy & Salhi 2007). Six different scenarios (Table 1) were included ranging over one year with time-periods of one month. Transport work measured as animal × km was estimated and compared between scenarios. In short, the first scenario is our reference point and it uses the actual reported transportations. In the second scenario, our 'linear' scenario, journeys are rerouted to minimise transport work and given slaughterhouse capacities limited according to reported data. In both the welfare standard and extended scenarios additional constraints are included in the linear scenario with extra costs for long journeys. In the small-scale scenario, instead, we introduced, into the linear scenario, the possibility of further minimising the transportation work by including the option to introduce small-scale or mobile slaughterhouses. Finally, in the last scenario, there is no capacity limit at slaughterhouses and all animals were transported to the nearest slaughterhouse.

The transport intensity varies throughout the year and, thus, months were used to capture this seasonality. In all scenarios, transportation time limits were set to 8 or 11 h according to Swedish regulations. A few farms had special dispensation for longer travel times due to greater distance from the nearest slaughterhouse. We used the direct routing time obtained from the system 'Krönt Vägval' and did not consider multiple pick-ups. Hence, the solution is a lower boundary of transportation distances.

To assess the standard available capacity of the slaughterhouses we measured the total slaughter at individual slaughterhouses each month during 2008 and added another 10% to ensure flexibility. When studying the effect of closing down slaughterhouses we moved capacities to the remaining establishments to maintain the total capacity of Sweden at a constant level. The total capacity (standard plus extra) that could be moved for a slaughterhouse corresponds to the maximum capacity during one month of 2008. For example, a slaughterhouse slaughtering 100 animals in January and 200 animals in November (the month with most animals slaughter over the year for this example) will have a standard capacity of 110 animals in

Table 1 Description of the six scenarios.

Scenario	Number of slaughterhouses		Description
	Cattle	Pigs	
Manual	46	40	The actual transports during 2008
Linear	13–46	7–40	Non-weighted animal transport
Welfare standard	13–46	7–40	Standard weights (Table 2). Long transports cost more
Welfare extended	13–46	7–40	Extended weights (Table 2). Extra care to reduce long transports
Small scale	46	40	Mobile slaughterhouses/small scale-slaughter houses introduced into the linear scenario
No capacity limit	46	40	All animals are transported to nearest slaughterhouse. Non-weighted animal transport hours. No capacity limit on the slaughterhouses

Table 2 Animal health impact weights depending on transport time for two settings, standard and extended.

Transport time (h)	Health impact: standard		Health impact: extended	
	Cattle	Pigs	Cattle	Pigs
0–1	0.40	0.65	0.40^2	0.65^2
1–2	0.45	0.70	0.45^2	0.70^2
2–3	0.55	0.75	0.55^2	0.75^2
3–4	0.65	0.80	0.65^2	0.80^2
4–5	0.75	0.85	0.75^2	0.85^2
5–6	0.90	0.90	0.90^2	0.90^2
6–7	0.95	0.95	0.95^2	0.95^2
7	1.00	1.00	1.00	1.00

January and 220 animals in November in all cases. Hence, the maximum capacity for the slaughterhouse was set to 220 irrespective of month and, where required, the capacity could also be set at 220 in January should some other slaughterhouses be shut down. We also tested the redistribution of slaughterhouse capacities so that animals only had to be transported to their nearest slaughterhouse.

To consider the possible negative effects of longer transit times on animal welfare we introduced two scenarios with time-weighting coefficients as an extra cost for longer journeys (Table 2) — the welfare standard and the extended scenario. The standard scenario is an estimation of the actual deterioration of animal health as travel time increases (B Algers, personal communication 2012) and the extended scenario seeks to test how we can decrease the use of longer transport times.

The cost coefficient of individual transportations in the optimisation model is then multiplied by the actual length of the transport. This means a direct scaling is imposed where a transport of 7 h is 100/65 times worse than a transport of 1 h. For example, suppose we have two transports for pigs. The first has a distance of 185 km and takes 4.5 h, and the second has a distance of 45 km and takes 1.5 h. The animal welfare objective for the first is 185 × 0.85 the second 45 × 0.70.

To analyse the impact of mobile slaughterhouses or new, small-scale slaughterhouses, we generated potential locations for small-scale slaughterhouses or locations from where mobile units could operate. We ran the analysis with the number of slaughterhouses used in 2008. The potential small-scale or mobile slaughterhouse locations were placed in every 10th farm and the standard health impact objective used. This gave more than 2,000 potential locations spread evenly out throughout those regions of Sweden where there are farms. The capacities of mobile/small-scale slaughterhouses were set to 750 cattle and 3,600 pigs per year.

The optimisation model is described in Appendix, section D (see supplementary material to papers published in *Animal Welfare* on the UFAW website: http://www.ufaw.org.uk/the-ufaw-journal/supplementary-material). Two main sets of decision variables are

https://doi.org/10.7120/09627286.25.2.255 Published online by Cambridge University Press

Table 3(a) Number of cattle transported within the time intervals for the different scenarios.

Scenario with number of slaughterhouses	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	Transport work (million animal × km)
Manual 46	163	122	76	40	22	4	0.9	0.5	0.2	0.03	48
Linear 46	243	153	24	7	2	0.1					29
Linear 20	213	162	41	10	3	0.3	0.1				33
Linear 13	192	168	50	13	4	0.7	0.3	0.2	0.2	0.2	36
Welfare standard 46	244	154	24	6	1	0.1					29
Welfare extended 46	235	171	16	6	0.3						29
No capacity limit 46	339	84	5	0.5	0.1						19
Small scale 1	252	148	20	7	2	0.2					28
Small scale 10	306	111	9	2	0.4						21
Samall scale 30	419	8	1	0.6	0.2	0.001					8

Table 3(b) Number of pigs transported within the time intervals for the different scenarios.

Scenario with number of slaughterhouses	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	Transport work (million animal × km)
Manual 40	1,045	904	458	399	239	55	10	2			389
Linear 40	1,365	996	436	233	54	20	8	0.9			289
Linear 20	1,356	1,003	438	232	54	20	8	0.9			290
Linear 7	1,203	728	688	358	58	39	16	16	5	0.6	360
Welfare standard 40	1,361	1,033	425	227	38	20	8				290
Welfare extended 40	1,339	1,069	414	236	27	18	8				290
No capacity limit 40	2,659	421	30	2							112
Small scale 1	1,408	996	436	233	29	1.0	8	0.9			278
Small scale 10	1,784	996	326	4	2		0.1				203
Small scale 30	2,563	517	27	4	0.6						117

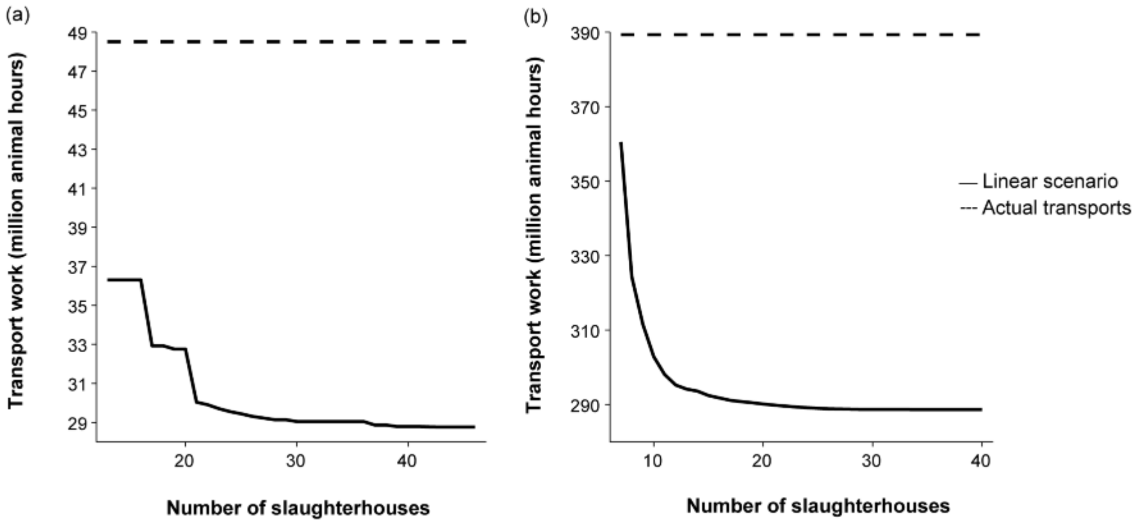
used. The first concerns the decision of whether or not to use a slaughterhouse, and the second relates to which slaughterhouse each farm should be allocated. The minimised function consists of three parts: i) transportation distances; ii) a fixed cost when a slaughterhouse is used; and iii) a penalty cost if maximum transportation time is exceeded. The main constraints concern the relationship between the decision variables and the logical requirements, such as: only using open slaughterhouses, restrictions to capacity and each farm being connected to one specific slaughterhouse.

All calculations were run on a standard PC with an i7 processor with 2.67 GHz and 6 GB of internal memory. We used the ILOG–AMPL modeling system, (ILOG Manual 2008). To solve the model, we used the ILOG–CPLEX solver (ILOG CPLEX version 11). To solve each problem (for a given number of slaughterhouses), we used a limit of 1 h of computing time.

Results

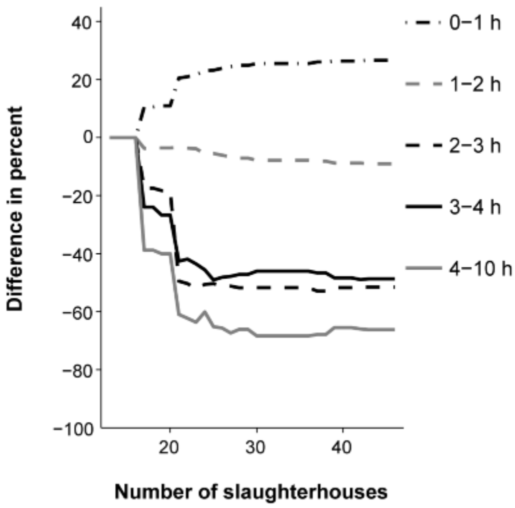
In general, we show that a huge potential exists to reduce today's transport work for pigs and cattle in Sweden through implementing optimal solutions. For cattle, this can be lowered by as much as 40%, according to the no capacity limit scenario compared to the manual scenario. For pigs, transport work can be reduced by 25%. Table 3 shows the total transport work for all scenarios with cattle and pigs.

Figure 2



Modelled transport work (solid line) depending on the number of slaughterhouses for (a) cattle and (b) pigs.

Figure 3



Change in percentages of cattle transported within specific transport times as number of slaughterhouses increases. Values are compared to the normalised case of 13 slaughterhouses.

Number of slaughterhouses — how many slaughterhouses are actually needed?

Figure 2 shows the total transport work for cattle and pigs at different numbers of slaughterhouses using the linear scenario. If the number of slaughterhouses is reduced to only 13 for cattle transportations (Fig 2[a]), the optimal destination increases the transport work to 36.3 million animals × km for cattle. This is still 25% less than the manual solution. Transport work increases with decreasing numbers of slaughterhouse more rapidly at the breaking point of 20 slaughterhouses. This implies that it is, from a total transport work perspective, possible to decrease the number of slaughterhouses from 46 to around 20 without impacting seriously upon the welfare of cattle. If the number of pig slaughterhouses is reduced down to 7 (Figure 2[b]), the optimal destination increases the transport work up to 360.5 million animal × km. This is 7% lower than the manual solution. The transport work increases more rapidly after and at the breaking point of approximately eleven slaughterhouses. Between 20 and 40 slaughterhouses, transport work is relatively stable for both pigs and cattle. This means that at this moment in time the number of Swedish slaughterhouses can be greatly reduced without impacting upon total animal welfare; measured in terms of transport work, if optimised transports are used.

How numerous are the long transports — is it dependent on the number of slaughterhouses?

Even if total animal welfare is decreased there may be certain individuals negatively affected by the decrease in slaughterhouses. We have thus recorded the number of animals in each time interval for each run. Figure 3 shows the example of cattle. Here, it is clear that the proportion of animals transported within the longer time intervals decreases with increasing slaughterhouse number. For example, the proportion of cattle transported within 4–10 h decreases by 66% as the number of slaughterhouses increases from 13 to 46. Results for pigs show a similar trend; more slaughterhouses reduce long journey times. This implies that the number of slaughterhouses is important for the welfare of those animals that are transported the longest.

Animal welfare impact — can we find a solution that reduces the amount of long journeys by using weighted transports?

With the animal welfare weighting it is possible to reduce the number of journeys with long routing times for pigs and cattle (Table 3). However, this results in a small increase in the transport work which will prove more expensive in monetary units. The total transport work for the scenarios with animal welfare constraints are

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increased by 0.5–1% compared to the optimal solution with all (46 [cattle] and 40 [pig]) regular slaughterhouses. In the welfare standard case the number of animals in journeys longer than 4 h is decreased by 42% for cattle and 21% for pigs compared with the linear case. The decrease for the welfare extended case is 84% for cattle and 35% for pigs, compared to the linear case.

Small-scale or mobile slaughterhouses — identifying areas with lack of slaughter capacity

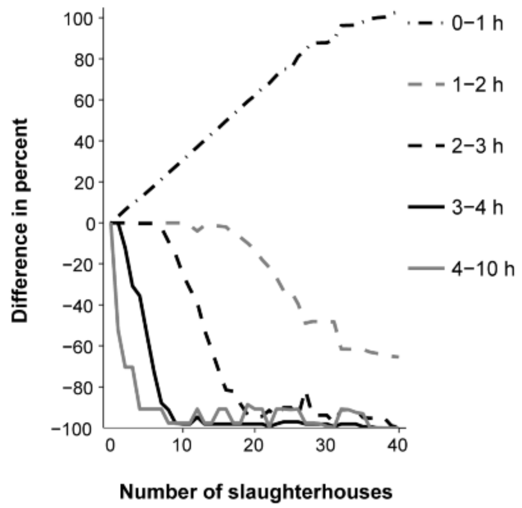
Introducing one new small-scale or mobile slaughterhouse would decrease the total transport work by 3–4% for cattle and pigs compared to the linear cases with 46 and 40 slaughterhouses, respectively. The number of animals transported more than 4 h would not decrease for cattle but would by 52% for pigs (Table 3). With five mobile or small-scale units the number of cattle transported more than 4 h is reduced by 78% and the number of pigs transported more than 4 h is reduced by 91% compared to linear 46 and 40 cases, respectively. Figure 4 shows how mobile and small-scale slaughterhouses would increase journeys shorter than 1 h and decrease the long transits for pigs. For example, the proportion of pigs transported within 1–2 h decreased by 50% with an increase in mobile slaughter houses from 0 to 30. With enough mobile and small-scale slaughterhouses there would need to be no journeys longer than 4 h anywhere in Sweden. For cattle, the same result emerged; the more mobile or small-scale units introduced, the fewer animals are transported long distances.

Nearest slaughterhouse — differences between farm and slaughterhouse capacities

An optimal solution both from an economic (in terms of transportation distances) and animal health perspective is to transport all animals to their nearest slaughterhouse. However, the capacity limits at slaughterhouses renders this impossible and often it is the second or third best slaughterhouse that tends to be used. Without slaughterhouse capacity limits, transport work for cattle would decrease to 18.65 million animal × km. The transport work for pigs would decrease to 111.6 million animal × km. Clearly, it is possible to greatly reduce transport work by redistributing slaughterhouse capacities. Sending animals to their nearest slaughterhouse would reduce total transport work by 61 and 71% for cattle and pigs, respectively, compared with the manual solution.

There are a number of farms that did not transport their animals to any of the nearest 30 slaughterhouses, according to existing data (Table 4). Even with optimisation, some animals were not able to be sent to any of the ten nearest slaughterhouses. It is, thus, of great interest, the capacities needed to ensure that each farm can transport its cattle or pigs to the nearest slaughterhouse. Figure 5 shows the relative size and location of slaughterhouses for 2008 for the optimised case with no capacity limits.

Figure 4



Change in percentages of pigs transported within specific transport times as number of mobile slaughterhouses increases.

Discussion

Strategic planning using optimal solutions for animal transportation has much potential to improve animal welfare via decreased transportation times as well as finding cost-reducing strategies. In the case of the Swedish system we found that many animals are not sent to their nearest or even second or third nearest slaughterhouse. There are several reasons for this. One is that transportations tend not to be co-ordinated and planning carried out at a late date. Another is the payment system to the animal owners whereby transport cost is taken solely by the slaughterhouse, leaving less incentive for animal owners to select the best option from a logistical perspective. By using an optimal logistic model we have shown that transport work could have been reduced by as much as 40% for cattle and 25% for pigs in 2008 compared to the manual solution. And this achievement was elucidated without needing to alter capacities of farms or slaughterhouses.

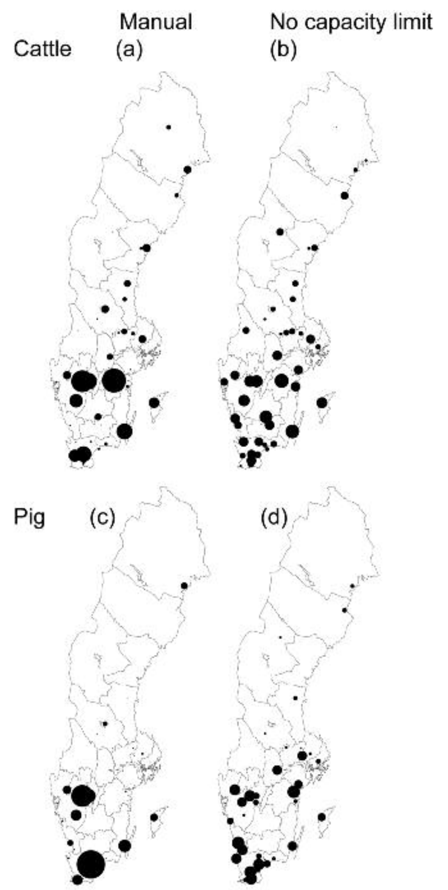
An even better solution, yet somewhat unrealistic, would be to allow for changes to the capacities of slaughterhouses. In the case of Sweden, we show that capacities of existing slaughterhouses would need to change for all animals to be sent to their nearest one. The transport work would thereby be reduced more than 60% compared with the manual solution found in the records. Interestingly, the additional gain compared only to transport redirection is not that large and hence the major welfare gain does not come from restructuring the industry and its slaughterhouses — simply from redirecting the transportations.

The results point out that animal welfare can be increased significantly through a reorganisation of transport planning within a region or country. This potential for increased welfare ought to promote actions from authorities and consumers, not to mention the industry itself. The

Table 4 The numbers of farms using the closest slaughterhouse followed by ever more distant choices for cattle (upper) and pigs (lower).

	Relative slaughterhouse distance (46 and 40 cattle and pig slaughterhouses, respectively)						
Scenario	**0**	**1–5**	**6–10**	**11–15**	**16–20**	**21–30**	**31–40**
Manual	5,652	9,686	2,576	995	970	324	5
Linear	8,821	10,359	963	60	6		
No capacity limit	20,209						
Welfare standard	9,112	10,267	790	32	8		
Welfare extended	8,798	10,755	636	20			
Manual	500	890	390	198	148	76	11
Linear	842	1,003	273	71	24		
No capacity limit	2,213						
Welfare standard	839	1,030	252	77	15		
Welfare extended	814	1,307	257	82	10		

Figure 5



Maps of Sweden showing location and relative size of slaughterhouses (black circles) for cattle (a-b) and pigs (c-d) with manual (a, c) and no capacity limit scenarios (b, d), respectively. The larger the circle the higher the capacity. For cattle, slaughterhouse capacities span between 49–28,414 animals per year and for pigs, 46–230,610 animals per year. ArcView-shape files for plotting contours of counties in Sweden were provided by Statistics Sweden (SCB).

animal welfare gain is also coupled with a reduced cost since shorter transport time also implies reduced transportation work. We have proposed a model to analyse transport work and animal welfare in various different scenarios as regards: number and capacities of slaughterhouses. The same model can also be used to analyse the potential of introducing mobile slaughterhouses and establishing the geographical location of these.

In the analysis of the number of slaughterhouses, we found there to be a large potential for decreasing the number of slaughterhouses without causing any substantial increase in total transportation work. This implies that, from the point of view of overall animal welfare, the number of slaughterhouses in Sweden is not as important as which animals are sent where and the capacities of said slaughterhouses. However, for those animals that travel the greatest the number of slaughterhouses is very important. With a national perspective on strategic planning the transport distances for these animals can be reduced.

Also, we show that by using non-linear animal welfare weights for the transportations we can reduce the total transport work at the same time as avoiding long journeys. Similar results were found by Algers *et al* (2006). The total transport work for the non-linear welfare scenarios are slightly higher than for the optimal linear scenarios without any special consideration for long journeys. The number of medium and long journeys (longer than 2 h) is reduced and the number of short journeys (less than 2 h) increased in the welfare scenarios. This, in turn, would allow for a better 'just in time' delivery and reduce the proportion of animals lairaged overnight, also contributing to improved animal welfare. Another possibility to reduce long journeys for animals is to introduce new slaughterhouses or even mobile slaughterhouses in areas where capacity is lacking. We have been able to pinpoint areas where it would be worthwhile to

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introduce these and they would effectively reduce the need for long journeys. Hence, from the overall regional and national perspective, one may conclude that an increase in animal welfare is wholly achievable by reducing the total transport time of animals through re-directing the transportations within the industry itself. However, to significantly reduce those instances where animal welfare is more severely affected, notably long journeys, specific actions are required and a determination of where new small-scale slaughterhouses or mobile units should be placed. For example, in Sweden, new, small-scale slaughterhouses offer little in the way of welfare promotion unless they are located in accordance with our analysis. This indicates that if the actual subsidies in Sweden for small-scale slaughterhouses were aimed for increased welfare, the subsidy ought to have been related to the location.

In order to carry out this analysis, access to detailed data on actual transports, geographical positions and detailed information about the road network used were imperative. The same analysis can be repeated in any country that has corresponding databases. In the model, we have no fixed cost to operate the slaughterhouses but it is easy to include it in the model as decision variables associated with whether it is open or not are available. If one includes fixed costs, the solution will balance animal welfare and costs. However, cost for transportation is truck × km and that is not the same as animal × km. It may be difficult to find correct cost values for both fixed costs and unit production costs. This would be useful were we to want to study the impact of one or more slaughterhouses closing down.

An interesting question is to whom responsibility falls when providing a slaughterhouse within reasonable distance from where animals are located? Is it the farmer/industry or society itself that is responsible for making sure that all animals are able to be transported to slaughter via a relatively short journey? For most other animal welfare issues it is obvious where one can place responsibility and enforce some actions by regulations or other means. Here, the potential exists to greatly enhance the welfare of a large number of animals yet society seems unable to handle either the spatial location or the network organisation.

Animal welfare implications

In conclusion, a massive potential exists for decreased transport distances to slaughter and, consequently, a potential to increase animal welfare. With strategic planning on a national or regional level, transportation times to slaughter can be largely reduced. In Sweden, one may reduce journey times by approximately 40 and 25% for cattle and pigs, respectively. The number of long journeys can be further reduced by increasing numbers of slaughterhouses (mobile or regular) or through animal welfare consideration in the optimisation model.

Acknowledgements

We would like to thank Swedish board of Agriculture for funding.

References

Algers A, Algers B, Franzèn U, Lindencrona M, Moen O, Ohnell S, Waidringer J and Wiberg S 2006 *Logistik i samband med transport till slakt. Livsmedel och miljöoptimerade djurstransporter.* Tech Rep 10, SLU Department of Animal Environment and Health, Sweden. [Title translation: Slaughter transport logistics. Food and environment optimised animal transports]

Anderson C, Lagerkvist C-J, Carlsson F, Hannerz N, Lindgren K and Frykblom P 2004 *Värdering av griskött på en lokal marknad - ur ett konsumentperspektiv.* Tech Rep 325 JTI - Institutet för jordbruks- och miljöteknik. Swedish Institute of Agricultural and Environmental Planning: Uppsala, Sweden. [Title translation: Valuation of pork meat on the local market from a consumers' perspective]

Carlsson F, Frykblom P and Lagerkvist C-J 2007 Consumer willingness to pay for farm animal welfare: mobile abattoirs versus transportation to slaughter. *European Review of Agricultural Economics 34(3)*: 321-344. http://dx.doi.org/10.1093/erae/jbm025

Flisberg P, Lidén B, Rönnqvist M and Selander J 2012 Route selection for best distances in road databases based on drivers' and customers' preferences. *Canadian Journal of Forest Research 42(6)*: 1126-1140. http://dx.doi.org/10.1139/x2012-063

Freund U 1997 The size and location of slaughtering plants in bavaria. *Fleischwirtschaft 77(5)*: 404

Gebresenbet G, Wikner I, Ladberg E, Holm P, Nilsson C and Svensson L 2005 *Effect of transport time on cattle welfare and meat quality.* Tech rep Department of Biometry and Engineering Rapport Miljöteknik och lantbruk 2005:02, Uppsala, Sweden

ILOG Manual 2008 *User's Guide to the Ilog ampl cplex system, version 11.0. Tech rep, ILOG Manual.* IBM: London, UK

Kaspersson E and Gullstrand J 2004 *Ekonomiska drivkrafter för djurtransporter. Tech Rep 7. Livsmedelsekonomiska institutet.* Agrifood Economics Centre, Lund, Sweden. [Title translation: Economic incentives to animal transports]

Kristoffersson J 2004 Transportdödlighet hos slaktsvin. *Svensk Veterinärtidning (12)*: 11-15. [Title translation: Transport mortality of fattening pigs]

Lundgren J, Rönnqvist M and Värbrand P 2010 *Optimization.* Studentlitteratur AB: Lund, Sweden

Malena M, Voslárová E, Kozák A, Bělobrádek P, Bedánôvá I, Steinhauser L and Večěrek V 2007 Comparison of mortality rates in different categories of pigs and cattle during transport for slaughter. *Acta Veterinaria Brno 76*: 109-116

Manteca I and Vilanova F 2007 Animal welfare at transport and at slaughter of livestock and poultry. *XIII International Congress on Animal Hygiene* pp 702-704. 17-21 June 2007, Tartu, Estonia

Nagy G and Salhi S 2007 Location-routing: Issues, models and methods. *European Journal of Operational Research 177(2)*: 649-672. http://dx.doi.org/10.1016/j.ejor.2006.04.004

Oppen J, Lokketangen A and Desrosiers J 2010 Solving a rich vehicle routing and inventory problem using column generation. *Computers & Operations Research 37(7)*: 1308-1317.

Schutz P, Stougie L and Tomasgard A 2008 Stochastic facility location with general long-run costs and convex short-run costs. *Computers & Operations Research 35(9)*: 2988-3000

Sigurd M and Pisinger D 2004 Scheduling transportation of live animals to avoid the spread of diseases. *Transportation Science 38(2)*: 197-209

Swedish Board of Agriculture 2008 *Transport database.* Swedish Board of Agriculture: Uppsala, Sweden