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Designing capacity and service level at ferry crossings

Finn Jørgensen [a], Gisle Solvoll [a,*]

[a]Business School, Nord University, Norway

Abstract

This paper first deduces how the transport capacity over a ferry crossing, measured by the number of passenger car equivalents, depends on the length of the crossing, the ferries' size, their speed, their efficiency of boarding and alighting them. Such calculations are essential in order to evaluate whether the ferry material used at a service has sufficient capacity fulfilling national quality standards like meeting required transport demand during the opening hours and a stated minimum probability for users to board their desired departure. Second, the paper derives a model that shows how welfare optimal frequency at a crossing depends on its level of traffic, ferry users' waiting time costs, the cost structure of ferry operations and the length of the crossing. The model demonstrates in a clear way the influences of crossing - and ferry fleet characteristics on optimal frequency. Using Norwegian data for ferry users' waiting time costs and for the costs of operating ferry transport services, the model's results indicate that the authorities recommend to low frequency, in particular at high traffic services. It is also emphasised that the length of the crossing has great impact on optimal frequency; optimal frequency at long crossings is less than a half compared to short crossings for all levels of traffic. Lastly, the model shows that it is more serious from a welfare perspective to undersupply frequency with X units than to oversupply it with X units.

1. Introduction

From an economic point of view, the service level in scheduled passenger transport is important for two reasons. First, important service elements, such as the quality of the transport means and the number of departures per day, strongly influence the direct and external costs of operating the services. Second, the service level influences the

* Corresponding author:
E-mail address: gso@uin.no

passengers' generalised travel costs and thereby their welfare. Together these two impacts affect the social surplus of the service in question. Consequently, setting the right service level for public transport is an important task for the transport operators and authorities (Mathisen and Solvoll, 2010; Preston, 2015).

Ferry services play an important role in the national transport system in many European countries, especially those with long coastlines and many inhabited islands. This is definitely the case in Norway. In 2014, there were 121 ferry crossings in Norway served by approximately 160 ferries. A total of 19 and 102 of the crossings were regulated at state and county level, respectively. With the exception of some small ferry crossings, the crossings were operated by four shipping companies[†]. A national administration reform implied, amongst other things, that the administrative responsibility for 78 of 95 national road crossings were transferred from the central authorities to the Norwegian county councils on 1 January, 2010. Because the counties do not necessarily have to follow the current national ferry standard, the transfer of responsibility paves the way for differentiation between crossings with respect to service level and fare setting.

Even though many ferry services in Norway have been replaced with bridges and underwater tunnels during the last two decades, the ferries still have a very important function in the transport infrastructure in coastal areas. Without these ferry crossings, many settlements and enterprises along the Norwegian coastline could not be upheld. For example, analysis shows that about 75% of the Norwegian ferry crossings were profitable from a social welfare point of view but only *one* was run without subsidies (Jørgensen et al., 2011). In 2014, the ferries carried over 21 million vehicles (34.5 million passenger car equivalents; PCE)[‡] and about 42.5 million passengers (including drivers). The costs of operating the ferry services this year was about 5,000 million NOK (about 590 million €), and the revenue from vehicles and passengers was approximately 2,600 million NOK. This resulted in a subsidy requirement of about 2,400 million NOK[§].

The aim of this article is first to deduce how the transport capacity (measured by the number of PCE) depends on the ferries' size, their speed, the efficiency of boarding and alighting them and the length of the crossing. Second, we will estimate optimal frequency, defined by the level of frequency that minimises total social costs of the ferry operations, at eight ferry crossings in Norway. These calculations are based on information about the crossings' level of traffic, the cost structure of ferry operations and the passengers' waiting time costs. These estimates are compared with the actual frequency on the same crossings.

The article is organised as follows. Section 2 briefly presents the Norwegian nationwide ferry standard. Section 3 gives a discussion of factors affecting the transport capacity at a ferry crossing. Section 4 presents a model to estimate optimal frequency for different ferry services. The model results are compared with the actual frequency for some important/representative ferry services in Norway. Finally, section 5 provides conclusions and possible implications for policy makers.

2. Literature review

Optimal service level and optimal pricing for public entities have been given attention from several researchers. Many contributions have focused on the socially optimal simultaneous choice of price and service level for monopolies; see, for example, Spence (1975) for a general discussion and Jørgensen and Pedersen (2004) and Jørgensen et al. (2013) for transport companies in particular. Jansson (1993) analyses the simultaneous optimisation of price and frequency. He emphasises two important effects of frequency on passenger behaviour. The first effect is the dual behaviour indicating that for low frequency services with a reliable timetable, travellers plan their trips according to the table, whereas they, for high-frequency services, prefer to arrive at the stops spontaneously rather than consult a timetable. The second effect relates to the fact that the disutility of waiting at stops is higher than that of waiting at home or at work, and that the passengers' waiting time costs may vary with the duration of the wait.

[†] For further descriptions of the Norwegian ferry industry, see, for example, Jørgensen and Mathisen (2012).
[‡] PCE is a compound production measure introduced to handle the multiproduct problems related to transporting different types of vehicles. For example, a passenger car (< 6 m) counts as 1.025 PCE, whereas a heavy goods vehicle (> 19 m) counts as 10.682 PCE. The PCE concept is more thoroughly explained by Mathisen (2008).
[§] The numbers for costs, revenue and subsidies are relatively rough estimates given by the Norwegian Public Roads Administration.

Panzar (1979), dealing with air transport, also determines optimal price and frequency, specifying demand as a function of these two variables and the load factor. Dandapat and Maitra (2015) demonstrate an approach for identifying optimal bus service giving due consideration to both user costs and operational viability. The effects of demand level and route length on optimal service attributes were also analysed. Chien, Byun and Bladikas (2010) investigate the relationship between stop spacing and headway, considering realistic wait time and operable transit capacity. Their model's objective function is users' travel time, which is minimised by the optimised stop spacing and headway, subject to the constraints of operable fleet size and route capacity. dell'Olio, Ibeas and Ruisanchez (2011) use an optimisation model for sizing the buses and setting frequencies on each route in the system with constraints on bus capacity and levels of demand. The model considers the optimisation of the system's social and operating costs; these are understood to be the sum of the user's and operator's costs. Hadas and Shnaiderman (2012) use a model were the objective function is to minimise the total costs of a public transit system with decision variables of either frequency or vehicle capacity (vehicle size). It is also relevant to mention the article by Fosgerau (2009), which develops a model that can be used to derive the marginal social cost of headway for a scheduled service. The model takes into account the travellers' scheduling considerations (i.e. the share of users who plan for a specific departure as a function of headway, the value of waiting time and the planning costs).

3. Guidelines regarding service quality

National Transport Plan 2014–2023 (Report no. 26 to the Storting, 2012–2013) defines the government's transport policy regarding all public transport infrastructure whether it is by road, rail, air or sea. Although the counties are responsible for quite a few ferry crossings, the Norwegian ferry operations are still highly regulated by the state with respect to fare setting and most of the quality service elements. One of the most important service standards with regard to frequency and opening hours is, according to the National Transport Plan, determined by the amount of traffic and the classification of the crossing. An extract from the national ferry standard is shown in Table 1.

Table 1. Extract from the national ferry standard for the Norwegian ferries.

Classification	Traffic[a]	No. of crossings[b]	Daily frequency	Opening hours (weekdays)
Main state roads	> 2,500 PCE ADT	1	38	24 h
	< 2,500 PCE ADT	9	36	24 h
Other state roads	> 2,500 PCE ADT	1	36	24 h
	1,000–2,500 PCE ADT	10	30	18 h
	500–1,000 PCE ADT	9	22	18 h
	100–500 PCE ADT	54	21	16 h

[a] PCE: Passenger Car Equivalents. ADT: Average Daily Traffic.
[b] A total of 15 state regulated crossings have an ADT of less than 100 and is not considered by the service standard.

The guidelines in Table 1 show that increased traffic requires an increased number of departures per day (frequency) and extended opening hours. For example, all main state roads along with other state roads with average annual daily traffic (ADT) exceeding 2,500 PCE are to offer round-the-clock operation. Additionally, for all ferry crossings run by the state, a service level of 98% (the proportion of vehicles able to board on their desired departure) is a stated goal. This 'boarding-ratio' is set by the Norwegian Directory of Roads. However, traffic data from 2008 indicates that 15% of the crossings have a service level lower than the standard (The Norwegian Public Roads Administration, 2009). This is principally crossings with high ADT.

4. Factors affecting transport capacity at a ferry crossing

4.1. Maximum transport capacity

Assuming the ferry is emptied and refilled at every port of call, the maximum number of PCE the ferry can carry

over the crossing per day (PCE^M) can be written as[**]:

$$PCE^M = \frac{24 \cdot A \cdot PCE^C}{\frac{L}{s} + 2 \cdot A \cdot t + 2 \cdot A \cdot q \cdot PCE^C} \tag{1}$$

in which s is the speed of the ferry in km/h, L is the length of a round trip in km, PCE^C is the size of the ferry measured in PCE, A is the number of calls per round trip, t is time used to dock and undock the port of call and q is time per PCE of boarding and alighting the ferry, measured in hours. Hence, the denominator in formula (1) is total time used per round trip.

From (1), it can be deduced that PCE^M increases concavely with A, PCE^C and s, and decreases convexly with L, t and q, meaning that the marginal effects of all variables in (1) on traffic capacity (PCE^M) diminish. A doubling of ferry size or speed will, for example, not double on the maximum transport capacity (PCE^M) at the crossing. Moreover, a doubling of the length of the crossing will reduce its transport capacity by less than half.

Formula (1) shows maximum transport capacity with the use of one ferry only. If one has Y-number of ferries of the same size available and they do not delay each other's operations, maximum transport capacity becomes $Y \cdot PCE^M$.

4.2. Transport capacity, ferry size and the number of ferries

Figure 1 shows the relationship between maximum transport capacity at a crossing (PCE^M) per day and ferry's size (PCE^C) when *the* length of a round trip is 10 km and 20 km and when one and two ferries of equal size are used. The figure confirms one of our earlier statements: transport capacity at a crossing increases concavely with the ferry size regardless of the length of the round trip.
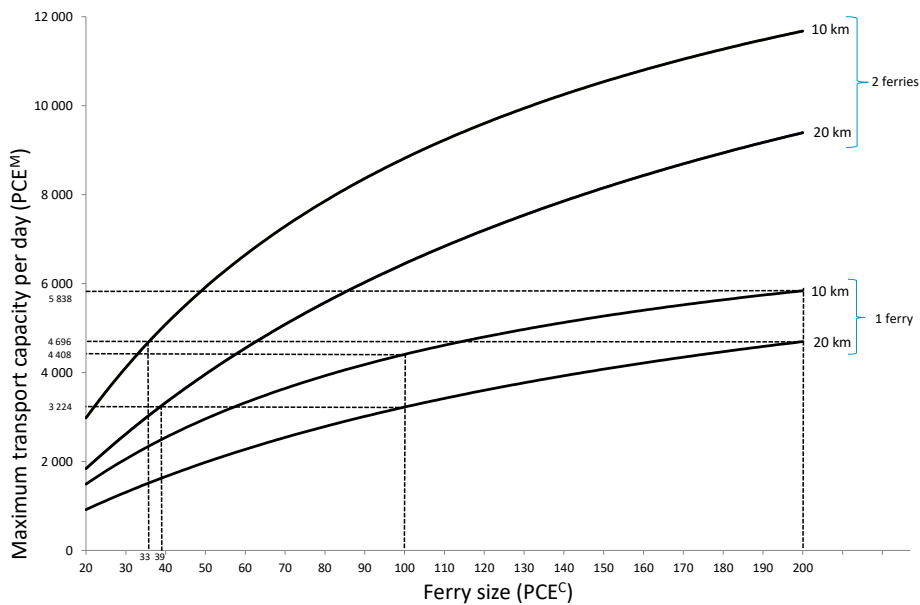

Fig. 1 Maximum number of PCE per day by ferry size, length of crossing and number of ferries. Assumptions: Speed = 25 km/h (13.5 knot), manoeuvring to and from ferry pier = 2 min. (t=0.033) and time to drive on board and ashore = 5 sec. (q=0.0014) per PCE.

[**] This will always apply when the ferry calls at only two ports of call. At crossings with more than two ports of call, this is an unusual case in practice since it usually will be cars on board that will not disembark at the nearest port of call. Therefore, formula (1) will usually overestimate predicted PCE^M at crossings with more than two ports of call.

When the length of a round trip is 10 km, Figure 1 shows that PCE^M per day increases from 4,408 PCE to 5,838 PCE (32% increase) when the ferry's size increases from 100 PCE to 200 PCE. If the round trip is 20 km, PCE^M increases from 3,224 PCE to 4,696 PCE (46% increase). Thus, the increase in transport capacity at a ferry crossing with use of larger ferries is higher the longer the crossing is, relatively speaking. This is true whether the service is operated by one or two ferries.

Another indicator of the same is that when a round trip is 10 km, the transport capacity is approximately the same by using two ferries each with a transport capacity of 33 PCE as using one ferry with a transport capacity of 100 PCE. If the length of a round trip increases to 20 km, the transport capacity at a crossing using two ferries each with a transport capacity of approximately 39 PCE is about the same as using one ferry with a transport capacity of 100 PCE. Large ferries are, thus, relatively more advantageous the longer the round trip is.

Figure 1 can be used to analyse how a given maximum ferry capacity at a crossing can be achieved at the lowest possible costs. For example, if a crossing of 10 km has 24 opening hours per day and transport capacity at 4,000 PCE, it can be deduced from Figure 1 that this can be obtained by using *one* ferry with a transport capacity of 83 PCE or two ferries each with a transport capacity of 29 PCE. Knowing the cost structure of ferry operations, it can then easily be determined which of the two alternatives results in the lowest costs.

Using formula (1) to estimate PCE^M on two of the ferry crossings in Norway with the most traffic in 2012 and round-the-clock operations (Mortavika-Arsvågen and Sandvikvåg-Halhjem) gives PCE^M values of 15,108 and 11,713, respectively. When we know that actual traffic was 6,605 PCE and 4,548 PCE per day this year, it is easy to deduce that 'total' capacity utilisation (PCE/PCE^M) was 44% and 39%, respectively

5. Optimal frequency for different ferry services

5.1. Optimal frequency and operators' goals

A thorough discussion of whether profit maximisation monopolies undersupply quality or not is given in Spence (1975). Jørgensen et al. (2013) discuss similar issues under specific assumptions regarding transport operators' demand and costs structures and when they place different weight on profits versus consumer surplus. The findings of these two works transferred to our problem imply that when transport operators wish to maximise profit and can control both fare and service level, their fare will be higher than a welfare optimal fare whilst it is uncertain whether they will undersupply service or not. The latter depends on both the demand functions and cost conditions that the operators are facing at the different crossings. Consequently, the degree to which operators' chosen service level differs from the welfare optimal one may vary between different ferry services, even though the operators pursue the same goals.

When the fare level is uncontrollable for the ferry operators (as in Norway), profit maximising ferry operators will always set a service level that is lower than the welfare optimal one. Whether the magnitude of the difference between welfare optimal quality and quality set by profit-maximising companies increases with the level of the predetermined fare is uncertain; see Jørgensen et al. (2013) for a thorough discussion of this issue. From a welfare perspective, frequency on a ferry service shall, for example, be increased until the costs of an extra trip exceed the reduction in waiting time costs for the passengers.

5.2. Model formulation and central assumptions

Let us take a closer look at optimal frequency at a ferry crossing from a welfare point of view when the size of the ferry (PCE^C) and traffic (PCE) are given. In further analysis, optimal frequency is defined as the value of F (F^{opt}) that minimises the sum (SC) of the passengers' waiting time costs and the ferry company's operating costs:[††]

$$MIN_F SC = 360 \cdot \frac{OH \cdot t_H}{2F} \cdot OH \cdot PCE + 360 \cdot \left(a + b\frac{OH}{2F}\right) \cdot t_W \cdot OH \cdot PCE + (C^* + 360 \cdot C \cdot F) \Rightarrow$$

$$MIN_F SC = 360 \cdot OH \cdot PCE \left[\frac{OH \cdot t_H}{2F} + \left(a + b\frac{OH}{2F}\right) \cdot t_W\right] + (C^* + 360 \cdot C \cdot F)$$

(2)

[††] Note that F is frequency per day. Hence, ($360 \cdot F$) is frequency per year following that 360 is increased frequency per year when frequency per day increases by 1.

In formula (2), OH is the opening hours of the crossing, PCE the average traffic per hour, F the frequency during the opening hours, t_H waiting time costs per hour hidden waiting time, t_W waiting time costs per hour waiting time at the ferry quay ($t_W > t_H$), C^* fixed annual ferry costs (independent of the number of round trips) and finally C operating costs of doing an extra round trip. The first expression on the right hand side of (2) denotes passengers' hidden waiting time costs, the second one their waiting time costs at the ferry quay and the third one the costs for the transport operators of serving the crossing. Moreover, it is assumed that $a > 0$ and $0 < b \leq 1$; if the vehicles arrive randomly at the quay, $a \approx 0$ and $b \approx 1$; if not, $a > 0$ *and* $b < 1$. It can be seen from formula (2) that an increase in F influences waiting time less the lower the value of b. When $F \rightarrow \infty$, waiting time approaches a. Hence, a can be interpreted as vehicle minimum waiting time. A thorough discussion of the model is given in Jørgensen et al. (2007).

From formula (2) follows the first order conditions for social costs minimisation:

$$F = F^{opt} = OH \cdot \sqrt{\frac{PCE \cdot (t_H + bt_W)}{2C}} = OH \cdot PCE^{0.5} \cdot (t_H + bt_W)^{0.5} \cdot (2C)^{-0.5} \tag{3}$$

From formula (3), it can be deduced that the optimal number of departures (F^{opt}) increases concavely with traffic (PCE), hidden waiting time costs per hour (t_H) and waiting time costs at the ferry quay (t_W). This means that the higher traffic and waiting time costs are initially, the less will an increase in these variables increase F^{opt}. Furthermore, optimal level of round trips decreases convexly with the costs of sailing an extra round trip (C). This implies that an increase in C has less impact on the number of round trips the higher these costs are to start with.

A more specific interpretation of formula (3) is achieved by looking at the following elasticities:

$$EL_{PCE}F^{opt} = 0.5, \ F^{opt} = 0.5, \ EL_C F^{opt} = -0.5$$

These elasticities imply that:

- When traffic (PCE) increases by X%, optimal frequency increases by *0.5X%*.
- When both types of waiting time costs (t_H and t_W) increase by X%, optimal frequency increases by 0.5X%.
- When the costs of an extra round trip (C) increases by X%, optimal frequency decreases by *0.5X%*.

5.3. Estimation results

The use of formula (3) to estimate optimal frequency at a ferry crossing implies that we need values for the passengers' waiting time costs and ferry costs. Based on recommended waiting time costs values in cost–benefit analyses at Norwegian road projects given in Statens vegvesen (2014), the following waiting time cost per vehicle, in 2013 NOK, is used in the analysis:

- Ordinary waiting time costs (t_W): 355 NOK per vehicle per hour.
- Hidden waiting time costs (t_H): 178 NOK per vehicle per hour.

The values above are calculated using values for average composition of vehicles on Norwegian ferries. Because the common production measure in ferry transport is PCE, waiting time costs per hour per PCE is estimated by dividing waiting time costs per vehicle with average PCE per vehicle on the crossings in question.

The cost structure for ferry operations is estimated using production and cost data from 43 Norwegian ferry crossings in 2003, 2004 and 2005. The following model is used:

$$C = \beta_0 + \beta_1 \cdot PCE^C \cdot F + \beta_2 \cdot PCE^C \cdot F \cdot L \ \ \beta_0, \beta_1, \beta_2 > 0 \tag{4}$$

Formula (4) implies that the cost of an extra round trip $\left(\frac{\partial C}{\partial F}\right)$ is:

$$\frac{\partial C}{\partial F} = \beta_1 \cdot PCE^C + \beta_2 \cdot PCE^C \cdot L \tag{5}$$

The first term on the right hand side in formula (5) can be interpreted as distance-independent trip costs whilst the second term is distance-dependent trip costs; $(\beta_2 \cdot PCE^C)$ is the extra round trip costs when the trip length increases by 1 km. They increase proportionally with the size of the ferry (PCE^C). The estimation results from an ordinary least squares regression analysis are presented in Table 2.

Table 2. Estimation results.

Parameter	2003	2004	2006	Average 2003–2006 (2013 NOK)
β_0	7,538,933	8,400,999	10,000,000	9,857,174
β_1	15.23	14.10	10.29	15.06
β_2	1.86	1.90	1.80	2.11
N	42.00	40.00	43.00	-
R^2	0.93	0.94	0.91	-
F	275	302	226	-

[a] The parameter values from 2003, 2004 and 2005 are in nominal values.

t-statistics show that all parameters are significantly positive at 1% level or better, the proportion of variance explained, indicated by R^2, is generally high and the F-test indicates a good model fit. Further tests of the statistical properties of the analysis show VIF-values around 1.6, indicating no problems with multicollinearity. Both the Breusch-Pagan/Cook-Weisberg test for heteroscedasticity and the White's test for homoscedasticity show no serious problems with the residuals. Hence, the statistical properties are generally good and indicate that the estimation results from the ordinary least squares regression can be trusted.

Table 2 reveals that the parameter values vary a bit from year to year. In further analysis, we have used the average parameter values for these years converted to 2013 NOK using the consumer price index.

Using the estimated parameter values from Table 2, the cost of an extra round trip can be written as in (6):

$$\frac{\partial C}{\partial F} = 15.06 \cdot PCE^C + 2.11 \cdot PCE^C \cdot L \tag{6}$$

The average size of the ferries and average trip length in our dataset are 62 PCE and 13 km, respectively. This implies that the cost of an extra round trip for a representative service is 2,750 NOK, measured in 2013 NOK ($15.06 \cdot 62 + 2.11 \cdot 62 \cdot 13$). Distance-independent trip costs, thus, constitute for 34% of total trip costs.

5.4. Comparing model results with actual frequency at eight ferry services in Norway

Using formula (3), the recommended time cost values from the Directorate of Roads and the estimated cost structure, optimal frequency is estimated in Table 3 for eight ferry crossings. The model's results are also compared with actual frequency. In the following calculations, the value of *b* in formula (3) is set to *0.5*, meaning that a marginal increase in frequency has half as great impact on travellers' waiting time at the quays compared to when they arrive randomly.

Table 3 shows that the estimated optimal frequencies on all analysed crossings except two are higher than the actual frequencies according to the timetables. The difference varies from -7 to 20 daily round trips.

Table 3. Actual and optimal daily frequency in the summer season at eight Norwegian ferry crossings.

Name of crossing	Actual frequency 2012[a]	Estimated optimal frequency	Difference between estimated optimal frequency and actual frequency	
			Number	Relativity
Hjelmeland-Nesvik-Skipavik	25	36	11	48 %
Mortavika-Arsvågen	46	45	-1	-2 %
Sandvikvåg-Halhjem	33	26	-7	-20 %
Anda-Lote	35	54	19	52 %
Fodnes-Mannheller	54	64	10	18 %
Hella-Dragsvik/Vangsnes	24	44	20	84 %
Bognes-Skarberget	21	26	5	26 %
Drag-Kjøpsvik	9	15	6	64 %

[a] Actual frequency and traffic data are based on the summer traffic values in 2012.

6. Concluding remarks

This article deduces how transport capacity at a ferry crossing depends on ferry size, the speed of the ferry, the manoeuvring time to and from ferry pier, the time used to board and alight a vehicle and the length of the crossing. The article also analyses how optimal frequency from a welfare perspective at a crossing relates to the level of traffic, travellers' value of time and the cost structure of ferry operations. Based on data from eight ferry crossings in Norway, the use of our formula indicates that frequency at most of the crossings is far too low in order to minimise total social costs of ferry operations. Having in mind our previous discussion on how operators' goal function influences quality when fares are regulated by the state, the above results signal, as expected, that the state does place some weight on operator profits (or companies' subsidy needs) when designing service standards.

Admittedly, the derived formulas for calculating maximal transport capacity and optimal frequency at a crossing must be used with caution. As far as calculation of maximal capacity is concerned, we have not had access to accurate information about the manoeuvring time to and from ferry pier and the time used to board and alight a vehicle on the different ferry crossings. Therefore, these values are determined based on reasonable judgements. Because the topography near the ferry quays and the actual ferries used affect manoeuvring time, it is important to have accurate information about these factors for each crossing. Moreover, the composition of different types of vehicles as well as the boarding and alighting logistics vary between ferry crossings. Crossing specific information regarding these matters is therefore necessary in order to come up with more precise calculations. Finally, parking space and road system near the ferry ports will also influence how efficiently the vehicles can drive on and off the ferries.

When it comes to optimal frequency calculations, the model requires crossing-specific data on the composition of type of cars and travel purposes in order to come up with more precise waiting time values at different crossings. It is also worth noting that topographical and technical conditions give constraints on ferry size. At crossings where the ferries cross stretches of open sea, the vessels must be of a certain size to be able to achieve good regularity and give passengers a smooth trip. Moreover, narrow fairways and depth conditions set limits for the size of the ferries. Such bindings on the size and quality of the ferries at different crossings will in turn influence optimal frequency according to our model; larger ferries will, for example, increase trip costs and thereby reduce optimal frequency. What can be regarded as a 'right' dimensioning of the ferry service will, thus, vary from crossing to crossing depending on traffic volume, how large the ferries used can be and variations in demand throughout the day. It is therefore appropriate to move away from standardised requirements for all crossings. Another central assumption underlying our model of frequency calculation is that the traffic level at a crossing is unaffected by the level of frequency. This implies that the model underestimates optimal frequency, in particular at services where traffic is sensitive to the frequency provided. These are crossings where ferry users have good transport alternatives.

Although criticism can be raised against our models, they have, nevertheless, inferred (1) how transport

capacity at a crossing is influenced by characteristics of the ferries and the length of the crossing, and (2) how optimal frequency at a ferry crossing is influenced by the level of traffic, travellers' waiting time costs, the cost structure of the ferries and finally the length of the crossing. As tendering periods for ferry services in Norway usually are eight years, it may mean significant changes in passengers' waiting time costs, traffic and in ferry operating costs. Forecasts indicate an annual growth in the traffic on Norwegian roads until 2020 of approximately 1.3%. New technology on the ferries (e.g. ferries powered by gas or electricity) could also reduce round trip costs. Moreover, passengers' waiting time costs according to guidelines for calculating these costs should increase with gross domestic product (NOU, 2012: 16). Forecasts of gross domestic product per capita indicate an annual growth of approximately 2 %. All these developments indicate higher frequency in the years to come. Our model illustrates clearly how these factors affect optimal value of one of the most important service elements, namely frequency. It also shows the importance of having reliable forecasts for these variables over the contract period. The larger uncertainty in these variables, the more reasonable it would be for the Norwegian Public Roads Administration to design flexible tenders that can be changed during the contract period.

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