EMPIRICAL ESTIMATION OF EFFECTS OF FLEXIBLE WORKING ON MOBILITY AND CONGESTION IN THE NETHERLANDS 2000-2016

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ABSTRACT

Flexible working, enhanced by information and communication technologies, seems relevant for transport policy, but information about the development of flexible working in the Netherlands and the impact on mobility and congestion is incomplete. The KiM Netherlands Institute of Transport Policy Analysis devised a method to identify the development of flexible working and its impacts on mobility and congestion using an online panel survey and other data.

The research findings reveal that working at home and shifting hours to avoid using cars during peak hours are the most important types of flexible working in the Netherlands and that they increased between 2000 and 2016. If there had not been flexible working, the number of car kilometres on working days in the Netherlands from 2000 to 2016 on all roads would have increased 2.6% more than the observed development. Total public transport kilometres would be 2% higher.

The hours of delay with all types of flexible working on national roads in the Netherlands from 2000 to 2016 increased by 42%, instead of 60% if there had not been flexible working (an impact of 18% for flexible working). Working at home had the largest impact on congestion avoidance during the entire day. During peak hours, peak hour travel avoidance by car had the largest impact.

Approximately 0.1 hours of delay were reduced on national roads by working one day at home or by shifting hours from morning peak to off-peak one time. This reduction was approximately 0.2 during the afternoon peak.

Keywords: Traffic congestion, Travel behaviour, Transportation modes, Working conditions, Information and Communication Technologies, Socioeconomic factors

INTRODUCTION

Various types of flexible working aim to render working more effective, efficient and pleasant for the organisation and its workers. Developments of flexible working, enhanced by information and communication technologies, seem relevant for transport policy. Mobility patterns and road congestion are impacted if flexible working leads to more time- and place-independent work. Nevertheless, information about the development of types of flexible working in the Netherlands and the impact on mobility and congestion is rather incomplete. The KiM Netherlands Institute of Transport Policy Analysis (KiM) devised a method to identify the development of flexible working and its impact on mobility and road congestion.

The KiM defines flexible working by distinguishing six types of flexible working that impact mobility and road congestion:

1. Working at home (instead of at other work addresses), excluding overtime (regularly working at home was not considered as flexible working);
2. Working at another company location;
3. Working at a flex office (another location than the company or at home);
4. Shifting working hours at the regular working address (not working at home) to avoid car travel during peak periods;
5. Shifting working hours to avoid travelling on public transport during peak periods;
6. Avoiding car use for business trips.

The research questions are:

1. What was the development of flexible working in the Netherlands from 2000 to 2016?
2. What was the impact of the development of flexible working on the development of mobility by car and public transport, and on congestion on the main trunk road network (or national roads; especially highways)?

This paper presents the quantitative impacts of flexible working on mobility and congestion from 2000 to 2016 because types of flexible working have different long-term developments and because for that period sufficient data on flexible working, mobility and congestion are available. We provide a technical description of the applied methods. Another publication focuses especially on the characteristics of flexible working (1).

LITERATURE REVIEW

Flexible working arose in various countries, including the USA, Canada, Australia, South Korea, United Kingdom, Belgium and The Netherlands (2). In the USA, Alternate Work Schedules (AWS) comprise telecommuting, compressed work weeks and flexible working hours (3). Telecommuting means working at another location than the office using telecommunication. Figures pertaining to telecommuting, and scenarios about the potential development, are available for the USA and Japan (4). In 2014, the KiM Netherlands Institute for Transport Policy Analysis conducted research aimed at identifying the opportunities and obstacles of time- and place-independent work (5). In the USA, estimations were made of the level of telecommuting (6). The share of employees in the USA that works at least sometimes “remotely” (away from their manager or coworkers, e.g. transportation and construction) increased from 39% in 2012 to 43% in 2016 (7). The share of Americans working from home also increased from 3.9% in 2006 to 5.2% in 2017, while public transportation to work decreased to 5% (8). Higher income earners

seemingly telecommuted more frequently than lower income workers, but following similar patterns (9).

The impact of telecommuting on vehicle miles travelled was modelled using a multivariate time-series analysis of nationwide USA data from 1966-1999, revealing that telecommuting reduces annual vehicle miles travelled by 0.8% or less (10). Studies in the USA also found a reduction of the impact of telecommuting on vehicle miles travelled by car for home to work commutes by an increase of travelling for other purposes by members of the household (11). A comparison of the level of telecommuting in different countries and of telecommuting's impact on traffic was analysed in Australia (12) by modelling a supply and demand function indicating that telecommuting by reducing trips and switching routes leads to a new equilibrium of traffic flow and travel time on roads at peak times. In Belgium (13), telecommuting's rebound effects were also estimated in a model study that found that approximately 70% of the reduction in car use could be compensated for by increased energy use at home, longer commuting distances, and induced traffic. We found no literature providing quantitative impacts of flexible working on the historic development of mobility and congestion.

METHOD

Survey to measure flexible working and impacts on mobility and congestion 2014-2016

For the Netherlands, data sources ─ particularly the *Nationale Enquete Arbeidsomstandigheden* (National Survey of Working Conditions, NEA) (14) ─ are available regarding working at home by employees. However, no data are available for identifying other forms of flexible working, nor its impact on mobility and congestion.

To identify the degree and development of flexible working and its effects on mobility and congestion, KiM commissioned I&O Research to conduct online panel surveys in three waves in March 2014, 2015 and 2016, each involving 14,000 working people. These surveys made it possible to identify and determine the development of flexible working, its determinants, the impact that flexible working had on the use of transport modes (car, public transport and bicycle), and the routes avoided on the main trunk road network.

For each wave of surveys, I&O Research first derived a sample of 6,000 working people from online-panels for March 2014, 2015 and 2016. This sample was drawn at random and stratified according to age, gender and region, with aim being to present a representative sample. To identify impacts of flexible working, a sufficient number of flexible workers must be measured. Consequently, a second sample was drawn of 8,000 working people who had indicated that they would engage in one of the types of flexible working (types 1-4). Approximately half of respondents participating in the 2015 and 2016 samples also participated in the survey of the previous year. Approximately one-third of the respondents in the 2016 sample participated in all three surveys. We used the panel character of the surveys to measure developments in flexible working at the individual level to derive effects on mobility (we took into account, amongst others, developments in the number of days people work at their office or at home, the means of transport they use for commuting and the time periods they commute). The development of flexible working itself and the routes people (would) use by car were based on the total samples for each wave, the latter to make optimal use of all available data in the samples.

Using this two-stage sampling method, a sufficient number of workers with characteristics of flexible working were available to determine the impacts on mobility and congestion. Weighting factors were calculated to match the distribution of age, gender, education

(per region), sector, status (employee, independent contractor with or without employees), region, car use and public transport use for commuting, and shares of type of flexible working, to targets derived from the NEA, the first I&O Research sample, and Statistics Netherlands' OViN mobility survey. Different weighting factors were used for analyses per wave and for analyses based on respondents that participated in more than one wave.

Participants in the survey were asked on which days and hours they worked at home, at another location or flex office, or had shifted working times to avoid peak hour travel (7:00-9:00; 16:00-18:00). For respondents engaging in flexible working on fixed days of the working week, the frequency with which they engaged in types of flexible working was based on the hours during a recent representative week. People who had no fixed day(s) for types of flexible working, or did so less than once a week, were asked to indicate their average frequencies (e.g. 2 days per month). Moreover, the use of transport modes was determined on days that workers travel to their regular working address, to another location or a flex office, and for days they worked at home. Flexible workers were also asked which modes they would have used if they had instead travelled to their regular working address. Further, for people travelling by car, the routes (and time periods) on national roads they (would have) travelled on were determined. When people do not use their cars on a certain day to commute (e.g. because they work at home), it was determined if other members of the household used their cars on those days instead. All mobility data were summated and scaled up to determine the (nationwide) yearly totals.

For the survey years, the impact of flexible working on car and public transport use was determined by registering the changes that flexible working caused in how people used transport modes during each of the two consecutive years that they participated in the panels. Given the size of the samples in each survey, all results directly based on the surveys (development of flexible working in 2014-2016 and the effects on mobility) are obtained with at least 95% reliability and accuracy. Furhermore, by weighting the samples, these results are representative for the population of Dutch workers. Given the, weighted, representative total sample of approximately 14.000 respondents in each survey and over 8 million workers, the factor to scale-up the results of the samples to the total working populations remains just below 600 in each sample.

Method to measure the development of flexible working 2000-2016

To identify the development of flexible working in the years prior to the panel surveys, data from external sources were used, supplemented with analyses explaining the development of types of flexible working.

We measured the development of working at home and other locations (type 1-3) from 2014-2016 with the I&O survey. Next these developments were extrapolated to cover the total 2000-2016 period, using statistical data of 2000-2016. For type 1-2 number of jobs 2000-2016 were used and average hours per week since 2005 from the yearly National Survey of Working Conditions (NEA); for 2000-2005 a constant increase is assumed, consistent with the 2005-2007 trend. This 2000-2016 trend appeared to be consistent with the trend of telecommuters 2000-2016 identified with company suveys published by Statistics Netherlands. For type 3 (flex office) we used the development of telecommuting from yearly surveys of companies by Statistics Netherlands) to extrapolate the trend of type 3 to 2000-2016.

In order to extrapolate the development of shifting work hours to avoid peak hour travel (type 4 in table 1) to 2000-2016 a different approach had to be used, since no statistics were available that could be used directly. First, the frequency of shifting hours by was estimated with a logistic regression on the 2014-2015 I&O-samples, that included as explaining factors the

possibility of flexible work hours, sector, hours per week, distance to work, congestion and amount of traffic commuting to work, vehicle type, and region. Since statistics on these variables are available for 2000-2016 (from NEA, CBS and OViN), in a second step, the number of workers that shifted working hours was predicted for the entire period 2000-2016.

Method to measure the impact of flexible working on mobility 2000-2016

To determine the impact that working at home had on mobility from 2000 to 2016, data were obtained from the development of working at home (obtained in the previous step) and from observed developments in the (average) distance to work for each transport mode, and in the total and work-related mobilty for each transport mode and time period (peak, off-peak and day). Data pertaining to distances to work and mobility figures for 2000-2016 were obtained from the OViN mobility survey. The impact that shifting working hours had on transport mode use was determined by multiplying the degree of shifting and the impact of shifting, as estimated using the 2014-2016 surveys, while taking account of the yearly changes in distance to work. No historical information was available for the development of working at a company's other location (type 3) or in a flex office (type 4). Type 3 was therefore assumed to follow the development of working at home 2000-2016 (that is, similar to type 1), as working at a company's other location would have already existed prior to the year 2000. Type 4 was assumed to follow the development of telecommuting, because, like telecommuting, working at flex offices was virtually nonexistent in 2000, having been facilitated by the emergence of internet services.

To determine the impact of flexible working types 1-4 on the use of the main trunk road network, commuters in the surveys were asked which ramps and exits on the national road network they used (or would have used) to travel to work by car and at what time periods. Furthermore, respondents were asked if they used another route to work on days when travelling to work at another time than normally (e.g. if they first worked at home for a couple of hours). From these locations, the ArcGIS program's Network Analyst was used to reconstruct for each respondent in each situation the (fastest) commuting routes for their home addresses and regular working addresses. The changes in trips from each of the three survey waves 2014-2016 were converted to changes in traffic flow, with a distinction between day of the week and the nine time periods (two peak periods, four shoulders of the peak periods and three off-peak periods) of each working day.

The avoided (or shifted) traffic flows were matched to observed data of stretches of the main trunk road network. Data for approximately 3,000 stretches, with an average length of approximately 1 kilometer, are available, containing observed traffic flow, average speed and hours of delay per 15 minutes. Hence, the impact of flexible working on network use was obtained for each stretch of the network, each day of the week and each of the nine periods in a day. During peak hours, less traffic on average used the network because of flexible working (e.g. people instead work a day at home or travel to work later), while during off-peak hours network use on average increased because of flexible working. These general results may of course differ for individual road stretches. For the years 2000-2013 the same routes were used, but we took into account the developments in number of flexible workers and the frequency of flexible working for each form of flexible working using as described above to control for developments in the average number of (avoided) commuting cartrips in each time period (peak and off-peak).

Method to measure the impact of flexible working on congestion 2000-2016

To identify the impact on congestion (in terms of in vehicle hours of delay referred to as hours of delay), KiM used a regression-based method that it had previously developed for explaining trends in congestion on national roads in the Netherlands, as based on traffic amounts in vehicle kilometres, accidents, road works, weather, and policy measures (15, 16). The regression is based on monthly data per road stretch (around 2,500 stretches on average per month) and for a long time-series: 2000-2016 (Formula 1). To be able to calculate the effect of shifts between day time periods, separate regression analyses were conducted for AM peak, PM peak and off-peak traffic.

$$Y_{ijk} = C_k+\beta_{il}P_{il}+\gamma_s S_{il}+\delta_j Y_j+\phi_i M_i+\eta_1 V_{ijk}+\eta_2 V_{ijk}^2+\varepsilon_{ijk} \quad (1)$$

Y_{ijk} = hours of delay per month i, year j (2000-2016) and road stretch k
C_k = constant per road stretch k
P_{il} = set of indicators P defining whether a policy measure p on location l is active ("1") or not ("0") in month i (indicating the difference before and after the implementation of the policy measure); a location l is a set of road stretches k for which we estimate effects of the policy measure
S_{il} = set of indicators defining situational characteristics per month i on road stretches around location l with accidents, road works, weather conditions and the reciprocal of the road capacity (as constant)
Y_j = set of variables for each year (2000-2016)
M_i = set of variables for each month (Jan-Dec)
V_{ijk} = vehicle kilometers with and without flexible working per month i, per year j and road stretch k
$B, \gamma, \delta, \phi, \eta_2, \eta_2$ = partial regression coefficients indicating the impact on hours of delay per road stretch per month of the explain variables
ε_{ijk} = error term

The coefficients resulting from the regression were multiplied by the developments in the explanatory variables and related to the number of hours of delay in the base year (2000). To identify the impact of flexible working, two variants were calculated: one with the impact of the observed, actual traffic amount (including the impact of flexible working), and the other with the traffic amount that would have occurred without flexible working, as based on the traffic flows and routes measured in surveys (types 1-4). The difference between these two effects is the impact of flexible working in the survey years.

As the survey data provides detailed information on flexible working for 2014-2016, the regression analysis calculated the impact of flexible working on traffic congestion only for those years. To extend the analysis of flexible working's impact on traffic congestion from the survey years to the period 2000-2016, elasticities were estimated of the changes in traffic amount and hours of delay due to changes in flexible working. These elasticities were based on the impacts of flexible working for 2014-2016, as described above. Moreover, these elasticities were estimated for three time periods (7:00-9:00; 16:00-18:00; and rest of the day), for four regions (North of the Randstad agglomeration, South of the Randstad agglomeration, Noord-Brabant province, and rest of the country), and for each of the four types of flexible working. The impact that the four types of flexible working had on traffic amount and hours of delay was determined by applying the estimated elasticities to the development of these types from 2000-2016.

DEVELOPMENTS IN FLEXIBLE WORKING

The workers in the Netherlands (8.4 mln in 2016) not only included employees (84%), but also independent contractors without employees (12%), and independent contractors with employees (4%). Of all workers, approximately 35% worked at home in 2014-2016 (Table 1). Working at

home not only includes telecommuting at home (16% of workers in 2016 in NEA), but also other forms of working at home instead of at another regular working address without means of telecommunication (35% of workers in 2016, including teleworkers at home in NEA). Working at home (type 1) consists of several subtypes. Firstly, workers who combine in a single day working a few hours at home and thereby avoid using their car during peak hours (9%). Secondly, workers who work at home the whole day and thereby avoid travelling by car during the peak hours (13%). And thirdly, workers who work at home a couple of hours or the whole day but do not avoid peak hours by car (e.g. they use public transport for commuting or already drove by car during off-peak hours). The overview of types of flexible working in Table 1 reveals that working at home, instead of at another regular work location, and shifting work hours to avoid peak hours, had the highest occurrences.

Working at a company's other locations and at a flex office occurred less frequently than working at home and shifting working hours to avoid travelling by car during peak hours. Regularly working at home was not considered as flexible working.

TABLE 1 All six types of flexible working in the Netherlands 2014-2016 (I&O surveys).

Types of flexible working	**Share of workers (%)**		
	2014	**2015**	**2016**
0) Working at home regularly (no flexible working)	6.4	6.1	6.0
Shifting working location			
1) Working at home instead of other working address (including the avoiding of peak hour travel by car on the same day)	36.0	35.3	35.3
2) Working at another location of the company	1.1	1.0	1.0
3) Working at a flex office	5.3	6.2	6.2
Shifting working hours			
4) Shifting working hours at working address (not working at home) to avoid peak hour travel by car	10.3	10.9	11.2
5) Shifting working hours to avoid peak hour travel by public transport	4.1	4.9	5.0
Other forms of flexible working			
6) Avoid car use for business trips	1.4	1.2	1.2

The number of days people work at home consists partly (about half) of working full days and the rest of working only part of the day at home. Of the workers avoiding peak hours by shifting work hours, approximately 50% usually only avoid the morning peak, 20% only the evening peak, and 30% both. The number of hours that employees work at home instead of at another location increased from 10.1 million hours per week in 2000 to 13.9 million hours per week in 2016 (+38%)(see 3.2 for the method). The amount of peak avoidances by workers increased from 1.7 million in 2000 to 2.4 million per week in 2016 (+40%).

Of all workers in the Netherlands not working at home (61%), working at home is not possible for 41% and possible for 20% (I&O 2016 survey). Of all workers not shifting working hours to avoid peak hours by car (89%), 30% does not use a car, shifting working hours is not possible for 34% and shifting is possible for 25%. These figures are for all sectors about the same. These figures confirm the trend that further increase of flexible working is not only possible in persons, but also in intensity per person.

EFFECTS OF FLEXIBLE WORKING ON CAR AND PUBLIC TRANSPORT USE

If there had not been flexible working from 2000 to 2016, the car kilometres on working days on

all roads (national, regional and municipal) in the Netherlands would have increased by 2.6% more than the observed development with flexible working (Table 2). During peak hours (7:00-9:00; 16:00-18:00), the car kilometres on all roads (national, regional and municipal) in the Netherlands would have increased by 14% more if there had not been flexible working than the observed development. Total public transport kilometres would be 2% higher, and during peak hours 3% higher, than the observed development. The impact of flexible working prior to 2008 was higher than after 2008, owing to the economic recession and more lanes being added after 2008.

Further zooming in on the impact of flexible working on commuting, car kilometres for commuting on all roads would have increased 3% more if there had not been flexible working than the observed development. Both working at home and avoiding peak hour travel contributed to the increased impact of flexible working.

Table 2 Impact of flexible working (FW, types 1-6) on car use (vehicle kms Dutch passenger cars on all roads) and public transport (passenger kilometers) on working days per year from 2000 to 2016 in the Netherlands

	Observed kilometres travelled per year (with flexible working) (bn kms)			**Increase of kilometres travelled per year if there had not been flexible working per year (bn kms)**			**Increase of kilometres travelled per period if there had not been …**			
							flexible working		**work at home**	**shift hours**
	2000	**2008**	**2016**	**2000**	**2008**	**2016**	**08-16**	**00-16**	**00-16**	**00-16**
Mo-Fr										
Car, all motives	61.2	71.0	69.3	1.8 (+3%)	2.4 (+4%)	3.4 (+6%)	+1.8%	+2.6%	+2.6%	+0.0%
PT, all motives	18.3	19.4	19.2	0.6 (+9%)	0.7 (+8%)	1.0 (+13%)	+1.6%	+2.2%	+2.2%	+0.0%
Peak (7:00-9:00; 16:00-18:00)										
Car, all motives	23.3	27.3	26.5	+3.8 (+16%)	+5.3 (+23%)	+7.1 (+31%)	+8%	+14%	+10.6%	+3.8%
Car, commuting	10.5	17.7	17.0	+3.8 (+27%)	+5.3 (+23%)	+7.1 (+30%)	+7%	+3%	+0.8%	+2.2%
PT, all motives	8.4	9.4	8.4	+1,2 (+4%)	+1.6 (+5%)	+2.0 (+7%)	+2%	+3%	+0.9%	+2.1%
PT, commuting	3.0	4.8	3.8	+1,2 (+29%)	+1.6 (+25%)	+2.0 (+34%)	+5%	+9%	+1.5%	+3.8%

The impact of shifting working hours to avoid car use during peak hours is larger than the impact of working at home. The reason for this is firstly, that not all people who work at home instead of at their other working address routinely use cars (68% routinely use cars during 77% of the days), or do so during the peak hours (58% use cars during peak hours). Consequently, car use during peak hours was only actually avoided on 31% of the days spent working at home. Additionally, workers shifting working hours to avoid car use during peak hours did so during on average more days per week than workers working at home. Further, workers shifting working hours travel longer distances to work (38 km vs. 28 km for people who work at home) and have a relatively high share of use of the national road network (90% vs. 75% use of the national road network; 51% vs. 39% daily).

Flexible working also can have an impact on car use for business purposes (type 6), because, for example, workers might choose a location for conferencing that is situated close to their home address, instead of at the office of the inviting company. The impact of flexible working on car use for business purposes was estimated to be at maximum 0.25% of the 2 billion peak car kilometres devoted to business purposes on all roads in the Netherlands on working days in 2016. This impact is small in comparison to the impact that flexible working had on car use for commuting purposes. The estimation of 0.25% derives from the fact that 11% of the respondents stated that they made 25% fewer business trips during peak hours, which can be related to flexible working in 9% of the cases.

IMPACTS OF FLEXIBLE WORKING ON ROAD CONGESTION

Because of flexible working, the amount of traffic (in vehicle kilometres) on national roads (highways) in the Netherlands during the period 2000-2016 increased by 27%, instead of 32% without flexible working (an impact of -5 percentage points for flexible working) (Table 3). Moreover, because of flexible working, hours of delay (in vehicle hours, with reference to 100 km/h) increased by 42%, instead of 60% (an impact of -18 percentage points for flexible working). Working at home (-9%) had the largest impact on congestion avoidance during the entire day (Table 2). During peak hours, peak hour travel avoidance had the largest impact. Without flexible working hours of delay in 2016 on national roads would be 72 in stead of 62 million.

The impact that working at home and telecommuting had on hours of delay on national roads corresponds to the share of telecommuting workers working at home (49%). A separate calculation of a regression model ─ estimating (per stretch) hours of delay per year from population growth (per municipality), car use per inhabitant, working days per inhabitant, and teleworking days per inhabitant (from the NEA National Survey of Working Conditions) ─ found that the impact of the increase of telecommuters on hours of delay is -4%. Because the impact of the increase of working at home on hours of delay is 9%, this is consistent with the 49% share of telecommuters in workers at home.

In a previous empirical study of induced demand (16) we demonstrated that road extensions lead to shifts of routes, time and mode and to a return of traffic to the peak, but also that on average road extensions lead, peak and off-peak, to large reductions of congestion on the total road network. These findings are consistent with results of empirical studies in the US. Recent analyses by KiM show that the impact of road capacity investments on hours of delay reduces somewhat after 2 years (17).

It is possible that latend demand refills the spaces created on the roads by flexible working because of shifts of time, route and mode. But the question remains whether the impact of individual decisions about working hours and car use should be compared with impacts of external local changes in road capacity. Time shifts of home-work traffic are exactly the topic of this particular study and therefore it seems illogical to consider rebound effects for these. Additionally, for route shifts substantial effects are also not very likely, because flexible working has a similar effect on all roads and will affect the travel times on the chosen route and alternative routes alike. Furthermore, the research on latent demand of road capacity investments has shown that mode shifts are very limited.

A check of the validity of the impact of flexible working on congestion of 18% including rebound effect is that this corresponds with the average ratio that generally exists between the increase in traffic and the increase in hours of delay on national roads in the Netherlands from 2000-2016 (if traffic flow increases 1%, hours of delay increase on average approximately 3%).

Table 3 Impact of flexible working (types 1-6) on car use (vehicle kms) and hours of delay on national roads in the Netherlands 2000-2016, on working days and during peak hours*.

	Observed development (with FW)				Increase of development from 2000 without flexible working			Increase of development from 2000 without		
								work at home	work at other company location or flex office	shifting hours
	2000	2008	2013	2016	2008	2013	2016	2016		
Car use (vehicle kms)										
Day	100	113	117	127	+2%	+2%	+5%	+2%	+2%	+1%
AM peak	100	113	123	132	+19%	+19%	+30%	+7%	+2%	+21%
PM peak	100	109	121	128	+14%	+13%	+20%	+4%	+1%	+15%
Hours of delay										
Day	100	158	101	142	+11%	+9%	+18%	+9%	+4%	+5%
AM peak	100	142	92	117	+16%	+14%	+23%	+6%	+4%	+13%
PM peak	100	170	111	178	+33%	+25%	+49%	+20%	+8%	+21%

* Observed developments peak are 6:00-10:00 and 15:00-19:00. Impacts of flexible working are 7:00-9:00 and 16:00-18:00.

The impact of hours working at home on car use and hours of delay increased gradually from 2000 until 2016. The impacts of shifting working hours followed another pattern. From 2000 to 2008, the impact of shifting working hours on the decrease of car use and hours of delay during peak hours increased significantly, which can be explained by the increase in congestion during that period. From 2008 to 2013, the impact of shifting working hours remained at the same level. From 2013 to 2016, the impact of shifting working hours increased again, similar to the level of congestion. The reasons why shifting working hours has more impact on mobility than working at home (see previous paragraph) also apply here. The impact that shifting working hours to avoid peak hour car use has on hours of delay appears to be largely compensated for by the increase in hours of delay during off-peak hours, which is likely due to the fact that shifting primarily occurs on congested roads, and because congestion during the hours before and after the peak hours is partly caused by avoiding the peak hours.

There were no major regional differences in the development of flexible working in the Netherlands from 2014 to 2016. However, owing to differing levels of congestion per region, the impact on congestion does differ between regions. Flexible working had the largest impact on congestion on the national roads surrounding Amsterdam and Utrecht (Figure 1).

FIGURE 1 Change in traffic flows (vehicles per stretch per hour) on national roads in the Netherlands by flexible working morning peak (6:00-10:00) in 2014, as compared to 2013.

The impact of flexible working in the Netherlands has also been identified in general terms, in order to render the results applicable for other situations. Therefore we expressed the impact of working at home and shifting working hours to avoid car use during peak hours 2014-2016 in terms of the number of hours of delay reduced per day (or part of the day) working at home and per time of peak avoidance. For each person avoiding peak car use by working at home or shifting hours from peak to off-peak, on average approximately 0.1 hours of delay on national roads were reduced during the morning peak, 0.2 during the afternoon peak and 0.1 during the entire day. Since the afternoon peak is on average higher and wider than the morning peak, the effects of flexible working on congestion are larger in the afternoon-peak than in the morning peak.

These impacts of flexible working per day and per time can be compared with analyses we did to identify the impact of policy measures offering financial rewards for peak avoidance on certain roads in the Netherlands from 2012-2015. We analysed the hours of delay before and after introduction of the policy measures with the regression method described previously (17). These policy measures lead to a reduction of 0.1 hours of delay on national roads per peak avoidance during the morning and afternoon peaks. Because this impact of local policy measures includes latent demand effects and has a comparable magnitude with that of flexible working, this supports our assumption that the impacts of flexible working include latent demand effects.

DISCUSSION

This study demonstrates that by using survey data, statistics and traffic data the degree and development of flexible working can be identified, as well as its impacts on mobility and traffic congestion over many years. In order to develop this method, rather complex and time-consuming statistical analyses were required. The data requirements are also high, as sufficient coverage of the working population and the road network is necessary. This study shows that with these data and analyses, useful insights can be obtained about how flexible working contributes to historical trends in mobility and road congestion.

The results of the analyses presented in this paper were expressed in entities that allow for comparison with other studies. Moreover, the results in terms of these entities can be used for other applications, e.g. to estimate the impacts anticipated in other, comparable situations.

This study demonstrates that flexible working has played an important role in reducing the growth of car use and congestion in the Netherlands, especially during the peak hours. Similar results hold for public transport. The development of types of flexible working, as well as their impacts on the use of cars and public transport, are relevant for policy, suggesting that possibilities for further growth exist for all distinguished six types of flexible working.

To date, empirical research of flexible working patterns in relation to transport seemingly primarily focuses on telecommuting. Shifting working hours appears to be a particularly important factor in traffic congestion. Commuters reacting to traffic congestion by shifting hours and location of working and mode has not yet been studied by means of empirical data in the Netherlands.

Author Contribution Statement

The authors confirm contribution to the paper as follows: study conception and design: Han van der Loop, Rinus Haaijer, Jasper Willigers; data collection: Han van der Loop, Rinus Haaijer, Jasper Willigers; analysis and interpretation of results: Han van der Loop, Jasper Willigers; Rinus Haaijer; draft manuscript preparation: Han van der Loop. All authors reviewed the results and approved the final version of the manuscript.

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