Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
Examining the potential environmental and travel time saved benefits of remote working hubs

Brian Caulfield *, Anna Charly

Centre for Transport Research, Department of Civil, Structural and Environmental Engineering, Trinity College Dublin, Ireland

A B S T R A C T

Since the coronavirus pandemic hit in early 2020 many workers around the world, that can, have begun to work remotely. Many studies have been completed on the success or otherwise of this new trend in remote working and postulate that this trend will continue beyond the pandemic. One of the other trends that has been spoken about significantly with this renewed interest in remote working is the development of remote working hubs (RWHs). These are locations outside of main cities that are used by workers from different companies to work remotely in a flexible way. The research conducted in this paper examines several of these RWHs that are located on the periphery of Dublin city centre. The motivation for the research was to establish the potential emissions and travel time savings for commuters using RWHs. The study collected survey data from 514 participants that are currently using RWHs and questioned them on their travel and work habits. The analysis showed that users of RWHs were driving on average 60 km less per day and the majority were able to depart for work later. In the sample, 34% would have driven to their normal place of work and whereas 12% drove to their RWH. The results also point to substantial travel time and emissions savings from using RWHs. The findings suggest that on average those that drive alone could save 1.126 tonnes of CO₂ from working at a RWH 3 days a week for a year.

1. Introduction

Greenhouse gas emissions from urban transport contribute to air pollution and climate change (Brazil et al., 2013; Carroll et al., 2019; Lohrey and Creutzig, 2016). A large share of daily trips in urban area comprises of work commutes leading to congestion and pollution in urban areas especially during certain periods of the day (Tang et al., 2011). Transportation planners and policy makers have been researching ways to solve this problem by modifying the temporal and spatial patterns of work trips (Choi and Ahn, 2015). Increased growth of information and communication technology (ICT) in the past decade has paved way to several new possibilities in the daily work patterns in terms of diversification of workplaces and time-schedules. Employees, where permitted, began to choose working from homes or coffee shops rather than having to travel to office every day on a strict routine. This style of working came to be known as teleworking (Cerqueira et al., 2020; Felstead, 2012). Teleworking is viewed as a promising strategy for reducing congestion during peak periods as well as lowering the carbon footprint (Caulfield, 2015; Tang et al., 2011; Zhang et al., 2020).

The advent of Covid-19 pandemic in the early 2020, placed heavy restriction on travel and social interaction, thus making teleworking mandatory for several employment categories. This adverse situation challenged organisations to modify their work schedules to allow remote working wherever possible. The drastic change in work pattern revealed new insights on how organisations can effectively use space, time, and technology to be more productive (Gartner, 2020; Hensher et al., 2021). Statistics shows that remote working has doubled during the past year in the US, with one in four employees situated entirely at home (Laker, 2021). Around 50% Canadians are teleworking due to Covid-19 travel restrictions (Fatmi et al., 2021). In Ireland, about 34% of persons aged 15 years and over started remote working since Covid-19 (Central Statistics Office, 2020). Remote working has several advantages including less commute time, flexible working hours, more time spent with family and a lower carbon footprint. One of the most recent developments include Remote Working Hubs (RWH).

RWHs allow people to book desks, meeting rooms, and collaborative and co-working spaces which can be used by different employees or companies. These hubs provide the perfect opportunity for employees and employers to find a balance between home and office working. It will allow workers to be nearer to their home in a productive flexible work environment while counteracting the risks of individual remote worker isolation and loneliness (Motamed and Shirvanimoghaddam, 2021). RWHs are also expected to support community and rural regeneration as employees would be encouraged to choose rural areas for stay rather than being in proximity to the city center. In addition to the obvious advantage of reduced travel time, RWHs offer several other possibilities, the most significant one being its impact on the transportation system. A reduction in everyday work trips is expected to bring
an immense reduction in the transport emissions which were caused due to work trips. Individuals would prefer a RWH that is near to their home thus increasing sustainable modes of transport including walking and cycling.

The present study attempts to analyse the potential benefits of these remote working hubs and their role in reducing travel time and carbon footprint based on data from existing RWHs. While this topic has many aspects that one could investigate, the present study focuses upon the changes in commuting time and the subsequent environmental benefits. The study uses a detailed questionnaire data from existing RWH users in Dublin to understand the impact of such hubs on their travel pattern and subsequently, on emissions generated. It should be noted that in our paper remote working means, working for any part of the week away from a traditional office space. This could be at home or in an RWH. Also, all of the analysis presented in this paper looks at remote working from a RWH. The paper is structured as follows. Section 2 reviews the previous studies on remote working and its impact on the environment and travel behaviour. Review is conducted with focus on the benefits and cost of remote working and how it can lead to a reduction in emissions. Section 3 presents the methodology adopted in the study and a brief description of the data collected. The analysis and results are presented in Section 4. Section 5 provides a discussion of the results and inferences and conclusions from the study.

2. Literature review

2.1. Background

‘Teleworkers’ or ‘telecommuters’ are identified as the group of people whose main place of work is at a place other than their actual place of work or home (Aguilera et al., 2016). It encompasses a multitude of work styles including working from home, working from alternate places such as coffee shop, lounge and working while traveling. Existing studies have analysed the characteristics of teleworkers, the factors affecting their decision, frequency of telecommuting, and other demographical characteristics (Tang et al., 2011). Teleworking can potentially contribute to travel time savings, reduced congestion and reduced emissions (Caulfield, 2015; Cerqueira et al., 2020; Melo and de Abreu e Silva, 2017; Zhang et al., 2020). The impact of Covid-19 in the early 2020 had an increased traction on teleworking strategies both among employers and employees leading to a new possibility in teleworking. The literature has a large volume of work that examines the possible rebound impact from working from home. This current paper focuses upon the RWH’s and the potential impacts it could have.

2.2. Factors affecting an individual’s decision to work remotely

An individual’s choice to telecommute is a complex decision-making process and is often affected by a multitude of factors. Individuals working in the higher income category are more likely to work from home than their counterparts in the lower income category (Fatmi, 2020). This could be because individuals working in lower income category either do not have the facilities required to work from home or they are in a job that does not allow them to work from home. Another interesting finding in lines with the above observation is that the residential built environment plays a major role in influencing work from home behaviour. According to Tang et al. (2011), factors including how appealing it is to be at a particular location, and how easy it is to travel, influence a person’s choice of whether to work from home. A previous study based on the Irish census data from the year 2011 revealed that individuals living in more affluent areas and having poor public transport connectivity are more likely to work from home (Caulfield, 2015). Stanek and Mokhtarian (1998) modelled this complex decision-making process considering several important factors that facilitates telecommute including the desire to work, reduced work-related stress, autonomy, desire to spend more time with family, personal flexibility and control over one’s life, ideology drive like environmental awareness, and difficulties associated with travel. Few factors that were considered as constraints to telecommute including awareness of telecommuting, lack of employer support or disapproval from supervisor, suitability and need for personal interaction. Access to technology is another important factor that impacts an individual’s decision to work from home (Caulfield, 2015).

A handful of studies have analysed the travel behaviour of workers who chose to telecommute in the past from telecenters (Stanek and Mokhtarian, 1998; Varma et al., 1998). A telecenter is an office space shared by employees of different companies generally on a part-time basis, a concept similar to the remote working hubs. It was observed that attrition at the telecentres was quite high with 50% of telecommuters quitting within the first nine months (Varma et al., 1998). However, the reasons for quitting were not associated with personal dissatisfaction with telecommuting. The reasons were mostly related to the job or supervisor or closure of the center itself. Varma et al. (1998) arrives at an ideal distribution of work time at the workplace, telecenter, and home as 53.4%, 20.1%, and 14.2% respectively based on responses from telecommuters. Though the dropout rate for telecommuting seems to be high, it is speculated that many of these dropouts do return to telecommute in time and are unfortunately not captured in these studies as data is collected only for short duration. Hence it is important to develop behaviour models of telecommuting frequency and duration using large data samples.

A comparison study between working from home and working from telecenter revealed that those who work overtime are more likely to prefer working from a telecommute center (Stanek and Mokhtarian, 1998). Another interesting finding was that older respondents are more likely to prefer telecommuting from a center over home probably due to a more structured work environment. It was also observed that individuals who choose to telecommute are more likely to be adventure seekers and tend to live farther from work (David and Patricia, 2005). Adventure seekers are drawn to the idea of the still-novel option of telecommuting and would rather use the time saved from commute to pursue other adventurous activities (Cao and Mokhtarian, 2005; Clay and Mokhtarian, 2004).

Gender, education level, and presence of younger children has a significant influence on the mode of work (David and Patricia, 2005; Zhang et al., 2020). Females with children younger than six years old are less likely to commute to work, whereas those with older children are more likely to commute, probably to allow some separation from their grown up children (David and Patricia, 2005). Although one might assume that work from home is attractive for balancing family and work obligations, studies show that home is more favourable to work when children are absent. Further, there are several social and professional opportunities at and around the workplace including interactions with peers, shopping, and entertainment which could make working from home less attractive to many individuals. These drawbacks are balanced to a certain extent when one gets to choose a RWH nearer to their residence.

2.3. Impact of remote working

Changes affecting workplaces can have a significant effect on non-work trips in addition to work trips (Kim et al., 2015). Many employees conduct their non-work activities including shopping, recreation, and health-related trips based on their work trips. Hence, a change in the latter can lead to reduced segregation between work and non-work activities creating complex travel patterns (Cerqueira et al., 2020). Studies also indicate that there has been an increase in productivity as a result of working from home (Hensher et al., 2021). It has also been reported that few companies intend to shift some of their employees to remote work positions post Covid-19 (Gartner, 2020; Motamed and Shirvanimoghaddam, 2021).

Several studies have examined the impact of work from home on the
general quality of life and the transportation sector. Few studies in the past have also explored the attractiveness of telecommuting from telecenters. However, the post-pandemic scenario can be quite different and there seems to be a promising future in telecommuting. Remote working hubs are a recent development in teleworking and its effect on the general quality of life, transportation sector, and the environment has not been analysed yet. Reopening of the city and normal working culture along with a possible prolonged fear of public transportation may lead to a sudden increase in private car trips meant for work commute. This could interfere with the strategies taken to ensure carbon reduction and sustainability. Hence, there is a need to reinvestigate the future of teleworking in terms of RWHs as an alternative to work from home and work from office.

2.4. Impact of Covid-19 on travel behaviour and remote working

Covid-19 brought a drastic shift in the way people travel. Studies show that there are significant changes in various factors associated with trips before and after the pandemic including, trip purpose, mode choice, distance travelled, and frequency (Abdullah et al., 2020; Bucsky, 2020; Motamed and Shirvanimoghaddam, 2021). Restriction on travel and social interaction during the pandemic forced a large section of the population to work from home, thus eliminating their commutes (Barbour et al., 2021; Fatmi et al., 2021). The primary trip purpose during Covid-19 became grocery shopping and the primary mode of transport became private car and active transport (Abdullah et al., 2020). There was a huge surge in the demand of active modes of transport including cycling and walking to minimise coronavirus exposure. For instance, in New York city, the demand for shared bike services increased by 67% in March 2020 (Hu, 2020).

In addition to the government-imposed travel restriction, the perceived risk and fear of infection has also affected travel behaviour and mode choice. According to studies conducted during the early stages of the pandemic, the demand for public transport decreased considerably with more than 70% of the participants responding that they would avoid public transportation (Bucsky, 2020; De Vos, 2020; Kwok et al., 2020; Yildirim and Solmaz, 2020).

Fatmi et al. (2021) studied the effect of Covid-19 travel restriction on the travel behaviour of residents of medium sized cities using a web-based survey data collected from British Columbia, Canada. The study suggested that there was a reduction of about 50% out-of-home activities per person per day during Covid-19 as compared to the pre-pandemic period. Individuals spent around 5.5 h per day on teleworking while at home. Another interesting finding was that recreational or social activity was the only type of activity that was performed more than twice per day by an individual, out of which 32% trips were reported to be undertaken by walk or bike. Almost 15% of recreational or social activities shifted from private car to walk or bike. Several residents were reported to be engaged with household maintenance activities by more than 1 h a day as compared to the pre-pandemic scenario.

These change in behavioural patterns play a significant role in peoples’ work-related travel decisions and mode choice which further impacts the transport sector and the environment. Hence, it is important to understand the changing travel behaviour and make amendments to the system to keep the negative impacts of transportation under control. It is good to acknowledge the positive trend of increased popularity for cycling and walking. However, there seems to be a significant mode shift from public transport to private cars which cannot be ignored (Bucsky, 2020). The perceived risk associated with the pandemic can lead to a prolonged fear of public transportation, forcing a mode shift from public transport to private cars for long work commute once offices reopen completely (Motamed and Shirvanimoghaddam, 2021). In this context, RWHs could provide a working space near to home, thus eliminating these projected longer commutes by private vehicles.

The present study attempts to establish the potential of RWHs in travel time savings and carbon reduction by analysing the work trip characteristics of existing RWH users. The study strives to understand the parameters affecting their decision to telework in terms of personal and household characteristics, work trip characteristics before and after the pandemic, and the benefits and issues of teleworking. The methodologies adopted for the study, modeling approach and data collection are discussed in the next section.

3. Methods and data collection

3.1. Methodology

The overarching aim of the present study is to examine the potential of remote working hubs (RWHs) in realising the goal of carbon reduction. This is achieved by understanding the characteristics and travel patterns of existing RWH users and estimating the potential reduction in emissions and travel time savings. To accomplish this, it is necessary to understand several parameters related to work commute of RWH users before and after the pandemic. A questionnaire survey is a useful method to obtain meaningful information regarding individual travel patterns. Ethical approval for the survey was obtained from our research institution.

The questionnaire used in the study is designed to analyse three different categories of information. The questionnaire was designed after close consultation with the literature presented in section 2.2 (of this paper). These include user’s personal characteristics, household and vehicle ownership characteristics, work trip characteristics before Covid-19, work trip characteristics after Covid-19, potential benefits of working from home or workspace, and issues faced while working from home or workspace. The type of information include in each category is presented in Fig. 1.

3.2. Data collection

In order to obtain the data required for this study a survey was undertaken in June 2021. While other methods could have been used to collect the information required, it was deemed that an online survey would be able to acquire the data most efficiently. The survey was piloted, and ethical approval was obtained for the research at a faculty level in the research institution. The survey was circulated to the users of RWHs run by the company called NoCo (2021) and approximately 2,700 users received the survey. Fig. 2 presents the existing RWHs and their locations on a map. The authors recognise that this sample could have bias as it is people already using a RWH, the paper does not seek to make postulations on the entire population, rather the subset that are likely to use RWH’s. Previous research supports this argument and identifies that in many countries, like Ireland, only a subset of the entire population are in employment suited to remote working (Crowley et al., 2021).

The survey was open for responses for two weeks and 514 responses were received which equates to approximately a 20% response rate. Details of the sample collected are presented in Section 4.

3.3. Modelling approach

An individual’s decision to work remotely is influenced by several parameters as listed in Fig. 1. There are a multitude of variables that need to be assessed to arrive at meaningful results. All these variables might not have a significant effect on the user’s perception and a few of these variables might be interrelated. Hence, the variables and constructs that are significant in determining the decision to work remotely need to be identified. Principal component analysis (PCA) is a statistical analysis tool that reduces the dimensionality of a number of interrelated variables while retaining the maximum variability present in the data (Djukic et al., 2012; Sanders et al., 2015; Shiva Nagendra and Khare, 2003). PCA groups the variables that represents a particular construct and helps to validate the relation between variables. The data is...
transformed into a set of orthogonal variables, called as the principal components, arranged in decreasing order of importance and that are computed from correlation and covariance matrices. The principal component associated with the largest eigen value is known as the first principal component and accounts for the maximum total variability in the data. Generally, Principal components with eigen value greater than 1 are retained (Shiva Nagendra and Khare, 2003).

The Kaiser-Meyer-Olkin (KMO) verifies the results of the study and the adequacy of the sample for the analysis (Morton et al., 2016). It represents the ratio of the squared correlation between variables to the squared partial correlation between variables. A higher value of KMO (at least greater than 0.5) indicates that the PCA should yield reliable results (Field, 2013). Bartlett’s test of sphericity ($\chi^2$) tests the null hypothesis that the original correlation matrix is an identity matrix. A significant $\chi^2$ ($p < 0.001$) indicates that the correlation between variables is sufficiently large to justify the PCA. Further, the data obtained is analysed to understand the underlying factors affecting user’s choice of teleworking and consequent effect on travel time savings and reduction of emissions.

4. Results and analysis

The respondents examined in this study are those that indicated they had been using RWHs. Many of the respondents still had their “traditional” office space at their company’s main location. It is also true that many of the respondents followed a blended working approach, mixing home, hub and office-based working. The findings presented in this paper focus only on the potential changes if workers adopted to working from a RWH in greater numbers. The data collected through questionnaire survey is analysed to understand the various aspects of remote hub working. First, the personal and household characteristics of current RWH users are examined. Second, the impact of change of work style on the work trip characteristics of RWH users before and after Covid-19 is studied. Further, the benefits of RWHs and issues of working from home are analysed. This is followed by a computation of travel time savings and reduction in emissions achieved by using RWH. Finally, a principal component analysis is done to validate the grouping of parameters influencing the decision to use RWH and the results are discussed.
4.1. Personal and household characteristics of respondents

The data collected from 514 respondents was processed and tabulated. The descriptive statistics of the personal and household information collected is shown in Table 1. The respondents consisted of an almost equal share of men and women indicating the suitability of RWH for all irrespective of their gender. Most of the respondents were in the middle age group with an average of 36 years and standard deviation of 8.5. There is an even distribution between RWH respondents in terms of marital status including 24% single individuals, 34% married individuals without children, and 29% married individuals with children. Regarding vehicle ownership, 62% of respondents possessed one vehicle whereas 33% possessed two or more vehicles. Most of the respondents (69%) had an educational qualification of bachelor’s degree and above. Few participants (10%) had an advanced certificate or apprenticeship. As one can see, a majority of RWH users are highly educated professionals.

4.2. Work trip characteristics of respondents before and after Covid-19

The descriptive statistics of the data corresponding to work trip characteristics before and after Covid-19 is shown in Table 2. All the respondents considered in the study are currently working from RWHs. Out of these, only 9% of the respondents worked from home before the pandemic. This shows the drastic effect this pandemic had on the working style of employees. The interesting fact is that 91% of the respondents, who are current RWH users made a significant change in their working style, not just by working from home, but also by using a RWH which is a recent development in the field of teleworking. Before the pandemic, only 8% of the respondents were using nonmotorized transport for work commute, 23% were traveling to work in public transport, 9% by motorcycle, 20% drove a car alone to work and 14% travelled as a passenger in a car to work.

While examining the mode share after the pandemic, it is interesting to note that 39% of the respondents are traveling to their RWH using non-motorized mode of transport such as walk, and bicycle, a remarkable increase compared to 8% prior to the pandemic. The mode share of walking and cycling has increased significantly for RWH trips. Further, it is observed that 39% of the respondents used public transport to reach their RWH, a considerable increase over 23% before the pandemic. As can be seen, 20% of the considered RWH users used to drive to work alone in their car before the pandemic. These single car work trips reduced by 9% as a result of RWH. This has led to a high savings in distance travelled and emissions generated. Similarly, 14% of the considered RWH users used to travel to work as a passenger in a car before the pandemic. These car trips reduced by 9% as a result of RWH. It can also be observed that bus trips and rail trips increased by 8%.

Another interesting observation is that the employees were traveling an average distance of 36 km with a standard deviation of 17 for work commute before the pandemic. This has reduced to 4.6 km with a standard deviation of 3.8 after the pandemic. Similarly, the average time spent on work commute was 80 min with a standard deviation of 34 before the pandemic. This has reduced to 11 min with a standard deviation of 7.

To summarise this comparison, one may safely say that daily work trips made by car has reduced significantly due to the change in working space. Work trips made by walk and bicycle has increased tremendously, probably owing to the fact that the RWHs are nearer to the employee’s location. The same reason could explain the increase in work trips made by bus and rail. Overall, travel for work has reduced significantly leading to huge savings in distance travelled and time taken. Thus, one may dare say that the strategies which had to be forced on the system because of unprecedented pandemic has established the magnitude of travel savings and sustainable mode shift that can be realised by an alteration in work location.

Table 1
Descriptive statistics of personal and household characteristics.

| Gender                  | N  | %  | Age          | N  | %  |
|-------------------------|----|----|--------------|----|----|
| Male                    | 230| 45 | Average      | 36 |    |
| Female                  | 270| 52 | Standard deviation | ±8.51 |    |
| Prefer not to answer    | 14 | 3  |              |    |    |
| Total                   | 514| 100|              |    |    |

| Current marital status  | N  | %  | Highest level of education | N  | %  |
|-------------------------|----|----|---------------------------|----|----|
| Single (Never married)  | 123| 24 | No formal education/training | 7  | 1  |
| Married (with children) | 151| 29 | Primary education          | 12 | 2  |
| Married (without children) | 175| 34 | Lower Secondary            | 17 | 3  |
| Divorced/ Separated     | 27 | 5  | Upper Secondary            | 8  | 2  |
| Widowed                 | 38 | 7  | Technical or Vocational    | 8  | 2  |
| Total                   | 514| 100| Higher Certificate/ Apprenticeship | 60 | 12 |
| No. of cars/ household  | N  | %  | Ordinary Bachelor Degree  | 162| 32 |
| None                    | 23 | 4  | Honours Bachelor Degree/ Professional qualification | 142| 28 |
| One                     | 321| 62 | Postgraduate Diploma or Degree | 26 | 5  |
| Two                     | 139| 27 | Doctorate (Ph.D)           | 20 | 4  |
| Three                   | 16 | 3  | Total                      | 514| 100|

Table 2
Work trip characteristics of respondents before and after Covid-19.

| Work trip characteristics before the pandemic | N  | %  | Mean | Std. dev. |
|-----------------------------------------------|----|----|------|-----------|
| Prior to the pandemic, how did you usually travel to work? | Not at work | 43 | 8  |
| Walk                           | 24 | 5  |
| Bicycle                       | 16 | 3  |
| Bus                           | 61 | 12 |
| Rail                          | 56 | 11 |
| Motorcycle                    | 44 | 9  |
| Car - alone                   | 105| 20 |
| Car - as a passenger          | 72 | 14 |
| Other                         | 48 | 9  |
| Mainly worked from home       | 45 | 9  |
| Distance to work (km)         | 36 | ±17|
| Travel time to work (mins)    | 80 | ±34|

| Work trip characteristics after the pandemic | N  | %  | Mean | Std. dev. |
|----------------------------------------------|----|----|------|-----------|
| How do you usually travel to your RWH?       | Not at work | A  |      |           |
| Walk                                          | 121| 24 |
| Bicycle                                       | 79 | 15 |
| Bus                                           | 101| 20 |
| Rail                                          | 98 | 19 |
| Motorcycle                                    | 24 | 5  |
| Car - alone                                   | 33 | 6  |
| Car - as a passenger                          | 24 | 5  |
| Other                                         | 34 | 7  |
| Mainly worked from home                       | A  |    |      |           |
| Distance to RWH (km)                          | 4.6| ±3.8|
| Travel time to RWH (mins)                     | 11 | ±7 }
4.3. Comparison of work locations and start times before and after Covid-19

To examine the reason behind the mode shift before and after Covid-19, the location of work and RWHs were identified. To better understand the results, at first the locations of Dublin city and the surrounding counties are shown on the map of Ireland (Fig. 3). As can be seen, Dublin, which is the capital city of Ireland falls on the east coast of Ireland and is closely surrounded by counties including Louth, Meath, Kildare, and Wicklow.

The locations of work where respondents used to travel before Covid-19 and the location of RWH where the respondent works from after Covid-19 is shown in Fig. 3.

 Majority of the employees’ (83%) work was located in Dublin, which indicates they used to commute to Dublin every day before the pandemic. However, the RWHs that are currently used by majority of the respondents are in Kildare, Meath, Wicklow, and Louth, on the outskirts of Dublin (Fig. 3). One may infer that the change in work style has not only eliminated the employees’ need for travel, but also caused development of work-related activities in counties outside of Dublin. This shift points to regeneration of areas outside Dublin city and points to the Irish government’s plan to revitalise rural towns (Duffy, 2021; Keane, 2021).

Another interesting aspect to look for is the time at which each of the employees start their trip for work. The time at which employees used to start their journey for work before the pandemic and the time they start their journey to RWH are compared in Table 3. As can be seen, most of the respondents (58.9%) had to start their journey before 7:30 a.m. prior to the pandemic, however, the situation after the pandemic is drastically different. The findings show that a vast majority of people now travel after 7:30 a.m. This illustrates the travel time savings because of an alteration in the work location. Additionally, one can expect that saving some quality time during the morning can lead to increased productivity in work and better work-life balance for the RWH users (see Table 4).

An important factor for evaluating the success of any telecommuting

Table 3
Comparison of start time of work trip and frequency of remote working before and after Covid-19.

| Parameter | Response | Percentage (%) |
|-----------|----------|----------------|
| Prior to the pandemic, what time did you usually leave home to go to work? | Before 06:30am | 19.6 |
| | 06:30-07:00am | 17.4 |
| | 07:01-07:30am | 21.9 |
| | 07:31-08:00am | 11.2 |
| | 08:01-08:30am | 8.7 |
| | 08:31-09:00am | 6.6 |
| | 09:31-09:30am | 7.9 |
| What time do you usually leave home to travel to the RWH? | Before 06:30am | 7.2 |
| | After 09:30am | 6.0 |
| How many days a week do you work from RWH? | One | 7.8 |
| | Two | 37.8 |
| | Three | 33.3 |
| | Four | 6.2 |
| | Five | 6.2 |
| | More than five | 7.6 |
| How many days a week do you work from home? | One | 33.3 |
| | Two | 33.5 |
| | Three | 7.4 |
| | Four | 10.5 |
| | Five | 8.3 |
| | More than five | 6.4 |
| How many days pre-covid did you work from home? | Zero | 38.0 |
| | One | 36.6 |
| | Two | 5.0 |
| | Three | 5.0 |
| | Four | 5.4 |
| | Five | 4.8 |
| | More than five | 4.7 |

Table 4
Benefits and costs of remote working hubs.

| Rating Benefits and Costs | Mean | Std. dev. |
|--------------------------|------|----------|
| Benefits of working from home or RWH | | |
| No longer having to undertake your commute | 1.304 | 0.882 |
| Having more time to spend with your family | 1.379 | 0.819 |
| Reduced environmental impact | 1.671 | 0.692 |
| Decreased transport costs | 1.325 | 0.899 |
| More flexibility to undertake other tasks during the day (haircut, grabbing a coffee with friends, etc) | 2.166 | 1.075 |
| Ability to spend more time in your local area | 2.132 | 1.127 |
| Ability to spend more time with friends and non-household relatives | 2.051 | 0.986 |
| Reduced direct supervision from management | 2.509 | 0.959 |
| Costs of working from home | | |
| Increased heating and electricity bills | 2.053 | 0.462 |
| Longer working hours | 1.263 | 0.619 |
| Feelings of isolation | 1.389 | 0.779 |
| Lack of visibility in work (e.g., impact of promotion prospects and your perceived value as an employee) | 2.663 | 0.728 |
| WiFi or general connectivity issues | 1.786 | 0.684 |
| Slower speed of interaction with colleagues (inefficient teams etc.) | 2.130 | 0.749 |
| Inadequate home office space or equipment | 1.587 | 0.835 |
| Blurring of the distinction between home and work life | 1.986 | 0.539 |
| Privacy (due to house sharing, other family members, kids etc) | 1.391 | 0.808 |
| Lack of trust from employer | 2.786 | 0.624 |

Fig. 3. Location of Dublin and surrounding counties on the map of Ireland.
strategy is the frequency at which individuals partake in this activity (Caulfield, 2015). To understand the usage pattern of RWHs, the number of days a week an employee worked at workspace is compared with the number of days they worked from home and the number of days they worked from home before the pandemic (Table 3).

It can be observed that majority of the RWH users (70%) work at the RWH for two or three days a week. Most of the respondents (68%) work from home for one or two days in a week. Fig. 3 shows that 38% of the current RWH users were not working from home before Covid-19 while 37% of them were working from home for one day a week before Covid-19.

4.4. Comparison of benefits and cost of remote working hubs

The respondents were asked to rate the different benefits associated with working from home or from a local workspace on a scale with Major benefit, Minor benefit, Not a benefit, and N/A. ranked from 1 to 4 respectively. Respondents that indicated N/A have been taken out of the analysis below. The mean and standard deviations of ranking provided by respondents are shown in Table 3. The lower the mean values the greater the benefit derived from that option.

The major benefit of remote working that most of the respondents agreed upon was the elimination of commute. This was closely followed by decreased transport costs and availability of more family time. The least benefit was pointed out as reduced direct supervision from management. The results indicate that employees place high value on the travel time lost in commute and the associated travel cost. The major concern while working from home was reported as longer working hours. This was followed by feelings of isolation and privacy issues. Few other major issues faced by employees while working from home was inadequate home office space or equipment, WiFi and connectivity issues, and blurring of the distinction between home and work life, all of which are serious concerns that could affect the productivity and quality of life of an employee.

As can be seen from this comparison, the major benefits of working from home is the elimination of commute, cost of commute, and travel time savings, which are important parameters in enhancing one’s motivation to work remotely. However, when this remote work is undertaken from a home setup, it can lead to concerns including longer working hours and work getting affected because of privacy issues, inadequate work setup and merging of home and work life. All of these deterents could influence the employee to travel to office for work. These findings are in line with the previous studies on work from home and forms further evidence that RWHs can solve the issues related to working from home while retaining the benefits of the same. Hence, RWHs could be a promising way forward to ensure sustainability and carbon reduction.

4.5. Evaluation of reduction in emissions and travel time savings because of RWHs

Based on the data collected from the respondents, the study further aims to evaluate the reduction in travel and emissions because of choosing to work from a RWH instead of office. Four major modes of transport which contribute to emissions are considered in this evaluation. This included bus, rail, car (alone) and car (as a passenger).

First, the total distance saved per day because of the mode shift is computed. Further, the emission factor for this mode of transport is identified in terms of CO2 per km per person. These factors are used to compute the total emissions that were eliminated due to this mode shift. The results are shown in Table 5. As can be seen, the maximum savings in emissions was achieved because of mode shift from car to other modes of travel. The results also postulate the potential emissions reductions from members of the sample working at a RWH 3 days a week for a year (132 days).

Further, the travel timesavings as a result of choosing RWH is computed. The time taken to travel to workplace before and after the pandemic is compared to compute the total travel time savings. A value of time is considered in terms of Euro per hour to compute the total savings. The results are shown in Table 5. It can be seen that maximum savings in travel time is because of shift in mode from car, especially for those who were driving to work alone in a car before the pandemic. This is followed by car users who used to travel as a passenger and bus users.

Having established the benefits of working from a RWH, it is also necessary to identify the parameters that are impacting the decision to use a RWH. Such information would assist the companies and policy makers to focus on the most relevant factors to sustain this mode of work in the long-term.

4.6. Principal component analysis

Several variables were considered to evaluate the benefits and issues of working from home or RWH. In order to extract the constructs that affect the decision of RWH and to validate the groupings of variables, a principal component analysis (PCA) was conducted. As discussed earlier, PCA assists in reducing the dimensionality of variables while retaining the maximum variability, which is appropriate for the present study. All the eighteen parameters which were used to rank the benefits and costs were included in the analysis. Responses from 514 RWH users are included in the study, which is a sufficient sample for conducting PCA. Further, the analysis was completed using Varimax rotation method with Kaiser normalization. The results of the analysis are shown in Table 6.

The Kaiser Meyer Olkin (KMO) measure of sampling adequacy is greater than 0.5 which indicates that the sample is good enough to provide reliable results (see Table 7). Also, the Bartlett’s test of sphericity (χ2) is significant (p < 0.001) which indicates that PCA is justified. Three principal components are considered in the analysis based on a

| Table 6 |
|---|
| Travel time saved due to change in work location. |

| Mode of transport | Total time saved (per day) | Value of time (€) per hour | Mean (min) | SD | Total Value per hour | Mean |
|---|---|---|---|---|---|---|
| Bus | 72.83 | 34.52 | 4,516 | 9.67 | 11.65 | 723 |
| Rail | 62.47 | 32.33 | 3,561 | 9.67 | 10.00 | 570 |
| Car – alone | 66.31 | 34.65 | 7,029 | 9.67 | 10.61 | 1,125 |
| Car – as a passenger | 71.16 | 36.40 | 5,195 | 9.67 | 11.39 | 831 |

This establishes the magnitude of emissions that can be eliminated because of teleworking of 514 employees included in the present study.
Table 7
Results of principal component analysis.

| Variable                                      | Principal Components |
|-----------------------------------------------|----------------------|
|                                              | PC 1     | PC 2     | PC 3     |
| Lack of visibility in work (e.g. impact of   | 0.936    | −0.05    | 0.061    |
| promotion prospects and your perceived value  |          |          |          |
| as an employee)                               |          |          |          |
| Privacy (due to house sharing, other family   | 0.935    | −0.146   | 0.07     |
| members, kids etc)                            |          |          |          |
| Blurring of the distinction between home and  | 0.821    | −0.054   | 0.032    |
| work life                                     |          |          |          |
| Slower speed of interaction with colleagues   | 0.776    | 0.066    | 0.305    |
| (inefficient teams etc.)                     |          |          |          |
| Lack of trust from employer                   | 0.769    | −0.011   | 0.251    |
| Feelings of isolation                        | 0.755    | 0.097    | −0.343   |
| Inadequate home office space or equipment     | 0.738    | −0.252   | 0.009    |
| Longer working hours                         | 0.631    | 0.277    | −0.434   |
| Increased heating and electricity bills       | 0.575    | 0.256    | 0.082    |
| WiFi or general connectivity issues           | 0.446    | 0.303    | 0.24     |
| Ability to spend more time in your local area | −0.047   | 0.778    | 0.33     |
| Ability to spend more time with friends and  | −0.218   | 0.680    | 0.542    |
| non-household relatives                      |          |          |          |
| More flexibility to undertake other tasks     | −0.151   | 0.660    | 0.145    |
| during the day (haircut, grabbing a coffee   |          |          |          |
| with friends, etc)                            |          |          |          |
| Having more time to spend with your family    | −0.07    | 0.659    | −0.401   |
| No longer having to undertake your commute    | −0.205   | 0.582    | −0.126   |
| Reduced environmental impact                  | 0.129    | 0.529    | −0.472   |
| Decreased transport costs                     | 0.282    | 0.431    | −0.653   |
| Reduced direct supervisor from management     | 0.262    | 0.386    | 0.537    |

Eigen values: 5.943, 3.228, 2.073
Percentage of variance explained (%): 37.02, 19.93, 12.52

Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO): 0.627
Cronbach’s Alpha: 0.816
Bartlett’s Test of Sphericity: Chi-Square 319.590, df 153, Sig. .000

Extraction method: Principal Component Analysis.
Rotation method: Varimax with Kaiser normalization.

Scree plot. These principal components capture the major variability in the data (69.5%).

All the eighteen variables have factor loading greater than 0.3 indicating the impact of all these factors on an individual’s decision to work remotely. The first principal component comprises of the issues of working from home. Lack of visibility in work and privacy issues stand out as the variables with highest weightage indicating its high impact on an individual’s decision to work from home. Other parameters that seem to significantly deter one’s motivation to work from home in decreasing order of their weightage are blurring of the distinction between home and work life, slower speed of interaction with colleagues, lack of trust from employer, feelings of isolation, and inadequate home office space. The parameters that reportedly has the least impact on decision to work from home include longer working hours, increased electricity and heating bills, and internet connectivity issues.

The second principal component comprises of the benefits of RWHs. The benefit with highest weightage is the ability to spend more time in your local area. This is followed by ability to spend more time with friends, family, and flexibility to undertake other tasks. Decreased transport cost and reduced direct supervision from management are the least weighted benefits of RWHs. It is important to notice that the factor loadings for issues related to work from home including lack of visibility in work, privacy issues, and blurring of distinction between home and work life are much higher than the highest rated benefit of RWH. These results indicate the magnitude of impact of these parameters which deter individuals from working from home and encourage them to work from RWHs instead.

5. Discussion and conclusions

Several studies in the past have investigated the potential of remote working in solving traffic congestion, reducing emissions, and encouraging sustainable mobility. However, the frequency of adopting work from home strategies were not consistent in the past due to a combination of reasons including employer, job, and household characteristics. When interpreting the results presented in this paper one should be mindful of some of the limitations of adopting a policy of RWHs. The research does not examine any rebound impacts whereby those using this remote working model may end up substituting longer commutes with shorter local trips. The Covid-19 pandemic brought about an unprecedented change in the way people work and travel, thus popularising and regenerating the concept of remote working. The concept of RWHs offers immense potential in combining the advantages of remote working while eliminating the drawbacks of working from home. Thus, RWHs point to a more sustainable way of work, in terms of its impact on the environment, and on the possibility that the usage could be consistent this time.

As outlined in the methods section, the results of this paper should be considered with the caveat that the sample analysed is a subsample of the population and inferences can not be made upon the population as a whole, rather just those that use RWH’s in the study area.

Analysis of responses from current RWH users shows a 31% increase in the use of active modes of transport including cycling and walking for work trips. There is a significant decrease (23%) in the use of cars for work commute and an 8% increase in the use of public transport. The average distance travelled to work by employees reduced by 31 km by shifting from office to RWH and the average travel time to work reduced by 69 min. This also led to a shift in the time in which employees need to leave their home. Previously, 58.9% of employees had to leave their home for work before 7:30 a.m. While using RWH, 69.2% of employees left for work between 7:30 a.m. and 9 a.m. Results showed that employees prefer a flexible work routine including two or three days of working from RWH and one or two days of working from home. Findings suggest that the respondents who were driving alone to work can save about 1.126 tonnes of CO2 emissions if they would work from RWHs for three days a week for a year.

Comparison of benefits and concerns of remote work revealed that the issues related to work from home are much higher than the direct impacts of working from home which makes RWHs a desirable alternative for productive work aimed at overall work-life balance and sustainable society. The effect of the pandemic is bound to have long-term implications on how people work and travel. The fear of contracting infection could lead to a long-term fear of public transportation. With the opening of cities and normal work culture, the fear of public transport could lead to a huge increase in private car trip. In this context, developing and encouraging the use of RWHs could be instrumental in keeping private car trips at bay.

Author statement

Conceptualization Brian Caulfield, Methodology Brian Caulfield, Anna Charly, Software Brian Caulfield, Anna Charly, Validation Brian Caulfield, Anna Charly, Formal analysis Brian Caulfield, Anna Charly, Investigation Brian Caulfield, Anna Charly, Resources Brian Caulfield, Anna Charly, Data Curation Brian Caulfield, Anna Charly, Writing - Original Draft Brian Caulfield, Anna Charly, Writing - Review & Editing Brian Caulfield, Anna Charly, Visualization Brian Caulfield, Anna Charly, Supervision Brian Caulfield, Anna Charly, Project administration Brian Caulfield, Anna Charly, Funding acquisition Brian Caulfield.
Acknowledgements

This material is based upon works supported by Terrain-AI (Uncovering new insights to support effective climate change decision-making) SFI 20/SPP/3705, which is funded under the Science Foundation Ireland Strategic Partnership Programme.

References

Abdullah, M., Diaz, C., Muley, D., Shahin, M., 2020. Exploring the impacts of COVID-19 on travel behavior and mode preferences. Transp. Res. Interdiscip. Perspect. 8 (July), 100255 https://doi.org/10.1016/j.trip.2020.100255.

Aguilera, A., Lethais, V., Ballet, A., Proulhac, L., 2016. Home-based telework in France: characteristics, barriers and perspectives. Transport. Res. Pol. Pract. 92, 1–11. https://doi.org/10.1016/j.trp.2016.06.021.

Barbour, N., Menon, N., Manerring, F., 2021. A statistical assessment of work-from-home participation during different stages of the COVID-19 pandemic. Transp. Res. Interdiscip. Perspect. 11 (July), 100441 https://doi.org/10.1016/j.trip.2021.100441.

Brazil, W., Caulfield, B., Rieser-Schüssler, N., 2013. Understanding carbon: making emissions information relevant. Transport. Res. Transport Environ. 19, 28–33. https://doi.org/10.1016/j.trer.2012.12.002.

Bucky, P., 2020. Modal share changes due to COVID-19: the case of Budapest. Transp. Res. Interdiscip. Perspect. 8 https://doi.org/10.1016/j.trip.2020.100141.

Cao, X., Mokhtarian, P.L., 2005. How do individuals adapt their personal travel? Objective and subjective influences on the consideration of travel-related strategies for San Francisco Bay Area commuters. Transport Pol. 12 (4), 291–302. https://doi.org/10.1016/j.trp.2005.03.003.

Carroll, P., Caulfield, B., Ahern, A., 2019. Modelling the potential benefits of increased active travel. Transport Pol. 79 (May 2018), 82–92. https://doi.org/10.1016/j.tranpol.2019.04.020.

Caulfield, B., 2015. Does it pay to work from home? Examining the factors influencing working from home in the Greater Dublin area. Case Studies on Transport Policy 3 (2), 206–214. https://doi.org/10.1016/j.cstp.2015.04.004.

Cerqueira, E.D.V., Motte-Baumvol, B., Chevallier, L.B., Bonin, O., 2020. Does working from home in the Greater Dublin Area: Case Studies on Transport Policy 3 (2), 206–214. https://doi.org/10.1016/j.cstp.2020.02.026.020283217.

Laker, B., 2021. Why companies should adopt a hub-and-spoke work model post-pandemic. In: MIT Sloan Management Review: Vol. ISSN 1532–. https://eprints.reading.ac.uk/98259/%0A.

Lohrey, S., Creutzig, F., 2016. A ’sustainability window’ of urban form. Transport. Res. Transport Environ. 45, 96–111. https://doi.org/10.1016/j.trer.2015.09.004.

Melo, P.C., de Abreu e Silva, J., 2017. Home telework and household commuting patterns in Great Britain. Transport. Res. Pol. Pract. 103, 1–24. https://doi.org/10.1016/j.trer.2017.05.011.

Morton, C., Caulfield, B., Anable, J., 2016. Customer perceptions of quality of service in public transport: evidence for bus transit in Scotland. Case Studies on Transport Policy 4 (3), 199–207. https://doi.org/10.1016/j.cstp.2016.03.002.

Motamed, B., Shirvaniomghaddam, K., 2021. The local Co-working hub: a merging solution. Urban science, 5(1). https://doi.org/10.3390/urbansci5010015, 15.

NoCo, 2021. NoCo hub & workspace. https://nocoworkspace.com/.

Sanders, P., Zuidgeest, M., Geurs, K., 2015. Liveable streets in Hanoi: a principal component analysis. Habitat Int. 49, 547–558. https://doi.org/10.1016/j.habitat.2015.07.001.

Shiva Nagendra, S.M., Khare, M., 2003. Principal component analysis of urban traffic: characteristics and meteorological data. Transport. Res. Transport Environ. 8 (4), 285–297. https://doi.org/10.1016/S1361-9209(03)00006-3.

Staneck, D.M., Mokhtarian, P.L., 1998. Developing models of preference for home-based and center-based telecommuting: findings and forecasts. Technol. Forecast. Soc. Change 57, 53–74.

Tang, W.L., Mokhtarian, P.L., Handy, S.L., 2011. The impact of the residential built environment on work at home adoption and frequency an example from Northern California. 3–22. https://doi.org/10.5198/jtas.40.276.

Varma, K.V., Ho, C., Stanek, D.M., Mokhtarian, P.L., 1998. Duration and frequency of center-based telecommuting: once a telecommuter, always a telecommuter. Transport. Res. Pol. 106 https://doi.org/10.1016/j.tranpol.2021.04.008.

Yildirim, M., Solmaz, F., 2020. COVID-19 burnout, COVID-19 stress and resilience: initial psychometric properties of COVID-19 Burnout Scale. Death Stud. 1 https://doi.org/10.1080/03632751.2020.1818885, 0(0).

Zhang, S., Moeckel, R., Moreno, A.T., Shuai, B., Gao, J., 2020. A work-life conflict perspective on telework. Transport. Res. Pol. Pract. 141 (July), 51–68. https://doi.org/10.1016/j.trd.2020.09.007.