Evaluating the impacts of urban freight traffic: application of micro-simulation at a large establishment

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Heavy Goods Vehicles, HGV, and Light Goods Vehicles, LGV, are a significant contributor to air pollution problems in urban areas. This paper quantifies the contribution to the environment of the deliveries to a single, large city employer addressing a research gap in the literature. Analysis of data from comprehensive surveys carried out over two years demonstrated that freight delivery traffic generated by an urban establishment with multiple properties in a compact urban setting, is characterised by a high proportion of LGV consistent with recent national and international trends. Also, despite freight traffic is only 10% of local traffic, more than 50% serves the single establishment, suggesting a different approach to policy making driven by the employer should be explored. The modelling results showed, relatively, the largest contribution to total emissions comes from HGVs in the AM peak, 13.8%, 43.7%, 9.2% for CO_2, NOx and PM respectively. LGV contribute less, with 5.5%, 3.8%, 6% for CO_2, NOx and PM respectively but more responsible for local congestion due to their numbers. This research is the first known study of its type and with the unique combination of measurement and traffic micro-simulation allowed consideration of more effective traffic management strategies as well as providing evidence to support a consolidation centre for deliveries outside the city with fewer electric or low emissions last mile vehicles reducing substantially the environmental impact. The research outputs are relevant to many other similar cases in UK and Europe. The paper contributes to the ongoing development of research and policy looking to achieve sustainable urban logistics through receiver and purchasing led initiatives.

Keywords: city logistics, freight traffic, environmental impact, receiver-led initiative, transport policy.

1. Introduction

Clean urban freight plays a key role in the creation of environmentally sound, socially inclusive, and economically efficient European cities. Over 60% of the EU population currently lives in

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urban areas and contributes up to 85% of the GDP (European Commission, 2007). The European Commission's 2011 Transport White Paper set up scenarios and visions for the future of urban freight transport. These scenarios include minimising the number of freight movements and the distance required to carry them out; utilising low emission vehicles/trucks; and maximising the use of Intelligent transport systems (ITS) to increase the efficiency of delivery (European Commission, 2011).

Sustainability, encompassing economic, social and environmental aspects within the context of urban freight, has been the centre of discussion among urban freight researchers in the past decades (see for example: Anderson, Allen, & Browne, 2005; Behrends, Lindholm, & Woxenius, 2008). The initial focus leans towards addressing the negative environmental aspects of transport, as identified by the United Nations following the Rio Earth Summit in 1992 and the Kyoto Protocol agreement of 1994, which target nations to reduce carbon emissions. The need to address urban freight issues, alongside passenger transport, towards creating greener towns and cities was set as a high priority on the European agenda (European Commission, 2007). Such effort would mean increased costs for businesses with little environmental benefit as reported in a study in the Netherlands (Quak and de Koster, 2006). In the UK, the Engineering and Physical Sciences Research Council (EPSRC) funded the 'Green Logistics' project (2006-2010) that addressed these issues. Sustainable strategies for city logistics was a project priority, with a number of urban freight initiatives being discussed including low emission zones; urban consolidation centres; and freight quality partnerships (Allen & Browne, 2010). In France the "*Marchandises en Ville*" initiative was launched in 1993 as a joint initiative by the Ministry of Equipment, Transport and Housing and the Agency for Environment and Energy Management (Patier, 2002). At the European level, 'BESTUFS – BEST Urban Freight Solutions', an EC funded project (2000-2008), was a thematic network for urban freight professionals/practitioners to learn, exchange or adopt best practices in urban freight strategies, focusing on three main strategies: goods vehicles access and loading in urban areas; last mile solutions; and urban consolidation centres (Allen, Thorne, & Browne, 2007). Green Logistics, *Marchandises en Ville* and BESTUFS demonstrated urban, national and pan-European acknowledgement of urban freight as a pressing civic concern.

This concern, nonetheless, is not new and is one that has been traditionally addressed by local authorities reacting to problems arising from complaints made by residents and other road users. Generally local government planning, such as the Local Transport Plans in the UK, or the "*plans de déplacements urbains* (PDU)" in France, were drafted primarily focused on infrastructural issues or regulatory, with intervention targeted at vehicles through to transport operators. More recently in the UK and Sweden we have seen a collaborative approach develop with freight partnerships (Lindholm and Browne, 2013). There have been few examples of initiatives that have been consciously receiver led, although there are some that are de facto receiver led due to land ownership or regulation, such as the Hammarby Sjöstad development 2002-2010, or the Heathrow Consolidation centre 2000-ongoing (Egger and Ruesch, 2002).

Amongst recent initiatives for reducing social and environmental impacts of urban freight transport were the role of receiver (rather than carriers) it was in the Dutch *Binnenstadservice* (inner-city services) initiative that small shop owners were the focus of the service and in the UK, the role of receiver in reducing urban freight delivery was demonstrated by the relocation of a portion of Transport for London's Palestra offices (Browne, Allen, Nemoto, Patier, & Visser, 2012). One of the key ideas behind the concept of increasing delivery efficiency from the receiver perspective consists of adjusting the conventional working methods of some of the stakeholders (Verlinde, Macharis & Witlox , 2012). Of note, however, is that in the small retailer led *Binnenstadservice* it has been difficult to find a commercially viable business model, whereas the Palestra intervention was a corporate decision and not funded as a commercial venture.

The main objective of this study is to provide better understanding of the potential, in terms of reducing negative impact, of a more coherent freight strategy for a large urban establishment

such as a University. This paper adds to the analysis of previous publications (see: Zunder, Aditjandra, & Carnaby, 2012, 2014) and explores new insights into the impacts of freight deliveries and services local traffic at peak periods (morning and afternoon) in the vicinity of the University campus, which is part of the centre of Newcastle upon Tyne - a medium-sized British city. Analysis of observed traffic survey data was carried out, to investigate the contribution of the University as a traffic attractor, as well as generator, to the impacts on the local urban environment. The analyses are based on two sets of traffic survey data that are independent of each other. A consolidation of the results allows a better understanding of the freight characteristics at the University, one of the major freight receivers in the city centre.

The paper is structured as follows. Section 2 considers the literature about urban freight modelling. Section 3 describes the methodology adopted in the traffic surveys. The city logistics case study of Newcastle University is described in section 4. Section 5 presents analyses and results of the traffic surveys. Section 6 discusses the study findings, data production techniques and implication for freight transportation policy. Section 7 draws conclusion and lessons learned from the study.

2. Literature Review

Since the 1970's, urban freight studies have emerged in transport academic literature following concerns with urban (commodity) goods movement, as opposed to the movement of trucks in cities (Ogden, 1977). The term 'urban goods movement' has been defined as the movement of goods (as distinct from people) to, from, within, and through urban areas and can comprise goods or services that are produced and consumed in an urban system (Ogden, 1992). Since the main concern of urban freight was goods movement, the literature concerning urban freight focussed on the optimisation of urban freight transport network operation (Button and Pearman, 1981), leading to the establishment of the city logistics concept (Taniguchi, 2001). While this led to improved understanding of how to model urban freight traffic flow in the city environment, recent urban freight studies have focused on issues such as environmental impacts, sustainable economic growth, and the quality of urban life (Anderson et al., 2005; Behrends et al., 2008; Dablanc, 2008; Quak, 2011). The need for urban freight policy, as part of city strategies, has begun to be realised and cross-nation urban freight logistics best practices have been promoted (Zunder and Ibanéz, 2004). Urban freight policies and practices have been criticised as ineffective, inefficient and counterproductive, despite the growing and changing needs of urban logistics services and local policies (Dablanc, 2007; Lindholm & Behrends, 2012; Muñuzuri, Cortés, Guadix, & Onieva, 2012).

Urban goods movement data collection can be categorised into 4 survey types: (1) general – mainly based on typical national transport measurement of flow or commodity; (2) stakeholder specific – mainly based on interviews/questionnaires with freight operators/shippers; (3) vehicle specific – using vehicle movement data loggers; and (4) area specific – focused on a geographical region (Allen et al., 2014). These data are used to gain understanding of urban freight operation typically with targeted research goals and for policy-decision-making (Allen, Browne, & Cherrett, 2012). For the purposes of urban goods modelling, data are often categorised as vehicle journeys (the route), commodity flows (the quantity of goods), and vehicle activity (the movement) (González-Feliu and Routhier, 2012). Similarly, the modelling structure can be defined as truck/vehicle, commodity, and delivery based (Comi, Site, Filippi, & Nuzzolo, 2012). At the higher level, city logistics modelling can be categorised into classical, adapted, combined and class models, that basically estimate traffic flows by adapting and complementing a classical four-step process to produce origin and destination (O-D) matrices quantifying road occupancy impacts (González-Feliu, Cedillo-Campo, & García-Alcaraz, 2014). The overarching aim of modelling urban goods movement data is to enable urban freight demand forecasting, rather

than considering the behaviour of actors involved in the urban freight transport process (Nuzzolo and Comi, 2014; Russo and Comi, 2010) and the effect they have on the environment.

A number of efforts to improve city logistics modelling have been well documented. Russo and Comi (2010), in an attempt to evaluate the *ex-ante* of urban freight problems, demonstrated that many existing models did not integrate the aspect of passenger mobility thus pointed to the requirement to start modelling from the needs of the end-consumer. A two-level analysis was proposed, to integrate end-consumer trips (based on decisions made by the end-consumer) and logistic trips (based on several decision makers) (Russo and Comi, 2010). A macro simulation model was applied at a regional level to test the influence of time windows on the costs of urban freight distribution; the results confirmed the sensitivity of the model in approximating transportation costs, and supporting planning decision making (Deflorio, González-Feliu, Perboli, & Tadei, 2012). Anand, Quak, van Duin, & Tavasszy (2012) defined a multi-actors perspective to shape urban freight modelling and concluded that most urban freight modelling was designed to support (city) administrators by creating efficient urban freight transportation; consequently the efforts were centred on the city authority's view rather than considering other active stakeholders or specific establishment. Comi et al (2012), in reviewing the state-of -the-art of urban freight demand studied the relationships between different city stakeholders and proposed three different levels of planning horizons, namely: *strategic* (e.g. new infrastructures such as urban consolidation, vehicle technology), *tactical* (e.g. minor infrastructure changes such as loading and unloading zones) and *operational* (e.g. particular aspects of governance such as time windows). The review concluded that many measures/policies have been implemented to reduce the negative impacts of urban freight transport without *ex-ante* assessment and drew attention to the lack of understanding between measures/policies and urban freight stakeholder behaviours (Comi et al., 2012).

While most of the above models are European based, in the United States, the issue concerning the demand model for freight had recently been scrutinized for its accuracy since freight generation (FG) does not necessarily equate into freight trip (vehicle) generation (FTG) much in the same way as passenger trip generation equates to the corresponding vehicle trips (Holguín-Veras et al., 2011). This observation led to further studies to improve freight trip generation models and its uses, such as its transferability (Holguín-veras et al., 2013), land use and spatial effects (Lawson et al., 2012; Sánchez-Díaz, Holguín-Veras, & Wang, 2014; Ducret and González-Feliu, 2015), city logistics planning (Jaller, Wang, & Holguín-Veras, 2015), and the newly introduced concept of freight demand management (Holguín-Veras and Sánchez-Díaz, 2015). However, it should be noted that most of these works were based on mega city data such as New York City and especially in Manhattan business district, so its applicability to European cities remains unclear.

An analysis of the framework for freight demand data collection from previous studies; demonstrated that the freight traffic volume within a network is not covered by the sampling framework with sufficient integrity to support urban freight modelling (Holguín-Veras and Jaller, 2014). This particularly is true because freight surveys are aimed at an agent (i.e. shipper, carrier, and receiver), trip intercepts, vehicle and tour (trip chain), as discussed above. Furthermore, a number of gaps in urban freight data collection have been identified, including: LGV activity separate from HGV; the supply chain as a whole; the freight and logistics infrastructure in which urban freight activity takes place; and geographical detail about vehicle trips (Allen et al., 2014). Whilst recent urban freight data collection efforts have been made to address urban freight activity at city high street retail businesses (Cherrett et al., 2012; Danielis, Rotaris, & Marcucci, 2010; Russo and Comi, 2010), home shopping delivery (González-Feliu, Ambrosini and Routhier, 2012), large city traffic (Holguín-Veras, 2011), distribution centres and zonal traffic (Nuzzolo and Comi, 2014), and so forth; (please see references: Anand et al., (2012) for more urban freight modelling and Zunder et al. (2014) for recent urban freight strategies)

there is very little knowledge of urban freight activity focussed on a single, large, urban establishments; this paper aims to address this gap.

3. Methodology

Movements of freight in urban areas are often associated with few major generators and attractors. In fact, in many cases urban freight data collection has been aimed at addressing city transportation policy, with multi-stakeholder agents, there is very little known of data collection impact at a lower level city agent, such as a single organisation. Indeed, recent literature pays attention to the role of 'logistics receiver' in promoting sustainable last mile delivery, as well as being an alternative to the urban consolidation centre (Browne et al., 2012; Verlinde et al., 2012; Zunder et al., 2012). Newcastle University represents a clear example of a logistics receiver that is a single, large organisation, located in the city centre of Newcastle upon Tyne, UK. Newcastle University (established in 1825) with over 80 buildings and facilities, centred on a compact historic campus that has recently introduced a 'coherent campus initiative' to deter private car access. Facilities found within the city campus include shops, cafes, restaurants, offices, leisure centres and residential apartments all of which rely on regular delivery services.

In order to investigate the traffic impacts on the campus and its surrounding environment, two independent types of traffic survey were conducted. First a traffic survey designed to count traffic entering and exiting the University premises was carried out, in two consecutive years. A second traffic survey, of the network and junctions around the University premises, was carried out to develop a detailed micro-simulation model. With regards to the goods supply structure, previous analysis - using procurement record data as reported in Zunder et al. (2012) – had demonstrated that a number of departments had a higher purchasing frequency than others (with catering and medical supplies having the largest volume). However, there was little available knowledge of freight activity of specific buildings therefore these traffic surveys were aimed at improving understanding of the whole system, using the case study of Newcastle University.

The two traffic surveys described above represent the core data sources for analysis. Interviews with key stakeholders held prior to the traffic surveys helped contextualise the city logistics issue (goods delivery entry point) of the University and discussed in the next section 4. This is followed by data analysis. For the first traffic survey, traffic volume at different entry point was estimated whilst for the second traffic survey, the demand/traffic levels for model implementation were derived. The results and data collection techniques are discussed within the context of transportation freight policy.

4. Case study of Newcastle University

The City of Newcastle upon Tyne – population circa 300,000 – lies on the north side of the river and well integrated with the city of Gateshead on the south side and is within a total conurbation of circa 900,000 inhabitants. The majority of freight flow in the city region (Tyne and Wear) is via road, with 28 million tonnes of goods transported by HGVs in 2004 falling to 18 million tonnes in 2009, as the economy adapted to deindustrialisation. Maritime freight, through the Port of Tyne and Port of Sunderland, was 5.4 million and 8.0 million tonnes respectively (2008 data), while a small share of goods was transported by rail (of which more than 50% of loads were carrying imported coal (2010 data) (Tyne and Wear Integrated Transport Authority, 2011). Despite the volume of goods transported by HGV, this vehicle class accounted for only 4% of road traffic in Tyne and Wear, while LGVs accounted for 11% (Local Transport Plan Core Team, 2007). Moreover, these two classes of vehicle have shown opposing trends in recent decades, with LGVs increasing between 30% and 60% on local roads (1975-2005) and HGVs decreasing between 20%

and 50% across the entire network (Local Transport Plan Core Team, 2007). These trends are in line with the national level of LGV fleet and traffic growth in general in the UK between 1950 and 2005, as reported in Browne, Allen, Woodburn, & Piotrowska (2007). This demonstrates the increasing roles and impacts of LGVs in urban areas, as discussed in Browne, Allen, Nemoto, & Visser (2010).

Newcastle University launched a Coherent Campus Initiative in 2008, following a 'Think Tank' workshop hosted by the Vice-Chancellor. The initiative aims to improve the spaces between buildings to create "a sense of place that is welcoming, with well designed, linked social spaces". The campus aims to be "permeable, pedestrian and cyclist friendly". This has recently led to road closures on campus, parking space reduction, new buildings and pedestrianisation. However, there was no brief to address freight.

The focus of the first local transport policy (internal to the University) was on sustainable travel planning, part of the 'Smarter Choices' programme, introduced by the UK Department for Transport as soft policy measures, largely well known for promoting a reduction in carbon based travel to school and workplace, via a personalised travel plan (DfT, 2004). This soft transport policy activity, aimed at addressing driver/passenger transport at the University, was carried out working closely with the local city council. However, the presence of freight vehicles generates a steady flow of complaints from senior management, generating pressure on the Estate Service and the Purchasing Functions.
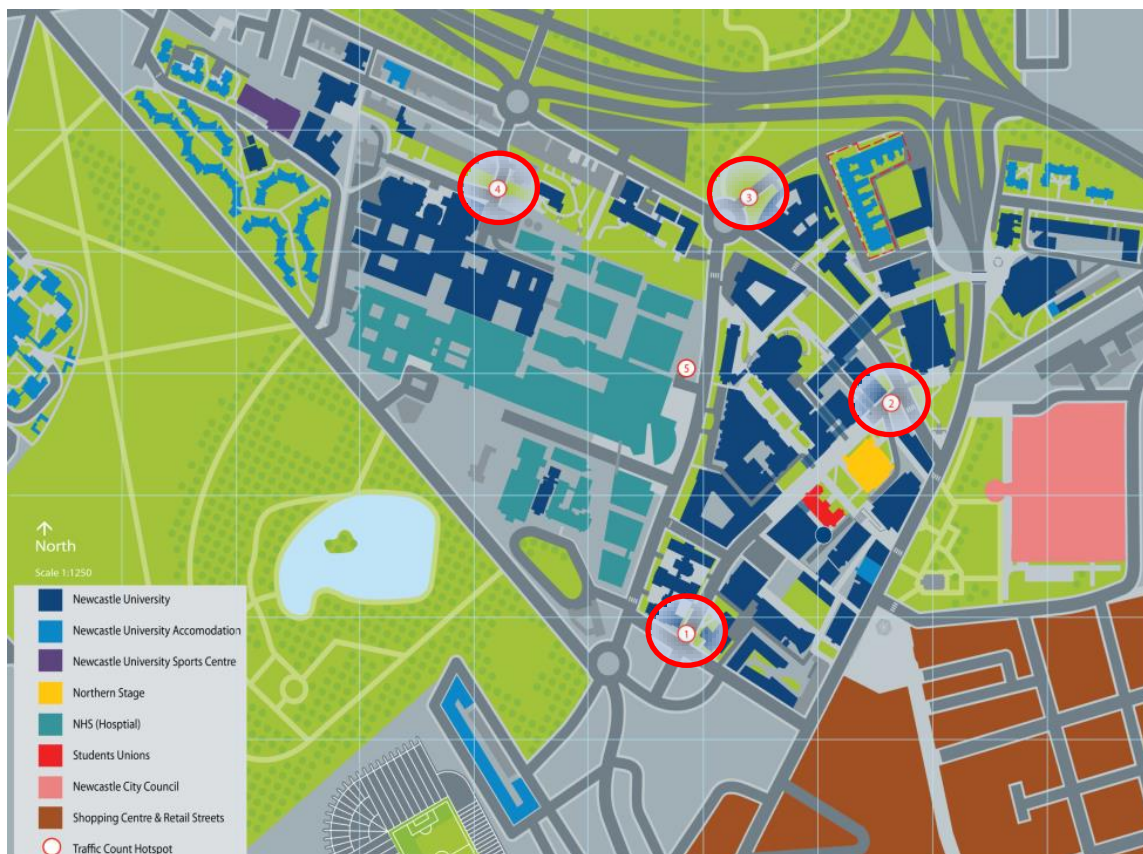

Figure 1. Main campus of Newcastle University with traffic count points numbered

The University's main campus is integral to, but separated from the main city. Other campus sites are located elsewhere in the city (Institute of Genetic Medicine – 1 mile south, at the International Centre for Life, close to the Newcastle City Central Station; Campus for Aging and Vitality - 2 miles west of the main campus site, near Newcastle General Hospital) (see Figure 1).

This study is focussed on the main campus only, because as an operational entity it is separate, whereas many other sites have dual ownership or use, often with local National Health Service (NHS) hospitals. The University main campus has over 144 schools/departments/institutes and over 80 buildings. There are around 5000 staff and 20000 students, making it the second largest employer in the city, after the NHS. Even on the main campus, there are organisations that are autonomous or semi-autonomous from the University. These include the Students Union and the Northern Stage theatre. Also catering outlets, whilst integrated, run separate purchasing and logistics systems.

5. Analysis and Results

5.1 Traffic generation and attraction

Following meetings with the University's Estates Service and Purchasing Functions, a number of traffic entrance points that are associated with the most used freight traffic locations were identified. An experienced surveyor was appointed to carry out the survey, during a term-time week (5 days, Monday to Friday), at 7 traffic count points in Spring 2012 (initial traffic count data analysis is reported in Zunder et al., 2012) and at 5 traffic count points in Spring 2013. However, this paper reports only the analysis of 4 main campus traffic count sites from each year, since the other sites (three in 2012 and one in 2013) were associated with hospital traffic and showed completely different patterns from the general University traffic. These have been excluded during the simulated peak hours, except for matrix estimation purposes required to allocate the differences in traffic flow entering and exiting the main street in front of the hospital. In this way, the four traffic count sites were kept the same for each year, allowing a more consistent estimation of the back to back surveys. Figure 1 shows the traffic count sites across the University main campus; traffic count site number 5, the entrance to the University hospital was excluded.

The campus survey was carried out each day for a period of 12 hours, from 7am to 7pm. The collected data included date, time, car registration plate number, type of vehicle and company logo of all freight vehicles, plus the direction of the vehicle's movement. Figure 2 shows the (simplified) difference in traffic composition between 2012 and 2013, from the four traffic count sites. The traffic classification included 7 types of freight vehicles: LGVs plus 6 types of HGV – 2; 3; 4 axle; and 4; 5 and 6 articulated - along with other types of vehicles including cars, taxis, ambulances, minibuses, coaches, motor cycles and others. Over the day 18,500 vehicles counts (including traffic entering/exiting the University premises) were recorded in 2012 and over 16,100 vehicle counts in 2013. The major proportion of the vehicle types were car (63% in 2012; 60% in 2013), followed by LGV (21% in 2012; 24% in 2013), taxi (8% in both 2012 and 2013), and 2 axle HGV (4% in 2012; 5% in 2013). The figures show an increasing proportion of freight vehicle visits to the University premises, but this is due to the enforcement of the coherent campus policy that limits car access. For example, the pedestrianisation of King's Road, located between traffic count site 1 and 2 (see in Figure 1) reduced car traffic entering the main University campus. It is important to note that car traffic associated with the 4 count sites reduced by 17%, in real terms, between 2012 and 2013 demonstrating the success of the workplace transport policy described above.
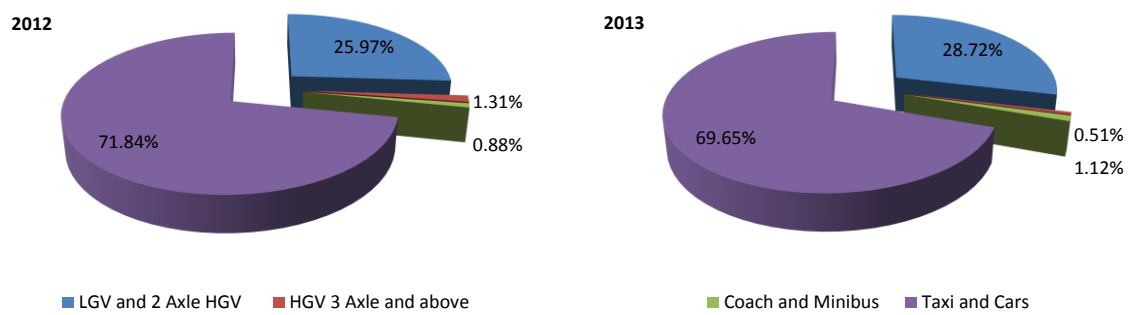
Figure 2. Traffic vehicle type compositions from four sites traffic count points in 2012 and 2013

The volume of freight vehicles visiting the University was relatively high, at over 25% of traffic recorded in 2012 and over 29% in 2013. In addition, there is an observed and persistent level of illegal parking along the external periphery of the site, largely couriers, but also by catering supplies vehicles. These percentages are almost double the average urban freight activity which, according to existing literature, is between 10% and 18% (European Commission, 2006; Woudsma, 2001). Despite the high percentage of freight visits to the University premises, the volume of freight traffic (LGV and 2 axle HGV) reduced by 4% from 2012 to 2013.

Further investigation of all traffic entering and exiting the University premises demonstrated steady flows of traffic, with morning and afternoon peaks as can be seen in Figure 3 and Figure 4. Wednesday was chosen as a relatively busier day for freight traffic (Zunder et al., 2012).
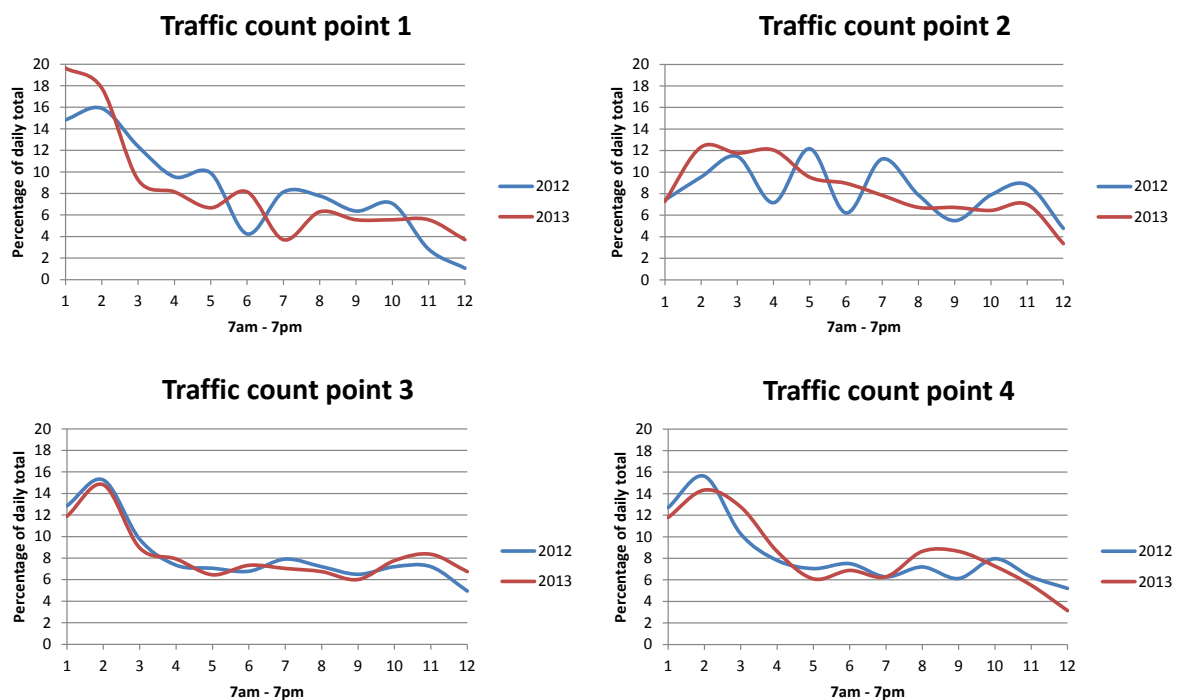

Figure 3. Hourly distribution of all traffic entering the University on Wednesdays
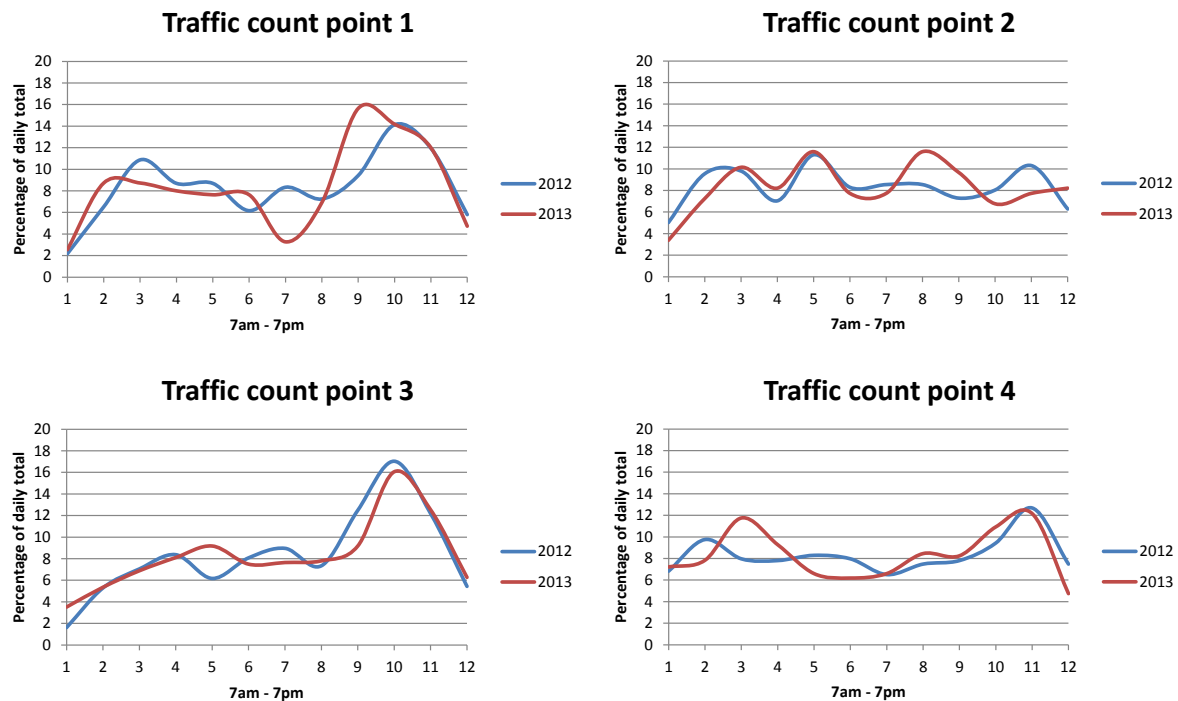
Figure 4. Hourly distribution of all traffic <u>exiting</u> the University of Wednesdays

Traffic count sites 1, 3 and 4 have similar characteristics, showing a peak of traffic entering the University in the morning (at about 8am) (Figure 3) and exiting the University in the afternoon (5pm) (Figure 4); these figures demonstrate typical commuting patterns for each half of the day. For traffic count site 2, the pattern is more variable, but this site is the main gate for public visitors entering the University, so traffic arrives and departs, often for meetings on the hour, throughout the day resulting in approximate sinusoidal profile as expected. This entry point is also the only way to access non-university establishments Northern Stage Theatre and the Students Union (see Figure 1).

5.2 Traffic impact on the network and environment

In order to estimate the relative impact of the University on the overall traffic, a bespoke traffic survey was designed and carried out at the three main junctions: a roundabout (J1), a signalised T junction (J2) and a mini roundabout (J3) (see Figure 5). Three video cameras were used to simultaneously record for two consecutive days (Tuesday, Wednesday) during two time periods of each day. The time periods – 7:30 – 10:00hrs and 16:00 – 17:45hrs – were chosen by considering the peak periods for both overall traffic and campus related traffic, for a total of 4 hours and 15 minutes synchronised video recordings per day. Further measurements were carried out to identify the characteristics of the numerous pedestrian traffic lights (green time duration and minimum offset between two consecutive green phases at each of the signalised pedestrian crossings), across the study area.

Figure 5. Junctions and pedestrian crossings where network traffic survey was performed

The traffic data collected were aggregated at 5 and 15 minutes resolution, taking into account four different vehicle categories: car, LGV, HGV and bus. For the micro-simulation model setup the 15 minutes resolution was considered adequate to evaluate the network performance and quantify the impact; however for future investigation, it would be possible to increase the resolution to 5 minutes.

The Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks (AIMSUN) micro-simulation model (http://www.aimsun.com/wp/) was set up and calibrated to replicate the traffic movements and the interactions across the study area. The model was used because of its ability to appropriately represent road network geometry; simulate in detail the behaviour of individual vehicles, to reproduce explicitly traffic signal control plans, see Table 1 – both pre-timed and actuated – and its easy-to-use graphical user interface. Also, a particular feature of AIMSUN is its ability to capture empirical evidence that influences driver behaviour, which often depends on local circumstances (including the acceptance of speed limits on road sections, the influence of gradients, and driver interaction whilst travelling in adjacent lanes). AIMSUN has an embedded pedestrian model (Legion, http://www.legion.com/) which in the case of a University campus added more realism to the simulation of the current situation and in the modelling of scenarios.

Table 1. Pedestrian traffic light settings

Signalised Pedestrian Crossing:	Green time (sec)	Min. offset (sec)	Tot. min. cycle (sec)
P1	12	30	42
P2	12	30	42
P3	24	30	54
P4	17	20	37
P5	23	15	38
P6	24	5	29

The micro-simulation model was set up to replicate movement at the major streets within the vicinity of the University campus area, including priority and signal control junctions, yellow box areas, pedestrian and pelican crossings, as illustrated in Figure 6. Different parameters, such as reaction time at traffic-lights, saturation flows at stop-lines, maximum/minimum acceleration

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and deceleration, headway and speed limits, were included and calibrated to improve the ability of the model to reflect driver behaviour at the signalized intersections simulated.

Origin-Destination (O-D) matrices at 15 minutes resolution for each vehicle class (Car, LGV, HGV, and bus) were derived using the traffic flows and turning movements measured during the video recording traffic survey periods, at the three junctions. Average flows and turning movements measured at the 5 sections corresponding to the entrance/exit to the campus centroids (based on 2013 traffic count data described in the previous section) were used to enhance the accuracy of the derived O-D matrices. This data was used to quantify the contribution (and matrices) associated with the University campus traffic movements. Further centroids, mainly relevant to car parks, were included also in the simulation.
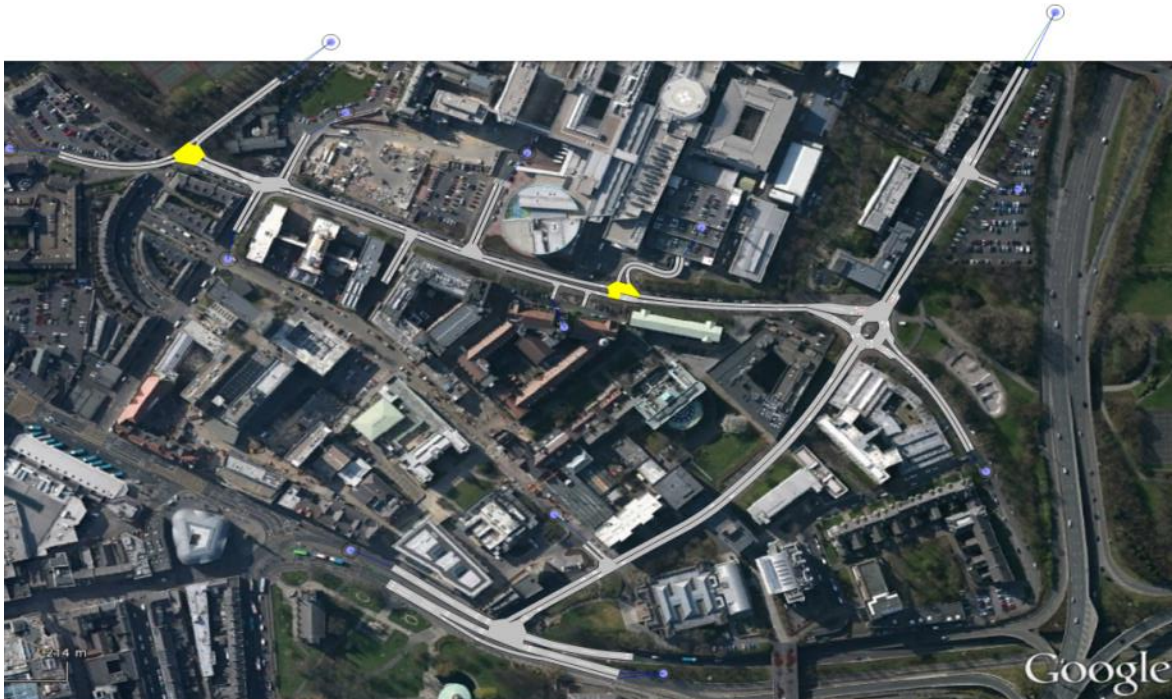

Figure 6. Micro-simulation network layout

The micro-simulation model was calibrated and validated against the data collected during the two days of traffic survey on the same week days (Tuesday, Wednesday) as the freight traffic count campus survey. Although two days are a limited dataset, they were found to be statistically similar at 95% level of confidence. Therefore, the first day was used for the calibration and the second for the validation of the model. The comparison of flows, from direct observation, with those predicted from the micro-simulation, showed good agreement (with a regression coefficient, R^2 of 0.91) for the whole flow range, 10 to 235 vehicles per 15 minutes. The results presented in this paper, for each scenario modelled, have been obtained by running 15 different random seeds and calculating the average values.

As the main objective of the micro-simulation was to identify the relative impacts of the freight movements from and to the campus centroids to the overall impacts from the traffic within the study area, two different sets of matrices, corresponding to two different scenarios, were set up. The first (Base Case Scenario) represented the overall traffic entering and exiting the study area, including the campus centroids. The second matrix (Scenario 1) was set up without taking into account the freight traffic movements associated with the campus area.

The difference between the results of the two modelling scenarios was the impacts associated with the freight traffic movements within the campus area. Overall the traffic was composed of

90% cars, 7.5% LGVs and 2.5% HGVs in the morning peak (AM) and 93%, 6% and 1% respectively in the afternoon peak (PM).

From the simulation results of the Base Case, although the percentages of vehicles associated with freight movements of 10% and 7% for the AM and PM peaks respectively appear quite low, the nature of the activities and the vehicle types used for freight transportation were found to emit more pollution than cars, resulting in a greater impact in terms of CO_2 and even more for toxic pollutants (PM, NOx) emissions.

Figure 7 shows that for LGV and HGV together, CO_2 emissions are 20% and 11% of the total CO_2 simulated emissions respectively for AM and PM peak. As expected, LGV and HGV together, contribute a much higher proportion of the total for NOx emissions with 48% and 29% for AM and PM peak respectively.
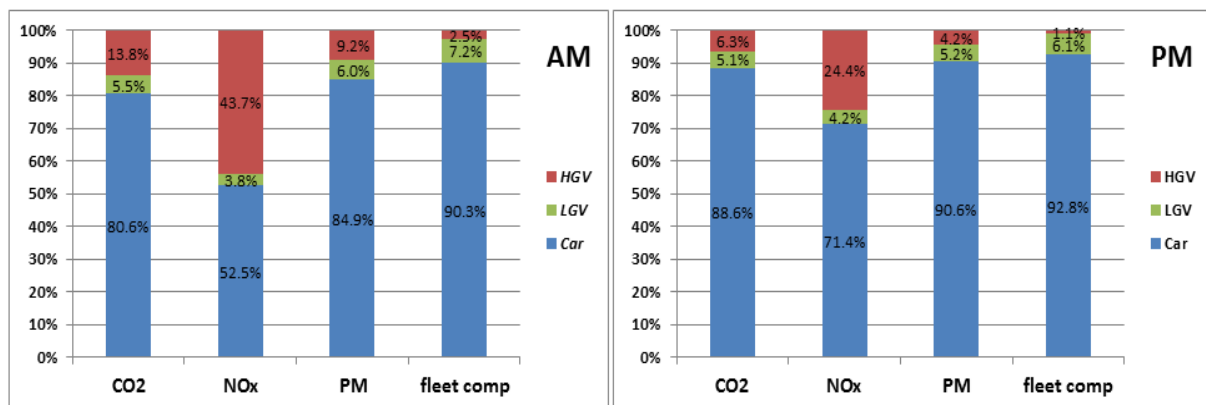

Figure 7. Source portion of CO_2 and pollution (NOx, PM) emissions

Considering the increasing difficulties that Local Authorities have in addressing the year on year expansion of the Air Quality Management Areas, mainly due to NO_2 exceedances, detailed knowledge of freight impacts provides a sound basis for formulating more effective mitigation strategies.

Comparing the results of the two scenarios modelled, Base Case against Scenario 1, Figure 8 shows how the vehicle movements, including small vans which are often recorded as cars, associated with the campus O-Ds, were responsible for more than 20% of the overall CO_2 emissions during the AM and up to 42% during the PM peak. Also, it is argued that this is an underestimate because, as indicated in the previous section, 5% of cars entering/exiting the University were likely to be on commercial business. The figures suggest that relative to LGV, HGV were by far the highest contributor to total emissions to NOx and PM.

Figure 9 illustrates the substantial reduction in emissions achievable if the LGVs and HGVs movements associated with the campus were to be completely avoided, for example by using electric vehicles. Emissions during the PM peak were typically 10–22% higher than in the AM peak, due to a more concentrated peak around 17:00, which causes major congestion across the network, with HGV contributing more compared to LGV. These levels represent a theoretical limit that gives an indication of the magnitude of the potential emissions reduction. These results provide evidence that there is much potential to reduce emissions if a coherent campus strategy for both internal and external freight movements including delivery was implemented.
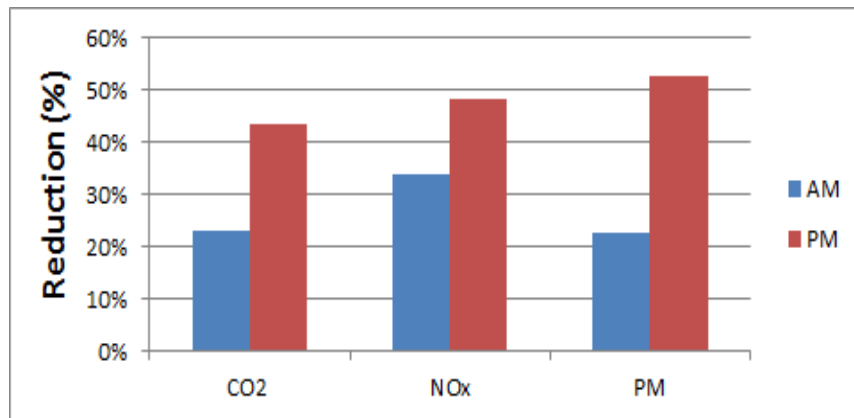
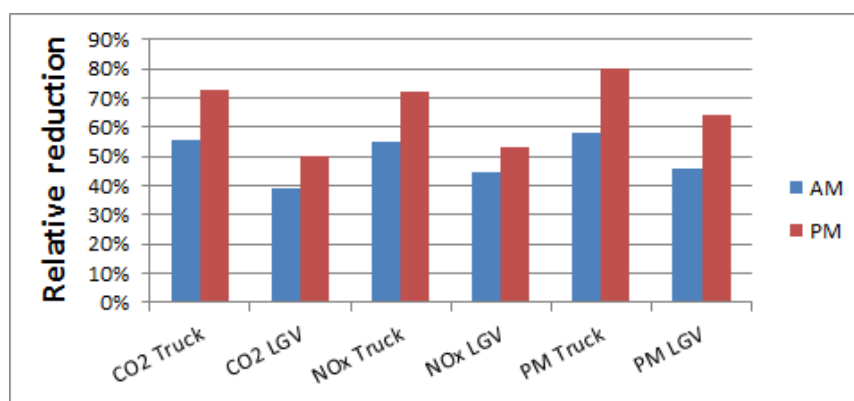*Figure 8. Impacts of emissions of campus related trips*

Figure 9. Relative reduction on emissions for scenario 1

During the survey period an interesting aspect of the network operation set up was identified. With reference to Table 1, the presence of several pedestrian crossings, regulated by traffic lights, often with limited offset co-ordination between two consecutive green phases of adjacent signals, is the cause of extra (and potentially avoidable) delay (and associated emissions) that occurs to travellers around the campus network. Therefore, a second Scenario 2, which adopted a minimum cycle time of 60 seconds to all the signalised pedestrian crossings to reduce the continual stopping particularly during the peak periods, was setup and run. The results of the simulation in terms of main emissions impacts, assuming the overall traffic (Base Case matrices), are presented in Figure 10.
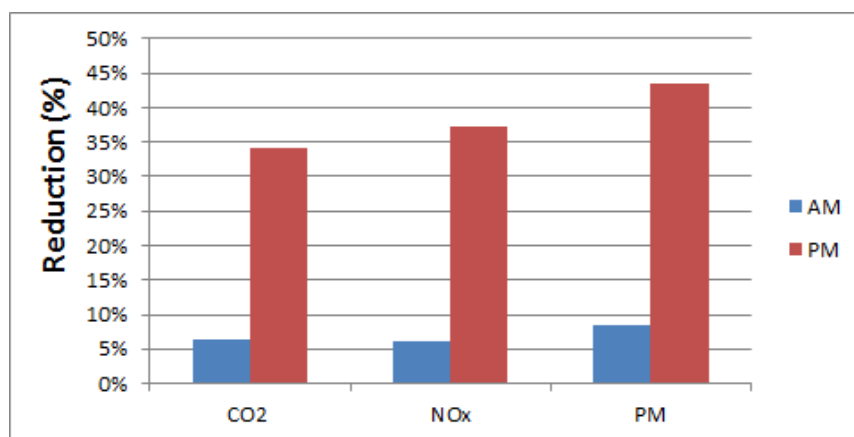

Figure 10. Impact of implementation of fixed-time signal control strategy at pedestrian crossings

Additional benefits of 6%, 6% and 8% for CO_2, NOx and PM respectively in the AM peak and substantially more 34%, 37% and 43% for CO_2, NOx and PM respectively in the PM peak.

These results demonstrated that potential reduction in pollutant emissions are significant and can justify investment in strategies to rationalise and consolidate deliveries to the University, but in consultation with the Local Authority to also ensure that policy changes can occur to allow local traffic control plans to be updated as appropriate.

6. Discussion on data production methods and transport policy

Before the data collection methods were adopted, a number of meetings were held between the University departments, including Estate Services and Purchasing Functions, to discuss transport policy for freight distribution that can be adopted alongside the coherent workplace campus plan. However, there was general hesitation among internal University stakeholders as to whether to create any internal freight policy or simply to adopt the Newcastle city (authority) promoted freight transportation policies. These include the use of an existing urban consolidation centre (supported by the city authority), or to comply with the low emission strategy plan with a greener technology vehicle fleet. The key issue was the lack of evidence that freight traffic at the University campus causes traffic problems. However, issues had been raised already by the Estate Services and Procurement Functions, following the launch of the Coherent Campus initiative (please see Zunder et al. (2014) for further discussion) given that building more infrastructure is restricting car access that consequently has increased the visibility of often illegally parked freight vehicles around the campus sites.

The data collection in this study demonstrates a novel framework to assess urban built environment impact of urban freight traffic. The first type of data collection helped to identify the freight traffic composition generated by the large urban establishment (the University), while the second was used to simulate the local traffic, allowing the freight traffic impact to be estimated. This is in marked contrast to previous urban freight data modelling efforts, that aim to simulate the whole urban freight system of a city, or even the whole region, that need a different – and in many cases much more comprehensive – dataset to quantify trip, delivery and commodity (see for example: González-Feliu et al., 2014; González-Feliu, Ambrosini, Pluvinet, Toillier, & Routhier, 2012; Nuzzolo and Comi, 2014; Russo and Comi, 2010), our approach is much simpler, with its focus on trips by vehicle type. This is based on the assumption that if we reduce the number of individual vehicle trips – in this case by using an electric truck and a consolidation centre as discussed in Leonardi, Browne, Allen, Zunder, & Aditjandra (2014) – we will then see a substantial reduction in the total number of freight trips to the receiving agent (the University), thus addressing economic efficiency, the environment and road safety.

The traffic survey data were used to estimate the total number of freight movements to and from a single large establishment/major employer, acting as big receiver rather than generator of goods. These data gave information on system operation, efficiency and potential improvements and were used to develop a comprehensive baseline of freight activity. Certainly the limitation of this type of data collection being 'area specific' (as referred to in freight data collection typology by Allen et al., 2014) is descriptive by nature and limited to within a certain geographical boundary. Nevertheless the implication for freight policy/planning decision making is crucial, because the data act as the baseline measure of the degree to which a current campus strategy impacts the local urban environment traffic in general and the University traffic in particular. The lessons learnt are important and applicable more widely in other similar city situations.

Linking to previous literature about city logistics modelling efforts, our study addresses the untouched 'urban structure' objectives domain, as discussed in Anand et al. (2012, p.111), where the impact on freight of the coherent campus initiative with extensive pedestrianisation etc. can

be explained. One reason why this objective has been missing in the literature is perhaps that urban freight modelling efforts focus on the interaction of the multi-stakeholder agent of a city logistics system, while our approach is simply focused on a single 'receiver' planning horizon, as discussed in Comi et al. (2012). However, it would certainly be of interest to model the whole system of the University's traffic, using the delivery and commodity data, to further improve our understanding of the goods movement of a single large (urban) establishment. A new data collection, such as a University supplier survey would be needed, to set up such a demand/supply model.

7. Conclusion

In this paper analyses of data from two different traffic surveys collected within the main Newcastle University campus and the surrounding transport network were presented. The rationale behind this was to use Newcastle University example to gain better understanding of the contribution to environmental impacts made by an urban establishment as a traffic attractor/generator to the local urban environment, so that it can be used for many other similar cases nationally and across Europe. This was identified as a major gap from the literature review, from which it is clear that, in the past, very few studies of urban freight (traffic) activity specific to urban establishments which form a large part of the city have been carried out. This is probably due, in part, to the nature of urban freight research that normally focuses on a city's retail/commercial business activity (see for example: Danielis, Maggi, Rotaris, & Valeri, 2012; Cherrett et al., 2012, González-Feliu et al., 2012). With the pressure of contemporary urban transport policies that limit car access to cities, a better understanding of freight traffic behaviour at urban establishments is of increasing important to lead to better urban transport planning and thus to inform more sustainable distribution methods.

From the first set of traffic surveys, carried out in two consecutive years (2012 and 2013), it was demonstrated that Newcastle University was largely served by LGVs. The introduction of the Coherent Campus initiative that included pedestrianisation reduced the total traffic visits to the University by 13%. The proportion of freight amongst the University's traffic was found to be high, with over 25% in 2012 increasing to over 29% in 2013, with more than 80% of the traffic represented by LGVs and HGVs with 2 axles. This figure, although relatively high compared to overall city freight traffic (typically less than 20%), represents a good example of the implications of pedestrianisation, or new parking regimes that deter car use (including freight) in city centre areas.

From the second traffic survey across the entire network, the total freight traffic within and vicinity of the study area was recorded at 10%, with more than 50% of that generated or attracted by the University. Moreover, from the modelling results, relatively, the largest contribution to total emissions comes from HGVs in the AM peak, 13.8%, 43.7%, 9.2% for CO_2, NOx and PM respectively. In terms of environmental impacts, despite being more responsible than HGV for local network congestion due to their numbers, LGV in the morning peak contribute less with 5.5%, 3.8%, 6% for CO_2, NOx and PM respectively to overall network emissions. Given that in the evening peak, there is an increase in number of private vehicles in the network, many collecting staff from the establishment, the HGV and LGV relatively have lower impact on the network as a whole.

These findings provide evidence that there is much potential to reduce emissions associated with an urban establishment, in particular through more effective local policy interventions specific to the University which reduces the number of vehicles to and from campus. This can be achieved through consolidation and co-ordination of deliveries outside the city with fewer low emission vehicles to, from and around the campus. This will improve the quality of the air in urban areas contributing towards achieving national and international objectives of reduction of pollution

exposure (e.g. Air Quality Management Areas in UK Local Authorities). Therefore, a strategy to promote the adoption of a delivery and servicing plan (please see Zunder et al. (2014) for further discussion) with urban consolidation centres seems the way forward.

Finally, from the results of scenario 2, it is clear that, for a comprehensive and fully effective strategy, a key issue in urban areas is the regulation of signalised pedestrian crossings, which can lead to additional significant benefits in terms of emissions reductions and network congestion improvements.

It is well known that many urban consolidation initiatives, when promoted by city authorities, have failed to deliver long-term successful operation. Therefore, a new policy approach centred on major employers and large urban establishments, became the motivation for this research. Our case study has provided the empirical evidence that a large urban establishment, particularly with multi-site buildings in a compact urban setting which already employs its own internal commuter transportation planning policies should consider also a bespoke freight policy and not necessarily follow the city or regional policy.

Acknowledgements

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