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Modelling the transportation of primary aggregates in England and Wales: Exploring initiatives to reduce CO_2 emissions

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ABSTRACT

Millions of tonnes of aggregates are transported across England and Wales each year, which causes constant concerns in regard to CO_2 emissions. Much of that concern arises out of the long journeys from quarries to construction sites, and the fact that the main mode of transfer is by road. The aim of this paper is to describe the construction of a spatial decision support system (SDSS) to examine the impacts of scenarios to reduce the level of CO_2 emissions. The SDSS is made up of a GIS containing a set of spatial models (including a spatial interaction model and a microsimulation model) underpinned by a detailed transport network of road and rail routes across England and Wales. The spatial interaction models are first calibrated to reproduce the existing set of flows of aggregates between quarries and local authority districts. The distance decay component is the travel distance equivalent across the road and rail networks. Based on these flows, linear models can be set up to estimate the amount of CO_2 emissions associated with the existing set of flows. Then a series of what-if scenarios are set up which look at how changes in any part of the geography of production, the level of demand in certain areas or the transport process will impact the CO_2 emissions. The paper demonstrates the capability of the SDSS in responding to the various spatial policies applied in different stages of the supply chain of the aggregates markets.

Introduction

Aggregates are essential for maintaining our economy and lifestyle, but their extraction, processing and handling are responsible for about 1.7 mt of CO_2 emission, accounting for 0.69% of total UK CO_2 emission (DTI, 2008). The carbon footprint of mineral production is a significant matter of concern for the UK mining industry and its regulators given that continued demographic growth can be expected to generate ever higher demand for commodities and construction materials, whilst the government is committed to substantial reduction in carbon emissions in accordance with various international protocols (e.g. Kyoto) (Defra, 2005; DECC, 2009). The transportation of primary minerals is responsible for around 40% of energy consumed by this industry (MPA, 2010; Defra, 2009). Although no figures are available, the proportion of energy consumed transporting bulk construction materials such as aggregates is likely to be even higher. Moves towards more sustainable procurement and transport of aggregates are therefore likely to have a significant positive impact on the overall carbon footprint of the minerals industry in the UK.

In this paper we describe the construction of a spatial decision support system to facilitate the estimation of carbon emissions based on the production and transportation of aggregates across England and Wales. The administrations in England and Wales operate a 'Managed Aggregates Supply System' (MASS) which aims to predict and provide a steady and adequate supply of aggregate by evening out imbalances in supply and demand through a regional and sub-regional apportionment process (Hicks, 2008). Scotland and Northern Ireland operate free market systems for aggregate supply (which are independent of the MASS in England and Wales). In this study, the spatial decision support system is made up of a Geographical Information System (GIS) containing a set of spatial interaction models underpinned by a detailed network of road and rail routes. The interaction models are calibrated to reproduce the existing set of flows of aggregates across England and Wales. These flows link together a series of origins and destinations, in which the origins are the set of quarries and the destinations are local authority areas (principally towns and cities where construction, and hence demand, is greatest). The pattern of flows is modelled taking into account the cost of transportation across the road and rail networks.

From these models, performance indicators can be articulated to estimate the carbon footprint associated with the existing interaction patterns. Then, a series of what-if scenarios can be set up which look at how changes in any part of the distribution process

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will impact on carbon emissions. These changes could relate to the demand side of the market (e.g. an increase in demand at various locations), at the supply side (e.g. the opening or closing of a new quarry) or could relate to the transport network (e.g. new roads or rail lines provided to quarries). In this paper we will examine four major what-if scenarios, each designed to reduce the carbon footprint of transporting aggregates. These four scenarios are:

(1) Development of new quarries nearer to places of high demand.
(2) Enabling more aggregates to be transported by rail rather than road.
(3) Modernising the fleet of lorries used to transport aggregates.
(4) Increasing the use of marine sources of aggregates.

All these are options currently under review by the UK aggregates industry. For example, the increased transfer of aggregates by the waterways (Scenario 4) has been widely touted as a policy option, and an important component in reducing the environmental impact of the construction work associated with the Olympics site at Stratford in London (LOCOG, 2009). Similarly, the potential of new vehicle types (Scenario 3) has been recognised as a real alternative to switching travel modes (Knight et al., 2008; BCG, 2009). This assessment of policy scenarios within a SDSS provides a unique combination of spatial data management within a GIS with a spatial modelling framework for the aggregates market; and in attempting to evaluate the carbon footprint of existing and future distribution patterns under alternative planning scenarios.

The rest of the paper is structured as follows. In section "The UK aggregates industry and its carbon footprint" we discuss the nature of the UK aggregates industry especially in relation to its geography within England and Wales and its carbon footprint. Then, in section "The spatial decision support system" we describe the structure of the spatial decision support system, including the modelling framework, the data sources used and the calibration procedures. Then, we outline the procedure for estimating carbon emissions based on the model outputs. The four scenarios are then presented in detail, and we examine the impacts they are estimated to have on carbon emissions.

The UK aggregates industry and its carbon footprint

The British Geological Survey (BGS) define aggregates as being hard, granular materials which are suitable for use either on their own or with the addition of cement, lime or a bituminous binder in construction (Highley et al., 2007). They are the most commonly used construction material. According to the Strategic Rail Authority (2005) 32% are used for road construction, repair and maintenance and 28% are used for new housing. Aggregates can be further classified into primary aggregates, secondary aggregates and recycled aggregates. Primary aggregates tend to be naturally occurring participate deposits of sand and gravel, or products of the crushing of hard, strong rock formations-mainly limestone, igneous rocks and sandstone. Consumption of primary aggregates was about 220 mt in 2005 (for the whole of the UK) with a per capita consumption of some 3.7 t (Strategic Rail Authority, 2005). They also represent the largest single material flow in the national economy (Brown et al., 2008). Secondary aggregates are defined as aggregates obtained as by-products of other quarrying and mining operations such as colliery spoil, slate waste and china clay waste; or aggregates as by-products of other industrial processes like blast furnace/steel slag, coal-fired power station ash, and spent foundry sand. Recycled aggregates come from a variety of sources including demolition of buildings and structures, or from civil engineering works. Recycled aggregates also include asphalt planings from resurfacing roads, and railway track ballast. For further details of the aggregates market see Smith and Collis (2001), Gunn et al. (2008), Hicks (2008), Bloodworth et al. (2009).

While England and Wales are largely self-sufficient in primary aggregates, geological resources and population density are unevenly distributed. As a consequence, there are significant regional imbalances in supply and demand, which require large inter-regional movement of aggregates. This process is planned, monitored and adjusted by governments in England and Wales through the MASS. Regional demand imbalances are greatest in South East England and London, where, in 2005, consumption was three times that of supply from within the two regions. On the other hand, supply is concentrated in the central areas of England (the West and East Midlands), South West England and Wales. Thus the transportation of aggregates plays a crucial role in equalising the imbalances between demand and supply. Most aggregates are transported by road with an average transport distance of approximately 40 km (BGS, 2007). In 2005, about 10% of primary aggregates were moved by rail (6–9% of the total: QPA, 2006; BGS, 2007) and coastal or inland waterway (1% of the total, excluding the waterborne transport between dredging sites and wharves for marine sand and gravel: BGS, 2007). These non-road transports are associated with longer average transport distances. In practice therefore, there are choices available to consumers of aggregates in terms of both the source of their products and the means of distribution. However, the impact of these choices is as yet poorly understood by decision-makers, as is the impact of changes in policy relating to spatial planning for mineral supply and transport policy.

With increasing concerns regarding the carbon footprint of the production and transportation of aggregates, a model to simulate the mass flow of primary aggregate minerals in England and Wales is likely to be a useful tool for industry, regulators and policy makers. It could be used for assessing the sustainability of different apportionment scenarios which might be carried out as part of the MASS. It might also be used in simulating and quantifying the impacts of other potential spatial planning and/or transport policy scenarios relating to aggregate mineral supply in general and the consequent carbon emissions in particular. The UK aggregates market produces around 1.7 mt of CO_2 per year (MPA, 2010). Although this is a small percentage of the total UK emissions, it is nevertheless important that all sectors of the economy contribute to the UK target to reduce CO_2 emissions by 80% by 2050 (UK Minerals Forum, 2009). To provide this capability of evaluating different impact scenarios, the rest of this paper describes the (spatial) decision support system (SDSS) in detail and provides a range of different policy scenarios to test the capabilities of the system.

The spatial decision support system

Model specification

In order to generate powerful capabilities to support planning decisions a set of *spatial interaction models* has been developed to simulate the transportation of aggregates across England and Wales. Spatial interaction models have a long history of successful application in geography and urban/regional planning (Wilson, 1974, 2010; Birkin et al., 2010), and in transportation studies (Erlander and Stewart, 1990; Miller, 1999) although they have never been applied to study the flows of aggregates in the UK. The Spatial Interaction Model (SIM) is a key element for the whole system as the interaction data is crucial for the estimation of carbon emissions, impact assessment and scenario evaluation. The equation can be written as:

$$\hat{m}_{ij} = A_i O_i B_j D_j f(d_{ij}) \quad (i, j = 1, 2, \ldots, r;\ i \neq j) \tag{1}$$