Changes in travel-related carbon emissions associated with modernization of services for patients with acute myocardial infarction: a case study

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ABSTRACT

Background Little attention has been paid on the carbon footprint of different healthcare service models. We examined this question for service models for patients with acute ST elevation myocardial infarction (STEMI).

Methods We estimated carbon emissions associated with ambulance (patient) transport under a primary percutaneous coronary intervention (pPCI) care model based in tertiary centres, compared with historical emissions under a thrombolysis model based in general hospitals. We used geographical information on 41,449 hospitalizations, and published UK government fuel to carbon emissions conversion factors.

Results The average ambulance journey required for transporting a STEMI patient to its closest care point was 13.0 km under the thrombolysis model and 42.2 km under the pPCI model, producing 3.46 and 11.2 kg of CO2 emissions, respectively. Thus, introducing pPCI will more than triple ambulance journey associated carbon emissions (by a factor of 3.24). This ratio was robust to sensitivity analysis varying assumptions on conversion factor values; and the number of patients treated.

Conclusions Introducing pPCI to manage STEMI patients results in substantial carbon emissions increase. Environmental profiling of service modernization projects could motivate carbon control strategies, and care pathways design that will reduce patient transport need. Healthcare planners should consider the environmental legacy of quality improvement initiatives.

Keywords angioplasty, carbon, dioxide, emissions, environmental, GIS, infarction, myocardial, patient, travel

Background

A recent NHS carbon footprint study identified ‘travel’ as a contributor to 18% of all healthcare sector related carbon emissions.1 A more detailed understanding of emissions directly generated by patient travel could help in carbon emission control or reduction efforts—for example, by motivating the design of clinically appropriate but less patient travel-intensive healthcare pathways.2 In the UK, under the Carbon Reduction Commitment, large public and private organizations, including the NHS, are likely to be monitored and taxed for their carbon emissions, from April 2010.3

Recently, the English NHS has committed to a strategy of modernizing care for patients with acute ST elevation myocardial infarction (STEMI) using primary percutaneous coronary intervention (pPCI) as opposed to thrombolysis.4 This decision was based on evidence of comparative clinical effectiveness indicating an absolute risk reduction in short-term mortality of up to 2% when using pPCI as opposed to thrombolysis (i.e. short-term mortality of 7 versus 9%, respectively, odds ratio 0.73, 95% confidence interval

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However, the clinical benefit of pPCI is critically dependent on its timely administration, and presentation delays can completely deny its clinical advantage. Moreover, a pPCI care service model requires the ‘24/7’ availability of an on-call expert multi-disciplinary team, which de facto limits the delivery of such services to a much smaller number of ‘pPCI centres’ (Box 1), to which the patient needs to be urgently transported by ambulance. Therefore, this modernization initiative, while being welcomed for improving the quality of patient care, has the potential to substantially increase patient travel related carbon emissions. The 2009 annual report of the Chief Medical Officer for England has highlighted the responsibility and potential contributions of the healthcare sector in reducing greenhouse gas emissions. We therefore set out to quantify the potential adverse environmental impact of this change, in an English region, as a case study.

**Box 1 Introduction of primary PCI for the management of STEMI patients: Clinical reasoning, and implications for ambulance journeys.**

- STEMI patients managed with pPCI have better clinical outcomes compared with those managed with thrombolysis. Evidence also indicates acceptable cost-effectiveness.
- However, pPCI benefits are critically dependent on its timeliness (more so than for thrombolysis). Clinical guidelines recommend than pPCI ought to be ideally carried out within 60 minutes from the time that administration of thrombolysis would have been possible, and within 90 minutes from ‘first medical contact’.
- Unlike thrombolysis that can be effectively and safely administered in the community (pre-hospital thrombolysis) or at a general hospital, primary PCI requires ‘24/7’ availability of an on-call interventional cardiology team and cardiac catheterization facilities. Clinical quality is best assured in high-volume centres.
- These factors restrict pPCI provision to a much smaller number of care points (i.e. tertiary cardiac units) compared with district general hospitals.
- In the ‘case study’ English region, the change in the pPCI care model for STEMI patients meant that ambulances will have to travel to three cardiac centres (as opposed to 18 district general hospitals in the historical thrombolysis model).

**Methods**

We calculated the additional geographical distance travelled, and associated carbon emissions that would be generated, from managing a ‘typical’ patient with a STEMI event occurring in an ‘average’ location within the geographical area of interest under a pPCI care model compared with the historical thrombolysis care model. Analytical steps are outlined below:

**Data**

For the East of England region, Hospital Episodes Statistics (HES) data were used to obtain information about the spatial distribution of patients admitted to an NHS hospital with a primary diagnosis of myocardial infarction (defined using International Classification of Diseases (ICD)-10 codes I21, I22, I29) during the 5-year period 2002–03 to 2006–07. Patients’ residential postcodes were assigned to their respective Lower Super Output Area (LSOA). All LSOA geographies were subsequently reduced to their population-based centroid points (the geographical average location where people live—‘centroids’ for brevity thereafter). 

**Geographical information systems analysis**

Two matrices of destination ‘care points’ were constructed, one for the thrombolysis care model (corresponding to the 18 regional district general hospitals with Accidents and Emergency departments) and one for the pPCI care model (corresponding to the three regional pPCI centres). ArcEditor GIS software with a Network Analyst extension was used to compute ‘real world’ distances from LSOA centroids to district general hospital Accidents and Emergency or pPCI centre destinations, using OS Meridian road network information. The distance from each LSOA centroid to its closest care point under the two models was selected from all other possible care point destinations (either one of 18 district general hospitals under the thrombolysis model or one of three pPCI centres under the new model) using ‘MIN’ formulas in Excel. For either service model, the total of (minimum) distances required for all STEMI patients to be transported from their LSOA centroid to their closest care point during the 5-year study period was averaged. This calculation produced the mean ambulance journey mileage required for the management of a STEMI patient under either service model.

**Conversion of distance to carbon emissions**

Mileage was converted to CO₂ emissions using standard coefficients, published by the Department for Environment Food and Rural Affairs. In the absence of a conversion factor specifically for ambulances, we were advised to use the CO₂ conversion factor for ‘large vans’ as an appropriate proxy, i.e. 1 km travelled to 0.2661 kg of CO₂. This conversion factor is estimated using average values for the UK van fleet in 2005. It is calculated based on the average speed and distance of UK trips and adds 15% on emissions to model ‘real world’ driving effects such as air-conditioning and road network inclines.
Results

Information about 41,449 myocardial infarction hospital admissions that occurred during the 5-year study period in the East of England was used in calculations.

The average journey distance required for the transport of a STEMI patient to their closest care point was 13.0 km under the thrombolysis model, and 42.2 km under the pPCI model, corresponding to CO2 emissions of 3.46 and 11.2 kg, respectively. Thus, introducing pPCI management more than triples the ambulance journey mileage and associated carbon emissions required for STEMI patient transport, i.e. by a factor of 3.24 (Table 1).

Using HES online data 2002–03 to 2006–07 for all myocardial infarction admissions (STEMIs and non-STEMIs) and multiplying by 0.4 to derive an estimate of only the STEMI events, about 3316 STEMI hospital admissions could be expected to occur annually in the East of England. If all those events occurred out-of-hospital and required transport to either a thrombolysis or pPCI care point, they would generate a total patient (ambulance) journey mileage of 43,100 km/year (or 11.5 tonnes of CO2 emissions) for the thrombolysis model and 139,000 km/year (or 37.2 tonnes of CO2) for the pPCI model. Thus, introducing a pPCI care model would result in an additional distance of 96,700 km/year travelled by ambulances and an additional 25.7 tonnes/year of CO2 emissions.

Sensitivity analysis

Conversion factor

If the conversion factor (CO2 emissions per km travelled) is changed from the baseline assumption of 0.2661 to 0.2042 (as for cars), then emissions per STEMI patient are proportionally reduced to 2.7 and 8.6 kg of CO2 under the thrombolysis and pPCI care models, respectively. If the conversion factor is increased to 0.4200 (half of the conversion factor value for an average bus) then emissions per STEMI patient would increase, again proportionally, to 5.5 and 17.7 kg of CO2, respectively (Table 1).

Number of STEMI patients

If the annual number of expected STEMI events requiring ambulance transfer to an NHS hospital was to be approximately halved to 1650 per year, the total distance travelled will be proportionally reduced to 21,500 and 69,600 km/year (or 5.5 and 17.7 tonnes for the thrombolysis and pPCI models, respectively). Using a conversion factor of 0.2042 (as for cars), the total CO2 emissions would be reduced to 3.5 and 11.2 kg for the thrombolysis and pPCI models, respectively (Table 1).

Table 1 Summary of comparative distance and carbon emissions statistics relating to ambulance travel under the thrombolysis and pPCI models

<table>
<thead>
<tr>
<th></th>
<th>Thrombolysis model</th>
<th>pPCI model</th>
<th>Ratio (pPCI/thrombolysis)</th>
<th>Difference (pPCI—thrombolysis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average distance required for ambulance transport of a single STEMI patient</td>
<td>13.0 km</td>
<td>42.2 km</td>
<td>3.24</td>
<td>29.2 km</td>
</tr>
<tr>
<td>Total distance for all expected STEMI admissions/year (n = 3316 admissions)</td>
<td>43,100 km/year</td>
<td>139,000 km/year</td>
<td>3.24</td>
<td>96,700 km/year</td>
</tr>
<tr>
<td>Average CO2 emissions generated by ambulance transport of a single STEMI patient</td>
<td>3.5 kg</td>
<td>11.2 kg</td>
<td>3.24</td>
<td>7.7 kg</td>
</tr>
<tr>
<td>Total CO2 emissions for all expected STEMI admissions/year (n = 3316 admissions)</td>
<td>11.5 tonnes/year</td>
<td>37.2 tonnes/year</td>
<td>3.24</td>
<td>25.7 tonnes</td>
</tr>
</tbody>
</table>

pPCI, primary percutaneous coronary intervention; STEMI, ST-elevation myocardial infarction.
Discussion

Main findings of this study

In an English region, we have calculated the carbon emissions produced by ambulance journeys for the management of patients with acute myocardial infarction under both a thrombolysis and pPCI care model. We found that the pPCI care model will more than triple the amount of ambulance journey-related historical carbon emissions associated with the thrombolysis pathway. Because both models rely on the same type of transport, (i.e. by ambulance) this proportional increase in carbon emissions associated with the pPCI model is robust to the assumed variance of the conversion factor values used, or the assumed number of patients treated during a year.

What is already known on this topic

This type of analysis could help inform a wider debate about the patient travel-related ‘carbon footprint’ of care models, and motivate further research (Box 2). Although calculation of the ‘carbon footprint’ of healthcare pathways will become increasingly important in healthcare sector efforts to prevent further climate change, we are only aware of two previous relevant studies. In addition, a recent study has attempted to quantify the carbon footprint of clinical trials—including that related to travel. To our knowledge, there are no published studies to date examining patient travel-related emissions in the context of management of an acute (emergency) condition.

What this study adds

Our study’s main contribution is methodological. It provides an example of a quantitative methodology that can be used to estimate carbon emissions associated with ambulance travel, as part of a more general ‘carbon accounting’ framework aiming to quantify the environmental impact of different healthcare interventions and services.

It is important to consider the environmental implications of patient-related travel in its generality. For certain conditions and related services, care is increasingly being centralized due to specialization of services, and such trends lead to greater travel-related carbon emissions—as for example is the case for cancer services. For other conditions and services, however, care is increasingly being de-centralized, leading to dramatic reductions in distances travelled by patients—an example is provision of haemodialysis in ‘satellite’ renal units. New care models reducing the need for patient visits to healthcare premises have been evaluated positively for breast cancer screening, breast cancer treatment follow-up and bowel cancer screening.

Therefore, modernization of services presents both threats and opportunities for carbon-emission control (Box 2). Identification and quantitative profiling of carbon emissions resulting from new healthcare services and interventions should become part of overall considerations about both the benefits and costs of the development of new care pathways and services.

Box 2 Examples of healthcare service models presenting either threats or opportunities for patient travel-related carbon emissions.

Centralization of services

- Cancer services centralization: between 1999 and 2004 there was a greater than 2-fold increase in total car miles travelled, equating to 400 tonnes of carbon associated with breast cancer radiotherapy treatment in the West Midlands.
- In the present study, a switch from a thrombolysis to a pPCI model for the management of STEMI patients is associated with a greater than 3-fold increase in carbon emissions.

Care closer to home

- In a case study, a switch from 2 fixed to 20 mobile unit locations for breast cancer screening could produce travel savings of 1.5 million km and an annual emissions saving of 75 tonnes of carbon.
- In the UK, expansion of the number and location of renal units has been associated with a reduction in travel time for the average patient, as well as journey distance, reducing the environmental impact of haemodialysis.

Tele-care

- A recent randomized controlled trial suggests that patient follow-up by telephone after breast cancer treatment is as effective and also acceptable to patients as hospital follow-up. This could help pave the way to ‘low carbon emission’ care models for this and other conditions.

Screening service models

- As a ‘first-step’ test, the NHS Bowel Cancer Screening Programme uses ‘home test’ faecal occult blood kits which are sent by post to reference labs. This programme prevents a great deal of patient travel and carbon emissions, if one compares it with other screening interventions that require the patient to visit a hospital, a screening unit or a general practice.
We do acknowledge that patient-related travel is but one component of the environmental impact of healthcare services, which also encompasses carbon emissions associated with the production, transport and use of medical devices or drugs, and ‘overhead’ carbon emissions associated with infrastructure use, maintenance, lighting and heating and staff transport. We did, however, feel that it was appropriate to focus particularly on carbon emission differences associated with patient-related travel in the context of our case study, as such differences were judged to be particularly relevant by the nature of the service models being compared.

The potential for assessing environmental impact as part of the cost and cost-effectiveness appraisal of new care models is being considered by policy-makers. A recent authoritative cost-effectiveness study comparing thrombolysis with pPCI for acute myocardial infarction found the latter to have a relatively low incremental cost-effectiveness ratio—but did not consider environmental impact.8 It is worth noting that clinical—as well as cost-effectiveness, deteriorate with longer pPCI-related delay, which is influenced by journey time. Patients who will require longer journeys to pPCI centres will derive less clinical benefit at a relatively higher cost to the environment. Incorporation of ‘environmental cost’ considerations to cost-effectiveness modelling of healthcare interventions will require a ‘paradigm shift’ in current health economics methods and practice, as well as a substantial change in policy-making culture. We provide empirical evidence that could help this debate in the future. In addition to the mere environmental impact associated with carbon emissions, a related consideration is that of the impact of increasing healthcare-related transport on total fuel use, and on fuel resilience.21 Decreasing reservoirs of fossil fuels are likely to translate into ever-increasing oil prices in the future—this again would advocate for the inclusion of such considerations into the economic analysis of relevant healthcare interventions.

We acknowledge that decision-making about the introduction of a new healthcare intervention or services is contingent upon a multiplicity of factors, including but not solely restricted to clinical and cost-effectiveness. Such factors include the financial cost of introducing the new service, availability of trained staff and appropriate premises, patient and public preferences and the impact on health inequalities. In relation to the latter, we have previously examined potential geographical inequalities that could potentially be generated by the introduction of pPCI services.22 We advocate the inclusion of environmental sustainability considerations and calculations into the complex matrix of decision-making processes relating to the development of new healthcare interventions and services.

**Limitations of this study**

Our study has certain methodological limitations as well as strengths. In order to maximize the precision of estimating the spatial distribution of STEMI cases, we used myocardial infarction hospital admission data from a 5-year period, and ICD-10 diagnosis codes inclusive of both STEMI and non-STEMI hospitalizations. It is reasonable to assume, however, that STEMI and non-STEMI geography overlaps (as both are stochastic manifestations of the same disease process) and using both STEMI and non-STEMI data results in a larger sample, therefore increasing the precision of overall spatial distribution estimates.

Our study assumed that the ‘geography’ of myocardial infarction events during the study period is predictive of the ‘geography’ of such events in future years. In other words, we assumed ‘permanence’ of the geographical distribution of incident myocardial infarction cases in the studied region. In reality, new ‘pockets’ of lower than historical myocardial infarction incidence may develop in the future, for example, resulting from regeneration of previously deprived areas, or vice versa. Such changes are likely to be subtle, and not apparent in the short-term. This issue nevertheless needs to be addressed by periodic update of the work, using timely data. Although future changes in the spatial distribution of cases may mean that some of the forecast mileage and emissions are inaccurate, such ‘absolute’ errors will be equally applicable to both care models compared, and do not therefore bias relative comparisons.

We used the LSOA centroid of patients’ residence as a proxy for the location of the myocardial infarction event. Some events will happen outside the patients’ residence, but while in some instances events will occur randomly closer to the care point, this will be offset by instances when the location of the events will be randomly further.22 Again, this assumption is unlikely to have introduced differential bias in relative comparisons between the two care models, as it is equally applicable to both.

Our analysis did not consider carbon emissions associated with visitor journeys, the patient’s own return journey (which may also involve an interim ‘step-down’ admission to a general, non-pPCI providing hospital) or any follow-up appointments in tertiary care centres. Under the pPCI care model, all these journeys will result in additional travelled mileage, and will hence be associated with additional carbon emissions. Therefore our study may have under-estimated the total environmental impact resulting from introducing pPCI. Similarly, we have not considered the potential use of helicopter ambulance to transport STEMI patients to pPCI centres, as advocated for patients.
whose myocardial infarct onset will occur at geographically remote areas. In doing so, we may have substantially underestimated the total environmental impact resulting from pPCI provision, if and when helicopter ambulance transfers become part of the integrated patient transport system supporting a pPCI care model. It is likely that ‘blue light’ ambulance driving conditions may be associated with greater fuel consumption, and therefore, a higher level of carbon emissions, than the conversion values used. However, the underestimation introduced by this mechanism should be largely applicable to both models. These are examples of areas where collection and use of further empirical data could help improve the accuracy of carbon-emission estimates in the future (Box 3).

Future research should aim to produce more accurate estimates of ‘global’ (i.e. within the care pathway) travel-related emissions for patients and relatives, as well as more accurate conversion factors for ‘blue light’ ambulance journeys. Further, as helicopter ambulance transfers for remotely located STEMI patients is increasingly being considered, research to quantify the carbon emissions associated with helicopter ambulance transport is needed.

We have assumed that all STEMI patients will be managed under a pPCI care model. In reality, it is possible that some STEMI patients would choose not to be transferred to a pPCI centre for personal reasons, such as being familiar with the local hospital, and wishing to be hospitalized closer to their family and friends, opting for ‘conventional’ local hospital-based management. Similarly, there may be a group of patients (e.g. very elderly patients) who ‘by protocol’ would not be transferred to a pPCI centre, but would instead be managed by thrombolysis. Under either of these scenarios, the difference in carbon emissions between the two care models would have been overestimated by our study.

Our study assumed all STEMI patients will be diagnosed correctly as such, without false-negatives or false-positives. In reality, some STEMI patients will be ‘missed’ by ambulance crews, and be taken to the Accident and Emergency department of the nearest district general hospital with another presumed emergency diagnosis. This scenario would lead to a reduction in total travel under the pPCI care model (as STEMI patients would travel shorter distances) leading to a smaller difference in carbon emissions between the two models than estimated. Conversely, some non-STEMI patients could be ‘over-diagnosed’ with STEMI by ambulance crews, leading to ‘false positive’ trips to a pPCI centre. In this case, the greater journey distance travelled by ‘false positive’ STEMI patients under the pPCI care model will lead to a greater difference between the two models than that estimated. No good empirical evidence exists about the degree and ‘direction’ of the diagnostic error described above, and therefore the degree and direction of imprecision or bias which may be introduced by this mechanism. Ongoing audit data collection, both regionally and nationally, will be important to help re-calibrate estimates in the future.

On considering the ‘external validity’ of our study, it should be noted that the findings are region- and context-specific. The relatively rural nature of the East of England region compared with more urbanized regions means that our results cannot be readily extrapolated to a national or
international level. While our results may be relevant to other regions or similarly rural geographical areas of other countries, we nevertheless recommend that the methodology used in our study is applied to such regions directly, using relevant local data.

In conclusion, we have estimated substantial additional carbon emissions associated with the introduction of a pPCI care model for the management of acute STEMI in an English region. Although absolute estimates of travelled mileage and carbon emissions associated with either care model may contain a degree of inaccuracy, the estimation of relative differences between the thrombolysis and the pPCI model is robust. Our study has important implications for the current paradigm of planning new healthcare services and interventions—which should aim to incorporate ‘environmental legacy’ considerations; and in illustrating that the incorporation of environmental costs in health economics analysis is increasingly important.

**Contributors**

G.L. conceived the initial idea for the study, which was subsequently further developed with the help from all authors; A.N., A.Z. and G.L. developed the study methods, with commentary from D.P.; A.N. conducted the GIS analysis and A.Z. conducted Excel-based calculations. All authors interpreted data, helped draft the paper and commented on the production of the final manuscript. G.L. is guarantor.

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