Towards a methodology to estimate carbon* emissions savings from local mode shift initiatives: a review of challenges and emerging technologies

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Climate Crisis: What more should transport planners be doing to address the climate emergency?

* As referring to all Greenhouse gas emissions

1. INTRODUCTION

There is international agreement on the need to act to limit carbon emissions[1]. Many nations have set reductions targets with the goal of keeping global warming within 1.5-2°C by 2050[2] to avoid disastrous climate change[3]. At its core, this research paper is about exploring ways to measure carbon dioxide equivalent[*] (henceforth, carbon) emissions impacts of local transport schemes, in line with global aspirations.

Why measure mode shift?

Carbon emissions cannot be monitored simply by measuring levels locally because the harmful effects occur at the global level[4]; even if dispersed by traffic displacement, the emissions contribute to overall global warming[5] [6]. Transport-related carbon emissions are calculated regionally and nationally from an understanding of vehicle fleet composition, distance travelled and mode share[7] [8] [9] [10] [11]. Thus, understanding mode share, and temporal trends revealing changes in mode share, is key to calculating (changes in) carbon emissions[12] [13].

International climate goals can only be met with regional and local action[14] [15] [16], and measuring changes in mode share is key to any insight into transport carbon savings. It is thus relevant and important to understand the mode shift impacts of individual schemes in terms of what works, what works best, for who, where and how.

Why does this need to be researched?

Although changes in mode share are captured to a certain degree nationally and regionally[17], there is a dearth of insight into changes in mode share and causation at a more local level, and little guidance and methodology on how such indicators could be explored. The carbon emissions impact of many smaller transport schemes is not known at all, while in larger schemes changes are usually marginal and do not impact on their economic appraisal[18]. There are limited studies about mode shift impacts of individual schemes (see section 2), which conclude what one might expect – walking and cycling infrastructure leads to increases in those modes [19] [20] [21] [22] [23]. However, such data is insufficient to understand carbon savings.

[*] Common unit to measure greenhouse gas emissions by using their warming impact equivalent to CO2 (Brander, 2012)

Some parameters

This paper focuses on London-based examples of measuring and understanding observable changes in mode share to calculate carbon emissions impacts on a smaller scale. It does not explore lifecycle emissions of transport projects, though that is an important area of research. Vehicle model data would be required to most accurately calculate transport-related emissions[24].

What counts as a mode shift project?

There are various barriers to using certain modes of transport, including overcrowding, cost, physical challenges, availability (time and distance), and concerns around safety and air pollution[25]. In this way, any project that reduces or removes these barriers in a certain area, for certain routes or groups of people could be considered a mode shift project[26]. The focus here is physical infrastructure projects, though the arguments demonstrating the need to understand carbon emissions impacts apply to non-infrastructure based projects, and they would benefit from similar research. Finally, much literature and practice focuses on active mode shift. However, in order to understand carbon emissions, the full range of changes across all modes must be considered.

A note on methodology

The research to produce this paper involved a review of academic literature and published information about practice and guidance; interviews with three staff at Transport for London (TfL) and conversations with relevant staff at Islington Council.

The interviewed TfL staff were:

- Policy Manager, City Planning
- Principal Portfolio and Benefits Realisation Officer
- Strategic Analysis Manager

Vivacity Labs were contacted with questions about their camera system, to which they responded.

2. UNDERSTANDING MODE SHIFT IMPACTS OF LOCAL PROJECTS: A CRITICAL REVIEW OF THE CURRENT LANDSCAPE

WHY IS IT SO HARD TO MEASURE LOCAL MODE SHIFT?

Despite the necessity to understand changes in mode share in order to estimate carbon savings, for individual local projects this is very rarely measured at a level of resolution necessary to estimate directly-attributable carbon savings. There are good technical reasons for this, ultimately boiling down to the fact it is very difficult to accurately measure modal *shift* and *attribute* it directly to a specific scheme[27] [28] [29].

Traditional practice

Before and after traffic counts, an established tool, do not necessarily identify changes in mode usage or traffic evaporation, for example they could simply be picking up diversion and displacement[30]. Additionally, they may mask other changes, such as demographic, that have impacted the shift[31], while if several policies or interventions are simultaneously introduced, one could not attribute changes to any single one of those interventions based on traffic counts alone[32]. Additionally, regional or national trends in 'mode shift' may be visible, but miss detail; someone shifting from public transport to cycling would be a smaller carbon saving than a shift from a private motor vehicle to cycling.

Another staple tool, before and after surveys or travel diaries, also encounter difficulties. A previous bursary paper[33] identifies three key challenges with establishing mode shift via surveys: inaccuracies in self-reporting; difficulties understanding the longevity of mode shift; and statistical significance of results for small projects being undermined by sample size, lower 'after' survey completion rate, and bias.

Both cross-sectional snapshot surveys and before and after counts are also subject to daily fluctuations in people's behaviour[34] and the weather[35]. While 'out of the ordinary' trips are part of the picture, they could obfuscate overall patterns of mode share. Both also come at cost and take a lot of time, travel diaries in particular[36]. Finally, in line with the specific focus of this paper on understanding scheme-level mode shift in order to calculate changes in carbon emissions, it is argued that this type of information can only be meaningfully captured at the wider network level to account for displacement[37].

Scarcity of existing guidance

Various units of the DfT's Transport Analysis Guidance (TAG) Toolkit provide guidance on the measurement of mode shift, including active travel modes and multiple inter-mode shift[38] [39]. However, TAG accepts that active travel impacts can be omitted from scheme appraisals. Thus, schemes focussing on promoting a single motorised mode may have a negative impact on active travel, but this would not be accounted for[40].

TAG Unit A5 [41], on the appraisal of walking and cycling, offers guidance on forecasting mode shift and calculating the impacts, such as in health or environmental terms. It suggests a variety of counts and surveys or interviews to measure mode shift in walking and cycling, but there is no advice specifically on accounting for the full complexity of changes, for example. Individual mode counts may miss mode shift occurring across several modes.

TfL recently published Cycling Quality Criteria, which seeks to provide a framework to measure the quality of the cycling environment with data such as traffic flows and how much space there is for cyclists and vehicles, to increase cycling[42]. It does not measure levels of other modes including public transport and pedestrians, though these could be a relevant indicators of success. There are no TfL requirements around measuring changes in mode share specifically for a scheme, and the environmental and health benefits shift which could result.

Ultimately, monitoring mode shift seems to be something whose value is understood theoretically, but is complex to measure and costly even to estimate with traditional practice.

CURRENT PRACTICE REVIEW: STUDIES AND CASES

While national and regional guidance and requirements nod to the advantages of measuring mode shift for projects but the difficulties and cost of doing so, there are studies that have used new framework approaches to measure mode shift of individual projects.

SURVEYS

Academic literature

Active travel uptake

The closest most studies come to gauging mode shift is to measure uptake in active modes, themselves even suggesting more research is needed to better understand the effects of the intervention, the role of socioeconomic and other demographic factors at play; and the detail of change in relation to carbon emissions[43] [44] [45] [46]. Applicable to carbon emissions, Fishman *et al*'s study[47] does consider previous mode to understand health impacts because of the different degrees of sedentariness of different mode users. That is, a switch from walking to cycling would have low to zero health (or carbon) benefits, while a switch from car would have a significant amount.

Dr Aldred *et al*'s recent study[48] of the mini-Holland schemes in London is perhaps one of the most comprehensive available examples of assessing the impact on active mode uptake resulting from a coordinated collection of small interventions as part of a neighbourhood scheme. Similar to Crane *et al*'s[49] review of cycle infrastructure in Sydney, Aldred *et al* carried out longitudinal surveys with a cohort before and after to find out about changes in active travel use in all three 'mini-Holland' boroughs (Enfield, Kingston and Waltham Forest). The study highlights the additional insight gained from breaking the survey into 'high-dose' and 'low-dose' areas because it assisted with the attribution of impact to the interventions[50], though, as it acknowledges, there were limitations in terms of respondent pool size and demographics [51] [52]. The 'dosage' of the areas was defined using local knowledge of officers from the boroughs and with TfL[53].

Despite its limitations, the study has value in demonstrating a methodology to assess impacts of local transport infrastructure schemes, as is suggested by the involvement of TfL[54]. However, in only looking at active travel uptake as opposed to modal shift more widely, it does not provide insight into carbon emissions impacts. Such considerations could perhaps be woven into future surveying using this methodology. The key remaining barrier, therefore, is one of cost and resource; the study had an academic team and funding, which simply are not available to local authorities for every mode shift infrastructure scheme, though perhaps increasing academic partnerships could be valuable in this arena.

Measuring on a small scale

Aldred and Croft[55] propose a low-cost methodology to combine qualitative intercept surveying (costing £5000 in the study) with count data (often gathered as standard practice) for local authorities to estimate impacts of small streetscape schemes. They are somewhat tentative because of their small sample size. However, they point out that, though stronger results would be obtained by longitudinal studies, with the alternative likely being no qualitative evaluation at all, this kind of method may represent a good-value-for-money way to gain insight into the impacts of small-scale schemes. Results indicated perceptions of the changed area were influential, with the study suggesting the addition of qualitative insight could provide local authorities with an understanding of *how* different types of intervention impact mode use comparatively[56].

Again, though the focus is on active travel uptake, there may be scope to incorporate more comprehensive mode shift analysis into the approach to combine traffic count analysis and low-cost surveying.

Intermodal shift

There are studies that focus on understanding intermodal shift[57] [58]. Hu and Schneider[59] used before and after surveys at a university that had implemented mode shift measures to understand new and previous mode and distance travelled, allowing for more accurate understanding of emissions impacts. Though this may only be applicable to concentrated destinations like universities, hospitals or business parks, if such places introduced mode shift measures this study offers a methodology to measure scheme impacts.

Current practice

London Travel Demand Survey (LTDS) / Travel in London Reports

The LTDS is an annual, cross-sectional snapshot survey that gathers information about respondents' travel habits on the previous day. It has an annual sample size of approximately 8000 and is the key data source for London resident mode share. The survey is thus very valuable, and indeed, is the predominant way to understand changes in mode share trends, drawn from three-year moving averages[60] . It has limitations, however, for the purposes of informing at a local and scheme level. Even to go to borough level, the survey loses statistical significance[61]. As a cross-sectional survey it does not provide the same insight into mode *shift* on an individual level that a longitudinal survey might, instead identifying overall changes in mode share. That is, it potentially incorporates exogenous changes such as demographic shifts in the same area and period[62].

National Travel Survey (NTS)

The NTS uses interviews and a seven-day travel diary to survey English households' travel behaviours[63]. In terms of measuring local scheme-level impacts, the sample is too small to sub-nationally break down and the travel diary methodology is, as explored, too resource intensive. It is useful for understanding the national context, which could inform more local analysis[64].

Healthy Streets Survey

TfL has developed the discretionary Healthy Streets Survey (2014), which focuses on perceptions and is meant to be conducted before and after local interventions. They advise on how to randomise collection, though users would have to consider how location might impact representation. It seems a missed opportunity not to include questions about mode use as well as perception (in fact the two might strengthen each other).

Global Positioning Services (GPS)

Studies analyse GPS devices (or the in-built GPS software in mobile devices) as a replacement or supplement to surveys and travel diaries[65] [66] [67] [68] [69], while an open platform has been developed to make GPS surveying for travel study purposes easy and accessible[70]. It is suggested such technologies can accurately identify mode of travel, thus avoiding the inaccuracies of self-reporting[71] [72]. Data protection must be a consideration, particularly for public authorities, to avoid GPS data being linked to personal data[73]. Aggregation and anonymisation may allow travel data to be gathered and used in a General Data Protection Regulation (GDPR) compliant way, though it may impact the richness of the data[74]. Even now, however, GPS can be used to enhance travel diaries and surveys[75], where data consent could be an explicit component of participation.

COUNTS

Academic literature, past practice and trials

Counting non-motorised travel

Ohlms *et al*[76] review US guidance and practice in counting non-motorised transport, suggesting there are existing technologies and methodologies to use counts to infer changes in mode share, as the Non-Motorised Transportation Pilot Program (NTPP) has indeed done at a scheme and neighbourhood level[77] [78].

The NTPP was a federal funding programme focused on walking and cycling, including public transport connectivity to these modes[79]. Mode shift was a key evaluation area. The NTPP developed new methodologies to calculate this at project, community and programme levels, using varying combinations of annual and bookend pedestrian, cyclist and traffic counts; intercept surveys; and National Household Travel Survey data[80] [81]. It assumed an increase in active modes corresponded to avoided vehicle miles, which is how it 'measured' mode shift in documentation[82], suggesting it does not avoid the issue of counting only diversion of modes. The methodologies used warrant further analysis[†].

Lu *et al*[83] (2017) propose a monitoring method to measure walking and cycling across a network – a rural town in their case – extrapolating one week of counts to estimate the annual average daily traffic. The study does not seek to understand change in mode share and does not give guidance on how understanding the network traffic may be attributable to local schemes.

Using mobile phone data to 'count' non-motorised travel

Mobile phone devices, which the vast majority of households own[84], make connection attempts with Wi-Fi, Bluetooth and mobile network antennae whenever they move into a new cell range, call, text or use data. This all passively generates a lot of rich but

[†] A methodology to interpret traffic counts to estimate mode shift from specific programmes was presented at the Transportation Research Board's 92nd Annual Meeting Compendium of Papers conference, though the paper is not available to be analysed.

depersonalised travel data[85] [86]. It also provides more information about public transport use than the oyster card, which only tracks when a user taps onto a bus[87]. Following a successful pilot in 2016[88], TfL has begun using Wi-Fi data to monitor congestion and route choices on the tube network with a view to other potential uses[89]. Another study suggests WiFi and Bluetooth can provide a rich yet anonymous understanding of individual pedestrian movements[90]. Companies already have frameworks and algorithms to interpret this data and provide insights for clients about trips and multiple mode use[91]. Because movements of a unique device are tracked but depersonalised[92] [93], it is a more easily GDPR-compliant way of gathering useful travel data, and thus could be implemented more quickly and on a wider scale than a GPS-powered system.

There are limitations, including WiFi connection issues or gaps, and the size of cell zones and vagueness of timestamps from mobile network data. However, improvements and expansions in networks may resolve those issues, and data fusion can already provide quite an accurate picture and identify mode[94]. Further research would be needed to test its accuracy in measuring mode share and modal shift.

Camera technology

Number Plate Recognition (NPR) Technology

NPR has been available for a while[95], and has been used to monitor average speed and enforce limits by calculating the average speed a registered vehicle travels between two points[96].

In March 2019, Islington Council began a trial on a camera enforced 7.5t lorry ban on a single road[97], using 'smart cameras' to identify vehicles by their size and confirm registered weight via a link with the Driving and Vehicle Licencing Agency (DVLA)[98]. It also measures time taken to identify if a lorry was there for 'legal' purposes i.e. to drop off a delivery, or if it was using the road as a 'rat-run' and, therefore, requiring a penalty[99].

Mode share-identifying camera technology

Technology is available that can in fact automatically identify different modes in real time from camera images, either via newly installed cameras or accessing existing CCTV cameras[100]. It appears that the technology is, at the moment, mainly being used to alleviate congestion and improve traffic flow[101], identify incidents, and inform modelling. However, Vivacity, who were contacted with questions about the applicability of their system to detect changes in mode share across a network, said that they believed the technology could be used for this purpose[102]. They noted some assumptions would be required regarding vehicle occupancy but suggest that changes in mode share could be estimated with reasonable coverage of a 'representative set of roads'[103], that is key roads and a sample of smaller roads. Once installed, mode share is anonymously and almost continuously measured[104], meaning averages accounting for daily fluctuation could be obtained. Even before considering applications of this technology in measuring mode shift and attributing it to specific schemes, such data could provide an accurate baseline of mode share across a network at say a local or borough level. It would also be possible to request access to data from other areas using the technology[105] to benchmark (see section 4).

3. WHITHER MEASURING MODE SHIFT?

As has been demonstrated, there are significant challenges in measuring changes in mode share and mode shift on a local level, and attributing the shift to an individual scheme or programme. A number of new technologies and methodologies, however, have also been explored, and there is clear potential to gather information about changes in mode share associated with individual schemes.

Mode shift is at the core of the Greater London Authority's key transport policy document, the Mayor's Transport Strategy[106], which is reflected in borough strategies. Islington Council's draft Islington Transport Strategy (ITS)[107] contains an initiative to introduce a borough-wide lorry ban (as currently being piloted[108]) by 2021 to reduce rat-running and encourage freight mode-shift. If this were rolled out at a neighbourhood level, it would be possible to identify vehicle movement in and out of residential areas. The draft ITS also contains an initiative to implement a liveable neighbourhood for every residential area in Islington, and with Liveable Neighbourhoods on the agenda for TfL[109], a way to measure the type of traffic and mode using those areas would be useful. Automatic count technology could even be used to measure the success of Liveable Neighbourhoods[110].

If a local authority had synthesised borough-wide coverage of some of the emerging 'smart' camera-technology that has been mentioned, which could identify vehicle type and journey purpose (for example rat-running, delivery or originating), it could provide a detailed picture of mode share and changes in mode share across the borough. With travel behaviours already being identified with technology such as NPR to inform scheme design[111] [112], such an approach may not be that much of an additional cost or use of resource, indeed, with a permanent network it would likely be less so.

This type of system would capture vehicular and active modes using the road and street network, while TfL gathers data about public transport use in boroughs (which may increase in accuracy with the use of mobile phone data). It could be overlaid against scheme information, such as location and temporal point of installation, and be used to identify unusually high or low change in mode share and associate it with a scheme. Furthermore, with borough-wide coverage, a local change in mode share could be contextualised to identify displacement.

It is recognised that, without a comprehensive large scale longitudinal survey, mode shift cannot be directly attributed to an individual scheme especially at local level[113] [114] (in this vein, boroughs could perhaps benefit from partnering with research institutions and offering innovative schemes to be the subject of academic resources, rigour and funding). Understanding changes in mode share could still be still informative, however, and may indeed suffice to estimate carbon emissions at a scheme level. Even if direct attribution may not be identifiable, causation can be inferred and presented with those caveats.

Following Aldred and Croft's methodology to synthesise this type of quantitative data with some degree of low-cost surveying that probed into motivation could enrichen the picture provided by counts, offering further insight into how a type of intervention had an impact [115]. Perhaps if TfL's Healthy Streets Survey incorporated questions about comprehensive mode use, it would make it easier and more appealing for boroughs to capture mode shift, not to mention if it were funded, and even required (for projects meeting certain criteria).

Identifying changes in mode share in a scheme area, including displacement to other areas, would be useful information in the context of impact analysis and appraisal. This would not only provide a fuller picture to estimate carbon savings more accurately; to be able to identify that a scheme has predominantly displaced traffic rather than encouraging an overall transition to walking, cycling and public transport would provide important insight about the impact of that type of approach, and be useful in directing future borough and city investment.

4. PREDICTING MODE SHIFT IMPACTS OF LOCAL PROJECTS: SOME CHALLENGES

Modelling – challenges on the smaller scale

Modelling can be done on an aggregate level, like that for the Mayor's Transport Strategy (MTS)[116]. Due to its overarching nature, however, it does not look at behaviour change mode shift specifically, nor necessarily predict mode shift between modes, and it is too strategic and granular to simply be broken down to a sub-borough level[117]. Regarding bespoke modelling for local projects, it can be a long process and, as the DfT remarks, it is 'not generally used and costly'[118].

Benchmarking – a way to set mode shift targets on a smaller scale?

Thus, modelling is not appropriate for predicting small-scale scheme impacts, but predicting potential impacts of a scheme is useful for setting ambition and measuring success. Benchmarking uses data from completed projects with similar characteristics to generate expectations and realist targets[119] and could be done for small scale projects[120] [121] from data captured using the methods explored in section 3.

In TfL's report on benchmarking, walking and cycling appear to have the least developed benchmarking, though increases in walking and cycling are comparatively measured against other European cities[122].

5. THE PRICE OF CARBON, THE VALUE OF NOTHING

CALCULATING EMISSIONS SAVINGS

Why translate carbon savings into a price?

The DfT's TAG Unit A3[123] provides carbon prices to translate carbon emissions savings into a financial saving to be used in cost benefit analysis (CBA). This has two elements: traded sector (such as electricity) and non-traded, such as petrol and diesel. For traded, the UK government has used the EU emissions trading scheme (EU-ETS) market price since 2009, prior to which it used a 'social cost of carbon' (SCC) [124 125]. The Department for Energy and Climate Change cited uncertainty of an SCC as the key driver for the switch[126], though the 'certainty' of a market value of carbon has its own downsides; across trading schemes it is widely recognised to vastly undervalue the cost of carbon emissions and the benefits of reducing them[127 128 129].

An SCC seeks to incorporate the cost of damages resulting from a unit of carbon in the atmosphere, taking account the amount of its atmospheric life[130]. It is a very complex and 'ambiguous'[131] thing to measure, but the report suggests that a reasoned estimate of the SCC would be more appropriate than the market value reached by trading schemes and is, in one form or another, something most OECD countries use in cost-benefit analysis[132]. Some argue that to translate Carbon savings into a financial saving at all undervalues the real world impacts of emissions and global warming[133 134]. While it is worth holding such arguments in mind, CBAs and impacts appraisals are used in scheme design and decision-making. In this context, it may thus be important to establish a cost of carbon that comes as close as possible to reflecting the real-world benefits of saving emissions and the serious costs of not doing so, while seeking ways to value non-monetised benefits in appraisal[135].

Existing benefits calculation tools

Tools like the WHO HEAT tool allows users to input active travel data to translate this into health benefits that are tangible and meaningful[136 137 138]. It is not applicable for calculating carbon emissions because of the sole focus on active travel uptake. However, with mode shift symbolising multifarious benefits, it may be useful to have a mode shift benefits calculator that allowed for more detailed input of changes in mode share data, and returned a wider array of impacts, including carbon savings and air pollution reductions.

COMMUNICATING

Demonstrating emissions savings associable with a scheme could have big impacts; in a study exploring reasons for climate policy support, one of the key factors is perceived effectiveness of the policy[139]. The question is, and it is only briefly being touched upon here, how to best use monitoring to communicate effectiveness.

An awareness of the 'real-world' impacts of global warming can be effective in motivating action on climate change[140], yet with such small scale emissions changes for local projects, it is hard to translate scheme-level savings into any meaningful 'real-world' impact.

However, the emissions savings on their own might be enough at this scale because many local and regional authorities have declared a climate emergency and set carbon neutral targets across the coming decade[141]. These small emissions scale reductions could acquire meaning for people when put in the context of progress towards these targets.

6. CONCLUSION AND RECOMMENDATIONS

Directly attributing mode shift and, thus, carbon savings to individual local transport schemes is not currently possible with absolute certainty. However, *estimating* changes in mode share that can be associated with a scheme may well be, to different degrees of accuracy depending on the method used, in turn dependent on available funding. While longitudinal survey studies may provide the most insight into the level of mode shift and the effectiveness of levers to achieve it, they are time, cost and resource intensive[142] [143] [144] . However, they may be appropriate and feasible for larger scale, innovative schemes, like the mini-Holland programme[145].

A network of emerging camera technology could provide borough-level and local insight for small schemes on a wider scale. Even a neighbourhood level network of cameras would provide useful before and after counts for that area (although they would lack a borough context and greater displacement insight). With camera technologies becoming ever more prevalent and multiuse, it would seem remiss not to use them to provide insight into (changes in) mode share alongside other uses. Furthermore, passively gathered mobile phone data, which can provide evermore sophisticated insight into all modes usage patterns, are increasingly available[146]. Combining such rich data with low-cost intercept surveys could provide a relatively deep understanding of mode shift and motivators, and could be used in benchmarking.

Beyond this, the development of an easy to use tool to calculate the impacts of change in mode share may make it easier for authorities to communicate the carbon, health and air quality benefits associated with any changes in mode share. Even without such a tool, to address the issue of only marginal change being included in standard TAG appraisals, where a price of carbon is used, the UK government CBA guidance should seek to establish an SCC and review its appraisal procedures[147] so that decisions are based on more 'realistic' costs and benefits. That is, not only acknowledging the 'real-world' costs of not doing mode shift and carbon-reduction schemes, but strengthening the case for the long-term cost effectiveness of delivering such schemes.

This research process has discovered many challenges and reasons why current attempts to measure local mode shift lack accuracy. It has also revealed, however, that there are emerging ways in which useful scheme- and borough-level information about changes in mode share could be gathered and important insights gained. With mode shift being an indicator for a myriad of co-benefits, any greater and more detailed understanding of what works is worth investing in to provide practitioners with useful insight and equip them to better communicate the impacts to residents to engender support for programmes[148]. In an age of climate crisis, if sophisticated estimates are the best available way to measure mode shift impact, they are not only sufficient, they are necessary.

ENDNOTES

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