ATKINS Jacobs

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Executive summary

Atkins-Jacobs Joint Venture (AJJV) has been commissioned by the Department for Transport (DfT) to undertake the Scheme Interaction Assessment Technique (SINAT) project. This research project aimed to explore and develop ways to assess the level of potential interaction between different transport schemes in an investment portfolio. The first objective of the research was to develop a technique which would allow identification of the likelihood of interactions between transport schemes more quickly than the full set of steps required to undertake full Programmatic Appraisal. The second objective was to develop an interactive visualisation of these interactions, which would be more accessible to a non-technical audience and thus be able to act as additional supporting analysis at the policy formulation stage.

To achieve these objectives, the research focused on the development of an analytical technique which uses traffic flow information from a transport assignment model to assess the potential for interactions between schemes in a hypothetical investment portfolio. The technique included the development of computational steps (an algorithm) for identifying and quantifying interactions. This is followed by an easy-to-use and transparent modern data visualisation and mapping techniques (Power BI) that ease the interrogation of flow interactions for potentially large portfolios of schemes.

The technique has been implemented in DfT's National Transport Model version 5 (NTMv5), and specifically in its national highway assignment model implemented in PTV Visum software. The methodology uses advanced processing of Select Link Analysis results and matrix manipulations to assess two types of interaction:

- Flow synergy – to describe interactions where schemes share the same traffic flows.
- Flow alternative – to describe interactions where schemes share the same ODs, but traffic can travel through either scheme.

The study has used an example of 11 fictitious schemes located in various parts of the Strategic Road Network to test the technique (the locations are purely hypothetical and have been selected by the study team at random). The results have proven to be intuitive and demonstrated significant flow synergies (shared traffic) between the hypothetical locations in relative proximity along the same corridor and that the strength of these synergies reduces with distance.

With regards to flow alternatives, the implementation results have confirmed that they tend to occur in adjacent parallel corridors, but the absolute traffic flows involved are small in magnitude. This suggests relatively weak effects and can be explained by a relatively large distance penalty associated with routes that significantly deviate from the most direct routes. This also implies that more interactions could occur in dense congested networks where there are more opportunities for alternative routes and congestion on the main routes may incentivise the use of alternatives.

The visualisation results have proven that the interactions are intuitive and can be easy to follow. The study developed a user-friendly viewer of interactions in a geographical format using Power BI dashboards. This approach overcomes the limitations of Select Link Analysis plots, particularly with regards to flow alternatives. It also avoids processing of a large quantity of results into Geographic Information Systems (GIS) software and requires no specialist programming skills to be operated.

Whist the theoretical underpinnings of the method are software-agnostic and can be implemented in any transport modelling software they are also applicable to other modes of transport (for instance rail). This study has investigated the principles behind the calculus to identify their strengths and limitations and found pragmatic solutions for the application of the method in the assessment of complex multi-link schemes, whilst minimising the computational burden and maximizing transparency of the results. Finally, the study offered recommendations for further research and potential extensions of the method to cover more aspects of scheme interactions.

1. Introduction

1.1. Background

Atkins-Jacobs Joint Venture (AJJV) has been commissioned by the Department for Transport (DfT) to undertake the Scheme Interaction Assessment Technique (SINAT) project. This research project aimed to explore and develop ways to assess the level of interaction between different schemes on the network.

The topic of scheme interactions, particularly in terms of user benefits, has been considered by earlier studies undertaken on behalf of DfT, such as the research into Programmatic Appraisal (*Department for Transport, Programmatic Appraisal Stage 5 Report, August 2019*). That study considered a range of potential interactions where a number of schemes implemented together may reinforce the benefits each of them delivers. In other words, the combined impact may be greater than the sum of constituent parts (and conversely, it may detract from the benefits each of them delivers). The research then considered a theoretical framework to measure these interactions for pairs as well as larger groups of schemes.

The updated Treasury Green Book also recommends that portfolio appraisal includes the optimisation of programmes and projects within a limited budget. Understanding scheme interactions can assist with such optimisation process and is key to supporting decisions about the composition of the investment programme.

DfT recognised the complexity associated with undertaking the full Programmatic Appraisal as set out in the previous research. It requires a significant number of model runs and can lead to prohibitive analysis times. This level of effort and time may be justified during the formal appraisal process of transport schemes, but is rarely available during the policy formulation stages, where large numbers of schemes may be under consideration.

The aim of this research is therefore to develop and implement a simplified method of revealing potential interactions based purely on traffic flows. Whilst it is recognised that the method may not be able to deliver the level of accuracy expected from the full Programmatic Appraisal, it is expected that it will offer DfT a greater chance of identifying schemes that may interact with each other (currently no analytical methods exist and assessment of the likelihood of interaction between schemes tends to be based on judgement).

To provide DfT with a better insight into the likelihood of interaction between schemes, this research aimed to deliver:

- A method for the assessment of scheme interactions based on client brief.
- A set of tools that will allow DfT the implementation of the method using NTMv5.
- A set up of a visualisation dashboard to present the results output from NTMv5.
- A report documenting the method (full set of deliverables is described later in this report).

1.2. Purpose of This Report

The purpose of this report is to document the approach, methodology, results, and the recommendations that emerged from this study. The report focuses on the demonstration of the feasibility of the method and does not constitute the analysis of actual transport schemes. Whilst the transport model owned by DfT has been used in the implementation of the method, the demonstration results reported here relate to fictitious schemes in hypothetical, random locations.

This report aims to provide information needed by practitioners, whilst being accessible to a non-technical audience. As such, the discussion about the methodology and implementation focusses on the principles of the method rather than documenting how to use the scripting routines. The guide to using the scripting routines is provided in a separate technical document aimed purely at the technical users of the tools and not replicated here in detail.

This report does not provide results of the analysis of any actual schemes. The discussion of results presented here relates to hypothetical network locations selected at random to represent fictitious transport interventions for the purposes of demonstration testing. The aim of this is to provide a guide to the interpretation of the results that can be obtained with this technique. This guide to the interpretation of the results, is followed by a discussion of strengths, limitations, and recommendations for further research.

This report has been prepared on behalf of Department for Transport, and is subject to, and issued in accordance with, the provisions of the contract between AJJV and the client. AJJV accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this document by any third party.

1.3. Contents of the Report

The remainder of this report is organised as follows:

- Chapter 2 - Sets out the methodology used in the study.
- Chapter 3 - Describes the implementation of the method of in NTMv5.
- Chapter 4 - Provides the discussion of the results.
- Chapter 5 - Sets out conclusions and recommendations.
- Appendix A - Provides additional example results.
- Appendix B - Summarises the approach and outcome of Quality Assurance checks.

2. Methodology

2.1. Introduction

This analytical technique developed in this study uses traffic flow information from a transport assignment model to assess the potential for interactions between schemes in a hypothetical portfolio. Of interest is the impact of implementing one scheme on the use of another scheme. Interactions may be positive when a scheme increases utilisation or benefits of another one.

A typical example may be two schemes along a single corridor. Negative interaction may arise when implementation of one scheme decreases utilisation, and therefore the benefits, of another one. The simplest example would be two schemes in proximity on parallel corridors. Positive interactions are also possible, such as two schemes on the same route, where building one will reinforce the benefits of the second. The interactions in practice will be more complex, particularly in congested conditions where the outcome of these interactions on journey time savings may be more nuanced. Detailed appraisal of individual schemes may still require pairwise, incremental and decremental analyses, as identified in Programmatic Appraisal research.

However, an early insight into the likelihood of schemes interacting with each other at the policy formulation stage increases the chances of developing a cohesive package. It is reasonable to expect that the likelihood of scheme interactions (positive or negative) is, at the minimum level, linked to the degree to which they share traffic and origins and destinations they cater for. Equally, schemes may not interact at all, for example when they are far away or when they simply do not serve the same destination. This information is useful to policy makers also. Obtaining such information in a consistent, reliable, and accessible way is the first practical analytical step that can help assess the likelihood of interactions and can contribute to the investment programme development in a timely manner.

This project included the development of the algorithm, implemented in DfT's National Transport Model version 5 (NTMv5). Specifically, it was prepared for NTMv5's national highway assignment model (HAM) implemented in PTV Visum software. However, the theoretical underpinnings of the method are software-agnostic and can be implemented in any transport modelling software.

The implementation of the technique was then followed with the setup of an easy-to-use and transparent modern data visualisation techniques (Power BI) that eases the interrogation of flow interactions for potentially large portfolios of schemes.

2.2. Definitions

The initial thinking about the method has been set by DfT in the project brief, which covered four types of interaction:

- Complementary (synergy), where traffic for the same Origins-Destination (OD) pairs uses two or more schemes, often situated along the same route.
- Substitute (competitors), where traffic between the same OD pairs can traverse one or more of a group of schemes which provide alternative 'parallel' routes.
- Mixture of the above two, where for some OD pairs there are a mixture of complementary schemes (in series) and substitutable schemes (parallel routes).
- Neutral – where the schemes serve completely different OD pairs.

The interaction between schemes can of course be more nuanced. The fact that two schemes share the same traffic flows does not necessarily mean that they reinforce each other in terms of user benefits (journey time savings), and this will require verification during the detailed economic appraisal. But experience from the appraisal of programmes such as A303 improvements suggests that the combined impact of the programme of schemes along the same corridor is likely to be greater than the sum of individual component parts. It is therefore reasonable to expect that the detection of shared flows increases the likelihood of positive interactions in terms of benefits and increases the chance of identifying a more optimal programme of schemes.

Similarly, the fact that traffic between the same OD pairs can travel through either of the schemes (e.g. parallel routes) does not necessarily mean that they subtract benefits from each other. Even though they may appear to be competing for the same traffic, they may still be complementary in many cases. For instance, improvement of only one of the parallel routes may be insufficient to address all traffic problems and improvement of both routes may optimize the distribution of traffic between them and therefore realise additional benefits.

For these reasons, particularly with regards to ‘substitutes’, such simple labelling may not reflect all the potential nuances. Nevertheless, given that these two types of interaction differ in terms of the computational steps and the interpretation of the outputs, separate terms are required to describe them. To reduce the scope for misinterpretation, during this study we elected to describe them as:

- **Synergy –** for interactions where schemes share the same flows. It continues to imply a positive interaction (which is generally assumed for this type of interaction) but avoids labelling it as complementary. This is because other types of interaction may also be complementary and reserving this term only to this type of interaction could be misleading.
- **Alternative –** to describe interactions where schemes share the same ODs, but traffic can travel through either of them. Again, the fact of having alternatives, does not necessarily mean that they compete or are mutually exclusive. They may still complement each other for a range of reasons and put simply, the existence of alternatives may be a benefit in its own right.

In Chapter 4 where results from demonstration tests are presented, we offer a further discussion and interpretation of the result and expand on the points made here.

The remaining interaction types - a mix of these two or no interaction - follow naturally and it is not necessary to consider the terminology in such detail. The next section therefore focusses on the principles of the calculation of synergies and alternatives.

2.3. Principles of the Calculations

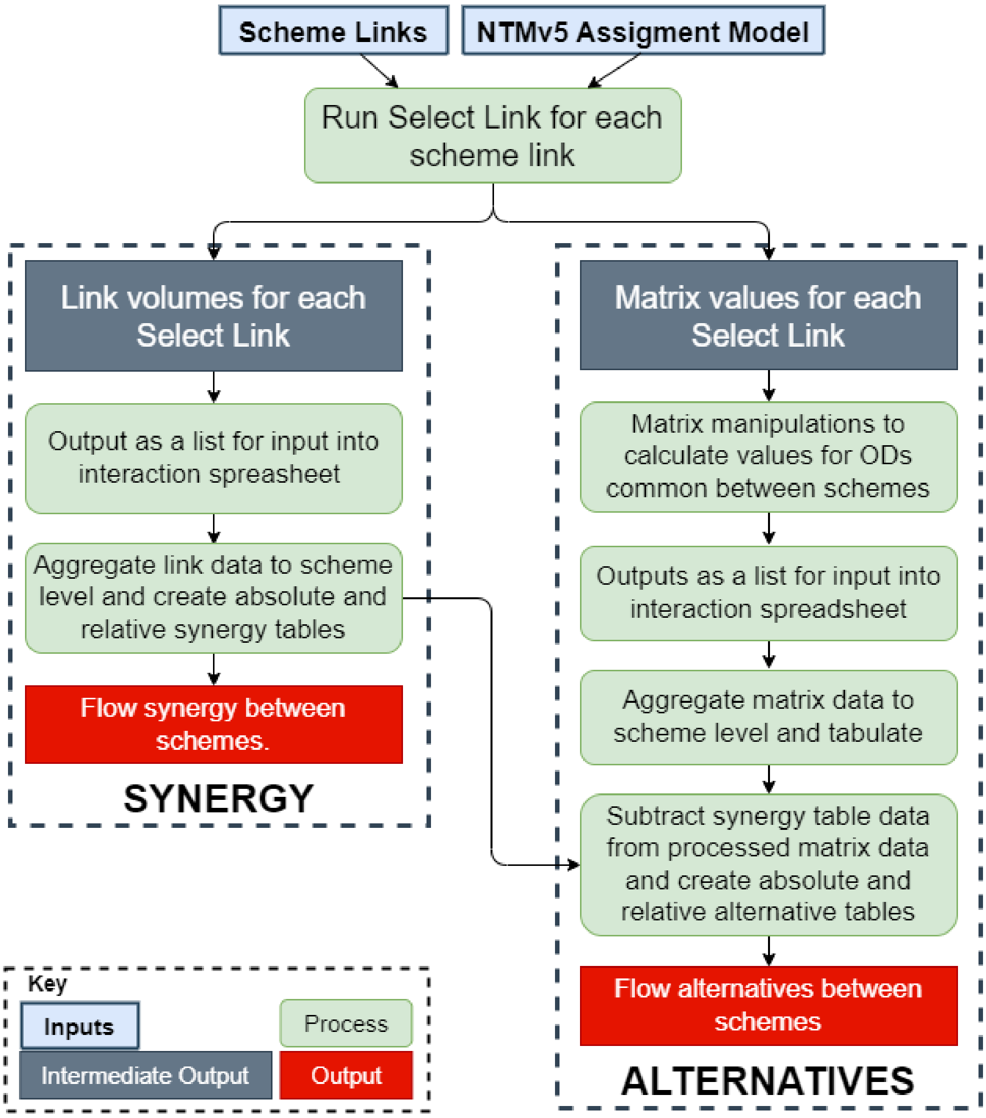
2.3.1. Overview of the Process

In broad terms, the overall process of deriving and analysing flow interactions (synergy and alternative) consists of three technical elements:

- Computation and processing of flow interactions within the NTMv5 environment, utilising available and bespoke modelling software processes.
- Aggregation of the outputs and derivation of scheme interaction tables undertaken in MS Excel.
- Visualisation of outputs in Power BI.

In this section we focus on the theory, computational steps, key assumptions, and practical considerations associated with the methodology used to compute the interactions summarised in Figure 2-1. The intention is to provide the reader with a comprehensive understanding of the overall method. Detailed steps and requirements for operating the software used to perform the calculations are set out in detail in User Guide provided in a separate technical document.

Figure 2-1: Methodology Overview



At the heart of the method is the use of Select Link Analysis (SLA) procedure on the assigned transport network within a transport model. SLA (also known as Flow Bundle in VISUM transport modelling software) is the term commonly used in highway modelling to describe the process of determining the origins and destinations for all traffic passing through a specific link, or group of links. An SLA provides to outputs:

- Output 1: All the OD movements which use the selected link(s), either in single direction or two-way. In effect, this is a subset of the whole OD matrix which has been assigned.

- Output 2: The routing and link flows corresponding to those trips (example of this can be found in Figure A-3 in Appendix A).

The remainder of this chapter explains the concepts of flow synergy and flow alternatives using simple numerical examples.

2.3.2. Flow Synergy

In this section we will present an illustrative example of what is meant by synergy and how it is calculated followed by the equations that describe the method. For the benefit of transparency and simplicity, the illustration is shown in Figure *2-2* below.

Figure 2-2: Illustration of Flow Synergy

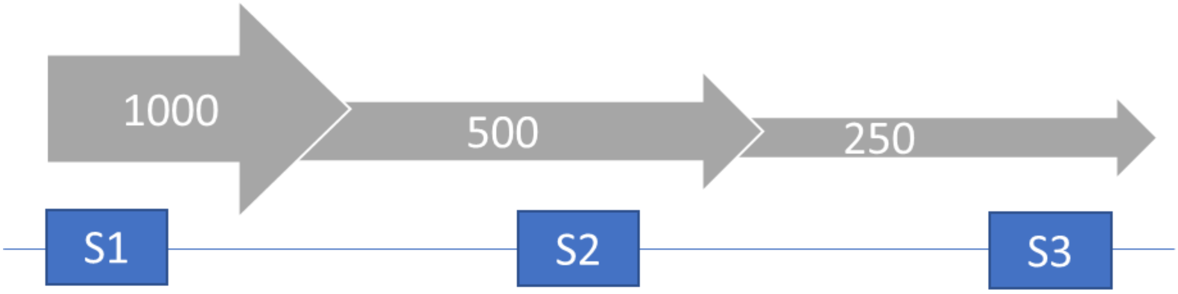


Figure *2-2* shows an example where traffic flow on Scheme 1 (S1) is 1,000, where 500 of these vehicles also continue their journey through Scheme 2 and a further 250 of these vehicles continue their journey through Scheme 3. Figure *2-2* shows that schemes located along the same route are likely to share the same traffic to some degree and that the proportion of traffic shared will reduce with distance. This is a reasonably common situation as many vehicles traversing the first scheme will, at some point, divert to their ultimate destinations. The computational steps required to derive the flow synergy between schemes are set out below.

For simplicity of the example, it is assumed that transport scheme is represented by a single link. Therefore, in this section the terms scheme and link mean the same thing and are interchangeable. We will deal with the problem of multi-link schemes at the end of this chapter.

Drawing on the example depicted in Figure 2-1, if Scheme 1 is chosen for the SLA, the calculation will record the total volume of traffic on Scheme 1 as well as the O-D movements passing through the link, and the routing of those trips across all links in the network. This corresponds to the two types of output described in the previous section. In this methodology, an SLA needs to be run for each scheme link separately and outputs saved for analysis. For the purposes of calculating flow synergy only Output 2 is needed. Output 1 will be discussed later when we describe the calculation of flow alternatives.

For each link in the network, Output 2 provides the flow through the link selected for the SLA, which also passes through other links. Therefore, the SLA for Scheme 1 in our example would have a value of 1,000 on Scheme 1, 500 on Scheme 2, 250 on Scheme 3, and possibly zero for most other links not used. In our method, these values are stored as attributes of the links on the network for processing in the next stage.

The flow synergy between links can then be presented by simply tabulating the results of each select link recorded in link attributes. This is done for all analysed schemes and each row in the table represents the result of SLA for a given scheme. The format is set out in Table *2-1*.

Table 2-1: The Format of the Absolute Flow Synergy Table

	Scheme 1	**Scheme 2**	**…**	**…**	**…**	**…**	**…**	**…**	**…**	**Scheme N**
Scheme 1	F_{S1}	$F_{S2\ S1}$								$F_{Sn\ S1}$
Scheme 2	$F_{S1\ S2}$	F_{S2}	…	…	…	…	…	…	…	$F_{Sn\ S2}$
…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…
Scheme N	$F_{S1\ Sn}$	$F_{S2\ Sn}$	…	…	…	…	…	…	…	F_{Sn}

Where:

- S1 to Sn are the analysed schemes.
- F_{S1} to F_{Sn} (intra-zonal) are the flows on the analysed links.
- $F_{Sn\ S1}$ are the flows on a given link S_n that traverse the analysed schemes S_1 (shared flows). So, this is the S_n flow that is in synergy with scheme S_1. Note that this is symmetric, as the absolute values $F_{Sm\ Sn} = F_{Sn\ Sm}$.

The table therefore takes the format of a matrix of interactions. This should not be interpreted as a conventional origin-destination matrix used in transport models. It is simply a matrix that shows the traffic volume from a given scheme that also traverses the other schemes.

It is worth noting that the intra-zonal values in this matrix depict the total flow of the link for which SLA was run. To illustrate further what should be expected from this table, a numerical example for the flows shown in Figure 2-1 is presented in the first row of Table *2-2* below with the remainder of the table populated with further illustrative data for three schemes.

Table 2-2: Numerical Example of Absolute Flow Synergy

	Scheme 1	**Scheme 2**	**Scheme 3**
Scheme 1	1,000	500	250
Scheme 2	500	800	700
Scheme 3	250	700	750

In Table *2-2* we can see SLA results for Scheme 1 in Row 1. This records a total flow of 1,000 vehicles: 500 vehicles that traverse Scheme 1 also traverse Scheme 2 (so 500 vehicles on Scheme 2 are in synergy with Scheme 1); and 250 vehicles that traverse Scheme 1 and Scheme 3 (so 250 vehicles on Scheme 3 are in synergy with Scheme 1). Each subsequent row records values of SLA for each subsequent scheme and depicts flow synergy with that scheme.

To calculate relative flow synergy between schemes, presented in percentage terms, the following calculation is required (Table *2-3*).

Table 2-3: The Format of the Relative Flow Synergy Table

	Scheme 1	**Scheme 2**	**…**	**…**	**…**	**…**	**…**	**…**	**…**	**Scheme N**
Scheme 1	F_{S1} / F_{S1}	$F_{S2\ S1} / F_{S1}$								$F_{Sn\ S1} / F_{S1}$
Scheme 2	$F_{S1\ S2} / F_{S2}$	F_{S2} / F_{S2}	…	…	…	…	…	…	…	$F_{Sn\ S2} / F_{S2}$
…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…
Scheme N	$F_{S1\ Sn} / F_{Sn}$	$F_{S2\ Sn} / F_{Sn}$	…	…	…	…	…	…	…	F_{Sn} / F_{Sn}

Effectively, the calculation returns the proportion of flow shared between schemes out of the total flow on the analysed scheme. The output from this calculation is tabulated in a matrix of identical dimensions to the absolute flow matrix. The relative flow synergy for the numerical example presented earlier, is shown in Table *2-4* below.

Table 2-4: Numerical Example of Relative Flow Synergy

	Scheme 1	Scheme 2	Scheme 3
Scheme 1	100%	50%	25%
Scheme 2	62.5%	100%	87.5%
Scheme 3	33.3%	93.3%	100%

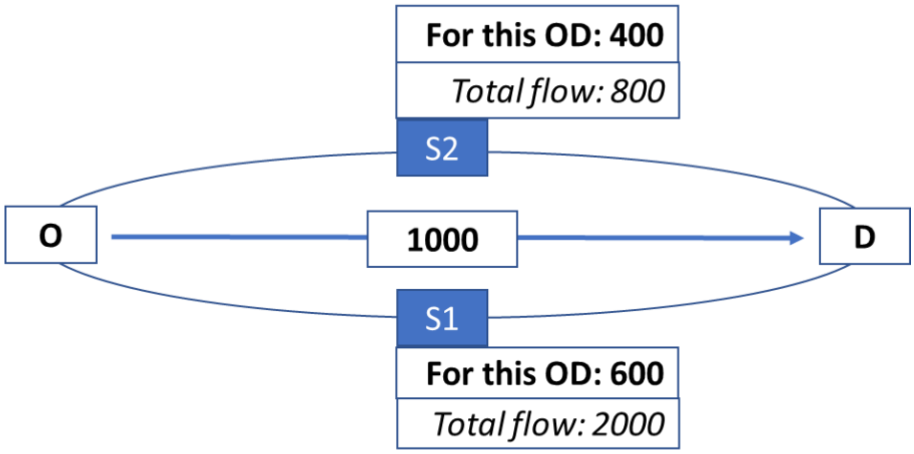
It is worth noting that that the diagonal of this table will always show 100% (scheme flow on itself). This number has no value for the analysis, and it is later omitted in the presentation of results. Note also that whereas the absolute values in Table *2-2* are symmetrical, the proportions are not because the flow on the selected scheme for each row is the denominator.

Once the flow synergy matrix has been created the process can proceed to the derivation of flow alternatives.

2.3.3. Flow Alternative

In this section we will illustrate what is meant by flow alternatives and the process to derive the numerical values that represent this type of interaction. A simplified example of flow alternatives for a single origin-destination (OD) pair is presented in Figure *2-3*.

Figure 2-3: Illustration of Flow Alternative



In Figure *2-3* we can see a flow of 1,000 vehicles between one OD pair. This flow splits into 600 vehicles on Scheme 1 and 400 vehicles on Scheme 2. Apart from this OD pair both schemes carry traffic for other OD pairs (different OD pairs, not shared between these two schemes) and total traffic on Scheme 1 is 2,000 and on Scheme 2 it is 800.

In terms of flow alternative interaction, this should be interpreted as:

- 600 vehicles out 2,000 on Scheme 1 is in alternative to Scheme 2.
- 400 vehicles out of 800 on Scheme 2 is in alternative to Scheme 1.

To compute the flow alternative interactions, the following steps are required:

- A select link matrix (Output 1 of the SLA as listed in Section 2.3.1) needs to be saved for each SLA run as M_n.
- Then for the analysed scheme (say Scheme 1) the SLA matrix is compared with another SLA matrix (say Scheme 2) to detect shared ODs. The volume of vehicle-trips from the SLA matrix for Scheme 1 summed across OD pairs that are common with Scheme 2 is recorded as V_{1-2}.
- The process loops across all scheme pairs (so for 10 schemes, 100 comparisons of SLA matrices are performed). The results populate a table of vehicle-trips for ODs that the schemes share (Table *2-5* below).

Table 2-5: Table of Flows for OD Pairs Shared by Schemes

	Scheme 1	Scheme 2	…	…	…	…	…	…	…	Scheme N
Scheme 1	V_1	V_{1-2}								V_{1-n}
Scheme 2	V_{2-1}	V_2	…	…	…	…	…	…	…	V_{2-n}
…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…
…	…	…	…	…	…	…	…	…	…	…
Scheme N	V_{n-1}	V_{n-2}	…	…	…	…	…	…	…	V_n

Table *2-5* effectively forms a table of matrix sub-totals. In each row, an SLA matrix for the analysed scheme is compared with other schemes recorded in columns. Each column for that row saves a sub-total of that matrix that sums trips for OD pairs shared with the scheme in that column. This table therefore represents all traffic for ODs that a given scheme shares with other schemes.

However, it is important to note that this will record both trips split between parallel schemes as well as trips in consecutive schemes (schemes in synergy) as schemes that share the same traffic share the same ODs too (Section 2.3.1). Therefore Table *2-5* represents more than just scheme alternatives (parallel routes) – it represents a total of flow alternatives as well as flow synergies. To isolate pure alternatives, it is therefore necessary to subtract Table *2-1* from Table *2-5*. It is clear that the process always needs to start with generating a table of synergies, to allow the derivation of alternatives in the second step.

In many cases flow alternatives and flow synergies are mutually exclusive, but that is not always the case. In many cases two schemes can have both flow synergies and flow alternatives and the subtraction described above is necessary to derive a correct result.

2.4. Assumptions

2.4.1. General Assumptions and Simplifications

Before the application of the principles of the calculation set out in Section 2.3 a number of key assumptions and simplifications should be noted:

- Only the traffic assignment component of the model is required. The analysis uses assigned traffic flows available as an output from the NTMv5 model run, but this output will be available from any traffic model.
- The allocation of traffic between a given origin and destination to different routes depends on the results of traffic assignment in the model and as such, it will depend on the assignment parameters and the accuracy of the origin-destination trip matrix. However, in calibrated traffic assignment models this should be treated as a reasonable approximation of how traffic may spread between different routes.
- It is not necessary to run the model for each scheme separately as the analysis does not require a comparison of scenarios. It is not the scheme impact that is being measured, but the flows that traverse the scheme area (as well as the area of all other schemes) in a single model run. The model run selected should however be appropriate for this purpose.
- Given that the actual scheme impacts are not analysed, it is not necessary to code the schemes. Whilst scheme implementation may change traffic flows (induced or re-routed traffic), in most cases it is sufficient to identify the part of the network where the scheme would be located and measure traffic that travels through it to detect interactions. However, if interactions of completely new highways need to be tested (e.g. new connections such as bridges, tunnels

or major roads where no roads existed before), explicit scheme coding would be needed and a specific model run undertaken.

- If no new scheme coding is necessary, the analysis can be performed using the model base year. Interactions of base traffic in future scheme locations will already provide valuable information about the likelihood of scheme interactions. Alternatively, a future year ‘do minimum’ run could be used.

For the purposes of this study all example hypothetical network locations have been used to test the principles of the method. The locations have been identified as two-way with SLA run for each direction and aggregated to a two-way fictitious scheme (although in principle it is possible to analyse each direction separately, it could lead to excessively large interaction tables). This does introduce the concept of aggregation of the results to the scheme level and we will now proceed with the explanation of methods that deal with examples that consist of multiple links.

2.4.2. Representation of Multi-Link Scheme in the Analysis

In previous sections we set out steps to calculate flow synergies and flow alternatives using a simplifying assumption that a scheme is represented by a single link. This assumption makes the examples set out above more accessible and allows the method to be more easily understood.

However, in practice, schemes represented in transport models rarely consist of a single link. We cannot simply select all scheme links and then add their SLA results together. This is because it would lead to double counting of traffic that traverses consecutive links. To avoid such double counting, it is necessary to select links that capture traffic traversing the scheme, but which are mutually exclusive.

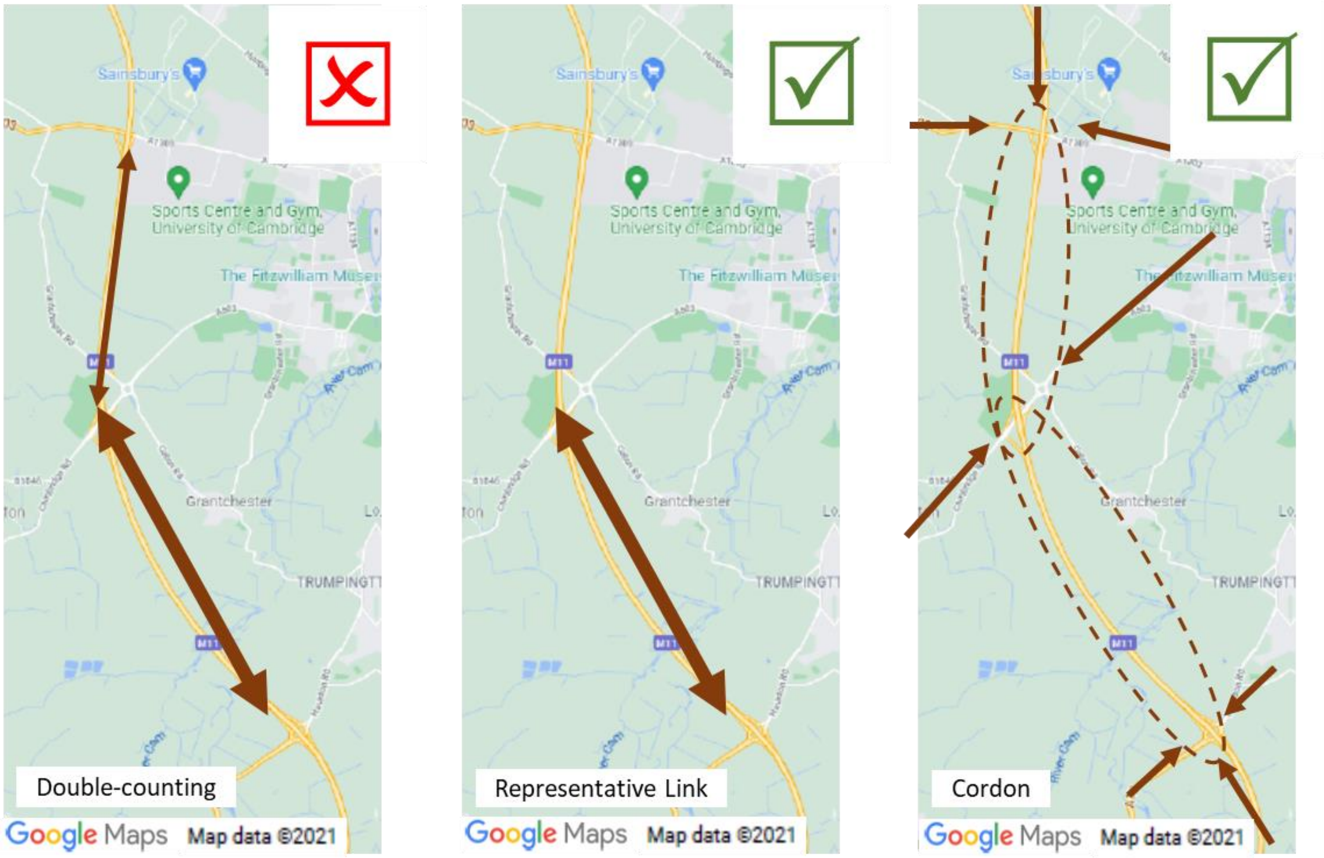
The solution to this challenge could be SLA analysis for pairs of schemes, so that the synergy could be automatically saved in the form of matrix totals and using link attributes could be avoided. However, the drawback of this solution is that SLA analysis would need to be run for all combinations of schemes so the number of SLA runs would be equal to N^2 where N is the number of schemes. For large numbers of schemes, the SLA run times would be prohibitive.

Therefore, the solution needs to use individual link flows, but be capable of avoiding the problem of double counting. Two options are available:

- Selecting a single main representative link – this will capture the majority of traffic traversing the scheme if a single dominant link can be found. This method would be suitable for instance on sections of a road between major junctions where little traffic leaves or joins the highway between junctions.
- Selecting traffic entering the scheme area, using a cordon around the scheme – this method will capture all traffic that enters any part of the scheme, but each of these entry points carries traffic flows that are mutually exclusive. This method is particularly suitable to cordoning junctions or schemes that span multiple road sections.

Both methods, are shown in Figure *2-4* below alongside the ‘incorrect’ method. The methods are illustrated using the example of one of our fictitious scheme examples used in this study (Example 8), results of which are also discussed in Chapter 4. In this example we assume a hypothetical network improvement that covers a section of M11 between Junctions 11 and 13, inclusive of the junctions. As the example spans two consecutive sections of the road it is not correct to simply select both links as traffic will be double counted (left box in Figure *2-4*). It is necessary to either identify a dominant link that captures most flows that traverse both sections (middle box in Figure *2-4*) or select cordon links around the network locations we want to analyse (right box in Figure *2-4*).

Figure 2-4: Examples of Suitable Scheme Selections



Most schemes on the network will require the cordon method depicted on the right in Figure *2-4*. This is not problematic as in most cases it is possible to select a suitable cordon. In cases of very complex schemes, which consist of many phases or components separated geographically, it would be advisable to split them into parts for the purposes of analysis (so consider defining smaller sub-schemes). Using cordons requires the user to select watertight entry links that avoid double counting described above.

Once the method is applied to mutually exclusive links that capture traffic flowing the location selected for analysis, it is then possible to simply aggregate (sum) the results for individual links. The advantages of this approach are:

- The results can be viewed in aggregate form (by scheme) as well as by individual links. The latter not only facilitates deeper analysis of components of the schemes, but also facilitates an easy and almost instantaneous verification of whether entry links are indeed mutually exclusive and that the method has been applied correctly. Examples of such a verification are set out in Chapter 4.
- It automatically deals with aggregating uni-directional links into two-way totals as flows on uni-directional links can generally be considered mutually exclusive. Although it is theoretically possible to find examples of U-turns, these can be generally considered to be extremely rare and therefore negligible for the purposes of scheme interaction analysis. Furthermore, the verification method described above would also detect such cases and strengthens the reliability of the method.

3. Implementation

3.1. Introduction

In the previous chapter we set out the principles of the method. In this chapter we set out the key points about the implementation of the method in DfT's National Transport Model version 5 (NTMv5) as well as the preparation of final outputs in MS Excel and their visualisation in Power BI. We do not attempt to replicate instructions to run these tools here as these are documented in a separate technical document, SINAT User Guide, focused solely on the operation of the tool.

3.2. Implementation in NTMv5

The method has been scripted using a combination of Visum software procedures supported with a limited use of Python code to automate repetitive processes. The user is required to input a list of scheme links to analyse, using one of the suitable selection methods described in Section 2.4.2 and appropriate labelling that allows the aggregation of the results to the scheme level.

The principles of the method can be scripted in any transport modelling software, but in case of the implementation in NTMv5, the following points need to be noted:

- Longer run times associated with the size of the model are mitigated by the simplicity of the method and the avoidance of SLA for multiple pairs of schemes.
- The method has been designed to be dynamic – it can run and create link attributes for any user-defined number of SLA runs and therefore provides full automation even for many schemes and links in the analysed portfolio.
- The results of the SLA analysis and matrix calculations are output into the format of easily transferable text files, which can be used by any downstream analysis software.

3.3. Processing of Outputs – Aggregation Spreadsheet

The outputs from Visum are imported into an MS Excel tool which performs the aggregation of the results and allows the derivation of tables of interactions. While doing this the tool also performs the final step in the calculation of the flow alternative interactions: the subtraction of flow synergy. After the completion of the calculations, the tool allows the interactions to be viewed at individual link level as well as aggregated to a scheme level through appropriate pivot tables. The final function of the tool is to prepare outputs in a format appropriate for import into the Power BI Dashboard, the functionality of which is described in the in the next section.

3.4. Visualisation in Power BI

The Power BI dashboard reprints the interaction tables in both the absolute and relative format, but with a modification which allows the data to be displayed in Power BI in an intuitive way. It displays total flow on the analysed link so that the size of flow interactions can be understood in the context of the total flow on the link.

A number of presentation options have been explored such as Sankey or Circular Charts, but these tools do not perform well with large numbers of schemes. For ease of interpretation, the dashboard presents the results on a map background. It displays the geographical distribution of interactions (so connects schemes which have interactions). The display also shows the relative size of interactions – between each other and relative to the size of the flow on the scheme.

The idea behind the tool is that it can be easily updated, and it is easy to use without the need for programming skills. It also allows an easy operation – selection of schemes or groups of schemes on the map for easier analysis of subsets of data. It has the capability to display link-based outputs (before aggregation), although admittedly, this is treated as a secondary functionality for deeper analysis as the very large number of links makes the interpretation more time consuming.

4. Results

4.1. Introduction

In the implementation phase, we tested the method on 11 example network locations selected at random solely for the purposes of testing the operation of the tool. We analysed interactions between all 11 of these examples. In this section we summarise the results and discuss the interactions providing guidance on the interpretation of the results. We then investigate these results in more detail using the most complex example in our sample. Results for a selection of other interesting examples are presented in Appendix A.

The remainder of this chapter is organised as follows:

- Section 4.2 – Presents the location of the fictitious schemes on the network.
- Section 4.3 – Sets out an example of flow synergy.
- Section 4.4 – Sets out an example of flow alternatives.

4.2. Analysis Examples

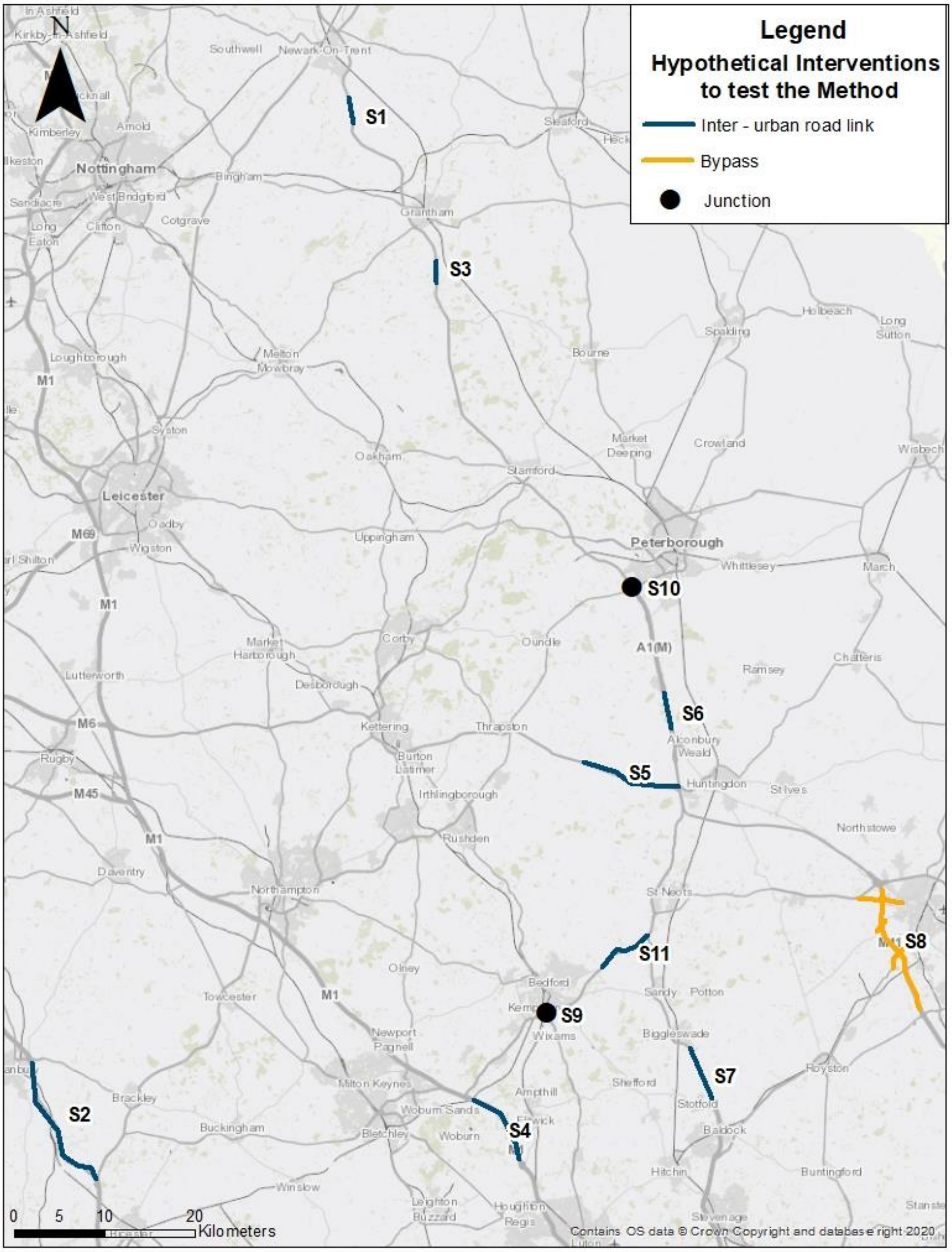
The example network locations used to test the method have been selected at random. Their location does not matter as long as they are close enough to allow detection of interactions (it is reasonable to expect for instance, that a scheme in South West would not interact with a scheme in the North East). For the purposes of this project, we elected to use fictitious locations across East Midlands and East of England regions concentrated along the A1 corridor.

The selection covers example locations in the same corridor and on parallel and perpendicular corridors. It also covers different types of examples including link improvements, junctions, and longer sections of the route such as city bypass or stretches of the motorway. The random list of the example, hypothetical locations generated to test the method is presented in Table 4-1 and depicted on the map in Figure 4-1.

Table 4-1: List of Hypothetical Examples for Testing

Number	Example Label	Description	Number of Links	Example Type
S1	A1 Newark	2-way link south of Newark-on-Trent	2	Link
S2	M40	2-way link between Bicester and Banbury	2	Link
S3	A1 Grantham	2-way link south of Grantham	2	Link
S4	M1	2-way link between A5 and A421	2	Link
S5	A14	2-way link between A1 and A605	2	Link
S6	A1 Peterborough	2-way link south of Peterborough	2	Link
S7	A1 Biggleswade	2-way link north of Biggleswade	2	Link
S8	Cambridge East	M11 J11-13 inclusive of junctions	8	Bypass
S9	A6/A421	Grade separated junction	4	Junction
S10	A1/A605	Free flow turns between A1 and A605	4	Junction
S11	A421	2-way link between A6 and A1	2	Link

Figure 4-1: Location of Hypothetical Examples on the Network



4.3. Example Flow Synergy Results

4.3.1. Results for All Examples

The results for flow synergy between the examples depicted in Figure 4-1 are shown below: Table 4-2 shows the absolute flow synergy between the example schemes and Table 4-3 shows the relative flow synergy. The results are derived from base year NTMv5 inter-peak assignment and represent hourly two-way flows. As described in the methodology section, the intrazonal values depict the total flow traversing the analysed scheme obtained from the SLA.

Table 4-2: Absolute Flow Synergy Between Example Locations

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
S1	2,921	-	2,386	21	-	1,701	253	1,004	46	17	68
S2	-	5,406	-	-	-	-	-	-	-	-	-
S3	2,386	-	3,168	27	-	1,888	280	1,074	57	22	85
S4	21	-	27	7,542	-	125	-	1	511	35	245
S5	-	-	-	-	2,348	14	25	467	-	-	0
S6	1,701	-	1,888	125	14	4,335	639	1,705	317	895	413
S7	253	-	280	-	25	639	2,377	-	26	161	79
S8	1,004	-	1,074	1	467	1,705	-	6,928	109	254	51
S9	46	-	57	511	-	317	26	109	4,343	115	1,273
S10	17	-	22	35	-	895	161	254	115	1,810	140
S11	68	-	85	245	0	413	79	51	1,273	140	2,087

The following observations can be made from Table 4-2:

- The largest synergies can be expected between examples in corridors with large absolute traffic flows and located close to each other. This can be seen for example S3 (A1 Peterborough) and example S1 (A1 Newark): Example S3 has a flow of 2,386 vehicles in synergy with example S1, which is large and almost as large as the flow on example S1 itself. This means that most of the vehicles that traverse example S1 also continue through example S3. The interpretation of this is that example S1 can have a significant impact on flows that also use example S3 and vice versa.
- It is worth noting that the absolute flow synergy table is symmetrical. The synergy of example S1 with S3 is the same as the synergy of example S3 with S1. This is intuitive as SLA for both schemes detected flows for the same of ODs that these two schemes share, and this value should be identical if two-way flows are analysed on both occasions.
- As expected, the flow synergy between any given pair of schemes reduces with distance. This is illustrated by example S6 which has only 1,701 vehicles in synergy with example S1. This is because it is further away from example S1 than S3 was, and many trips that crossed S1 left the A1 corridor before they could reach S6 and therefore they do not interact as much.
- Another observation, again in line with expectations, is that parallel examples have weak flow synergy. An extreme example of this is S2 (M40) which is some distance away from the other examples and does not cater for the same traffic (trips between the same origin-destination pairs). It therefore has no interactions with other examples.
- Overall, the flow synergies are very intuitive and easy to sense-check as they closely align with what would be expected from SLA outputs familiar to most transport modellers (in fact, with some effort, these relationships can be unpicked manually from SLA results). This will be discussed again in Appendix B where QA checks undertaken on the calculations have been presented.

The absolute flow synergies discussed above provide useful information about the size of the flow between the same ODs that the two schemes share, which is indicative of the scale of interaction. But it is also useful to put it in context and to do this we need the relative flow synergies (Table 4-3 below). Here we deliberately do not show the intrazonal results, which would be 100% in each instance (interaction of scheme on itself) and would not add any value to the discussion. All figures presented below have been rounded to the nearest percentage.

Table 4-3: Relative Flow Synergy Between Examples

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
S1		-	82%	1%	-	58%	9%	34%	2%	1%	2%
S2	-		-	-	-	-	-	-	-	-	-
S3	75%	-		1%	-	60%	9%	34%	2%	1%	3%
S4	-	-	-		-	2%	-	-	7%	-	3%
S5	-	-	-	-		1%	1%	20%	-	-	-
S6	39%	-	44%	3%	-		15%	39%	7%	21%	10%
S7	11%	-	12%	-	1%	27%		-	1%	7%	3%
S8	14%	-	16%	-	7%	25%	-		2%	4%	1%
S9	1%	-	1%	12%	-	7%	1%	3%		3%	29%
S10	1%	-	1%	2%	-	49%	9%	14%	6%		8%
S11	3%	-	4%	12%	-	20%	4%	2%	61%	7%	

Following on from the results discussed earlier, the relative flow synergy table shows that example S3 is 82% in synergy with S1. This means that a very high proportion of trips that cross S3 are also observed on S1.

Approximately, the reverse is true, but the figures are not completely symmetrical as is the case for absolute flows. Example S1 is only 75% in synergy with S3 and only 39% in synergy with S6. This is because the result is relative to the size of the flow of the example against which the synergy is measured. The relative flow synergy between two examples will be similar only if the total flow for both examples is similar.

This is a useful property of the relative synergy metric as it tells the user how significant the impacts of one scheme on the other scheme could potentially be. For instance, the analysis of example S6 and S10 in Table 4-2 shows 895 vehicles in synergy between them. However, the total flow on S6 is 4,335 and the total flow on S10 is 1,810, meaning that:

- 895 trips on S10 are in synergy with S6, but that is only 21% of S6 flow.
- But looking the other way, 895 trips on S6 are in synergy with S10, but this time it is nearly half of the flow on S10 (49%).

Therefore, the flow shared between these two examples can have a larger impact on S10 than S6.

4.3.2. Results for Selected Examples

To provide further guidance on the interpretation of the results, here we discuss an extract of the synergy results, for one example specifically (S8). This is the most interesting example in our sample as it happens to have both flow synergy and alternative (discussed later) interactions. It is composed of multiple links, which allows discussing the results at aggregate scheme level (this section) and the individual link level (next section).

The most useful presentation of the results is the geographical output of the Power BI dashboard prepared for the project. Figure 4-2 shows all examples that are in synergy with example S8, with their geographical distribution as well as the size of interaction. In addition, the dashboard shows the extract from the full interaction table for this single example.

Figure 4-2: Flow Synergy Dashboard for Example S8

Scheme Synergy Flow Map

●Sc_08

Microsoft Bing Microsoft Bing product screen shot(s) reprinted with permission from Microsoft Corporation.

SCHEMEID	SCHEME_NAME	No_of_Links
Sc_01	A1 Newark	2
Sc_02	M40	2
Sc_03	A1 Grantham	2
Sc_04	M1 between A5 & A421	2
Sc_05	A14	2
Sc_06	A1 Peterborough	2
Sc_07	A1 Biggleswade	2
Sc_08	Cambridge_Bypass_InBoundLinks	8
Sc_09	A6/A421 Jtn	4
Sc_10	A1/A605 Jtn	4
Sc_11	A421	2

Scheme Synergy Matrix - Absolute Values

Origin	Sc_01	Sc_03	Sc_04	Sc_05	Sc_06	Sc_08	Sc_09	Sc_10	Sc_11	Scheme Flow
Sc_08	1004	1074	1	467	1705	6928	109	254	51	6928
Scheme Flow	**1004**	**1074**	**1**	**467**	**1705**	**6928**	**109**	**254**	**51**	**6928**

Scheme Synergy Matrix - Proportions

Origin	Sc_01	Sc_02	Sc_03	Sc_04	Sc_05	Sc_06	Sc_07	Sc_08	Sc_09	Sc_10	Sc_11
Sc_08	14%		16%	0%	7%	25%			2%	4%	1%

Figure 4-2 shows that mostly examples in the A1-M11 corridor have flow synergy with example S8. In other words, this example shares traffic with examples S6, S3 and S1 as it caters for traffic using the M1-A14-A1 corridor between the East of England and East Midlands. The size of the circle reflects the total flow that crosses any part of S8. The thickness of the 'arms' that depict which examples are in synergy with S8 is relative to the size of the S8 flow. As expected, S6 has the greatest synergy with S8. The level of flow synergy reduces for S3 and S1 as they are further away from S8. Other examples have a minimal level of synergy with S8, but some can be detected for S5 (A14 west of A1) as this could be a viable route between the M11 and West Midlands.

It is worth noting that the mapping of synergies is intended to help the user with sense-checking of the results. It allows a quick identification of anomalies in the results and allows the user to verify the plausibility of the results by reviewing the geographical spread of the interactions. However, the size of interactions is scaled to the size of the flow, it only serves as a depiction of the geographical distribution of the interactions. For the full understanding it is still necessary to use the tabulated results as they are an accurate reflection of the size of the absolute and relative flow synergy and the dashboard automatically provides the user with this output for the selected example.

4.3.3. Results Broken Down by Link

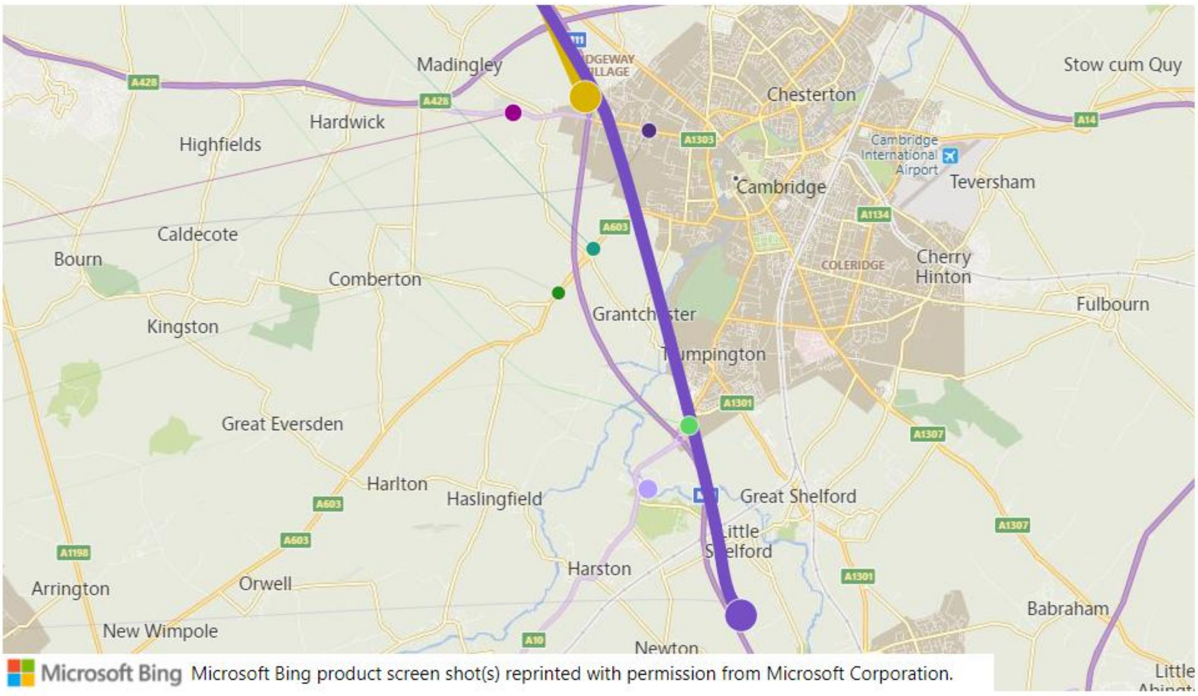
Example S8 consists of multiple sections of the motorway as well as junctions and we discussed earlier methods of cordoning links around such schemes to allow the aggregation of the results to the total scheme level. But the individual cordon link results remain available to the analyst and it may also be useful to interrogate them for other reasons:

- To check that the cordons around the schemes have indeed used links with flows that are mutually exclusive – if that is the case, the results should show zero flow synergy between the cordon links.
- To interrogate if the interactions with the adjacent schemes differ between parts of the scheme we are analysing.

The tools developed as part of this research enable such analysis. As the tables of interactions between individual links can get very large, this is best analysed graphically, using the Power BI dashboards. Figure 4-3 below maps out flow synergies of the individual links that form a cordon around example S8. The map deliberately zooms in on the example area to show the interactions between the links that form this cordon (denoted by the circles in Figure 4-3, with the interactions seen as dark purple and yellow lines).

Figure 4-3: Flow Synergy at Link Level for Example S8.

Link Synergy Flow Map



LinkID_A	1	2	5	6	7	8	9	10	11	12	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Link Flow
15	493			531				169		833	2,218								34			16	126		13		2		**2,218**
16	1			1				5		4		656							2				1				1		**656**
17	2			4	0			10		17			299						18			0	6		0		0		**299**
18					0									336					7								17		**336**
19	3			3				8		13					563				14			1	3		1		0		**563**
20						1										474		14		0	1							32	**474**
21																	250	17			0								**250**
30		504	536				275		838															87		2,132			**2,132**

Figure 4-3 shows that there are indeed no interactions between links that form the cordon around the example S8 (links numbered 15-21 and 30 in the table above and shown as dots on the map). There are no connections between the dots that represent the cordon links, and the interaction table shows nothing apart from intrazonal values (traffic on those links). This confirms that an appropriate cordon around S8 has been selected. As expected, the greatest contributors to the interactions of this example with the other network locations are the mainline M11 links (Link 15 and Link 30).

4.4. Example Flow Alternative Results

4.4.1. Results for All Examples

In Section 4.3 we discussed flow synergy between the 11 example network locations. In this section we will focus on flow alternatives for the same examples. Absolute flow alternatives are shown in Table 4-4 below and the results for the relative flow alternative follow in Table 4-5.

It is worth noting that this time the interpretation of intrazonal differs slightly. In most cases where the scheme is represented simply by single links (in both directions) there is no intrazonal value as opposite directions of the same link cannot be alternatives to each other. But in cases where the example uses multi-link cordons, it is likely that the intrazonal values will appear. This is because individual links selected to cordon the area can form alternatives to each other – this will be explained further in the discussion of the results below.

Table 4-4: Absolute Flow Alternatives Between Examples

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
S1	-	3	0	129	3	14	41	114	20	39	17
S2	3	0	5	353	0	4	3	1	2	1	2
S3	2	3	-	139	3	17	47	124	27	43	23
S4	91	235	92	0	26	119	205	101	193	19	14
S5	8	0	8	33	0	144	6	182	52	6	42
S6	38	3	40	268	71	0	144	247	145	354	112
S7	10	1	10	226	19	1	-	101	174	51	165
S8	21	2	21	135	69	32	66	1,378	23	87	83
S9	4	0	4	76	106	4	161	151	201	55	66
S10	29	0	29	53	2	9	39	40	74	5	62
S11	3	0	3	41	62	1	145	54	86	63	-

The following observations can be made from Table 4-4:

- The flow alternatives between the selected examples tend to be smaller in magnitude than the flow synergies discussed in Section 4.3. This means that a much smaller proportion of traffic for the same ODs gets allocated to alternative routes in NTMv5 traffic assignment. This is not unexpected as distribution of traffic across many alternative routes on the SRN would involve significantly longer distances and such route choice would likely be suboptimal, even in multi-routing assignment. It is reasonable to expect that flow alternatives would increase in highly congested networks with high density of available alternative routes. For instance, such conditions could arise in urban areas, although this would be of less consequence for the assessment of interactions between SRN schemes.
- Nevertheless, noticeable flow alternatives can be observed for example S4 (M1), which is to be expected. This scheme would offer alternative routes to the North and North West to schemes located on A1, M11 as well as M40. This is confirmed in the results as example S4 has the highest flow alternative with examples S2 (235), S7 (205) and S9 (193).
- Similarly, schemes that have previously shown large flow synergies, tend to show weak flow alternatives. This can be seen for examples S1 and S3 that show almost no interaction. Again, this is entirely expected as adjacent schemes along the same corridor are most likely to share traffic rather than act as alternatives.
- Example S2 (M40) shows noticeable interaction with the parallel M1 as M1-M6 corridor can also be used for travel between South East and West Midlands or North West. But the interaction with the A1 corridor is negligible – these two corridors are simply too far apart to cater for a large number of the same ODs.
- The flow alternatives table is not symmetrical, which was discussed earlier.
- Intra-scheme interactions may arise for large schemes represented by many cordon links. For instance, example S8 consists of two consecutive motorway links and three junctions and is represented by cordoning all entries into the scheme area. It is reasonable to expect that adjacent junctions form alternative access points to the scheme area (motorway) and therefore compete with each other. In fact, this appears to be the largest of interactions in the table as it is simply a sum of all combinations of interactions. Similarly, there is also an intra-scheme interaction for example S9 (grade separated junction of A6 and A421) this is because the junction can be approached from the A6 or the M1-A421, both of which form viable alternative routes. Whilst reported in Table 4-4, these values have no meaning for the analysis as these links form one scheme, so they are omitted in the final visualisation in Power BI dashboards.

- Overall, the flow alternative results presented in Table 4-2 are also intuitive and easy to sense-check as they closely align with expectations for alternative routes. This will be discussed again in Appendix B where QA checks undertaken on the calculations have been presented.

The absolute flow synergies discussed above provide useful information about the size of the flow between the same ODs that is distributed to alternatives, which is indicative of the scale of interaction. Analysis of relative flow alternatives (where interactions are shown relative to the size of the flow on alternative links) complements this picture (Table 4-5). Similarly, to earlier examples, the relative intra-scheme interactions are not shown as they have no useful meaning.

Table 4-5: Relative Flow Alternatives Between Examples

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11
S1		-	-	4%	-	-	1%	4%	1%	1%	1%
S2	-		-	7%	-	-	-	-	-	-	-
S3	-	-		4%	-	1%	1%	4%	1%	1%	1%
S4	1%	3%	1%		-	2%	3%	1%	3%	-	-
S5	-	-	-	1%		6%	-	8%	2%	-	2%
S6	1%	-	1%	6%	2%		3%	6%	3%	8%	3%
S7	-	-	-	10%	1%	-		4%	7%	2%	7%
S8	-	-	-	2%	1%	-	1%		-	1%	1%
S9	-	-	-	2%	2%	-	4%	3%		1%	2%
S10	2%	-	2%	3%	-	-	2%	2%	4%		3%
S11	-	-	-	2%	3%	-	7%	3%	4%	3%	

Here we can observe that the relative flow alternative interactions remain low in percentage terms. This is because generally, across the sample of schemes, the absolute flow alternative values are small in comparison with the total scheme flows. Again, similarly to the observations for flow synergies, the results are not symmetrical as flows to which the relative interactions are compared differ by scheme.

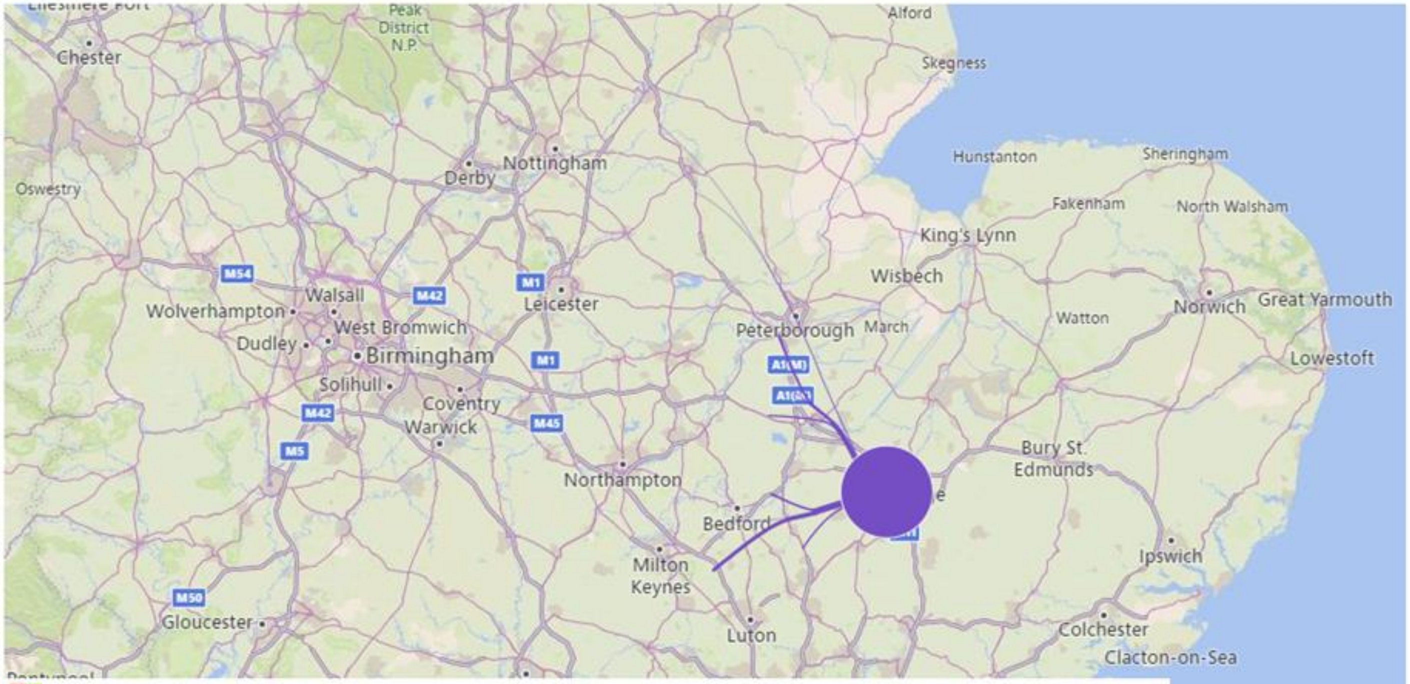
4.4.2. Results for Individual Scheme

In the previous section we discussed flow alternative results for all schemes. Here we will focus on flow alternative results for a single scheme. As with flow synergy, we will discuss example S8, which consists of a multi-link cordon, which allows for a number of flow alternative interactions to arise. The results are shown in Figure *4-4*.

Figure 4-4: Flow Alternative Dashboard for Example S8

Scheme Alternative Flow Map

●Sc_08



Microsoft Bing Microsoft Bing product screen shot(s) reprinted with permission from Microsoft Corporation.

SCHEMEID	SCHEME_NAME	No_of_Links
Sc_01	A1 Newark	2
Sc_02	M40	2
Sc_03	A1 Grantham	2
Sc_04	M1 between A5 & A421	2
Sc_05	A14	2
Sc_06	A1 Peterborough	2
Sc_07	A1 Biggleswade	2
Sc_08	Cambridge_Bypass_InBoundLinks	8
Sc_09	A6/A421 Jtn	4
Sc_10	A1/A605 Jtn	4
Sc_11	A421	2

Scheme Alternative Matrix - Absolute Values

Origin	Sc_01	Sc_02	Sc_03	Sc_04	Sc_05	Sc_06	Sc_07	Sc_08	Sc_09	Sc_10	Sc_11	Scheme Flow
Sc_08	21	2	21	135	69	32	66	6928	23	87	83	6928
Scheme Flow	**21**	**2**	**21**	**135**	**69**	**32**	**66**	**6928**	**23**	**87**	**83**	**6928**

Scheme Alternative Matrix - Proportions

Origin	Sc_01	Sc_02	Sc_03	Sc_04	Sc_05	Sc_06	Sc_07	Sc_08	Sc_09	Sc_10	Sc_11
Sc_08	0%	0%	0%	2%	1%	0%	1%		0%	1%	1%

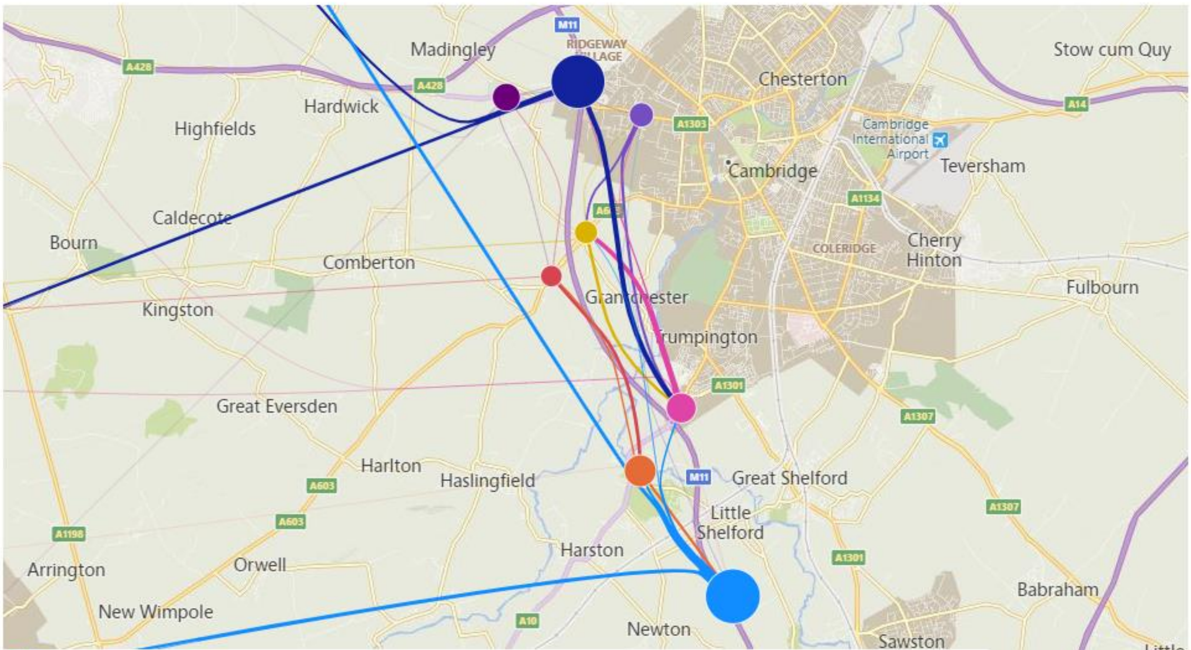
As seen earlier, the absolute flow alternatives interactions between other examples and example S8 are very low compared to the total flow of S8 itself. As highlighted earlier, the flow alternatives are generally expected to be weaker in sparse networks. The interpretation of this result would be that in case of the lack of investment in S8, a large majority of the flow crossing this area would not benefit from any of the other schemes in this example analysis. If there were large problems on this part of the network, they could not really be addressed effectively by alternatives to S8.

4.4.3. Results Broken Down by Link

Based on the results set out in the earlier section we concluded that flow alternatives tend to be weaker between schemes in sparse networks. We also explained that intra-scheme alternatives have no useful meaning for comparisons between schemes. But the fact that results are also available at link level allows intra-scheme analysis to provide insights into how different scheme components interact. This is illustrated in Figure 4-5.

Figure 4-5: Flow Alternative at Link Level for Example S8.

Link Alternative Flow Map



Microsoft Bing Microsoft Bing product screen shot(s) reprinted with permission from Microsoft Corporation.

LinkID_A	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
15	14			2		15		81		40		6	30		2,218	76
16	0					0		1		1		0	0		89	656
17	0					0	0			3		0	0		1	
18							0	0		5			0		16	
19	0					0	0			11		0		0	6	
20							0	0	5					4		1
21								1	1				3	0	6	182
30		6	0		5		51		4		26			28		
Link Flow	**14**	**6**	**0**	**2**	**5**	**15**	**51**	**81**	**5**	**40**	**26**	**6**	**30**	**28**	**2,218**	**656**

LinkID_A	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	Link Flow
15	23	9	56		2	3	1			8	21		8		5	3	**2,218**
16				1	55	2	0	0	0		0		0		1	2	**656**
17	299	24	135				1			1	0		1	3	22		**299**
18	102	336	113				0							0	0		**336**
19	184	28	563				1			1	0		1	35	17		**563**
20				474	9	0	0		0					10	0		**474**
21				29	250	2		0	0				0	1		25	**250**
30	1	11	160	10	0	3	8					46		2,132	8	0	**2,132**
Link Flow	**299**	**336**	**563**	**474**	**250**	**3**	**8**	**0**	**0**	**8**	**21**	**46**	**8**	**2,132**	**22**	**25**	**2,218**

Figure 4-5 shows that different entries into the area of example S8 can act as alternatives to each other. This is shown by the connections between the dots that represent the S8 cordon links as well as the data in the table which shows sizeable flow alternative interactions between these cordon links. Analysis at this level could help shape decisions about the inclusion of certain elements of complex schemes.

5. Conclusions and Recommendations

5.1. Summary

This research project has delivered a technique and a set of tools which allow an easy identification of schemes that interact in terms of flow, and as a result may also interact in terms of economic impacts. The technique has been implemented in the simplest and most practical manner to reduce the analytical and computational burden on analysts who need to respond to urgent policy questions.

The user-friendly approach has major strengths but also some limitations which should be noted. The use of traffic flows as the primary metric to describe interactions also has some methodological limitations, although we believe that the advantages outweigh drawbacks. Identified strengths and limitations, recommendations for user application and recommendations for further research are described in the following sections.

5.2. Strengths and Limitations of the Method

The following strengths of the method delivered in this research project have been identified:

- Ease of implementation – the method does not need advanced programming or modelling skills it uses a highway assignment model rather than the full demand model, which simplifies implementation and reduces run times. It relies on some of the most basic transport modelling processes such as Select Link Analysis (SLA) and matrix calculations as well as simple formulae and pivot tables in MS Excel.
- Speed of application – as described above, the method requires only a completed traffic assignment model and does not actually need to repeat model runs apart from SLA, which happens to be a relatively quick process in the Visum software. Further efficiencies include:
    - Avoidance of need to run SLA for pairs of schemes (where the number of permutations grows exponentially with the size of sample), meaning the method can be run in a relatively short time. Even for large portfolios of complex schemes it is at most an overnight batch process.
    - In most cases, the analysis does not require the actual schemes to be coded in the network, it only requires their location and traffic flows that traverse that location to be able to identify flow interactions.

  Fundamentally, it is the speed of application that brings value to policy customers.
- Simplicity – the two-step approach to undertaking the analysis by individual scheme link and then aggregating them to the scheme level is intuitive and allows the user to choose and modify the levels of aggregation. The method does not require advanced maths or complex theories and is accessible to practitioners with the knowledge of basic transport modelling techniques. Crucially, this simplicity also means that the interactions are more accessible to non-technical audience and can be more readily interpreted by policy customers.
- Transparency of interpretation - summations that create the interaction tables are performed in MS Excel which can be easily interrogated without advanced programming skills. Also, the two-step approach to analysis means that the low-level (link-level) results can provide additional insights into intra-scheme impacts as well as an additional assurance tool.
- Implementation based on contemporary state-of-the-art tools such as DfT's National Transport Model and modern visualisation techniques.
- Powerful and easy to use visualisation technique, which does not require specialist programming, modelling software or GIS skill.

- User-friendly quality assurance – outputs draw directly from SLA results and some interactions can be visually cross-checked with SLA results displayed on the model networks. Furthermore, the choice of map background for visualizing interactions allows quick and intuitive sense-checks of the interactions as a function of the location and distances between schemes.

SINAT has been designed with speed and simplicity in mind. This means that there are limitations of the method, which include:

- SINAT does not offer a definitive answer whether the scheme interactions are positive or negative (whether they reinforce or reduce each other's benefits). This is because the method does not measure benefit interactions. It only highlights the likelihood that scheme benefits interact, based on the fact that their flows interact. The type of flow interaction suggests that interactions can be either synergetic or competitive, but the size and direction of benefit interactions should be confirmed formally through the economic appraisal of individual schemes, or through further expansion of the SINAT method (see the next section).
- Appreciation of the types of highway schemes and what they aim to achieve is required from the user. This is so that the user can make appropriate selections of links or cordons that represent the schemes, or in case of very large schemes, choose to split them for the purposes of analysis. Necessarily, regardless of choices the user makes, the method is indicative and plausible approximations of scheme extent are sufficient to inform policy choices.
- The results are derived from modelled data rather than observed data. As such the traffic assignment methods used in the model and the calibration of their parameters will influence the size of interactions, particularly the flow alternatives. As a result, there could be differences in the scale of interaction detected if the method is applied in two different models. But this is true of any modelling results – two different models are likely to generate different answers. However, well calibrated assignment models should be treated as reliable tools for forecasting and if that is the case the application of SINAT in such models should also be seen as reliable. The scope of the model is also important, for instance, given the national nature of NTMv5, it should be seen as the best place to start with national-level analysis.

5.3. Recommendations for the Application of the Tool

Given that the method does carry some limitations and to maximise the value of its strengths, the following recommendations for its application can be made:

- The user should consider the extent of the scheme and, looking at the scheme layout, judge which traffic movements are likely to be impacted. For instance, an online improvement between junctions will most likely require selecting a single link. Improvement of a junction, or a section of a motorway including junctions, will benefit traffic crossing the scheme in many directions and as such it is more appropriate to cordon the entire scheme area.
- Following from this, the user needs to make sure that the cordon links are mutually exclusive in terms of traffic they carry (so the same traffic should not cross more than one selected link). To achieve this, it is most practical to select one-directional entry links into the scheme area, as traffic can enter a given 'area' only once in most cases. This will capture any traffic that traverses any part of the scheme and form a suitable basis for approximating interactions.
- In a similar way, the method can be easily applied to two-way links where the scheme is represented by a single link. This is because each direction of a single link is usually mutually exclusive in terms of traffic it serves.
- After the run of the tool for very complex schemes, the user should inspect the full interaction table of individual links, to make sure that there are no synergies between links that form the cordon around the scheme. A lack of synergies between links within the scheme confirms that the selected cordon links are mutually exclusive. The data to perform that inspection is readily available within the outputs from the tool.

- The user should consider if very large or complex schemes should be split to ease the analysis. For instance, a series of junction improvements located on the same road but separated by sections of the highway that see no improvements, would be likely candidates for splitting into sub-schemes as the analysis can then focus solely on the improvements in question and avoids picking up too many different flows.
- If high flows are identified to be in alternative to a given scheme the user should review context of both schemes and their aims. This does not necessarily mean that only one should be implemented and in fact, as discussed earlier, they may still be complementary. But the strength of interaction would suggest that it may be beneficial to consider such interactions in the individual appraisal of such schemes. Also, the discussion about schemes being substitutes or complements should consider the relative flow alternative interaction as there may be a lot of other traffic that each scheme serves.

5.4. Recommendations for Future Research

The presence of some of the limitations within the method suggest that it could benefit from further research and expansion, whilst building on what has already been achieved:

- The method could be expanded to cover interactions between schemes in terms of journey times. This would of course not constitute full appraisal but given that journey time savings usually form the largest proportion of scheme impacts, it would confirm with greater certainty the extent to which scheme interactions are likely to be synergetic or competitive. The following steps would be necessary to achieve this:
    - The actual schemes would need to be coded into the networks so that the impacts can be compared against Do-Minimum and so that journey time savings can be measured.
    - This would require running the model for each scheme individually and for a pair of schemes together. The time savings from the combined pair of schemes could be compared with time savings of the constituent parts. If they are greater, it confirms that time savings are also definitely in synergy. It is clear that this would require multiple models runs and the number of pairs in the portfolio of schemes is equal to the number of schemes squared. However, the method could be applied to selected scheme pairs only – those with the greatest potential for scheme interaction based on the size of the flow interaction.
    - It would be sufficient to assess vehicle-hour savings calculated from network outputs as the analysis would be based on fixed demand matrices and using Rule-of-Half to calculate benefits (method used in TUBA software for matrix-based benefit calculations) would be unnecessary.
    - The drawback is that not all scheme detail can be represented in NTMv5. For instance, junction signal improvements could not be represented as this level of detail is not available in NTMv5. Nevertheless, the analysis could be applicable to some types of schemes. It is worth noting though the methodology is transferable into other models if such detail was required. Although scripts specific to other transport modelling software packages would need to be prepared and checked, the mathematical formulation of the method, the analysis spreadsheet and Power BI dashboards could be directly adapted.
- Following on from this and mindful of the recommendations of DfT's Programmatic Appraisal research, the pair-wise analysis could be extended to groups of schemes. The greatest contributors to synergy and competition between schemes could be identified by implementing incremental and decremental analyses as set in the research. Again, what makes the analysis quicker to implement in this context is that purely vehicle-hours could be used as an indication of time savings.
- In terms of simpler improvements of the currently implemented flow-based method, it could be beneficial to modify the scripts to allow the analysis of selected user classes. Currently, the method loops through all user classes and sums the result to a total vehicle flow. Analysis of

commuting trips or Heavy Goods Vehicles specifically could be of interest in some contexts, for instance for schemes that improve access to ports or large places of employment.

- Even the current, flow-based method could potentially be extended to public transport in models other than NTMv5, for instance to support the development of rail scheme portfolios. The benefit of the flow-based method is that it would not require the modelling of passenger over-crowding (public transport equivalent of congestion) as the assessment of journey times would be unnecessary. So as long as a simple network model is available, the method can be applied reliably.
- We discussed that the method currently relies on the modelled, rather than observed data. It could potentially be improved if large volumes of good quality observed data were available in the format that resembles demand matrices and is allocated to the network with a possibility of deriving SLA. For instance, TomTom data provider has recently released a feature that enables ‘data select link analysis’ which in theory could enable similar computations.
- Finally, the method set out in this report could be scripted and applied in nay transport model, such as for instance the Saturn-based Regional Traffic Models (RTMs) developed and owned by National Highways. Such application would be able to reuse the spreadsheet and Power BI Dashboard prepared as part of this research and the only element that would need adaptation to Saturn is the SLA and matrix manipulation process. All concepts and features of the method would remain the same.

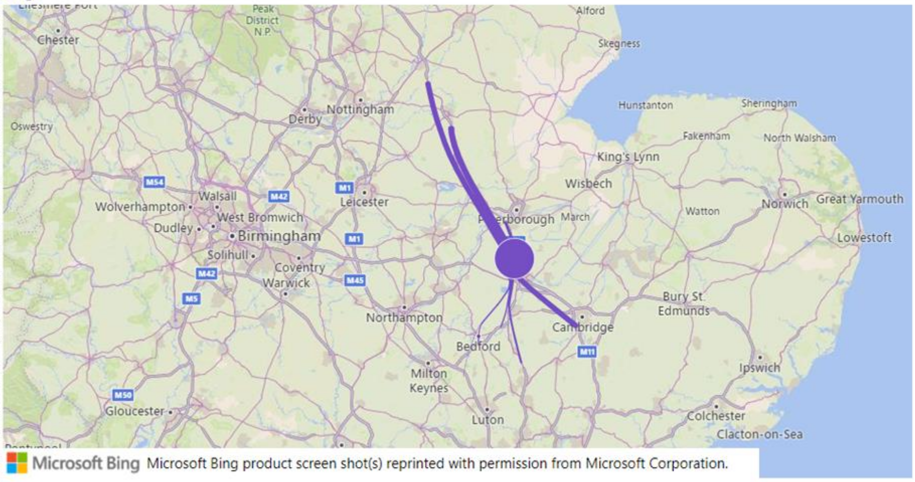
Appendix A. Further Example Results

A.1. Example S6

Figure A-1 Flow Synergies with Example S6 (A1 near Peterborough)

Scheme Synergy Flow Map

●Sc_06



SCHEMEID	SCHEME_NAME	No_of_Links
Sc_01	A1 Newark	2
Sc_02	M40	2
Sc_03	A1 Grantham	2
Sc_04	M1 between A5 & A421	2
Sc_05	A14	2
Sc_06	A1 Peterborough	2
Sc_07	A1 Biggleswade	2
Sc_08	Cambridge_Bypass_InBoundLinks	8
Sc_09	A6/A421 Jtn	4
Sc_10	A1/A605 Jtn	4
Sc_11	A421	2

Scheme Synergy Matrix - Absolute Values

Origin	Sc_01	Sc_03	Sc_04	Sc_05	Sc_06	Sc_07	Sc_08	Sc_09	Sc_10	Sc_11	Scheme Flow
Sc_06	1701	1888	125	14	4335	639	1705	317	895	413	4335
Scheme Flow	**1701**	**1888**	**125**	**14**	**4335**	**639**	**1705**	**317**	**895**	**413**	**4335**

Scheme Synergy Matrix - Proportions

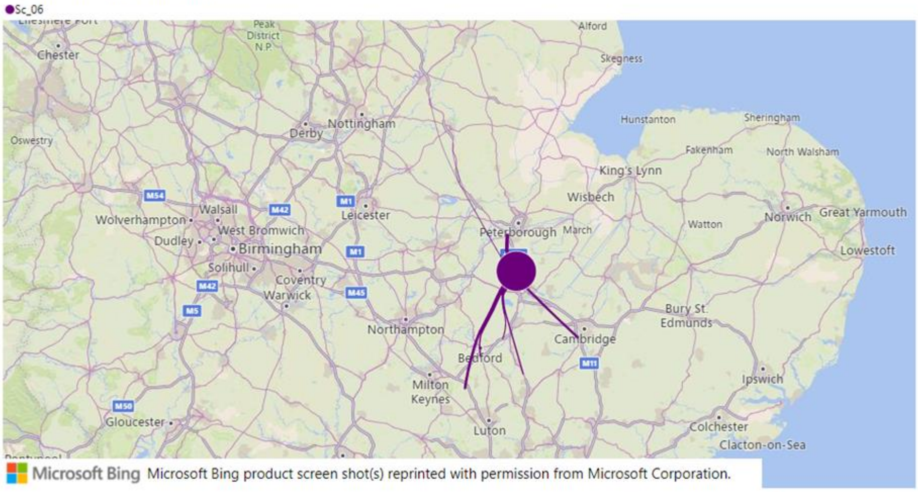
Origin	Sc_01	Sc_02	Sc_03	Sc_04	Sc_05	Sc_06	Sc_07	Sc_08	Sc_09	Sc_10	Sc_11
Sc_06	39%		44%	3%	0%		15%	39%	7%	21%	10%

Figure A-1 shows the geographical distribution of schemes which are in synergy with Example S6. It confirms observations set out in the report that the synergies tend to be aligned along the same strategic corridors and are stronger for schemes close to the analysed scheme.

Figure A-2 Flow Alternatives to Example S6 (A1 near Peterborough)

Scheme Alternative Flow Map

●Sc_06



SCHEMEID	SCHEME_NAME	No_of_Links
Sc_01	A1 Newark	2
Sc_02	M40	2
Sc_03	A1 Grantham	2
Sc_04	M1 between A5 & A421	2
Sc_05	A14	2
Sc_06	A1 Peterborough	2
Sc_07	A1 Biggleswade	2
Sc_08	Cambridge_Bypass_InBoundLinks	8
Sc_09	A6/A421 Jtn	4
Sc_10	A1/A605 Jtn	4
Sc_11	A421	2

Scheme Alternative Matrix - Absolute Values

Origin	Sc_01	Sc_02	Sc_03	Sc_04	Sc_05	Sc_06	Sc_07	Sc_08	Sc_09	Sc_10	Sc_11	Scheme Flow
Sc_06	38	3	40	268	71	4335	144	247	145	354	112	4335
Scheme Flow	**38**	**3**	**40**	**268**	**71**	**4335**	**144**	**247**	**145**	**354**	**112**	**4335**

Scheme Alternative Matrix - Proportions

Origin	Sc_01	Sc_02	Sc_03	Sc_04	Sc_05	Sc_06	Sc_07	Sc_08	Sc_09	Sc_10	Sc_11
Sc_06	1%	0%	1%	6%	2%		3%	6%	3%	8%	3%

Figure A-2 shows the distribution of schemes which are alternatives to example S6. It also confirms earlier findings that it is mostly parallel corridors that tend to act as alternatives, which was expected. It also confirms that the alternatives are unlikely to be distant parallel corridors.

Figure A-3 Select Link Result for Example S6 (A1 near Peterborough)

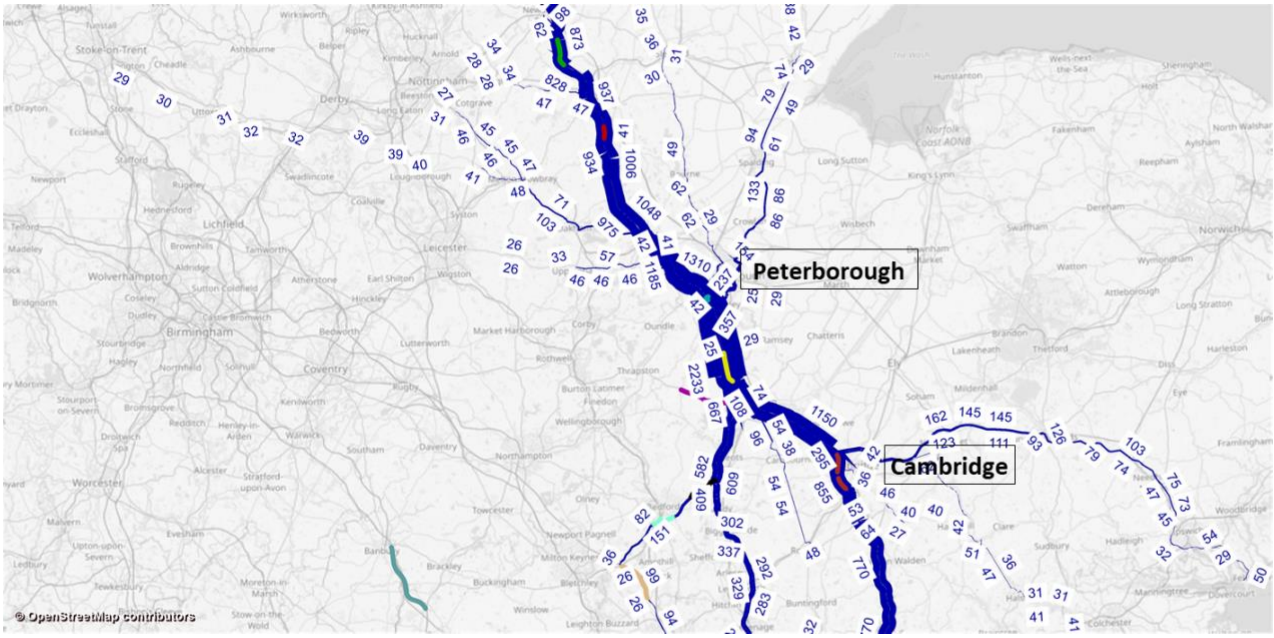


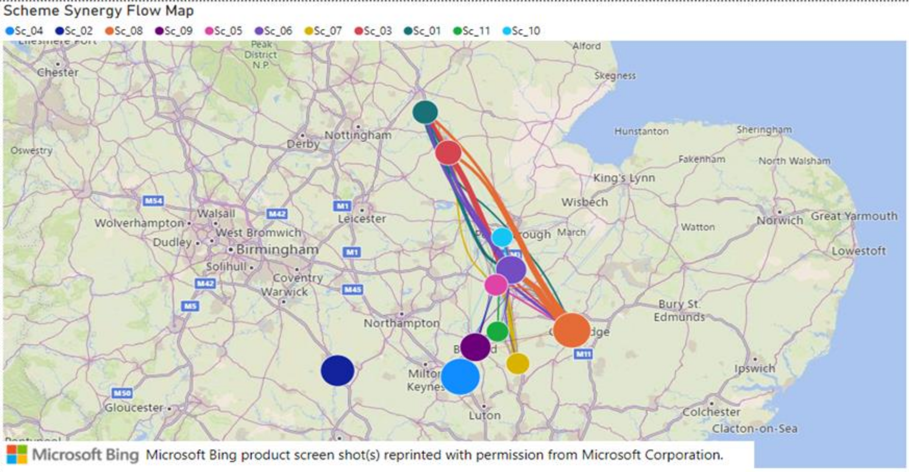
Figure A-3 illustrates select link flows for example S6. It shows why, with distance, synergy of other examples with S6 will be weaker as traffic leaves A1 to their ultimate destinations. It also illustrates how traditional model outputs differ frow the Power BI visualisation. Select link plots show all flows that use a given example and it is harder to use them to depict scheme alternatives.

The Power BI visualisation clearly points to the location of examples which interact with a given example as well as illustrates the strength of that interaction relative to the size of the analysed example. However, select link plots can be used as additional evidence or illustration of the results and in this study have been used to support quality assurance.

A.2. Example S2

Figure A-4 Flow Synergies with Example S2 (M40 near Banbury)

Scheme Synergy Flow Map



SCHEMEID	SCHEME_NAME	No_of_Links
Sc_01	A1 Newark	2
Sc_02	M40	2
Sc_03	A1 Grantham	2
Sc_04	M1 between A5 & A421	2
Sc_05	A14	2
Sc_06	A1 Peterborough	2
Sc_07	A1 Biggleswade	2
Sc_08	Cambridge_Bypass_InBoundLinks	8
Sc_09	A6/A421 Jtn	4
Sc_10	A1/A605 Jtn	4
Sc_11	A421	2

Scheme Synergy Matrix - Absolute Values

Origin	Sc_01	Sc_02	Sc_03	Sc_04	Sc_05	Sc_06	Sc_07	Sc_08	Sc_09	Sc_10	Sc_11	Scheme Flow
Sc_01	2921		2386	21		1701	253	1004	46	17	68	**2921**
Sc_02		5406										**5406**
Sc_03	2386		3168	27		1888	280	1074	57	22	85	**3168**
Sc_04	21		27	7542		125		1	511	35	245	**7542**
Sc_05					2348	14	25	467			0	**2348**
Sc_06	1701		1888	125	14	4335	639	1705	317	895	413	**4335**
Sc_07	253		280		25	639	2377		26	161	79	**2377**
Sc_08	1004		1074	1	467	1705		6928	109	254	51	**6928**
Sc_09	46		57	511		317	26	109	4343	115	1273	**4343**
Sc_10	17		22	35		895	161	254	115	1810	140	**1810**
Sc_11	68		85	245	0	413	79	51	1273	140	2087	**2087**
Scheme Flow	**2921**	**5406**	**3168**	**7542**	**2348**	**4335**	**2377**	**6928**	**4343**	**1810**	**2087**	**7542**

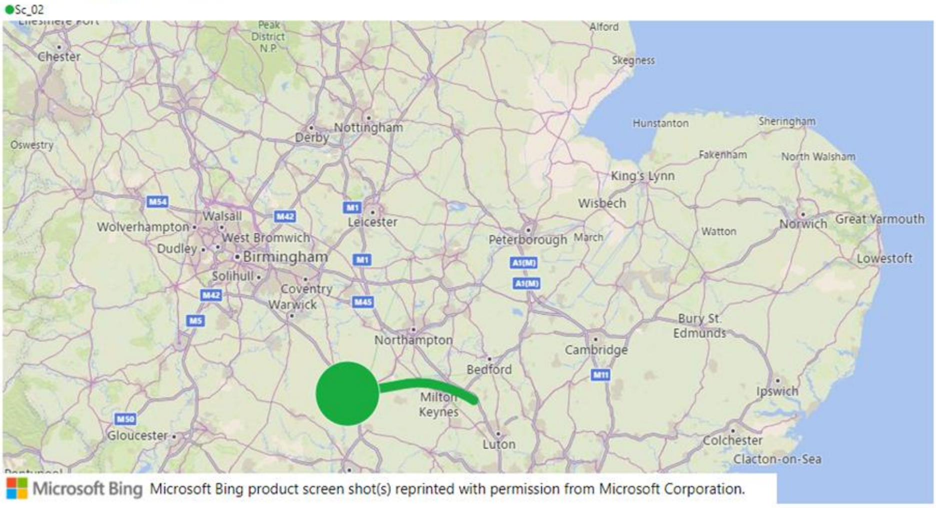
Scheme Synergy Matrix - Proportions

Origin	Sc_01	Sc_02	Sc_03	Sc_04	Sc_05	Sc_06	Sc_07	Sc_08	Sc_09	Sc_10	Sc_11
Sc_01			82%	1%		58%	9%	34%	2%	1%	2%
Sc_02											
Sc_03	75%			1%		60%	9%	34%	2%	1%	3%
Sc_04	0%		0%			2%		0%	7%	0%	3%
Sc_05						1%	1%	20%			0%
Sc_06	39%		44%	3%	0%		15%	39%	7%	21%	10%
Sc_07	11%		12%		1%	27%			1%	7%	3%
Sc_08	14%		16%	0%	7%	25%			2%	4%	1%
Sc_09	1%		1%	12%		7%	1%	3%		3%	29%
Sc_10	1%		1%	2%		49%	9%	14%	6%		8%
Sc_11	3%		4%	12%	0%	20%	4%	2%	61%	7%	

Figure A-4 shows results of flow synergy with a particular focus on example S2. In this figure synergies of all schemes need to be shown, rather than just for S2. This is because no examples are in synergy with S2 and highlighting this scheme only would result in an empty display. Selecting all examples allows the figure to be populated and shows that no other analysed examples point to S2 (furthest to the left).

Figure A-5 Flow Alternatives to Example S2 (M40 near Banbury)

Scheme Alternative Flow Map



SCHEMEID	SCHEME_NAME	No_of_Links
Sc_01	A1 Newark	2
Sc_02	M40	2
Sc_03	A1 Grantham	2
Sc_04	M1 between A5 & A421	2
Sc_05	A14	2
Sc_06	A1 Peterborough	2
Sc_07	A1 Biggleswade	2
Sc_08	Cambridge_Bypass_InBoundLinks	8
Sc_09	A6/A421 Jtn	4
Sc_10	A1/A605 Jtn	4
Sc_11	A421	2

Scheme Alternative Matrix - Absolute Values

Origin	Sc_01	Sc_02	Sc_03	Sc_04	Sc_05	Sc_06	Sc_07	Sc_08	Sc_09	Sc_10	Sc_11	Scheme Flow
Sc_02	3	5406	5	353	0	4	3	1	2	1	2	5406
Scheme Flow	**3**	**5406**	**5**	**353**	**0**	**4**	**3**	**1**	**2**	**1**	**2**	**5406**

Scheme Alternative Matrix - Proportions

Origin	Sc_01	Sc_02	Sc_03	Sc_04	Sc_05	Sc_06	Sc_07	Sc_08	Sc_09	Sc_10	Sc_11
Sc_02	0%		0%	7%	0%	0%	0%	0%	0%	0%	0%

Figure A-5 shows that example S4 on the M1 acts as a relatively noticeable alternative to S2, although the interaction is still low in absolute terms. There are no or negligible interactions with other analysed examples, which confirms earlier conclusions that alternative corridors cannot be far apart.

Figure A-6 Select Link Results for Example S2 (M40 near Banbury)

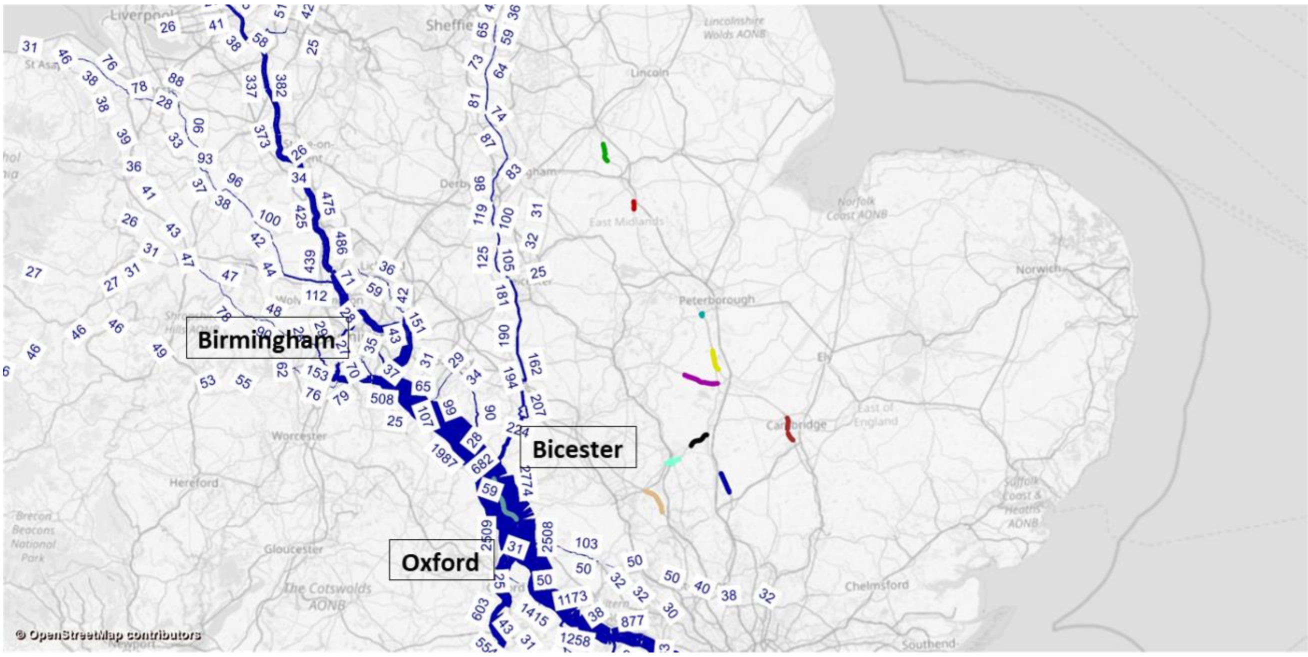


Figure A-6 demonstrates why the example has no synergies with adjacent locations. Flows it serves are primarily to West Midlands and North West, with schemes along A1 unlikely to be serve.

Appendix B. Quality Assurance

B.1. Verification of Synergy

Figure B-1 Synergy of Example S6 with Example S8

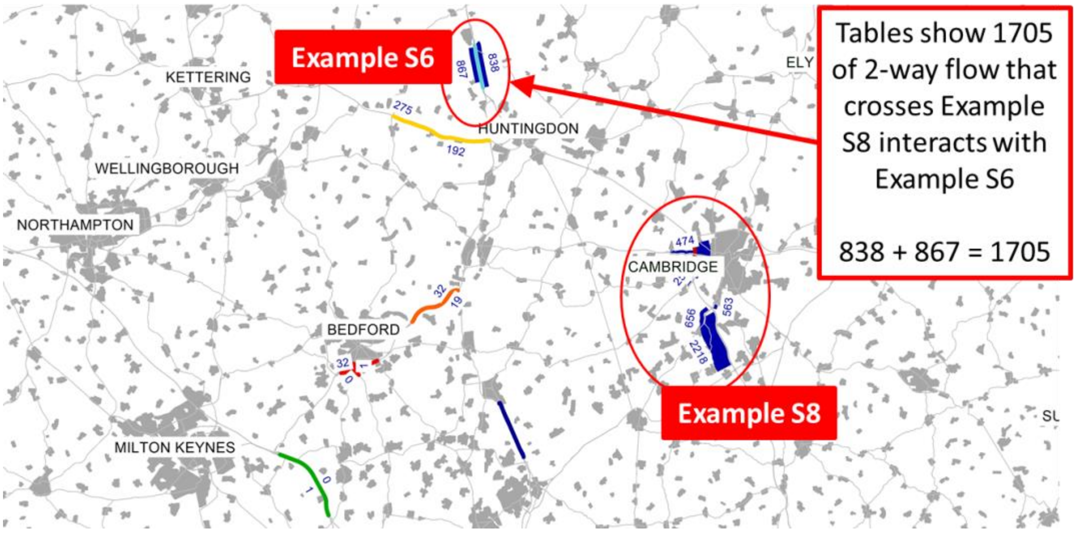


Figure B-1 shows select link flows for example S8 that also cross S6 (two-way). The values amount to 1,705, which is consistent with the flow synergy of S6 with S8 reported in the tables.

Figure B-2 Synergy of Example S3 with Example S1

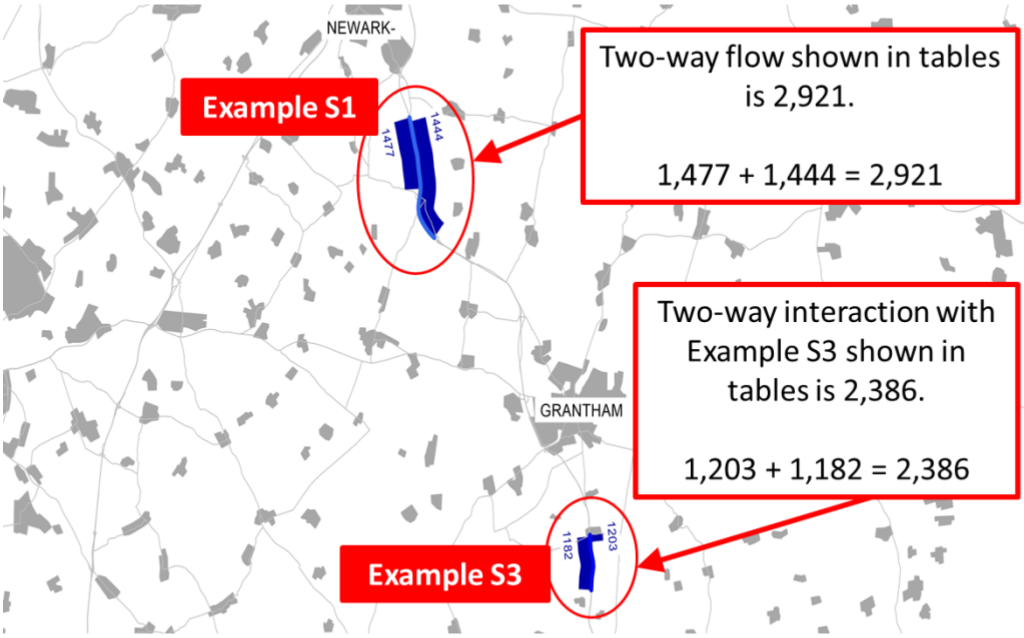
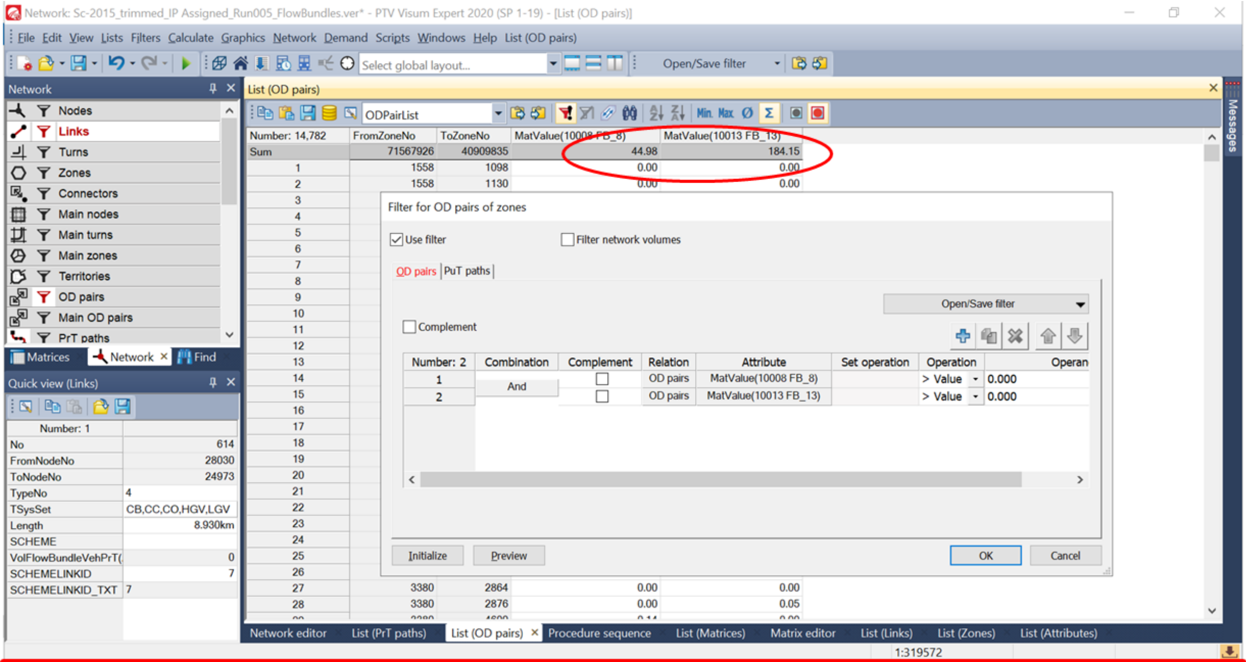


Figure B-2 shows select link flows for example S1 that also crosses S3 (two-way). The flow amounts to 2,386, which is consistent with the flow synergy of S3 with S1 reported in the tables.

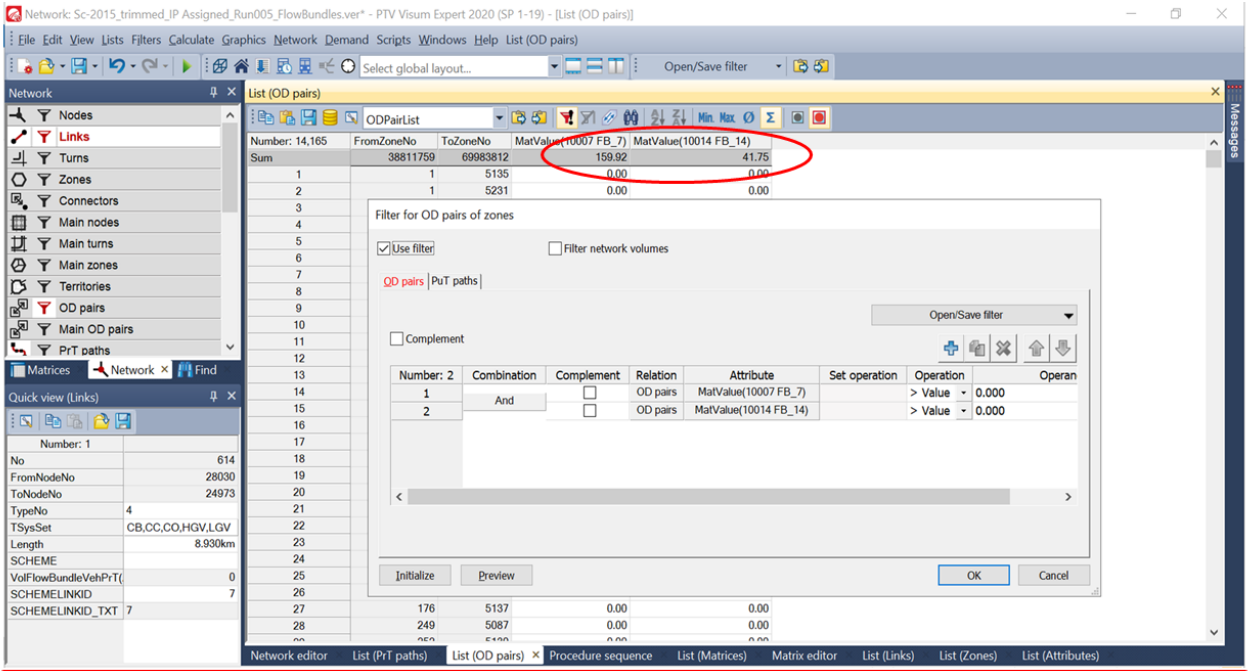
B.2. Verification of Alternatives

It is complex to visualise scheme alternatives due to the requirement for matrix manipulations. Below we present a result of manual verification of matrix calculations need to identify traffic on example S4 and S7 for the OD pairs shared between these example locations. Figure B-3 shows the filtered common ODs for these two locations by direction. The figure illustrates 42 trips on S7 and 159 trips on S4 in one direction and then 184 and 44 trips respectively in the other direction.

Figure B-3 Verification of Common ODs Between Example S4 and Example S7



FB_13 of Example S7 & FB_8 of Example S4 are parallel and alternatives. 184 trips out of 1140 trips on FB_13 share the same OD pairs with 44 trips out of 3705 trips on FB_8.



FB_14 of Example S7 & FB_7 of Example S4 are parallel and alternatives. 42 trips out of 1237 trips on FB_14 share the same OD pairs with 159 trips out of 3838 trips on FB_7.

This amounts to 42 + 184 = 226 trips on S7 which share ODs with S4. For S4 this amounts to 159 + 44 = 205 trips which share ODs with S7. As S4 and S7 were reported to have no flow synergy no subtraction is needed, and these figures directly represent the flow alternatives between these two example locations (Figure B-4).

Figure B-4 Verification of Flow Alternatives

Row Labels	Sc_01	Sc_02	Sc_03	Sc_04	Sc_05	Sc_06	Sc_07	Sc_08	Sc_09	Sc_10	Sc_11
Sc_01	-	3	-	129	3	14	41	114	20	39	17
Sc_02	4	-	5	353	-	4	3	1	2	1	2
Sc_03	2	3	-	139	3	17	47	124	27	43	23
Sc_04	91	235	92	-	26	119	205	101	193	19	14
Sc_05	8	0	8	33	-	144	6	182	52	6	42
Sc_06	38	3	40	268	71	-	144	247	145	354	112
Sc_07	10	1	10	226	19	2	-	101	174	51	165
Sc_08	21	2	21	135	69	32	66	1,378	23	87	83
Sc_09	4	0	4	75	106	4	161	151	201	55	66
Sc_10	29	0	29	54	2	9	39	40	74	5	62
Sc_11	3	0	3	41	62	1	145	55	86	63	-

B.3. Verification of Aggregation of Link Results

Figure B-5 Aggregation of Results for Example S8

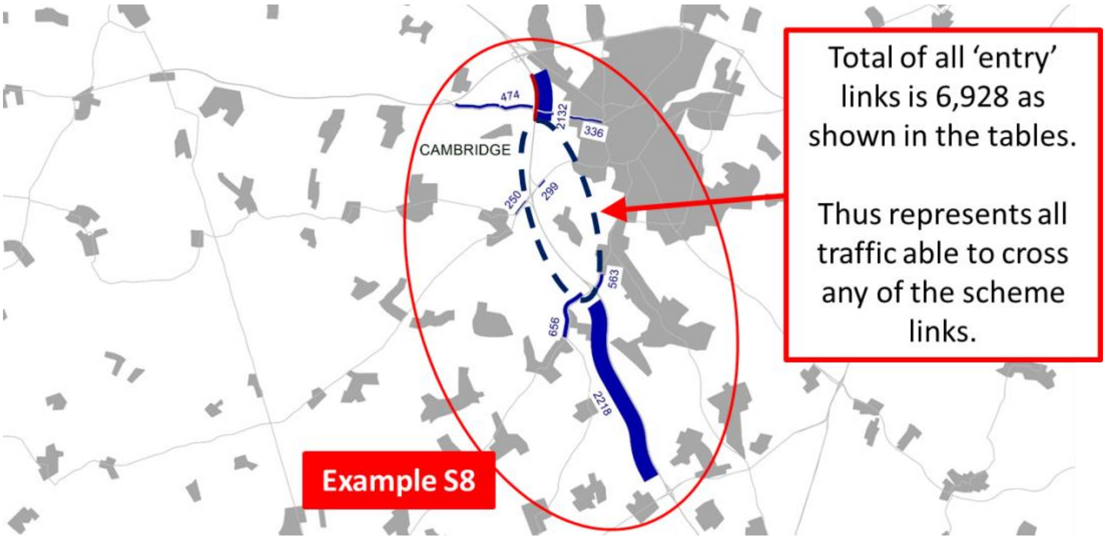


Figure B-5 shows the accuracy of the individual link flow aggregation routines. The total traffic for each cordon 'entry' Select Link sums to 6,928 vehicles, which is the value reported as total traffic that crosses S8 in synergy tables in this report.

ATKINS Jacobs