GIS-Based Models and GIS-Tools for Sustainable Transport Planning in Israel and Palestine

("GIS-Verkehrsplanung")
PL 188/6-2

Phase 2
1 March 1999 – 31 March 2001

Final Report

31 March 2001

Prof. Dr. Lutz Plümer
Institut für Kartographie und Geoinformation, Universität Bonn

Prof. Dr. Michael Wegener
Institut für Raumplanung Universität Dortmund

Prof. Dr. Ilan Salomon
Department of Geography Hebrew University of Jerusalem

Prof. Dr. Jad Elias Isaac
Applied Research Institute Jerusalem Bethlehem
# Table of Contents

1 **Introduction** ................................................................................................................ 3

2 **Context and Project Operation** ................................................................................. 5

3 **Results** ......................................................................................................................... 9
   
   3.1 The Modelling System ............................................................................................... 9
   3.1.1 Analytical Framework ....................................................................................... 9
   3.1.2 Interface between ArcInfo and EMME/2 ......................................................... 11
   3.1.3 Network Extension Tool .................................................................................. 14
   
   3.2 The Integrated Database ......................................................................................... 20
   3.2.1 Digital Terrain Model ..................................................................................... 20
   3.2.2 Road Network Database ............................................................................... 22
   3.2.3 Zone System .................................................................................................. 27
   3.2.4 Socio-Economic Data .................................................................................... 27
   
   3.3 Policy Scenarios ...................................................................................................... 30
   3.3.1 Background .................................................................................................... 30
   3.3.2 Policy Analysis ............................................................................................... 31
   3.3.3 Definition of Scenarios .................................................................................. 35
   3.3.4 Simulation Results ........................................................................................ 38

4 **Conclusions and Future Work** .................................................................................. 46

5 **Appendix** ..................................................................................................................... 48
   
   Appendix 1: Co-operation Partners ............................................................................. 48
   Appendix 2: Staff ........................................................................................................... 49
   Appendix 3: Theses and Publications .......................................................................... 50
   Appendix 4: Setting Up the D-GPS ............................................................................ 51
   Appendix 5: Completing the DTM ............................................................................. 52
   Appendix 6: Traffic Flows ........................................................................................... 53
1 Introduction

The objective of the trilateral (German-Israeli-Palestinian) project "GIS-Based Models and GIS-Tools for Sustainable Transport Planning in Israel and Palestine" was the development and adaptation of GIS-based models and GIS tools for sustainable, i.e. resource preserving, transport planning in a regional context that, because of its high dynamics and the current political conditions, puts high demands on the flexibility of the methods to be applied.

Sustainable transport planning in Israel and the emerging Palestinian state faces major uncertainties and challenges. With rising income levels and car ownership, problems of road congestion, air pollution and traffic noise are expected to multiply in this densely populated region. While on the Israeli side massive road construction has replicated trends in other developed countries, the transport infrastructure in the Palestinian territories has been neglected for decades. The by-pass roads built by the Israeli authorities to link Israeli settlements with Israel and the restrictions on travel by Palestinians aggravate the problems of inequity in mobility. Air pollution generated by traffic in the conurbations of central Israel is transmitted to the West Bank due to prevailing air flows. These conditions have made transport planning proposals for Israel and the West Bank highly sensitive conflict-laden issues.

The trilateral project was to contribute to the rational solution of these conflicts by providing state-of-the-art tools to assist in the rational assessment of the long-term equity and environmental implications of alternative transport planning policies for the West Bank and adjacent areas of Israel and Jordan. In view of the need to reach significant results in a short time, and in line with the recommendations of the reviewers of the proposal, the focus was on the adaptation of existing rather than on the development of new models.

The project was conducted in two phases. Project Phase 1 started in March 1997 and ended in February 1999. Phase 2 started in March 1999 and officially ended in February 2000. However, because of difficulties in communication between the project partners caused by external circumstances, the actual work was not completed before March 2001.

- Phase 1. The first, and most important, achievement of Phase 1 was the development of an integrated, homogeneous database from a variety of heterogeneous data sources providing all data required for computer-based transport planning in the study area consisting of four components: a digital terrain model, a road network database, a system of traffic analysis and land use zones, and socio-economic data for these zones. In addition, a set of models and tools required for sustainable transport planning in the study area will was developed: a software interface for the data exchange between a geographic information system and a transport planning package, a meso-meteorological model and a tool for designing road network extensions. To lay the ground for the simulation of transport policies in Phase 2 of the project, a range of transport policies and their major assets and consequences were analysed and combinations of policies or 'policy packages' were defined. In addition, exogenous scenarios reflecting long-term socio-economic trends or policies in other policy fields were identified. The results of Phase 1 were summarised in a report to the Deutsche Forschungsgemeinschaft dated 15 September 1998.

- Phase 2. The proposal for Phase 2 proposed an extension of the model framework by sub-models for public transport and paratransit, freight transport and meso-scale and local environmental impacts as well as extensive applications of the extended model framework to a large number of policy scenarios. However, instead of this larger three-year project, only a
one-year extension of the project with a much reduced set of tasks was approved by the DFG. The only remaining objective of Phase 2 of the project was to complete, test and apply the integrated spatial database and the models and tools developed in Phase 1 to a smaller number of policy scenarios in order to demonstrate the usefulness and applicability of the developed framework.

Despite this reduction of tasks, work on Phase 2 started in an atmosphere of great optimism with regard to the success of the project. Final preparations for the model simulations, such as refinements of the integrated database, model calibration runs and discussions on the policy scenarios to be simulated were conducted during 1999. For the end of the project a major workshop in Bethlehem or Jerusalem with invited experts and decision makers from both the Israeli and Palestinian side was planned.

However, the re-intensification of conflict between Israeli and Palestinians and the outbreak of the "Second Intifada" in the year 2000 had its impact on the project. Communication between the Israeli and Palestinian project partners was becoming increasingly difficult, so that agreement on the policy scenarios to be simulated was not reached until early 2001. There is presently no prospect that the planned workshop in Bethlehem or Jerusalem will take place.

These externally imposed difficulties have prevented the project to reach its ultimate goal to serve the planning practice in the West Bank and support the co-operation of Israeli and Palestinian researchers and planners in the joint pursuit of sustainable transport.

This report therefore has the limited function to present the tools developed and the results achieved so far in the hope that further collaboration with the Israeli and Palestinian partners will be possible in the not too far future.
2 Context and Project Operation

The objective of the trilateral (German-Israeli-Palestinian) project "GIS-Based Models and GIS-Tools for Sustainable Transport Planning in Israel and Palestine" was the development and adaptation of GIS-based models and GIS tools for sustainable, i.e. resource preserving, transport planning in a regional context that, because of its high dynamics and the current political conditions, puts high demands on the flexibility of the methods to be applied.

Sustainable transport planning in Israel and the emerging Palestinian state faces major uncertainties and challenges. With rising income levels and car ownership, problems of road congestion, air pollution and traffic noise are expected to multiply in this densely populated region. While on the Israeli side massive road construction has replicated trends in other developed countries, the transport infrastructure in the Palestinian territories has been neglected for decades. The by-pass roads built by the Israeli authorities to link Jewish settlements with Israel and the restrictions on travel by Palestinians aggravate the problems of inequity in mobility. Air pollution generated by traffic in the conurbations of central Israel is transmitted to the West Bank due to prevailing air flows. These conditions have made transport planning proposals for Israel and the West Bank highly sensitive conflict-laden issues.

The trilateral project was to contribute to the rational solution of these conflicts by providing state-of-the-art tools to assist in the rational assessment of the long-term equity and environmental implications of alternative transport planning policies.

The study area of the project comprised the West Bank and adjacent areas of Israel and Jordan; a larger area containing the major economic and social activities of Israel and the Palestinian territories was treated with less detail (see Figure 1).

In view of the need to reach significant results in a short time, and in line with the recommendations of the reviewers of the proposal, the focus was on the adaptation of existing rather than on the development of new models. ArcInfo (Environmental Systems Research Institute, Redlands, California, USA) was selected as the main geographic information system and EMME/2 (INRO Consultants, Montreal, Canada) as the transport modelling software.

The project was conducted in two phases. Project Phase 1 started in March 1997 and ended in February 1999. Phase 2 started in March 1999 and officially ended in February 2000. However, because of difficulties in communication between the project partners caused by external circumstances, the actual work was not completed before March 2001.

Phase 1

The first, and most important, achievement of Phase 1 was the development of an integrated, homogeneous database from a variety of heterogeneous data sources providing all data required for computer-based transport planning in the study area consisting of the following four components:
Figure 1. The study area.
- a digital terrain model based on three panchromatic SPOT stereo scenes taken in October/November 1997 describing the mountainous relief of almost the entire study area (see Figure 1) at a very high level of detail and accuracy;

- an integrated and homogeneous road network database containing all major Israeli and Palestinian roads in the study area derived from several partial network databases of different origins, coordinate systems and precision;

- an integrated system of traffic analysis and land use zones consisting of 104 zones in the West Bank and 155 zones in Israel extracted from existing sources and made geometrically homogeneous with the digital terrain model and the road network database;

- socio-economic data such as population, households, economically active persons, car ownership, work places and built-up areas.

In addition to the integrated spatial database, a set of models and tools required for sustainable transport planning in the study area was developed:

- a software interface for the two-way data exchange between the geographic information system ArcInfo and the transport planning package EMME/2 consisting of conversion tools written in the ArcInfo macro language AML;

- a meso-meteorological model to predict air flows at an intermediate scale (4x4 km²) for an area from the Syrian border in the north to Eilat in the south and a subsequent air pollution dispersion model (1x1 km²) calculating pollution in each grid cell from vehicle emissions based on registered vehicle density;

- a tool for selecting road network extensions that minimise a cost function between two points consisting of a prototype integrating the digital terrain model and the network data using constrained Delaunay triangulation and the interactive identification of intermediate or Steiner points.

To lay the ground for the simulation of transport policies in Phase 2 of the project, the range of transport policies and their major assets and consequences were analysed. Four categories of policies were identified: transport technology policies, transport infrastructure policies, transport regulation policies and transport taxation policies. To take account of synergies (as well as of negative interactions) between policies, combinations of policies, or 'policy packages', were defined.

In addition, exogenous scenarios reflecting long-term socio-economic trends or policies in other policy fields were identified. Four types of possible exogenous scenarios were identified: political scenarios, economic scenarios, population scenarios and land use scenarios. A 'policy scenario' to be simulated with the model system developed in the project is therefore a combination of a political scenario, an economic scenario, a population scenario, a land use scenario and a transport policy package.

The results of Phase 1 were summarised in a report to the Deutsche Forschungsgemeinschaft dated 15 September 1998.
Phase 2

The proposal for Phase 2 proposed an extension of the model framework by submodels for public transport and paratransit, freight transport and meso-scale and local environmental impacts as well as extensive applications of the extended model framework to a large number of policy scenarios. However, instead of this larger three-year project, only a one-year extension of the project with a much reduced set of tasks was approved by the DFG.

The only remaining objective of Phase 2 was to complete, test and apply the integrated spatial database and the models and tools developed in Phase 1 to a smaller number of policy scenarios in order to demonstrate the usefulness and applicability of the developed framework. During Phase 2, the four project partners performed the following tasks:

- The Palestinian partner, the Applied Research Institute of Jerusalem (ARIJ), collaborated with the Israeli partner, the Department of Geography of Hebrew University (DG), in finalising the system of traffic analysis zones (Section 3.2.3) and updating the road network database to include checkpoints and road links prohibited for Palestinian vehicles (Section 3.2.2). In addition, ARIJ extended the digital terrain model developed in Phase 1 to include the missing north-western part of the West Bank (Section 3.2.1) and updated the demographic data to accommodate the Palestinian census data (Section 3.2.4). In several meetings, members of ARIJ and DG discussed and finally agreed on three policy scenarios to be simulated in Phase 2 (Section 3.3.3).

- The Israeli partner, the Department of Geography of Hebrew University, collaborated with ARIJ in finalising the system of traffic analysis zones (Section 3.2.3), in updating the road network database to include checkpoints and road links prohibited for Palestinian vehicles (Section 3.2.2) and in the definition of the three policy scenarios to be simulated (Section 3.3.3). Based on the implementation of the three policy scenarios in ArcInfo by IRPUD (Section 3.3.3), DG conducted the simulation of the three policy scenarios using the transport model EMME/2 (Section 3.3.4).

- The Institute of Spatial Planning of Dortmund University (IRPUD) extended the software modules of the two-way interface between ArcInfo and EMME/2 to include the new data items described above (Section 3.1.2). IRPUD entered the road network updates and changes of socio-economic and network data for the three policy scenarios provided by ARIJ and DG into ArcInfo and, after several iterations and cross-checks, converted them to EMME/2 input format using the ArcInfo-EMME/2 interface (Section 3.3.3). After the simulation, IRPUD converted the EMME/2 results of the three policy scenarios to ArcInfo using the EMME/2-ArcInfo interface and prepared the result maps presented in this report (Section 3.3.4).

- The Institute of Cartography and Geoinformation of the University of Bonn (IKG) developed the network extension tool (Section 3.1.3) and was in charge of overall project coordination.

Communication between all four project partners – besides the personal meetings between ARIJ and DG – was conducted via e-mail and the common project server maintained at IKG. The planned concluding workshop involving planners and decision makers of both the Palestinian and Israeli side was not conducted because of the political situation.
3 Results

The description of the results of the project in this section is structured in three parts. The first part (Section 3.1) presents the modelling system developed and used in the project. The second part (Section 3.2) describes the integrated database. The third part (Section 3.3) presents the results of the three policy scenarios. The presentation focuses on the results of Phase 2, results of Phase 1 are referred to only where necessary.

3.1 The Modelling System

The integrated modelling system originally envisaged and partially developed in Phase 1 of the project was more comprehensive than the one actually used in Phase 2. In order to explain the context of the components actually used, first the intended analytical framework is presented (Section 3.1.1). Subsequently, the modules implemented and used in Phase 2 are presented: the interface between ArcInfo and EMME/2 (Section 3.1.2) and the network analysis tool (Section 3.1.3).

3.1.1 Analytical Framework

During Phase 1 of the project, an integrated model system for forecasting environmental impacts of transport policy scenarios in the study area was developed.

Figure 2 is a diagrammatic representation of the structure of the proposed system of models and tools as seen from the perspective of the user. Transport policies are entered at the Policy Analysis level subject to assumptions about political, economic, population and land use scenarios and are modelled using the integrated model system. The results of the simulations are converted to raster cells for processing in air quality or traffic noise models or to the triangulation used for the design of network extensions. The indicators produced by the transport model and the environmental sub-models are evaluated with respect to sustainability criteria such as equity, environment and efficiency.

The components of the integrated model system are:

- ArcInfo. The geographical information system ArcInfo (Environmental Systems Research Institute, Redlands, California, USA) is used to maintain, edit, plot and facilitate the spatial database. In that, ArcInfo serves as the core tool of the modelling system providing and receiving data to and from other (sub-)models, such as EMME/2, the Network Extension Tool and the Raster Module.

- EMME/2. The transport simulation model EMME/2 (INRO Consultants, Montreal, Canada) is used to model the specified scenarios to derive information on traffic flows, congestion and travel times.

- Raster Module. The results of the simulations are converted into ArcInfo format from which they are converted to raster cells for further processing in the Raster Module. This module is designed to simulate social and environmental impacts of the transport flows modelled.
Figure 2. The integrated model system.
- **Network Extension Tool.** Based on information provided by ArcInfo, the Network Extension Tool determines road optimum alignments for new road projects. The tool minimises a cost function between two or more locations by (i) integrating the digital terrain model and the network data by constrained Delaunay triangulation and (ii) automatic identification of intermediate or Steiner points.

- **Windfield Model.** A meso-meteorological model was developed to predict wind flows on an intermediate scale based on equations for horizontal motion, continuity, temperature and relative humidity within the atmosphere.

- **Photochemical Reaction Model.** This model simulates trace movements and photochemical reactions leading to ozone concentrations.

The indicators produced by the integrated model system are finally evaluated with respect to sustainability, i.e. with respect to equity, environment and efficiency.

Because of reduced time frame of Phase 2, of the above comprehensive modelling framework, only the interface between ArcInfo and EMME/2 and the network extension tool were implemented in Phase 2 of the project. They are described below.

### 3.1.2 Interface between ArcInfo and EMME/2

In order to take advantage of the superior data organisation of geographic information systems, a software interface for the two-way exchange of data between ArcInfo and EMME/2 was developed. The software performs two-way conversion between the different representations of network and zonal data of the two software packages. The interface consists of the following four conversion tools written in the ArcInfo Macro Language (AML):

- The macro `arc2emme` performs the transfer of network data from an ArcInfo coverage to EMME/2 batch file format

- The macro `emme2arc` performs the conversion of EMME/2 network data from EMME/2 batch file format to an ARC/INFO coverage.

- The macro `tab2matrix` converts ARC/INFO Polygon Attribute Tables (PAT) to EMME/2 origin or destination matrices.

- The macro `matrix2tab` converts EMME/2 origin, destination and origin-destination matrices to ARC/INFO Polygon Attribute Tables (PAT).

All conversion operations preserve all relevant information and attributes throughout the transformation process. All macros are executed from the Arc prompt within ArcInfo. Two additional macros serve as shell for the conversion tools:

- The macro `trnets` controls conversion from ArcInfo to EMME/2. It extracts scenario data from the ArcInfo database and calls the macros to convert them to EMME/2 format.

- The macro `putback` controls conversion from EMME/2 to ArcInfo. It extracts EMME/2 results from the EMME/2 database and calls the macros to convert them to ArcInfo format.
The macros take account of different approaches of network representation within ArcInfo and EMME/2. A road network in ArcInfo consists of nodes and links. The alignment of the links can be described in great detail with up to 500 intermediate vertices (Figure 3, top). The ArcInfo network is based on real-world co-ordinates. Information about the network can be overlaid with other geographic information (e.g. land use). The user can design her own network information system with a relational database management system. Every spatial element has an attribute table with a set of predefined items used by the system. This table can be expanded with user-defined items.

The EMME/2 network, too, consists of nodes and links (see Figure 3, bottom). However, the EMME/2 network is only a generalised representation of the real network. The geographic position of the nodes is not defined in real-world co-ordinates, and the links do not represent the alignment between nodes. The whole network can be established in a model-specific coordinate system. Each link has its own attributes (e.g. number of lanes or travel time). Every element of the network has a special set of attributes. Moreover, collections of links such as transit lines may be defined. All roads - except one-way roads - are represented by two links. Nodes, links, turns and transit lines may have up to three additional user-defined attributes.

The comparison of the two network representations of ArcInfo and EMME/2 in Figure 3 shows that the network in ArcInfo is more detailed. Furthermore, ArcInfo links are not assigned a specific direction in terms of driving directions (of course, ArcInfo uses internal arc orientation as well) whereas in EMME/2 each link is attributed with a direction. The ArcInfo data model does not limit the number of attributes associated with a data item.

When building an interface between ArcInfo and EMME/2, two main implications have to be solved: the way links are represented and network aggregation and conflation:

- **Network representation.** By transferring the network from ArcInfo to EMME/2 each two-way ArcInfo link is represented as two one-way links in EMME/2. In addition, the attributes associated with the two directions have to be transferred to the two links in EMME/2. For the reverse case, when results of EMME/2 are to be transferred to ArcInfo, the attributes of the two EMME/2 links must be transferred to one arc in ArcInfo. Different values for both directions must be stored in two items in the Arc Attribute Table.

- **Network aggregation and conflation.** Building a transport information system for the study area involves a detailed road network where all sorts of roads are stored in the GIS. For the purpose of transport modelling, however, it is sufficient to consider major roads between the transport zones only. Therefore, a network aggregation process is required before the network can be converted from ArcInfo to EMME/2. From the complete network with various categories of roads so-called ‘strategic links’ are selected (step 1), i.e. the most important road links in the study area. These strategic links are transferred to a new coverage, whereas the remaining road categories are excluded (step 2). In the third and final step redundant nodes, i.e. nodes without intersections or changes in attribute characteristics are deleted before the network is transferred from ArcInfo to EMME/2 (step 3). When re-converting results of EMME/2 to ArcInfo, the same steps must be performed in the reverse direction. The results of EMME/2 have to be converted first to the aggregated ArcInfo coverage and then in a second step to the original full road network. This process is called conflation.
Figure 3. Network representation in ArcInfo (top) and in EMME/2 (bottom).
3.1.3 Network Extension Tool

The aim of the network extension tool is to connect multiple locations with least construction and travel cost. Shortest-path algorithms are not suitable to connect more than two locations. The proposed network extension tool introduces Steiner points, additional vertices to the network. Finding optimal Steiner Points is known to be NP-hard, i.e. algorithms which guarantee optimal solutions are exponential in the worst case. Thus powerful heuristics are needed.

Interaction of the network extension tool with ArcInfo and EMME/2

The developed algorithm is based on a two-level model which exploits the geomorphology of cost mountains by dividing the problem into smaller ones (divide-and-conquer technique) and using an essential extension of the Dijkstra single-source shortest-path algorithm to retrieve a restricted number of Steiner points.

Fixed local costs, such as topography, political restrictions or nature reserves, are represented in the cost surface by a homogenous constrained Delaunay triangulated model developed in Phase 1. Global costs, such as traffic volumes, are taken into account during the generation of paths between locations. The model supports the consideration of construction costs and of the travel costs supplied by EMME/2 via the EMME/2-ArcInfo interface (see Figure 2). The relationship is presented in more detail in Figure 4:

![Figure 4. Interaction of the network extension tool with ArcInfo and EMME/2](image)

Geomorphology: water flow

The prototype for deriving network extensions developed in Phase 1 of the project was extended to eliminate minor problems like intercepting triangles at the border of the study area. In addition, two approaches of retrieving water catchment areas (basins) were studied. The first approach takes any hollow to generate a basin. Since this leads to a crude partitioning of the research area, this approach was rejected. In the second approach hollows are processed in descending order of their z-value. This approach leads to aggregation of catchment areas, where one area may contain several other areas depending of their depth. Figure 6 illustrates this for a test area north of Ramallah in the West Bank (Figure 5).
Figure 5. The test area north of Ramallah

Figure 6. Non-deterministic (left) and deterministic (right) retrieval of basins
The water flow of each triangle of the triangulation is described by its edges, transfluent, co-fluent and diffluent (Figure 7). Triangles with two outflow edges cannot unambiguously assigned to one water catchment area. This leads to a splitting of these triangles and recursively of its predecessors of water flow for preserving a triangulation of the surface.

![Figure 7. Water flow (left) and pseudo edges (3 right figures)](image)

**Geomorphology: passes**

Three different kinds of passes are extracted by the model. At first the 'normal' or 'significant' passes are extracted. These are passes satisfying the description of passes, i.e. they lie on a border between basins, present a local minimum on this border, and there exists a subsequence minimum–maximum–minimum–maximum. Next, 'insignificant' passes are extracted which do not lie on a border between basins but fulfil the remaining criteria. These passes are irrelevant for the solution. Finally, 'artificial' passes are extracted which fulfil all pass criteria except the subsequence on borders between two basins without 'normal' passes.

**Shortest paths: detail level**

The 'divide' step is performed by the extraction of basins (Figure 8). The lower level of the two-level model restricts the examination of basins. Each basin contains passes and further locations like towns to connect.

![Figure 8. Partitioning of the study area in basins and the two-level model](image)
For connecting three or more locations a method exploiting the Dijkstra shortest-path algorithm was developed: The shortest path from each location to all other vertices of the basin is calculated by taking local edge-cost (handicap), edge-length, slope, difference in altitude/z-value and the angle between the edges of the path into account.

Eventually, each vertex has an array with the costs to each location of its basin. The sum of these costs represents the total cost from the vertex to all locations of the basin. The vertex with the lowest total cost in the basin is a Steiner point. Figure 9 shows an example of a basin with three locations highlighted in black, magenta and orange. The number halfway along an edge between two vertices is the cost associated with that edge. The vertex circled in blue is the Steiner point, i.e. the vertex for which the total of the costs of the shortest paths to the three locations (shown in blue) is the lowest of all vertices in the basin.

![Figure 9. Derivation of a Steiner point in a basin](image)

**Shortest paths: aggregate level**

The higher level of the two-level model represents the 'conquer' step. Now each basin is represented by a vertex. Neighbouring basins with common passes are represented by edges in the graph. The cost of each edge is determined during the lower-level phase as the cost between the Steiner points of the two basins and the least-cost pass between the two basins. There are special vertices representing basins which contain (one or more) locations to connect. The aim of the aggregate level is to connect these special vertices. The shortest paths and a Steiner point can be derived by applying the extended Dijkstra algorithm already used in the lower-level phase. Finally all vertices retrieve an array of costs to each special vertex. In contrast to the lower level, there are no passes to consider here. The vertex with the lowest total cost is a Steiner point.
Running time

The running time of deriving Steiner points at the detail level is $O(v_b^2 l_b)$ per basin, where $v_b$ represents the number of vertices and $l_b$ the number of locations, passes included, per basin. At the aggregate level the running time for deriving Steiner points is $O(b^2 l_b)$, where $b$ represents the number of basins and $l_b$ the number of locations. The total running time is $O(b^2 l_b + b (v_b^2 l_b))$ plus the running time of the extraction of the geomorphology $O(v_t)$, where $v_t$ is the total number of vertices. Thus the running time is $O(v_t^4)$ in the worst case.

Interfaces

Since the digital terrain model (DTM) data of the project are held in ArcInfo, the network extension tool supports the import of triangulated irregular network (TIN) data in ArcInfo’s net-file format. Parameters, such as the weights of edge length, slope factor and angle factor and which nodes are to be connected are imported as well.

The results of the network extension tool, the extended networks, are exported to ArcInfo employing the concept of simple features, a standardised interoperable data format defined by OpenGIS (Open GIS Consortium).

In addition, the network extension tool provides a visualisation component which shows the alignment of the optimum network extensions and other features, such as passes shortest paths or geomorphology. Figure 10 is a screenshot of a typical situation. The light gray lines are the triangulation of the cost surface. The edges of basins are shown in blue, whereas shortest paths are indicated in red. Locations to connect are shown in orange, passes in red, artificial passes in green and chosen Steiner points in dark green. The user can select the features to be displayed and the colour scheme in an interactive menu (Figure 11). The viewer is a powerful and important tool to retrieve a quick visual verification of the results, whereas a manual verification of coordinates would be very time-consuming due to the huge amount of data.
Figure 10. Screenshot visualisation of network extensions

Figure 11. Screenshot visualisation of feature and colour selection menu
3.2 The Integrated Database

The integrated database for computer-based transport planning developed in Phase 1 of the project consisted of four components:

- a digital terrain model based on three panchromatic SPOT stereo scenes taken in October/November 1997 describing the mountainous relief of almost the entire study area at a very high level of detail and accuracy;

- an integrated and homogeneous road network database containing all major Israeli and Palestinian roads in the study area derived from several partial network databases of different origins, coordinate systems and precision;

- an integrated system of traffic analysis and land use zones consisting of 116 zones in the West Bank and 155 zones in Israel extracted from existing sources and made geometrically homogeneous with the digital terrain model and the road network database;

- socio-economic data such as population, households, economically active persons, car ownership, work places and built-up areas.

This database was described in the report on Phase 1. In this section, only the updates of the database necessary to conduct the scenario simulations presented in Section 3.3 will be described.

3.2.1 Digital Terrain Model

The digital terrain model developed in Phase 1 of the project was processed to accommodate for the missed section in the north-western part of the West Bank. Appendix 4 explains the technical procedure followed to produce and integrate the DTM.

The DTM developed in Phase 1 was extracted from three stereo pairs SPOT scenes acquired for the year 1997. Unfortunately, the three scenes did not cover the north-western part of the West Bank. The integration of the whole area was carried out in Phase 2. The missing data were substituted from contour maps that were digitised and registered in the GIS projection used for the other maps in the project (UTM WGS84). The integration of the data involved three major steps. The first step was cleaning the digitised contours for the missing area. The second step involved creating a grid out from the cleaned contours using the GRID function of ArcInfo. The third step was linking the new grid to the DTM developed in Phase 1. The resolution of the new DTM is 20 metres. Because the contours for the missing area are 20 metres in resolution, it was considered important to adopt this resolution for the whole DTM.

The resulting DTM is shown in Figure 12. The map shows the extreme differences in elevation in the study region. Whereas cities such as Jerusalem, Hebron or Nablus are located between 600 and 800 m above sea level, the city of Jericho, only 25 km east of Jerusalem, is located nearly 400 m below sea level. Steep mountains and narrow valleys giving rise to potentially very high road gradients are major constraints for transport infrastructure planning. In the project the DTM was mainly used for the development and implementation of the Network Extension Tool (see Section 3.1.3).
Figure 12. The digital terrain model
3.2.2 Road Network Data

Even though a major part of the road network was completed in Phase 1 of the project, the road network database was updated several times in Phase 2:

- Several iterations of cross-checking by the Palestinian and Israeli partners revealed inconsistencies requiring correction. Figure 13 shows the final network database of the year 2000. The database contains all major Israeli and Palestinian roads. Roads are classified by categories such as motorways, main roads, regional roads and local roads. All traffic analysis zones are linked to the road network by connector links. The network database contains the current road network and future networks for each of the three scenarios (see Section 3.3).

- It became necessary to accommodate future extensions of the road network, such as planned 'bypass' roads designed to link Israeli settlements in the West Bank with Israel. The planned changes were extracted from hardcopy maps provided by the Israeli partners.

- Israeli checkpoints affect the flow of traffic on the road network, so it is important that checkpoints are taken account of in the model. Checkpoints in the West Bank were surveyed by using the Differential Global Positioning System D-GPS (see Appendix 3 for further information on D-GPS). Figure 14 presents these checkpoints. The checkpoints were classified according to their location with respect to the green line separating the West Bank from Israel and with respect to Jerusalem. Three classes were adopted: (i) checkpoints in close proximity to the Green Line. (ii) checkpoints on Road 60 allowing access to Jerusalem from the West Bank and (iii) the remaining checkpoints. Checkpoints were recorded both by coordinates and road link.

- Some roads in the study area are prohibited for Palestinian vehicles, so it was necessary to identify these links in the road network database. The criteria for identifying such roads were as follows: (i) all roads in East Jerusalem, (ii) roads giving access to and within Israeli settlements, (iii) roads terminating at the border of the West Bank allowing access to Israel and (iv) all roads in Israel. Figure 15 shows the allowed and prohibited roads.

- One of the changes since the Oslo Accord has been the 'safe passage' corridors between the West Bank and Gaza. The 'safe passage' roads were incorporated into the road network database by assigning a value of 1 to the links resembling 'safe passage' roads and a value of 0 otherwise. Figure 16 shows the 'safe passage' roads.
Figure 13. The road network in 2000
Figure 14. Checkpoints
Figure 15. Roads prohibited to Palestinian vehicles
Figure 16. ‘Safe passage’ roads between West Bank and Gaza
3.2.3 Zone system

The final zones system of the model consists of 271 traffic analysis and land use zones in the study region. Of these, 116 zones are located in the West Bank and 155 zones in Israel. Figure 17 shows the model zone system.

3.2.4 Socio-Economic Data

In Phase 1, demographic data of the 1997 Palestinian census were not yet available. However, these data became available during Phase 2. Therefore, the estimates of household and population data in the model database were substituted by more precise data from census sources. Based on these new figures, the number of cars and trucks was updated for each zone by accounting the population and household for each zone. Figure 18 shows population density in 1997. The database contains also forecasts for the three scenarios to be analysed (see Section 3.3).
Figure 17. Traffic analysis and land use zones
Figure 18. Population density in 1997
3.3 Policy Scenarios and Simulation Results

In this section the results of first pilot applications of the modelling system developed in the project are presented. The presentation proceeds in four steps. After a brief presentation of the background of scenario building (Section 3.3.1), the three policy scenarios defined are presented (Section 3.3.2). Section 3.3.3 explains how the policy scenarios were translated into model input data. Finally, the simulation results are presented in Section 3.3.4).

3.3.1 Background

Scenarios are "images of the future" which can be used to anticipate impacts of situations in the future. Scenarios are sometimes mistaken to be forecasts of the future. They are not and should not be used as such. Scenarios can only be used as forecasts if the probability of their becoming real is given. As a description of one of many possible future situations, a scenario is used to assess answer questions, such as "What will happen, given the background defined in the scenario?" The scenario planning approach does not produce a forecast but assumes one. Scenario building is instrumental in 'imagining' the future environment so that its impacts can be discussed.

The image of the future is an outcome of numerous factors which can be classified, among others by the degree to which professionals and decision makers in transport planning and policy have the ability to intervene or affect transport policy or other related policies. Clearly, the future of the peace process in Israel and Palestine does not belong to the policy field transport planners can influence. However, policies regarding the level of public transport supply fall within the jurisdiction of transport planners. This distinction is of relevance when scenarios are used for policy analysis.

As will be shown below, the number of possible scenarios is a function of the number of dimensions and the number of values assumed for each dimension. As the costs of performing analyses is high, generating a large number of scenarios is prohibitive. For purely pragmatic reasons, no more than four or five scenarios, which represent a broad range of possible futures should be selected.

In the context of the trilateral project, the scenarios selected need to reflect the potential dynamics of the region. Unlike in most countries in the European Union, which exhibit relatively stable trends in most relevant dimensions (e.g. demographic and economic development), the study area region can be characterised as experiencing quite dynamic changes in many relevant dimensions.

The process of scenario building includes five steps. Defining scenarios is often an iterative process, in which critical reviews of the assumptions are given, and the scenarios are modified until the research team agrees on a set that will be used for further analysis:

(1) Identify the major components of relevant scenarios. These are the factors which define the context that affects the transport-environment realm for the study area. The three major factors in the study area are suggested to be: the political context, population development and the economic context.
(2) Set quantitative or qualitative values (or ranges of values) to be assigned to each of the major factors. These values reflect the researchers' views of what can happen, or what may be of interest to explore, even if it is an unrealistic case. The choice between qualitative and quantitative values depends on the nature of the factor. For example, peaceful relations are a qualitative factor which may reasonably take two to four values: adversary to warm peace at the extremes. Automobile ownership (a secondary factor) must be given a quantitative value.

(3) Identification of secondary factors, usually derived from the major components. To a certain extent, these can be seen as a consequence of the major components, but they may also be determined independently. For example, growth in the labour force (a secondary factor), is clearly a result of population growth (a major factor). However, a change in the labour force may also result from social change, such as growing labour force participation of women.

(4) Assignment of values to the secondary factors. Again, these values are either quantitative or qualitative, depending on available information or desired level of detail.

(5) Selection of scenarios. A major consideration is the number of scenarios to be constructed. As the number of factors increases, the combinatorial set of scenarios grows rapidly. Although some combinations are actually 'empty' cases, it is still possible to drown in a huge number of possible scenarios. It is the task of the researchers to select the relevant and interesting scenarios for further study.

Scenarios should be designed with a time horizon in mind (e.g. 2010 or 2020). This is necessary to reduce uncertainty, as all participants have a common time frame to evaluate target values of current or forthcoming trends.

3.3.2 Policy Analysis

To understand the following section, it is useful to know that the definition of the scenarios to be simulated was done jointly by the Palestinian and Israeli partners prior to the renewal of hostile relationships in the area in September 2000.

Major Factors

It is clear that three major factors will determine the future situation of the study area:

- **Peace.** The political situation in the study area is the most important factor distinguishing between adversary, cold or warm relationships between Israelis and Palestinians.

- **Population.** Population development in the region is a most important factor, as it directly affects the quantity of activities (mainly employment and education) and travel, as well as the demand for housing, which in turn generates changes in the distribution of travel and freight movement. Population growth is a quantitative dimension which can be grouped for the purpose of scenario building into a few categories (e.g. slow, fast, stagnant).
- *Economy*. The state of the economy in the Palestinian and Israeli areas. These can be assigned as being in a 'growth' mode, a 'stagnant' state or a 'declining' state. Each of these three levels can be defined in terms of growth rates, based on available data. However, it is not necessary to make such quantitative definitions. The economic situation is likely to affect both the ability to invest in infrastructure as well as the growth in the use of cars.

Assuming a three-level categorisation for the above factors *Peace* and *Economy* and a two-level grouping of *Population*, 18 combinations can be identified, as shown in Table 1.

**Table 1. Eighteen possible basic scenarios**

<table>
<thead>
<tr>
<th>Adversary</th>
<th>Economic growth</th>
<th>Economic stagnation</th>
<th>Economic decline</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Major population growth</td>
<td>Minor population growth</td>
<td>Major population growth</td>
</tr>
<tr>
<td>Cold</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Warm</td>
<td>13</td>
<td>14</td>
<td>15</td>
</tr>
</tbody>
</table>

As the three dimensions described in the table are mutually dependent to some extent, some of the scenarios shown in the table can be screened out, as they are neither likely nor very interesting. For example, scenarios 1 and 2 are not likely, due to the dependence of economic growth on peaceful relationships in the study area. Given the likely interdependence between peace and economic growth, it is useful to select the diagonal cells as candidate scenarios for further analysis.

Population growth is also somewhat dependent upon the previous two dimensions. Population growth is more likely in peace than otherwise and more likely in a growing economy than otherwise. Hence, scenarios 5, 9 and 14 can be screened out. However, the most important determinant of the population growth is the issue of the returning Palestinian refugees. This will make the difference with regard to population growth. As this issue is to be dealt with in the political process in the study area, it is also possible that the population growth will be independent of the other two dimensions, implying that the remaining set of three scenarios will have to be expanded.

At this point, we suggest to use scenarios 6, 10 and 13 as candidate scenarios, and to explore further the role of the 'secondary' factors in forming additional relevant scenarios.
Secondary Factors

The secondary factors focus on the determinants of the transport-environment context. Each of the following factors is subject to some extent to policy decisions and they are interdependent. These include:

- **Commuting patterns.** The length of work trips depends on the relationship between the location of residence and employment opportunities. Whether or not long-distance (25+km) work trips will prevail, will probably be a result of the degree of integration of the two economies, which in turn will depend on the outcome of the Peace Process (assuming that by 2010 the relationship will have been finalised). The colder the peace, the shorter the commute distances, as less Palestinians will work in Israel. The commute distance, as noted above, depends on the location of employment and residences. It is reasonable to assume that the spatial distribution of residences will remain as is, if population growth is low. However, if growth will include a significant number of returnees, residential patterns will change. A likely pattern is of spreading of suburban development around the large cities in the West Bank. It is also likely that more contacts with the Israeli economy will serve as a magnet to develop residences closer to the Israeli border. Hence, the length of work trips will be related to both population growth and economic growth.

- **Car ownership and public transport provision.** Car ownership and public transport are likely to demonstrate inverse relationships: the more cars are available, the less will be the use and supply of public transportation. Growth in car ownership is likely to continue. The question is at what pace? Economic growth will certainly encourage car ownership and vice versa. The authorities can introduce policies which will curb the growth of motorisation. However, this is unlikely as car ownership is a result of popular demand and hence curbing it is politically wrong at times and places where satisfying growth indicators is important. The reliance on public transport services between towns and villages will depend on car ownership and commuting patterns. Public transport service will probably not grow and the range of possible futures may distinguish between maintaining present levels or decline.

- **Network attributes** refer to the quantitative and qualitative characteristics of network density, by type of road. The relevant parameters are capacity and level of service. Road capacity is determined primarily by the number of travel lanes in each direction, ranging from 0.5 in rural areas to two or three lanes. The geometric design of these road types determines the design speed, and hence the capacity. However, some older roads have been improved over the years, without a change in the basic geometry. A clear example is the Wadi-al-Nar road which leads from Beit Sakhur - Beit Lehem to Ramallah, bypassing Jerusalem from the east. The physical design, including horizontal and vertical features provide a low level of service with regard to speed and safety. Generally, the Region’s road network does not experience much congestion which can be attributed to an imbalance between demand and supply. The relatively low income and auto ownership are underlying the low demand. Congestion of a unique form is that which is attributed to police and military road checkpoints, is discussed below.

- **Accessibility** refers to the possibility and ease of access to locations and facilities. Are all people free to choose any link on the network or are there separate networks for the Palestinians and the Israelis? The situation described refers to the period prior to the recent outbreak of violence in September 2001. The issues at stake here are checkpoints, access to Jerusalem, access to roads and bypass roads:
- **Checkpoints.** There are three types of checkpoints. Permanent checkpoints are set along the 'Green Line', the border which separates Israel from the West Bank. These are designed to prevent Palestinians who do not have a permit from entering Israel. The second type of checkpoints are located on the roads leading to the large Palestinian cities defined as "A" regions. These are under Palestinian security forces. The third type of checkpoints are the irregular checkpoints set periodically and temporarily to facilitate security checks.

- **Access to Jerusalem.** The most serious problem of free access to the road system is the closure of Jerusalem. It requires those living in the southern and northern parts of the region to use the very long, old and poorly maintained Wadi-al-Nar road. This imposes severe costs on the Palestinians. Palestinians who live in East Jerusalem are not restricted from using the routes which cross the city. The construction of a ring road around Jerusalem is now entering the implementation stage and construction in some sections have started. The eastern ring (20 km) will facilitate through traffic by both Palestinian and Israeli vehicles to bypass the city. The first phase of the project is now budgeted for $75m and scheduled to be completed in 2002. The complete ring road is to be completed by 2010.

- **Access to roads.** For the purpose of understanding the accessibility issue it is useful to identify the types of roads in the region. Most of the network is the old road system, partially built during the British Mandate and during the Jordanian period, until 1967. Since the Israeli occupation, road development included trunk roads, often with multiple goals. Some served for improving access at an inter-regional scale (e.g. Roads 5 and 90). These roads also improve access to the settlements of Israelis in the West Bank. Some of these roads also play an important role in setting territorial facts. The Palestinian claim that these roads are designed to 'break' territorial continuity may be right.

- **Bypass roads.** A second type of road development in the region are the bypass roads. The motivation for their construction was partially the problems of Israeli settlers’ risk in passing through Palestinian towns and villages during the Intifada of 1987-1991. However, the claim by Palestinians claim that the bypass roads are restricted and that they may not use them, is inaccurate and not supported by traffic counts. Traffic counts on a number of bypass roads have revealed (in 1998) that on some sections Palestinian traffic accounts for 68% (Road 60, near Ofra), 55% (Road 60, Hebron bypass) or 49% (Road 5, east of Ariel). The Palestinian also adhere to the argument that bypass roads are built solely for Israelis, and they seem to disregard the benefits of bypass roads. Bypass roads are built in many countries as part of upgrading road systems. Such roads reduce through traffic, improve the environment and reduce safety hazards. This is done not only in the West Bank, but also in Israel and in many other countries.

A fully free-access network can only be expected under very warm peace. But even under warm peace, the sides may agree to maintain the conventional procedures separating two neighbouring states. Colder peace and adversary relations are more likely to lead to a continuation of the present situations, with some modifications resulting from the agreements of the Peace Process.
3.3.3 Definition of Scenarios

The selection of policy scenarios for the illustrative model runs was jointly done by the Palestinian and Israeli project teams in several meetings. The attention was directed towards getting a reasonable and meaningful set of scenarios that meet both the Palestinian and Israeli criteria without overwhelming one side. Finally, three scenarios were developed. They are summarised in Table 2.

Table 2. Definition of policy scenarios

<table>
<thead>
<tr>
<th></th>
<th>Scenario I: Status quo</th>
<th>Scenario II: Separation</th>
<th>Scenario III: Co-operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palestinian population</td>
<td>Natural growth</td>
<td>Natural growth plus 300,000 returnees</td>
<td>Natural growth plus 250,000 returnees</td>
</tr>
<tr>
<td>Israeli population</td>
<td>Natural growth</td>
<td>100,000 settlers evicted&lt;sup&gt;a&lt;/sup&gt;</td>
<td>200,000 Israeli settlers evicted&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Economic situation&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Decline</td>
<td>Stagnation</td>
<td>Growth</td>
</tr>
<tr>
<td>Road network changes</td>
<td>See Figure 19</td>
<td>See Figure 19 plus safe passage</td>
<td>See Figure 19 plus safe passage</td>
</tr>
<tr>
<td>Accessibility To roads&lt;sup&gt;d&lt;/sup&gt;</td>
<td>Limited</td>
<td>Checkpoints only along border</td>
<td>Minimal number of checkpoints</td>
</tr>
</tbody>
</table>

**Notes:**

- <sup>a</sup> These include all Israeli settlers scattered in the West Bank.
- <sup>b</sup> This includes neighbourhoods in the area annexed by Israel like Gilo, Pisgam-Zeev, etc.
- <sup>c</sup> This includes employment and car ownership.
- <sup>d</sup> There is some level of congestion build-up next to checkpoints, which varies widely with changes in the security, and overall, it is not considered as a major problem. See further discussion below.

The improvements to the road system assumed in the three scenarios are shown in Figure 19. It can be seen that they are similar in all three scenarios, except for the Separation Scenario in which a major new highway will be constructed linking Tel Aviv and Jerusalem north of the present motorway link. All three scenarios contain road projects already under or near construction, such as Road 6, a major limited-access highway that will, serve as an outer ring and a north-south connection for the Tel Aviv area, the Jerusalem Ring Road, which will circle Jerusalem to shorten trips between Bethlehem and Ramallah without entering the centre of Jerusalem, and Road 80, a north-south highway in the eastern slopes of the West Bank.

It may be asked why they are nearly the same in the three scenarios. This may appear strange as the trilateral project originally was to address issues of sustainable transport. However, the events of the last few months have made it all too clear that issues of access to locations and opportunities will remain dominant in the foreseeable future and will overshadow the attention paid to matters of environmental sustainability.
Figure 19. Road improvements in the three scenarios until 2020
Scenario I is called the **Status-quo Scenario**. This scenario reflects the current status if it is prevail until the year 2020. This scenario is considered as the benchmark for the analysis. This scenario assumes a natural growth in the Palestinian and Israeli population of the study area. As in the present time, no major change in employment trends is taking place; thus the scenario assumes decline in the economy. Road network development is assumed to take place in this scenario as in the other two scenarios: Road 6, the Jerusalem ring road and Road 80 are assumed to exist in 2020. Restrictions on roads to Palestinian vehicles will still exist, and there will be a large number of checkpoints resulting in a high level of delay on a number of road links.

Scenario II is called the **Separation Scenario**. This scenario assumes cold relations in which a rigid boundary between the Palestinian territories and Israel exists. The Palestinian population is assumed to grow naturally. In addition, some 300,000 Palestinian returnees are assumed to be distributed evenly across the Palestinian urban centres of the region. The scenario also assumes that 100,000 Israeli settlers are evicted from the West Bank. Since the region is assumed to have a high level of Palestinian population in the year 2020, the economic situation is assumed to go in the stagnation mode. Road network improvement in this scenario is the same as in the Status-quo Scenario except that a second, more northern connection between Tel Aviv and Jerusalem will be constructed and the safe passage corridors between The West Bank and Gaza (see Figure 16) will exist. Unlike the Status-quo Scenario, checkpoints within the West Bank no longer exist, however, the checkpoints along the border providing access to Jerusalem and Israel have medium delays.

Scenario III is the **Co-operation Scenario**. This scenario assumes friendly relations between Palestinians and Israelis. The scenario expects 300,000 Palestinian returnees and evicts 200,000 Israeli settlers from the West Bank. Unlike the Separation Scenario, the Co-operation Scenario assumes economic growth resulting from the low restriction on accessibility as all checkpoints and road restrictions are removed in this scenario. Employment levels and car ownership are expected to increase. The same improvements in the road network are expected to take place as in the Status-quo Scenario except that the safe passage corridors will exist.

It is important to note that the criteria embedded in the scenarios developed in this project do not resemble any political forthcoming opinion of the Palestinian National Authority, the Israeli government or the authors but are strictly developed for illustrative purposes in order to assess the impact of a certain policy or future image if it is to take place in the future.
3.3.4 Simulation Results

This section was originally intended to present results of the integrated model system. It should have presented the traffic and environmental effects of three scenarios and a comparison and explanation of similarities and differences between them. It was planned to present for each scenario trip distributions for selected zones with network assignment, average trip lengths, link volumes and NOx emissions, differentiated by Israeli and Palestinian population. The comparison would have focused on the differences between the scenarios in terms of vehicle km, vehicle hours, average trip length and link volumes and NOx emissions.

As explained elsewhere in this report, the political development of the last months in the study area made it impossible to extend the analysis beyond the three policy scenarios presented in the previous section. Therefore it is not possible to present the full range of simulation results as indicated above, in particular the envisaged results with respect to environmental issues cannot be shown. The results that can be presented are transport flows, traffic loads and system performance, safety effects and potentials for public transport and paratransit. These simulation results are obtained for the base year and for the year 2020 for each of the three policy scenarios.

Transport flows and activity levels

Total morning peak hour trips for the Israeli population accessing the road network as coded in the road network database total about 110,000 passenger-car equivalents (PCE) per hour. This number is to rise to over 213,000 PCE per hour in the forecast year 2020. This increase is due to the assumed natural population growth of the Israeli population. These trip levels are equivalent to rates of 0.06 PCE per hour per household today, rising to 0.084 PCE per hour per household in the future, with the bulk of the increase due to the forecast increase in vehicle availability and use. Similarly, the Palestinian population travel patterns are forecast to intensify from rates of 0.02-0.03 today to 0.04-0.06 in the forecast year.

Figure 20 presents transport flows in terms of link volumes in PCE for the base year separately for the Israeli and Palestinian population. It is evident that the highest link volumes can be observed in the Tel Aviv area and on the freeway linking Tel Aviv and Jerusalem. There is also a considerable amount of Israeli travelling around Jerusalem. However, Israeli travel in the West Bank is almost negligible, with the exception of the route Jerusalem-Hebron-Be’er Sheva. This is also the most travelled route for Palestinians in the southern part of the West Bank. North of Jerusalem, that route continues linking Jerusalem with Ramallah and Nablus. As to be expected, link volumes in the West Bank are by far lower than those in Israel.

The overall model results indicate that the planned improvements to the road system in combination with growing population figures for both Israeli and Palestinians as reflected in the model comprise an addition of 8-11% to the lane-kilometres of the road network (from 17,560 lane-km today to 19,000-19,500 lane-km depending on the scenario). The commensurate increase in vehicle-kilometres travelled (VKT) under the Co-operation Scenario is 43% (from 642,700 VKT today to 917,000 VKT in 2020). The other scenarios are expected to result in smaller increases in total travel due to the relative spatial segregation of the population groups: The Status-quo Scenario for the year 2020 results in a total of 662,000 VKT (3% increase), and the Separation Scenario in a total of 706,000 VKT (10% increase).
Figure 20. Modelled transport flows in 2000
However, as Figures 21, 22 and 23 show, these differences are reflected in different spatial patterns. A comparison between the Separation and Status-quo Scenarios (Figure 21) reveals that most of the differences take place in the Tel Aviv-Jerusalem corridor where a huge shift in transport flows from Freeway 1 to the newly created northern connection between Tel Aviv and Jerusalem can be observed. A similar phenomenon can be observed for the link between Bethlehem and Hebron. Considering the safe passage corridors between the West Bank and Gaza, it is expected that the traffic volumes will be reduced in the Separation Scenario. For all other links, only small differences between these two scenarios are expected. This pattern reflects the fact that in the Separation Scenario only limited exchange between the Israeli and Palestinian population groups is possible and that movements of people and goods are hindered by checkpoints and political obstacles.

The highest increase in VKT is expected for the Co-operation Scenario, and this increase is evenly distributed across all roads in the study area (22). Almost all major roads in Israel and the West Bank will experience increasing link loads, in particular roads around Jerusalem. This is consistent with expectations as when political, military and social barriers between the two population groups are torn down, this will lead to increasing transport flows in all areas. However, in the Israel areas planned improvements to the national road system (including Roads 6, 7, 45, 55, 431, 461, 471, 531, etc.) are expected to ameliorate the adverse effects of the additional traffic loads. In the Palestinian areas, local congestion problems can be expected, and additional improvements to the road system will become necessary.

The spatial patterns that appear when the Co-operation and Separation Scenarios are compared are not that clear (Figure 23). Most evidently, the greatest differences can be seen in the Tel Aviv-Jerusalem corridor. In the Co-operation Scenario, the southern link (Road 1) will be clearly more frequented than the northern link, which had higher link loads in the Separation Scenario. Interestingly, the roads in the West Bank have slightly higher traffic loads in the Separation Scenario, while the roads in Israel show higher traffic flows in the Co-operation Scenario. This may lead to the hypothesis that in the Co-operation Scenario people (in particular Palestinian people) are more attracted to travel to Israel than within the West Bank, whereas in the Separation Scenario traffic between Palestinian and Israeli areas is obstructed so that movements of Palestinians are limited to the West Bank.

Some additional tabular results of the traffic assignments are attached as part of the Appendix. These tables provide detail on traffic load and performance indicators for 24 classes of road segment types. The data present the number of road segments (links), the centre line kilometres and lane-kilometres of roadway, vehicle-hours-travelled (VHT) and vehicle-kilometres-travelled (VKT) and average and maximum speeds and volumes.

Traffic safety and travel times

A primary concern with the intensification of traffic is the issue of traffic safety. Traffic safety issues in the West Bank can be broadly characterised by three primary contributing factors: high travel speeds (especially in the western half of the area where more flatter terrain and long travel distances encourage higher speeds), dense built-up areas (where traffic congestion and heavy foot and bicycle traffic compound with poor road hierarchy to result in more chances for conflict), and finally the poor condition of roads (especially on the eastern slopes of the region, where steep topography results in winding roads and safety problems due to poor design and maintenance and sight-line issues).
Figure 21. Separation vs. Status-quo: difference in link volumes
Co-operation vs. Status Quo
Differences in transport flows
- Co-operation > Status Quo
- Co-operation < Status Quo
- No differences

Figure 22. Co-operation vs. Status-quo: difference in link volumes
23. Co-operation vs. Separation: difference in link volumes
An example of such safety problems indicated by the model results is the Wadi-al-Nar route connecting Bethlehem and Ramallah. Today restrictions on the travel of Palestinian vehicles through Jerusalem necessitates vehicles to take this more circuitous route on the eastern slopes of the Judean Mountains through the steep gorge of Wadi-al-Nar. In scenarios where travel through Jerusalem is restricted, hourly traffic volumes on this route are forecast to increase from 400-600 PCE today to 1,200-1,600 in 2020. In scenarios where travel through Jerusalem is allowed as a route from Bethlehem to Ramallah, traffic volumes in Wadi-al-Nar are expected to increase less precipitously to 800-1,200, mostly serving local access to growing neighbourhoods of East Jerusalem. The eastern part of the Jerusalem ring road is expected to provide additional needed capacity for this travel corridor.

Besides safety concerns, also travel times between Bethlehem and Ramallah are of interest for Palestinian people. In scenarios where they are allowed to travel through Jerusalem, the travel time between Bethlehem and Ramallah is expected to be half or even less of that travel time using the Wadi-al-Nar route, even though there will be congestion or waiting times at traffic lights in Jerusalem itself. However, this expected reduction in travel time between Bethlehem and Ramallah will also have considerable impacts on social contacts of Palestinians and on Palestinian economy.

**Potential for public transport and paratransit**

For the purpose of this study, data was collected regarding some 591 existing fixed-route public transport lines operating in the West Bank. The vehicle age for the buses and minibuses employed for this service is evenly spread over the years from the mid-1970s to the mid-1990s, and the vehicles are often seen out of service on the road shoulder due to their age and need for maintenance. Over the last several years, the West Bank has seen a dramatic growth in taxi-van and related paratransit services. It is expected that as dispersed development patterns continue on the West Bank, trip-making will continue to shift from a "many-to-few" pattern to a "many-to-many" pattern. Paratransit systems which can respond to this dispersed demand will be successful; lines to and between urban centres best suited to fixed-route buses should be protected from unnecessary competition, to preserve dependable and equitable access to transport services.

**Environmental impacts**

In addition to issues of system performance, equity and safety mentioned above, sustainable development requires an environmentally sound approach to balancing land use and transportation system investments. An environmental analysis of the alternative scenarios should include an assessment of the scenarios across a number of disciplines, including potential effects on natural resources (land, air, water, visual assets, sensitive habitats) as well as built and cultural resources (sensitive land uses or archaeological sites). In addition, an environmental analysis would take into account the potential effects of the environment on the transportation system, including geologic hazards, etc. Further work on this issue at a more detailed scale of analysis would allow for a more localised assessment of dispersion of air pollutants and exposure patterns to unhealthful air pollutant concentrations. In addition, such an analysis would allow for comparing the potentially differential effects (exposure) of the area's populations to air pollution.
On an overall level, the travel summary indicates that, while the Separation Scenario is expected to require the most substantial addition of roads and related transportation infrastructure, the Co-operation Scenario is forecast to result in the highest levels of traffic (in terms of number of trips, VKT and VHT). This in turn is expected to contribute to higher levels of air pollutant emissions. A worsening of emissions would erase the progress being made through cleaner cars entering the vehicle fleet. Under the Status-quo Scenario, increase traffic levels would be balanced by the improvements in the vehicle fleet, and emissions would stay about level with today's totals. Under the Separation Scenario, emissions would be expected to make a moderate 5-10% increase. Under the Co-operation Scenario, an increase of 10% or more would be expected.

However, as the differences in link volumes presented in Figures 21, 22 and 23 suggest, the spatial distribution of these increasing traffic emissions is expected to differ across the scenarios. For the Separation Scenario, it is expected that the corridor between Tel Aviv and Jerusalem will be affected above-average with additional emission compared to the base year and the Status-quo Scenario. Conversely, the Co-operation Scenario is expected to lead to additional emissions almost evenly distributed across the study area following the evenly patterns of increases in link traffic loads.
4 Conclusions and Future Work

This report concludes a project which was started in a era of optimism and great expectations about the prospects of peaceful co-operation between Israeli and Palestinian researchers and planners towards sustainable development.

And indeed, Phase 1 and the first part of Phase 2 of the project showed that such co-operation is possible. The significant achievements in establishing the integrated database in Phase 1 from both Israeli and Palestinian sources would not have been possible without great efforts of the Israeli and Palestinian partners to collaborate in a spirit of openness and co-operation. In particular the meetings in which the Israeli and Palestinian partners worked together on the definition of meaningful policy scenarios that were acceptable to both sides demonstrated the potential and power of co-operation on practical matters of mutual interest.

However, during the last months of the project it has become clear that progress towards peace will be much more long-term. The slowing down of the Peace Process during the year 2000 has had its effects on the important concluding phase of the project. Although significant progress in achieving the technical tasks of the project has been made, not all of its initial objectives could be accomplished. The individual components of the envisaged GIS-based methodology for sustainable transport planning in the West Bank have all been developed and tested and at least partly applied together in a pilot application. However, because of the political circumstances it has not been possible to establish the integrated methodology in a practical application framework beyond the duration of the project.

At a more detailed level, the project was successful in establishing a methodological framework for a linkage between a GIS and a transport model and environmental impact models. In particular the two-way macro-language interface between ArcInfo and EMME/2 represents a major advance over previous isolated applications of GIS and models in transport planning. Also the network extension tool developed is potentially a significant step beyond conventional ways of designing transport network extensions. The environmental impact submodels existing at Hebrew University and at IRPUD represent the state of the art in a rapidly developing field of research. However, the integrated framework consisting of ArcInfo, EMME/2, the ArcInfo-EMME/2 interface, the network extension tool and the environmental impact submodels has nowhere been implemented in its entirety. ArcInfo was implemented in Bethlehem, Dortmund and Bonn, EMME/2 in Jerusalem and Dortmund, the ArcInfo-EMME/2 interface only in Dortmund, the network extension tool only in Bonn and the environmental impact submodels only in Jerusalem and Dortmund. So the intended integration worked only in the virtual and non-permanent space of the project.

Another notable achievement of the project has been the establishment of the integrated database for GIS-based transport planning in the West Bank. The compilation and homogenisation of high-resolution digital terrain data from different sources, the joint efforts of all project partner to establish a consistent and detailed road network database, the agreement reached on a system of zone boundaries compatible with the political perceptions of both the Israeli and the Palestinians partners, and the close co-operation of the Israeli and Palestinian partners to assemble a consistent set of population, employment and car ownership data from Israeli and Palestinian sources not only represent a demonstration of the feasibility and benefit of co-operation but have also laid indispensable foundations for future joint transport planning in the West Bank.
The pilot applications of the methodology presented in this report demonstrate that the components of the methodology function together and produce meaningful results. The results of the simulations of three policy scenarios confirm that the hypothesis that peaceful coexistence would give rise to a more spatially distributed and hence more equitable and more sustainable pattern of movements. However, due to the restricted communication between the Israeli and Palestinian partners in the final phase of the project, the selection of policy scenarios more limited than initially intended. Original plans to examine also more fundamental policy options, both in terms of political and socio-economic scenarios and in terms of transport infrastructure alternatives could not be implemented. Nevertheless, it must be counted as a significant success that the Israeli and Palestinian partners were able to reach consensus about a common set of policy scenarios, something hardly imaginable in the frosty political climate of today.

What remains unachieved by the project will have to be left for future work. From the perspective of the project team, the following tasks should be addressed:

- First priority on a future research agenda would have the completion of the integration of the modelling framework as it is illustrated in Figure 2 of this report at one site.

- This would include the full integration of the network extension tool into the software system and the linkage between the GIS and the transport model with the already existing environmental submodels.

- The extension of the network database to include all bus lines and the existing shared-taxi paratransit system would allow to investigate environment-friendly transport policy options.

- The set of policy scenarios examined should be greatly extended to include different combinations of transport policy packages and political and socio-economic scenarios.

It is hoped that the project partners will have an opportunity to resume their productive cooperation in the not too far future.
5 Appendix

Appendix 1: Co-operation Partners

_Lutz Plümer, Professor Dr. (Project Coordinator)_
Institut für Kartographie und Geoinformation (IKG)
Universität Bonn
Meckenheimer Allee 172
D-53115 Bonn, Germany
Phone: +49 228 73 17 50
Fax: +49 228 73 17 53
E-mail: pluemer@ikg.uni-bonn.de
http://www.ikg.uni-bonn.de/

_Michael Wegener, Professor Dr.-Ing._
Institut für Raumplanung (IRPUD)
Universität Dortmund
D-44221 Dortmund, Germany
Phone: +49 231 755 2401/2291
Fax: +49 231 755 4788
E-mail: mw@irpud.rp.uni-dortmund.de
http://irpud.raumplanung.uni-dortmund.de/irpud

_Ilan Salomon, Professor Dr._
Department of Geography (DG)
Hebrew University of Jerusalem
Mount Scopus
Jerusalem 91905, Israel
Phone: +972 2 5883 345
Fax: +972 2 820 549
E-mail: msilans@pluto.mscc.huji.ac.il
http://atar.mscc.huji.ac.il/~eppp/index1.htm

_Jad Isaac, Professor Dr._
Applied Research Institute Jerusalem (ARIJ)
Caritas Street
P.O. Box 860
Bethlehem, Palestine
Phone: +972 2 741889
Fax: +972 2 277 6966
E-mail: jad@arij.org
http://www.arij.org/
Appendix 2: Staff

Bonn (IKG)
Research Associate:
Student Research Assistant:
Jan 2000 – Mar 2000: Ariane Middel
Jan 2000 – Mar 2000: Udo Quadt
Jan 2000 – Mar 2000: Jörg Steinrücken
Contributors:
Dr. Gerhard Gröger
Dr.-Ing. Jochen Schiewe

Dortmund (IRPUd)
Research Associate:
Student Research Assistant:
Feb 1999 – Jan 2000: Alessandro Morosin
Contributors:
Dipl.-Ing. Meinhard Lemke
Dipl.-Ing. Carsten Schürrmann
Dipl.-Ing. Klaus Spiekermann

Jerusalem (DG)
Research Associate:
Mar 1999 – Feb 2000: Jay Kaplan-Wildman, Ph.D. student
Contributors:
Galit Cohen, Ph.D. student, The Free University of Amsterdam
Gil Tal, MA Student, The Hebrew University of Jerusalem.

Bethlehem (ARIJ)
Research Associate:
Mar 1999 – Feb 2000: Hanna Maoh
Mar 1999 – Feb 2000: Isam Ishaq
Mar 1999 – Feb 2000: Violet Qumsieh
Student Research Assistant:
Mar 1999 – Feb 2000: Sophia Sa‘ad
Mar 1999 – Feb 2000: Majed Abu Kobe’a
Mar 1999 – Feb 2000: Khaldoun Rishmawi
Appendix 3: Theses and Publications

Bonn (IKG)

Dortmund (IRPUD)

Bethlehem (ARIJ)
Appendix 4: Setting Up the D-GPS

Following the purchase of the Differential Global Positioning System (D-GPS), ARIJ was faced with the problem of installing and calibrating the antenna of the system at the headquarters of ARIJ. Therefore, it was important to obtain an exact and accurate geodetic position of the building at which the antenna should be installed. Through the use of Bethlehem 2000 project maps, ARIJ was able to determine the geodetic position of the antenna in the Palestinian Grid with an accuracy of 19 cm.

The work conducted at ARIJ required to precisely geocode the spatial data in UTM WGS84. A formula that enables transfer from the Palestinian grid to UTM projecting system was obtained from Trimble reseller in Israel. The formula is described to be reasonably accurate (2-3 m x-y accuracy). The other potential solution is to use the Path Finder Base Station (PFCBS) to average UTM WGS84 readings for 10-12 days. The solution offered by Trimble states a spatial accuracy of 2 m but the procedure is not always recommended.

The geodetic position derived from Bethlehem 2000 maps was projected into UTM WGS84 using Pathfinder Office. The derived value in UTM WGS84 is \( x = 3511770.834 \), \( y = 708929.241 \) and \( z = 804.44 \) m. The solution derived from the station after averaging half a million readings is \( x = 3511770.48 \), \( y = 708925.93 \) and \( z = 807.415 \) m. The derived solution for defining the geodetic position of the antenna showed a shift in position equal to \( dy = 3.31 \), \( dx = 4.354 \) and \( dz = 0.035 \) m. Based on this observation, another six days of reading data was allowed. The result of the 12 days of reading resulted in a shift in coordinate position that did not exceed the 1 m. Thus the base station was calibrated to correct surveyed reading up to the accuracy of 1 m. Currently the D-GPS and base station and running efficiently.
Appendix 5: Completing the DTM

The digital terrain model (DTM) developed in Phase 1 was extracted from three stereo pairs SPOT scenes acquired for the year 1997. Unfortunately, the three scenes did not cover the north-western part of the West Bank. The integration of the whole area was carried out in Phase 2. The missing data were substituted from contour maps that were digitised and registered in the GIS projection used for the other maps in the project (UTM WGS84). The integration of the data involved three major steps. The first step was cleaning the digitised contours for the missing area. The second step involved creating a grid out from the cleaned contours using the GRID function of ArcInfo. The third step was linking the new grid to the DTM developed in Phase 1. The resolution of the new DTM is 20 metres. Because the contours for the missing area are 20 metres in resolution, it was considered important to adopt this resolution for the whole DTM.

Source of data:
- DTM data extracted from the SPOT images (10 meters)
- British Mandate Contour maps for the North West region of the West Bank (25 meters)

Approach:
1. The contours (25 m) for the missing area were cleaned using ArcInfo
2. The contours were geocoded in order to fit with the SPOT DTM projection units.
3. The TOPOGRID procedure was used to create a DEM with 40 m pixel size from the 25-m contours.
4. From the resultant grid 25-m contours were extracted.
5. 20-m contours were extracted from the 10-m DTM developed in Phase 1.
6. The TOPOGRID procedure was used to merge the contours from Steps (4) and (5) in order to produce a 25-m grid of the entire West Bank

Reevaluation of the process:
When checking the accuracy of the data, it was found that the north-western part of the resultant DTM is of less terrain detail than the parts extrapolated from the SPOT stereo pairs. The interpolated grid from the contour lines near the Dead Sea gave values of less than 405 below sea level, although the minimum value of the SPOT DTM was equal to 405 below sea level. The problem was approached by applying a logical expression in ArcInfo.

Cross Checking the DTM:
Digital image differencing was performed between the SPOT DTM and the derived DTM. The maximum difference in elevation values was equal to 54.4 m.
Appendix 6: Traffic Flows

The following four tables show modelled traffic flows by link category for the base scenario for the year 2000 and for the three policy scenarios for the year 2020. The following EMME/2 results are provided:

- Number of links
- Centreline-km
- Lane-km
- Vehicle hours travelled (VHT)
- Vehicle kilometres travelled (VKT)
- Minimum speed
- Average speed
- Maximum speed
- Average traffic volume
  - Palestinian
  - Israeli
  - Total
- Maximum traffic volume
  - Palestinian
  - Israeli
  - Total
Share by class
  - Lane-km
  - Vehicle hours travelled (VHT)
  - Vehicle kilometres travelled (VKT)
### Base Scenario: Year 2000 (average AM peak hour traffic forecast, pce)

| Type | Links | CL-km | Ln-km | VHT | VKT | Speed Min | Speed Avg | Speed Max | Average traffic volume Min | Average traffic volume Avg | Average traffic volume Max | Maximum traffic volume Min | Maximum traffic volume Avg | Maximum traffic volume Max | Share by class | Share by class | Share by class |
|------|-------|-------|-------|-----|-----|-----------|-----------|-----------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|---------------|---------------|---------------|
|      |       |       |       |     |     |           |           |           | Palest                      | Israeli                    | Total                       | Palest                      | Israeli                    | Total                       | Ln-Km | VHT | VKT |
| 112  | 50    | 188   | 415   | 19  | 2,032| 105       | 105       | 105       | 11                         | 1,118                      | 1,129                       | 106                         | 4,667                      | 4,740                      | 100% | 100% | 100% |
| 121  | 30    | 56    | 131   | 2   | 178  | 105       | 105       | 105       | 3                         | 1,896                      | 1,899                       | 17                          | 3,106                      | 3,113                      | 100% | 100% | 100% |
| 122  | 32    | 132   | 273   | 8   | 811  | 105       | 105       | 105       | 6                         | 3,216                      | 3,222                       | 27                          | 7,424                      | 7,427                      | 100% | 100% | 100% |
| 131  | 36    | 65    | 185   | 1   | 132  | 105       | 105       | 105       | 2                         | 2,086                      | 2,088                       | 9                           | 6,378                      | 6,387                      | 100% | 100% | 100% |
| 132  | 16    | 28    | 57    | 4   | 466  | 105       | 105       | 105       | 16                        | 5,784                      | 5,801                       | 32                          | 9,043                      | 9,048                      | 100% | 100% | 100% |
| 211  | 226   | 785   | 1,201 | 102 | 10,664| 34        | 104       | 123       | 14                        | 825                        | 839                        | 402                         | 4,015                      | 4,015                      | 100% | 100% | 100% |
| 212  | 218   | 437   | 779   | 509 | 48,566| 16        | 95        | 123       | 111                       | 840                        | 951                        | 1,322                       | 5,111                      | 5,158                      | 100% | 100% | 100% |
| 221  | 182   | 442   | 717   | 9   | 862  | 99        | 101       | 101       | 2                         | 1,662                      | 1,664                      | 233                         | 9,253                      | 9,257                      | 100% | 100% | 100% |
| 222  | 164   | 414   | 606   | 60  | 5,948 | 49        | 99        | 101       | 14                        | 1,383                      | 1,397                      | 129                         | 5,028                      | 5,030                      | 100% | 100% | 100% |
| 231  | 114   | 150   | 280   | 148 | 15,776| 83        | 106       | 119       | 105                       | 1,635                      | 1,740                      | 1,313                       | 6,815                      | 6,826                      | 100% | 100% | 100% |
| 232  | 26    | 36    | 70    | 4   | 341  | 96        | 97        | 101       | 10                        | 3,091                      | 3,101                      | 702                         | 5,866                      | 5,867                      | 100% | 100% | 100% |
| 311  | 604   | 3,391 | 3,606 | 247 | 23,731| 11        | 96        | 113       | 7                         | 116                        | 123                        | 605                         | 2,989                      | 2,998                      | 100% | 100% | 100% |
| 312  | 1,028 | 2,274 | 2,276 | 2,527| 229,575| 11        | 91        | 113       | 101                       | 106                        | 207                        | 1,731                       | 2,389                      | 3,537                      | 100% | 100% | 100% |
| 321  | 744   | 1,812 | 1,859 | 1,065| 96,986| 24        | 91        | 107       | 54                        | 248                        | 302                        | 535                         | 2,837                      | 2,898                      | 100% | 100% | 100% |
| 322  | 42    | 126   | 132   | 23  | 2,021 | 49        | 89        | 91         | 16                        | 266                        | 282                        | 102                         | 704                        | 704                        | 100% | 100% | 100% |
| 331  | 890   | 696   | 702   | 584 | 46,016| 35        | 79        | 92         | 66                        | 229                        | 295                        | 825                         | 4,384                      | 4,391                      | 100% | 100% | 100% |
| 332  | 180   | 165   | 184   | 68  | 5,090 | 18        | 75        | 78         | 31                        | 286                        | 317                        | 704                         | 1,455                      | 1,455                      | 100% | 100% | 100% |
| 411  | 60    | 194   | 311   | 51  | 3,833 | 33        | 75        | 78         | 20                        | 35                         | 55                         | 244                         | 663                        | 664                        | 100% | 100% | 100% |
| 412  | 896   | 1,665 | 1,678 | 1,907| 102,210| 19        | 54        | 73         | 61                        | 11                         | 73                         | 1,637                       | 570                        | 1,643                      | 100% | 100% | 100% |
| 421  | 188   | 546   | 557   | 267 | 13,242| 18        | 50        | 61         | 24                        | 57                         | 81                         | 535                         | 2,015                      | 2,018                      | 100% | 100% | 100% |
| 422  | 26    | 65    | 65    | 16  | 718  | 45        | 46        | 55         | 11                        | 79                         | 91                         | 181                         | 559                        | 560                        | 100% | 100% | 100% |
| 431  | 580   | 477   | 525   | 596 | 15,196| 15        | 26        | 38         | 32                        | 34                         | 66                         | 761                         | 3,232                      | 3,239                      | 100% | 100% | 100% |
| 432  | 2     | 11    | 11    | 0   | 0    | 32        | 32        | 32         | 0                         | 0                          | 0                          | 0                            | 0                           | 0                           | 100% | 100% | 100% |
| 999  | 544   | 315   | 944   | 611 | 18,327| 30        | 30        | 30         | 58                        | 915                        | 973                        | 2,275                       | 4,686                      | 4,691                      | 100% | 100% | 100% |

**Sum** | 6,878 | 14,469 | 17,563 | 8,827 | 642,722 | 11        | 73        | 123        | 44                        | 374                        | 418                        | 2,275                       | 9,253                      | 9,257                      | 100% | 100% | 100% |
### Status-quo Scenario: Year 2020 (average AM peak hour traffic forecast, pce)

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