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Geographic information — Location-based services — Multimodal routing and navigation

Information géographique — Services basés sur la localisation — Routage et navigation multi-modes

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 19134 was prepared by Technical Committee ISO/TC 211, *Geographic information/Geomatics*.

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Introduction

In everyday life in metropolitan areas in the world, a typical traveller is involved in using various modes of transportation for daily activities: e.g. walking, driving, park-and-ride, mass transit and taxi. The traveller frequently faces the problem of finding the optimal or best route combining several modes, from the origin to the destination, passing through the locations (waypoints) where the traveller might want to engage in activities such as shopping and meeting people, possibly satisfying a set of constraints such as the sequence constraints like “activity 1 before activity 2”, “location 1 before location 2”, etc. A typical intercity traveller faces situations requiring decisions to be made such as which station (junction) and by which mode to travel in order to take which system among the available transportation modes between an origin and a destination. The decision will depend on the overall cost that includes the line-haul, parking, routing, stopping at stations (junctions), stopping at intermediate places, etc.

This International Standard provides a conceptual schema for describing the data and services needed to support routing and navigation application for mobile clients who intend to reach a target position using two or more modes of transportation. This conceptual schema is a standard schema such as the spatial schema (ISO 19107) or the temporal schema (ISO 19108). This International Standard provides a description of a service type to support routing and navigation for a mode that operates either on a fixed route or with a fixed schedule, a description of data type for transfers, and a description of data type for schedule information and route information of a mode with a fixed route and/or schedule.

Based upon ISO 19133:2005, this International Standard specifies additional classes as well as extensions to existing classes to be used for multimodal routing and navigation. As in ISO 19133:2005, this International Standard assumes that all requests for services will be encapsulated in a request/response pair between the mobile client and the client application or its on-web proxy application. Therefore, this International Standard describes service operation types and a set of request/response data types associated with some operations which are necessary for multimodal routing and navigation.

By way of adding and/or expanding ISO 19133:2005, standardized conceptual schemas for multimodal routing and navigation of mobile clients will increase the ability to share geographic information among multimodal location-based service applications. These schemas will be used by multimodal location-based service applications, mostly in metropolitan areas, and in all intercity travelling environments to provide consistently understandable spatial data structures.

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Geographic information — Location-based services — Multimodal routing and navigation

1 Scope

This International Standard specifies the data types and their associated operations for the implementation of multimodal location-based services for routing and navigation. It is designed to specify web services that may be made available to wireless devices through web-resident proxy applications, but is not limited to that environment.

2 Conformance

Conformance to this International Standard depends on the type of entity declaring conformance.

Mechanisms for the data exchanges are conformant to this International Standard if they contain record implementations of the object types described within this International Standard, as specified in A.2.

Web services for routing and navigation are conformant to this International Standard if their interfaces implement one or both of the subtypes of service defined in this International Standard, as specified in A.3.

Details of the conformance classes are given in the Abstract test suite in Annex A.

3 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 19101, *Geographic information — Reference model*

ISO 19107, *Geographic information — Spatial schema*

ISO 19108, *Geographic information — Temporal schema*

ISO 19112, *Geographic information — Spatial referencing by geographic identifiers*

ISO 19133:2005, *Geographic information — Location-based services — Tracking and navigation*

4 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

4.1
application
manipulation and processing of data in support of user requirements

[ISO 19101]

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4.2
application schema
conceptual schema for data required by one or more **applications**

[ISO 19101]

4.3
cost function
function that associates a measure (cost) to a **route**

[ISO 19133:2005]

NOTE The normal mechanism is to apply a cost to each part of a route, and to define the total route cost as the sum of the cost of the parts. This is necessary for the operation of the most common navigation algorithms. The units of cost functions are not limited to monetary costs and values only, but include such measures as time, distance and possibly others. The only requirement is that the function be additive and at least non-negative. This latter criteria can be softened as long as it is not zero or less cost is associated to any loop in the network, as this will prevent the existence of a "minimal cost" route.

4.4
junction
single topological node in a **network** with its associated collection of **turns**, and incoming and outgoing **links**

[ISO 19133:2005]

NOTE Junction is an alias for node.

4.5
link
directed topological connection between two nodes (**junctions**), consisting of an edge and a direction

[ISO 19133:2005]

NOTE Link is an alias for directed edge.

4.6
location
identifiable geographic place

[ISO 19112]

NOTE A location is represented by one of a set of data types that describes a position, along with metadata about that data, including coordinates (from a coordinate reference system), a measure (from a linear referencing system), or an address (from an address system) [ISO 19133:2005].

4.7
location-based service
LBS
service whose return or other property is dependent on the **location** of the client requesting the service or of some other thing, object or person

[ISO 19133:2005]

4.8
navigation
combination of **routing**, route traversal and **tracking**

[ISO 19133:2005]

NOTE This is essentially the common term navigation, but the definition decomposes the process in terms used in the packages defined in this International Standard.

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4.9
network
abstract structure consisting of a set of 0-dimensional objects called **junctions**, and a set of 1-dimensional objects called **links** that connect the **junctions**, each **link** being associated to a start (origin, source) **junction** and end (destination, sink) **junction**

[ISO 19133:2005]

NOTE The network is essentially the universe of discourse for the navigation problem. Networks are a variety of one-dimensional topological complexes. In this light, junction and topological nodes are synonyms, as are link and directed edges.

4.10
position
data type that describes a point or geometry potentially occupied by an object or person

[ISO 19133:2005]

NOTE A direct position is a semantic subtype of position. Direct position as described can only define a point and therefore not all positions can be represented by a direct position. That is consistent with the "is type of" relation. An ISO 19107 geometry is also a position, but not a direct position.

4.11
route
sequence of links, and/or partial links, that describe a path, usually between two positions, within a network

[ISO 19133:2005]

4.12
routing
finding of optimal (minimal **cost function**) **routes** between **locations** in a **network**

[ISO 19133:2005]

4.13
tracking
monitoring and reporting the **location** of a **vehicle**

[ISO 19133:2005]

4.14
transportation mode
means that travellers can choose for transportation

4.15
turn
part of a **route** or **network** consisting of a **junction** location and an entry and exit **link** for that **junction**

[ISO 19133:2005]

4.16
traveller
person subject to being navigated, or tracked

cf. vehicle

[ISO 19133:2005]

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4.17
vehicle
object subject to being navigated or tracked

cf. traveller

[ISO 19133:2005]

5 Symbols and abbreviated terms

5.1 Acronyms

BPR Bureau of Public Roads

GDF Geographic Data Format

GIS Geographic Information System

GML Geographic Markup Language

GPS Global Positioning System

ITS Intelligent Transportation System

LBS Location-Based Service

LBMS Location-Based Mobile Services

LP Linear Programming

PCU Passenger Car-equivalent Unit

UML Unified Modeling Language

5.2 UML Notation

The UML notation used in this International Standard is described in ISO 19107, and differs from standard UML only in the existence and interpretation of some special stereotypes, in particular “CodeList” and “Union”.

As in ISO 19133:2005, the term “context diagram”, as used extensively in the naming of figures in this International Standard, means a diagram that illustrates the context of a specified central type meaning the types of its attributes, operations and association targets. This is the information most useful to the implementer of this central class.

5.3 Package abbreviations

Two-letter abbreviations are used to denote the package that contains a class. Those abbreviations precede class names, connected by a “_”. The International Standard in which those classes are located is indicated in parentheses. A list of those abbreviations follows.

MM Multimodal Network (ISO 19134)

MN Multimodal Navigation Service (ISO 19134)

NS Navigation Service (ISO 19133:2005)

NT Network (ISO 19133:2005)

TM Temporal (ISO 19108)

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6 Multimodal LBS for routing and navigation

6.1 Semantics

The model for multimodal LBS for routing and navigation consists of the ISO 19133:2005 package and five leaf packages: Multimodal Network, Multimodal Routing, Multimodal Constraint and Advisory, Multimodal Cost Function, and Multimodal Navigation Service. In addition to the appropriate types and classes of ISO 19133:2005, the five leaf packages contain types and classes which are necessary to create a multimodal LBS routing and navigation service. Figure 1 shows the dependencies among those leaf packages, including the ISO 19133:2005 package.

Multimodal location-based service utilizes networks of public transportation modes that operate on fixed and/or flexible schedule routes, using either road networks or guided networks. Preferable travel modes are decided and travel costs are calculated based on user preference and/or on cost functions.

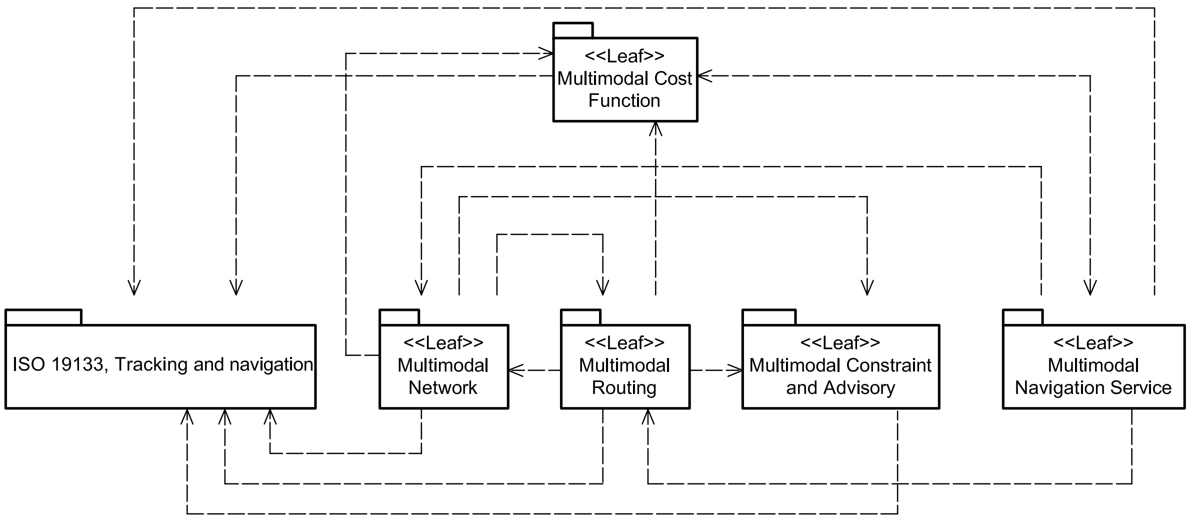

Figure 1 — Package dependencies

6.2 Multimodal Network

6.2.1 Semantics

The multimodal network model in this International Standard extends NT_CombinedNetwork and related classes from ISO 19133:2005, in order to specify multimodal LBS for routing and navigation. Multimodal network consists of component route segments and transfer nodes as shown in Figure 2. Modal transfer occurs only at a transfer node.

EXAMPLE One can transfer at NODE 112 from BUS # 2 to SUBWAY # 5. Transfers from walking or taxi to line-haul modes can be done at other nodes in Figure 2.

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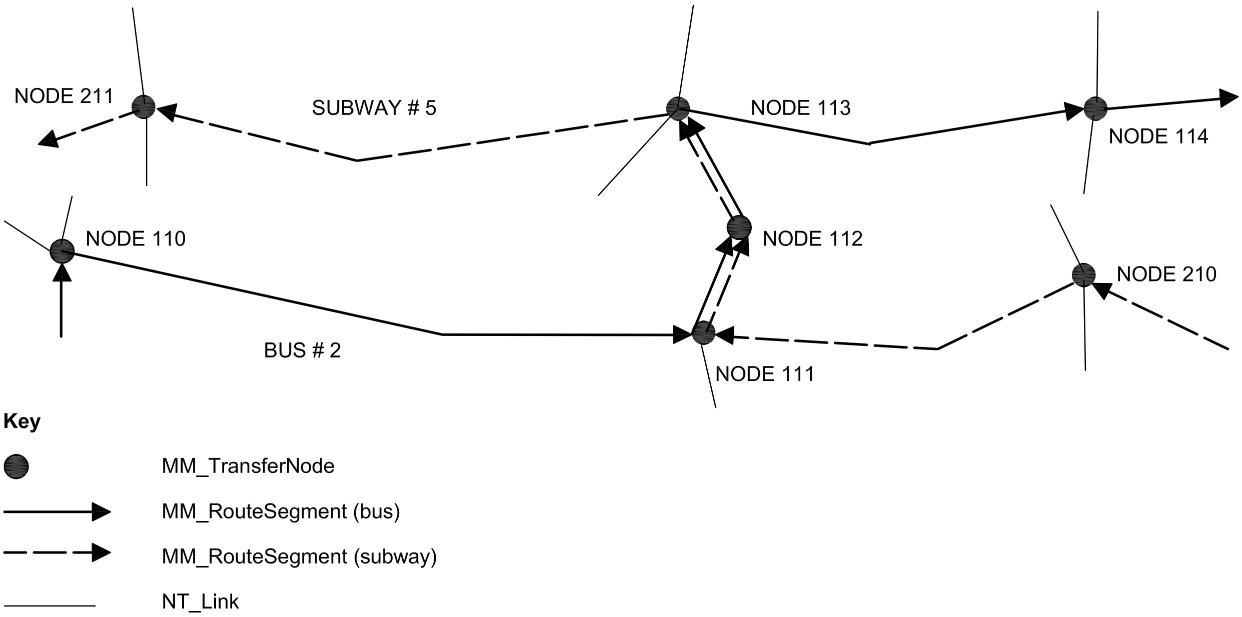

Figure 2 — MM_TransferNode and MM_RouteSegment in the MM_MultimodalNetwork

The route segment, MM_SingleModeLink, is a subtype of NT_Link specified in ISO 19133:2005.

EXAMPLE Figure 3 shows a base network for a multimodal network of which NT_SingleModeLink and its associated NT_SingleModeJunction are composed.

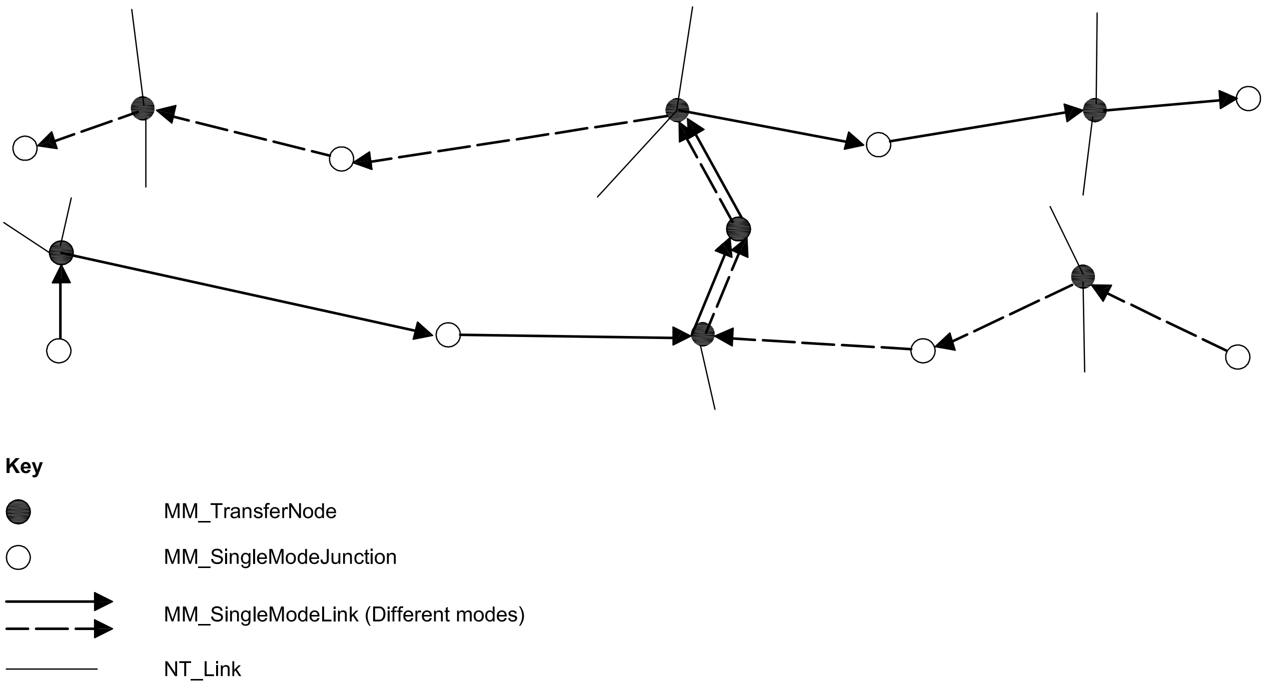

Figure 3 — NT_SingleModeLinks and NT_SingleModeJunctions in the MM_MultimodalNetwork

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Figure 4 shows how the principal classes defined in this package are related to classes defined in ISO 19133:2005.

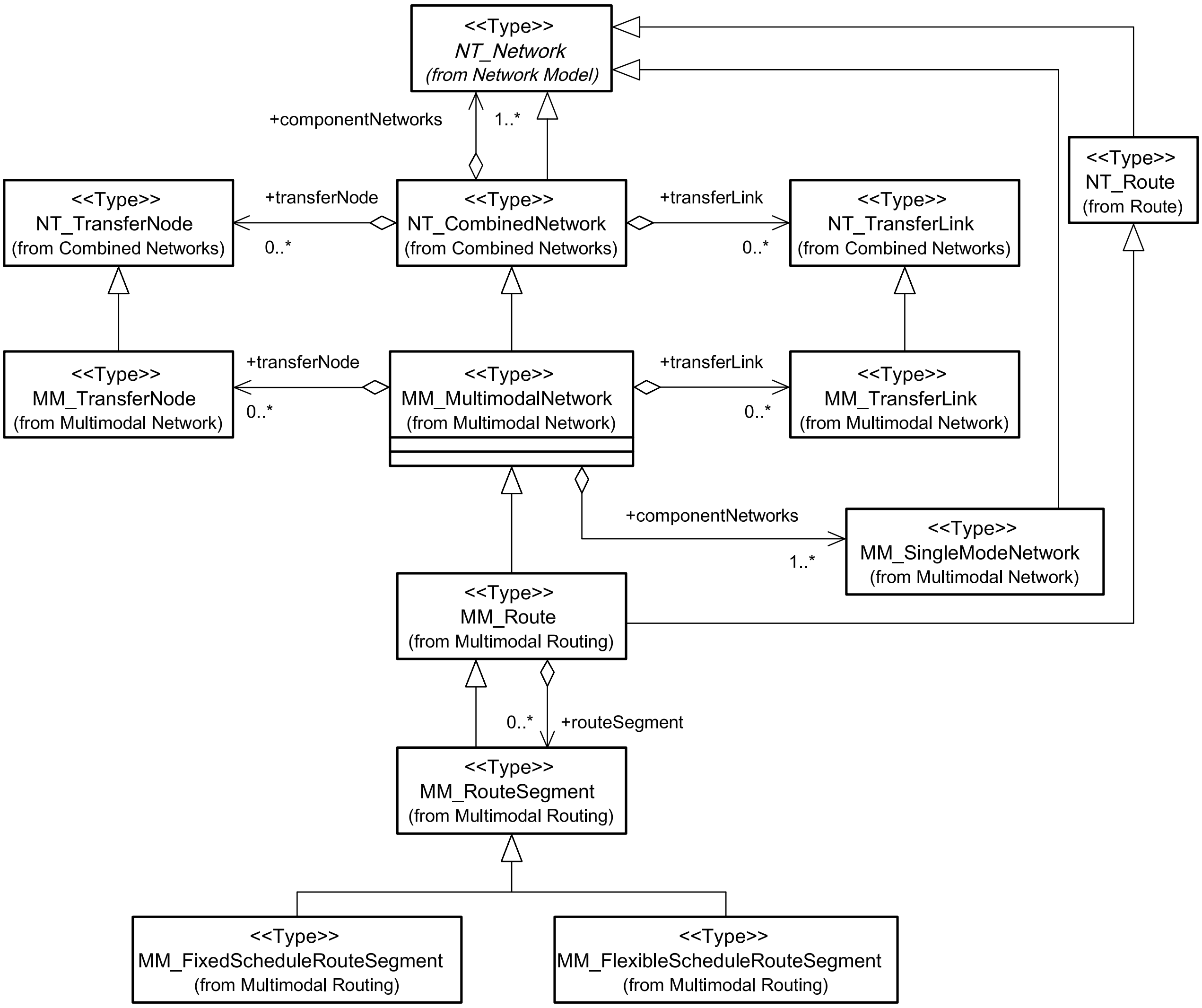

Figure 4 — ISO 19133:2005 and ISO 19134

6.2.2 MM_MultimodalNetwork

6.2.2.1 Semantics

The type MM_MultimodalNetwork is a type which aggregates MM_SingleModeNetworks into NT_CombinedNetwork for multimodal routing and navigation. Using MM_TransferNodes or MM_TransferLinks, a MM_MultimodalNetwork merges a set of single mode networks (MM_SingleModeNetwork) into a larger multimodal network. The UML diagram for MM_MultimodalNetwork is given in Figure 5.

6.2.2.2 Role: componentNetworks : MM_SingleModeNetwork

The association role componentNetworks is the inherited association role from NT_CombinedNetwork in ISO 19133:2005, which specifies the single mode networks from which this multimodal network is created:

```
MM_MultimodalNetwork :: componentNetworks : MM_SingleModeNetwork
```

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6.2.2.3 Role: transferLink : MM_TransferLink

The association role transferLink is the inherited association role from NT_CombinedNetwork in ISO 19133:2005, which specifies the transfer link used by this multimodal network to link other single mode networks from its component single mode network list:

```
MM_MultimodalNetwork :: transferLink : MM_TransferLink
```

6.2.2.4 Role: transferNode : MM_TransferNode

The association role transferNode is the inherited association role from NT_CombinedNetwork in ISO 19133:2005, which specifies the transfer nodes used by this multimodal network to join other single mode networks from its component single mode network list:

```
MM_MultimodalNetwork :: transferNode : MM_TransferNode
```

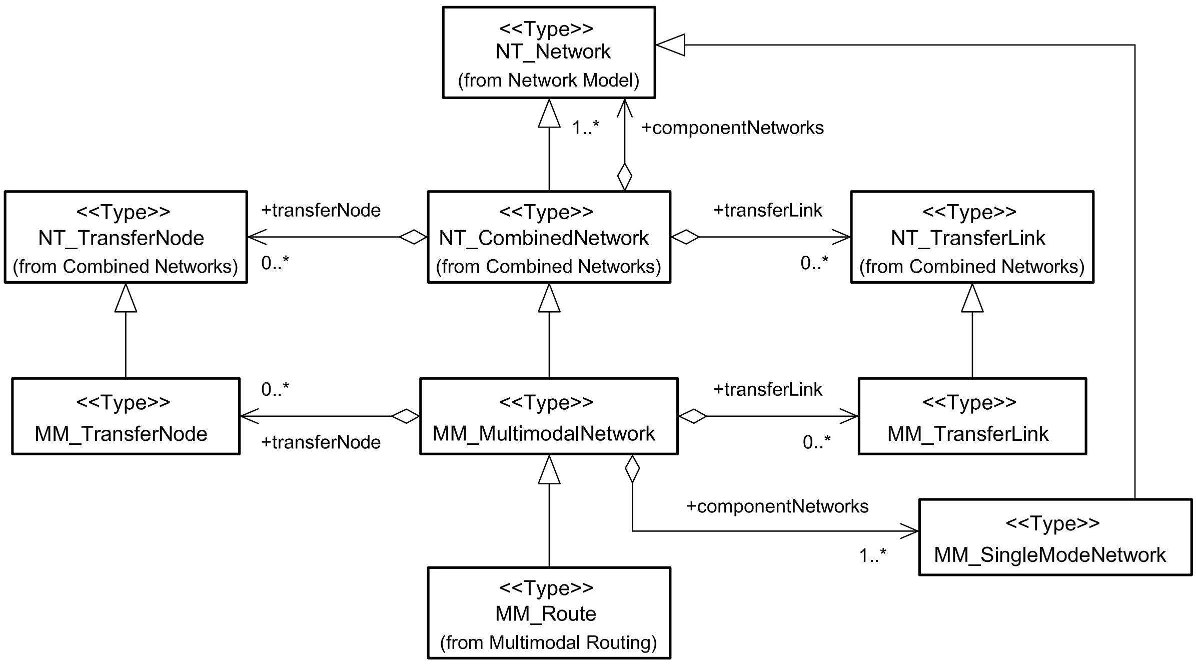

Figure 5 — Context Diagram: MM_MultimodalNetwork

6.2.3 MM_TransferNode

6.2.3.1 Semantics

The type MM_TransferNode is a subtype of NT_TransferNode from ISO 19133:2005, which is a topological node connected to network links in two different single mode networks. The UML diagram for MM_TransferNode is given in Figure 6.

6.2.3.2 Attribute: junctionType[0..1] : MM_TransferNodeType

The attribute junctionType overrides the inherited attribute of NT_TransferNode from ISO 19133:2005, which is used to specify the type of this transfer node:

```
MM_TransferNode :: junctionType[0..1] : MM_TransferNodeType
```


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6.2.3.3 Attribute: disabledAccessible : Boolean

The attribute disabledAccessible indicates if this transfer node is accessible for the disabled:

```
MM_TransferNode :: disabledAccessible : Boolean
```

6.2.3.4 Role: turn : MM_Transfer

The association role turn specifies the turns (subtyped as MM_Transfer from NT_Transfer) that are located at this transfer node:

```
MM_TransferNode :: turn : MM_Transfer
```

6.2.3.5 Operation: entryLink

The operation entryLink overrides the inherited operation of NT_TransferNode from ISO 19133:2005, which returns a list of all single mode links that enter this transfer node:

```
MM_TransferNode :: entryLink() : MM_SingleModeLink [1..*]
```

6.2.3.6 Operation: exitLink

The operation exitLink overrides the inherited operation of NT_TransferNode from ISO 19133:2005, which returns a list of all single mode links that exit from this transfer node:

```
MM_TransferNode :: exitLink() : MM_SingleModeLink [1..*]
```

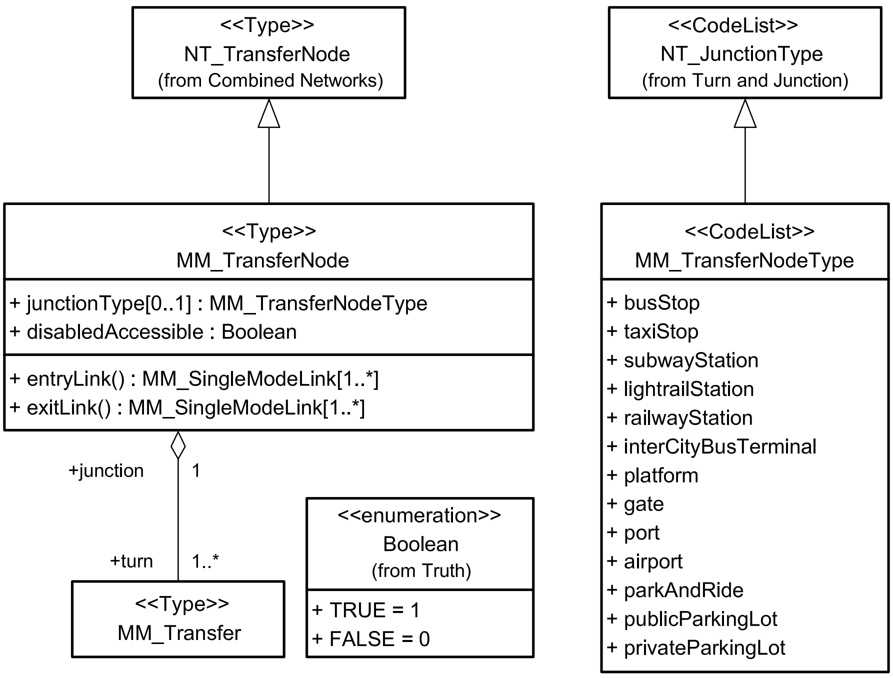

Figure 6 — Context Diagram: MM_TransferNode

6.2.4 MM_TransferNodeType

The code list MM_TransferNodeType extends the inherited code list NT_JunctionType in ISO 19133:2005, which is the value domain for the transfer nodes. The list includes: bus stop, taxi stop, subway station, lightrail

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station, railway station, intercity bus terminal, platform, gate, port, airport, park-and-ride, public parking lot, and private parking lot. The UML diagram for MM_TransferNodeType is given in Figure 7.

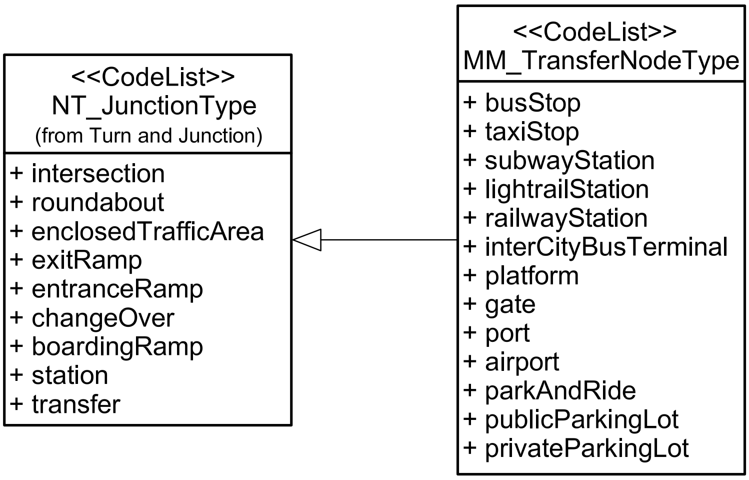

Figure 7 — Context Diagram: MM_TransferNodeType

6.2.5 MM_Transfer

6.2.5.1 Semantics

The type MM_Transfer is a subtype of NT_Transfer from ISO 19133:2005, which is used to represent a multimodal transfer that occurs at a transfer node of the multimodal transportation network. MM_Transfer specifies both which route segment (as a set of MM_SingleModeLink) enters the transfer node and which route segment (as a set of MM_SingleModeLink) exits the transfer node. The UML diagram for MM_Transfer is given in Figure 8.

6.2.5.2 Attribute: disabledAccessible : Boolean

The attribute disabledAccessible indicates if this transfer is usable for the disabled:

```
MM_Transfer :: disabledAccessible : Boolean
```

6.2.5.3 Role: junction : MM_TransferNode

The association role junction specifies the transfer node at which this transfer occurs:

```
MM_Transfer :: junction : MM_TransferNode
```

6.2.5.4 Role: maneuver : MM_TripScheme

The association role maneuver specifies the trip schemes associated to this transfer:

```
MM_Transfer :: maneuver : MM_TripScheme
```


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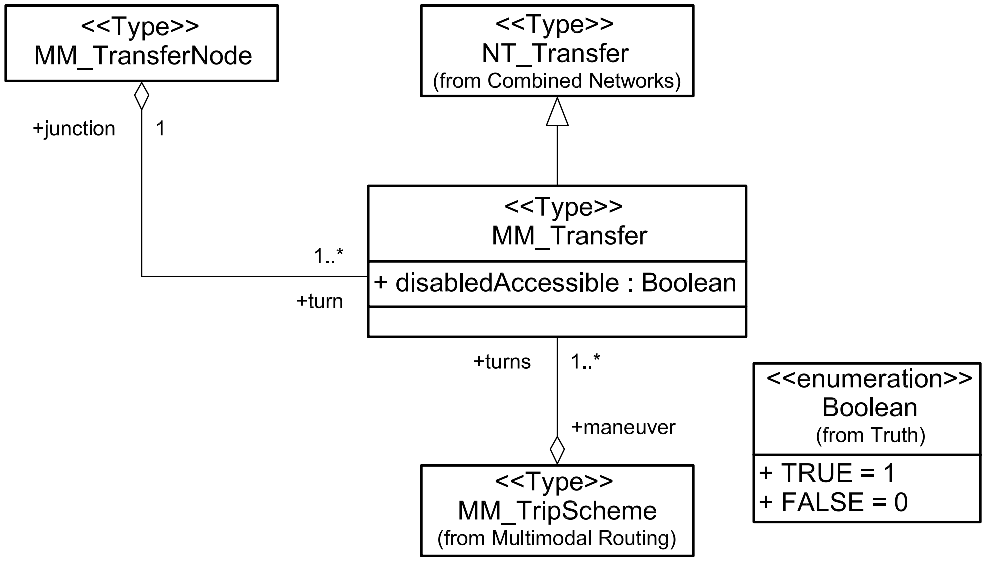

Figure 8 — Context Diagram: MM_Transfer

6.2.6 MM_TransferLink

The type MM_TransferLink, a subtype of NT_TransferLink from ISO 19133:2005, is used to represent links in a multimodal network whose boundary nodes are in different component single mode networks. The UML diagram for MM_TransferLink is given in Figure 9.

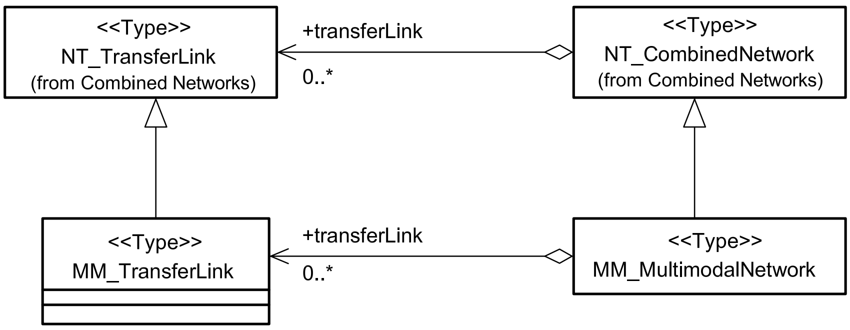

Figure 9 — Context Diagram: MM_TransferLink

6.2.7 MM_SingleModeNetwork

6.2.7.1 Semantics

The type MM_SingleModeNetwork is a component network of MM_MultimodalNetwork. It is a subtype of NT_Network. The UML diagram for MM_SingleModeNetwork is given in Figure 10.

6.2.7.2 Attribute: mode : MM_TransportationModeType

The attribute mode is used to specify the type of the transportation mode of the single mode network:

```
MM_SingleModeNetwork :: mode : MM_TransportationModeType
```

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6.2.7.3 Role: link : MM_SingleModeLink

The association role link aggregates all the single mode links contained in this single mode network:

```
MM_SingleModeNetwork :: link : MM_SingleModeLink
```

6.2.7.4 Role: element : MM_SingleModeJunction

The association role element aggregates all the single mode junctions contained in this single mode network:

```
MM_SingleModeNetwork :: element : MM_SingleModeJunction
```

6.2.7.5 Role: turn : MM_SingleModeTurn

The association role turn aggregates all the single mode turns contained in this single mode network:

```
MM_SingleModeNetwork :: turn : MM_SingleModeTurn
```

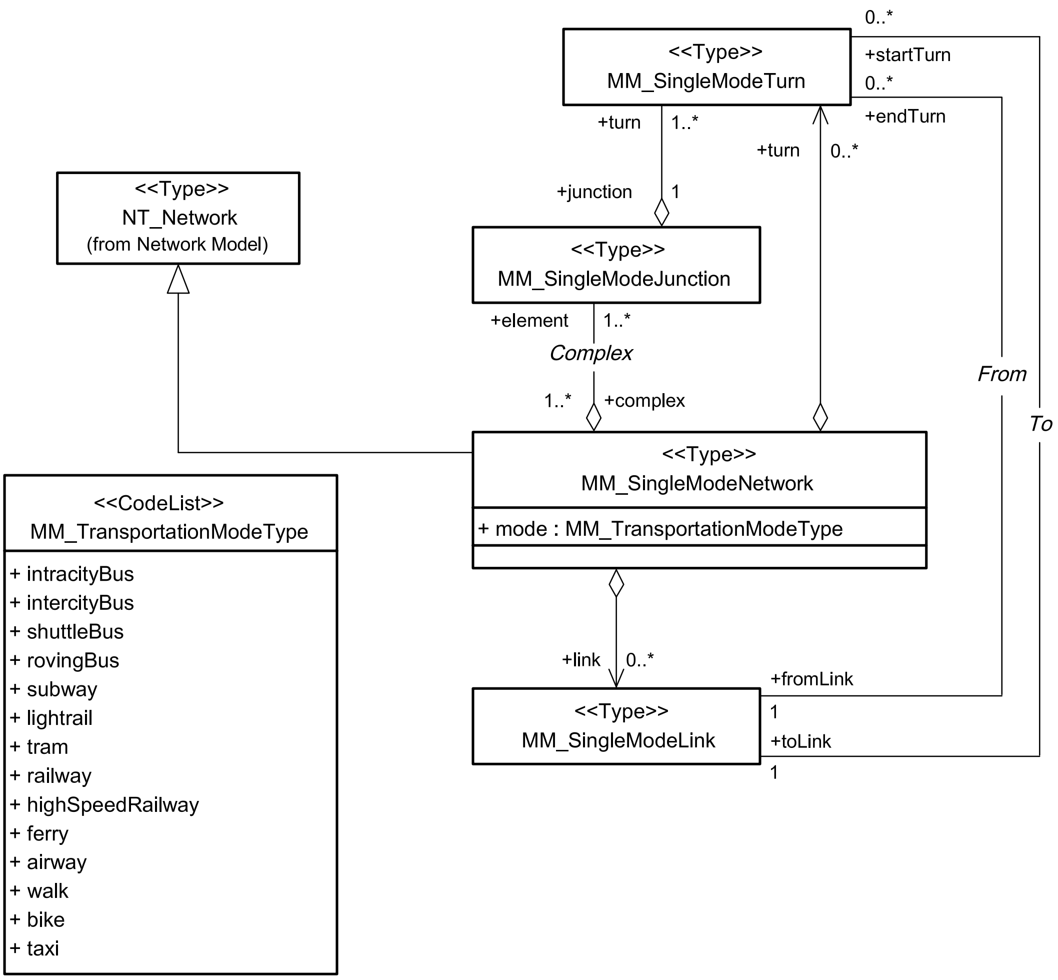

Figure 10 — Context Diagram: MM_SingleModeNetwork

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6.2.8 MM_SingleModeTurn

6.2.8.1 Semantics

The type MM_SingleModeTurn is a subtype of NT_Turn from ISO 19133:2005, which represents a mechanism for traversing from one single mode link to another. The UML diagram for MM_SingleModeTurn is given in Figure 11.

6.2.8.2 Role: toLink : MM_SingleModeLink

The association role toLink specifies the single mode link into which this turn navigates:

```
MM_SingleModeTurn :: toLink : MM_SingleModeLink
```

6.2.8.3 Role: fromLink : MM_SingleModeLink

The association role fromLink specifies the single mode link from which this turn navigates:

```
MM_SingleModeTurn :: fromLink : MM_SingleModeLink
```

6.2.8.4 Role: junction : MM_SingleModeJunction

The association role junction specifies the single mode junction at which this turn occurs:

```
MM_SingleModeTurn :: junction : MM_SingleModeJunction
```

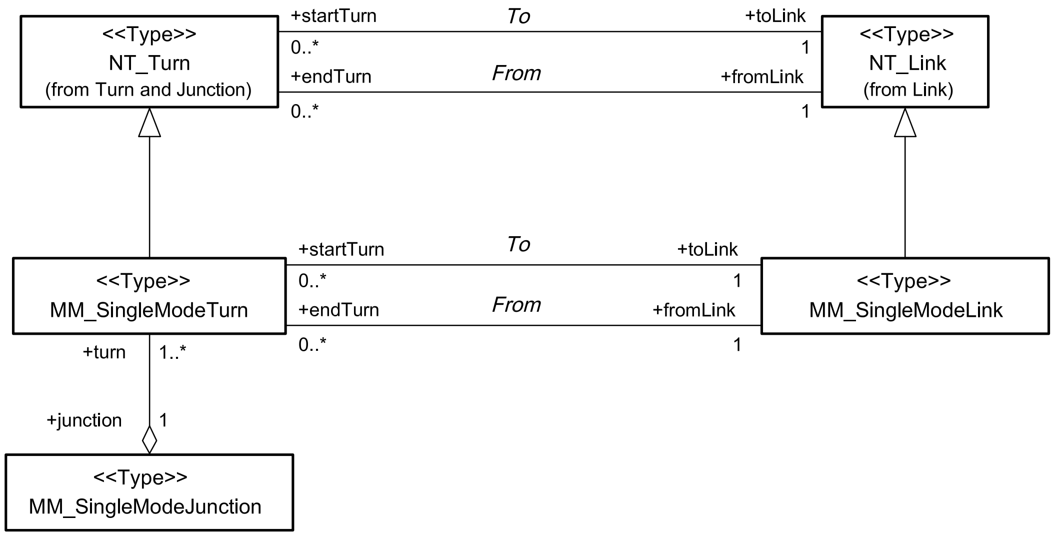

Figure 11 — Context Diagram: MM_SingleModeTurn

6.2.9 MM_SingleModeJunction

6.2.9.1 Semantics

The type MM_SingleModeJunction is a subtype of NT_Junction (from ISO 19133:2005), which is a place turns occur. The UML diagram for MM_SingleModeJunction is given in Figure 12.

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6.2.9.2 Role: turn : MM_SingleModeTurn

The role turn is inherited from NT_Junction, which aggregates all MM_SingleModeTurns that occur at this junction:

```
MM_SingleModeJunction :: turn : MM_SingleModeTurn
```

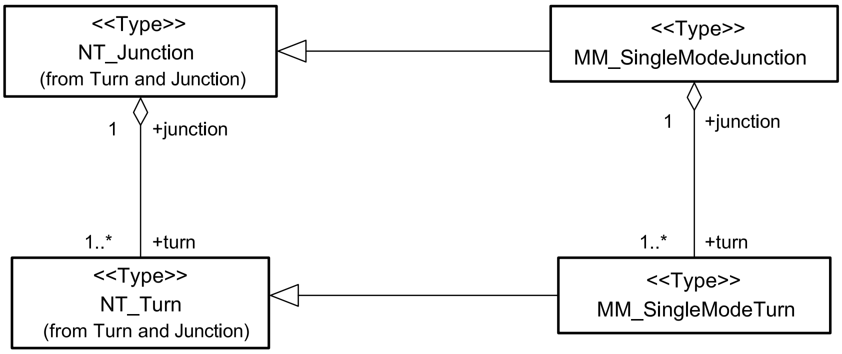

Figure 12 — Context Diagram: MM_SingleModeJunction

6.2.10 MM_SingleModeLink

6.2.10.1 Semantics

The type MM_SingleModeLink describes a route segment (as a link in the network) of the mode as specified in the attribute routeSegmentCategory, which is overridden from NT_Link to include a richer selection of categories. The UML diagram for MM_SingleModeLink is given in Figure 13.

6.2.10.2 Attribute: routeSegmentCategory [0..*] : MM_TransportationModeType

The attribute routeSegmentCategory is used to specify the type of the transportation mode of the single mode link. This attribute overrides the inherited attribute routeSegmentCategory of NT_Link from ISO 19133:2005:

```
MM_SingleModeLink :: routeSegmentCategory [0..*] : MM_TransportationModeType
```

6.2.10.3 Role: startTurn [0..*] : MM_SingleModeTurn

The role startTurn associates this link to all potential single mode turns that can be used to enter this link:

```
MM_SingleModeLink :: startTurn [0..*] : MM_SingleModeTurn
```

6.2.10.4 Role: endTurn [0..*] : MM_SingleModeTurn

The role endTurn associates this link to all potential single mode turns that can be used to exit this link:

```
MM_SingleModeLink :: endTurn [0..*] : MM_SingleModeTurn
```


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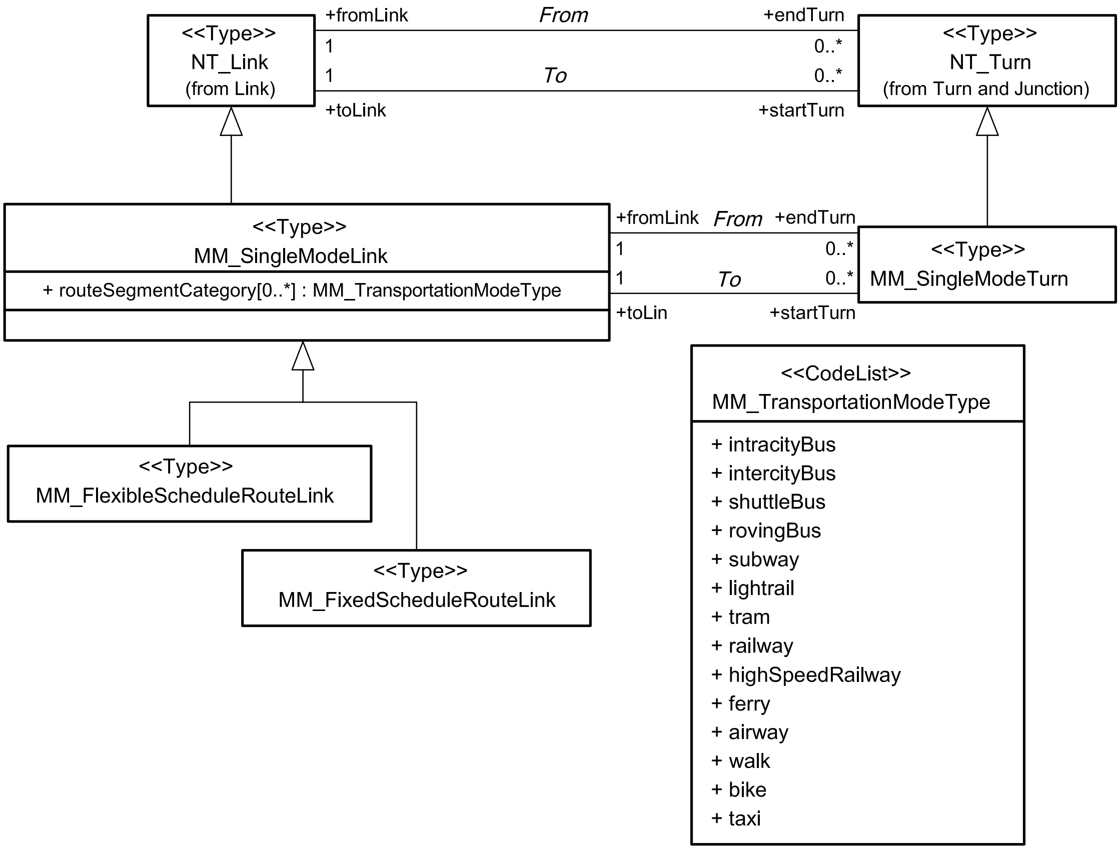

Figure 13 — Context Diagram: MM_SingleModeLink

6.2.11 MM_FixedScheduleRouteLink

6.2.11.1 Semantics

The type MM_FixedScheduleRouteLink describes a route segment (as a link in the network) of public transport modes which operates on predefined schedules. The modes are specified in the attribute routeSegmentCategory inherited from MM_SingleModeLink. The UML diagram for MM_FixedScheduleRouteLink is given in Figure 14.

6.2.11.2 Role: scheduleInfo [1..*] : MM_ScheduleInfo

The association role scheduleInfo aggregates all schedule information on the fixed route segment:

```
MM_FixedScheduleRouteLink :: scheduleInfo [1..*] : MM_ScheduleInfo
```

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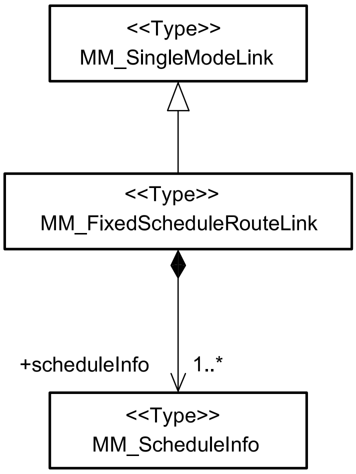

Figure 14 — Context Diagram: MM_FixedScheduleRouteLink

6.2.12 MM_FlexibleScheduleRouteLink

The type MM_FlexibleScheduleRouteLink describes a route segment not operated based on a predefined schedule. Route segments may be chosen by a traveller or by an operator of the mode on the route segment at their will. For example, the route segments by a taxi are likely to be defined by either the traveller or the taxi driver, but not by a predefined schedule. The UML diagram for MM_FlexibleScheduleRouteLink is given in Figure 15.

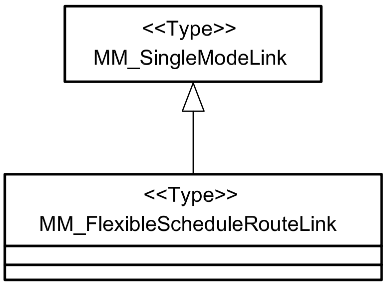

Figure 15 — Context Diagram: MM_FlexibleScheduleRouteLink

6.2.13 MM_TransporationModeType

The code list MM_TransportationModeType extends the code list NT_RouteSegmentCategory, which is the value domain for multimodal route segment categories. The list includes: intracityBus, intercityBus, shuttleBus, rovingBus, subway, lightrail, tram, railway, highSpeedRailway, ferry, airway, walk, bike and taxi. The UML diagram for MM_TransportationModeType is given in Figure 16.

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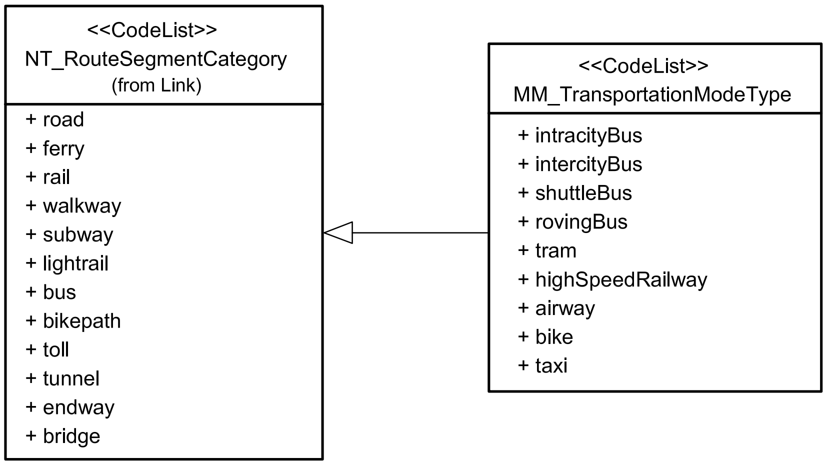

Figure 16 — Context Diagram: MM_TransportationModeType

6.2.14 MM_ScheduleInfo

6.2.14.1 Semantics

The type MM_ScheduleInfo describes time schedules for a fixed route segment. The UML diagram for MM_ScheduleInfo is given in Figure 17.

6.2.14.2 Attribute: arrival : TM_Primitive

The attribute arrival specifies a scheduled arrival time at the end point of the fixed route segment (a transfer node):

```
MM_ScheduleInfo :: arrival : TM_Primitive
```

6.2.14.3 Attribute: departure : TM_Primitive

The attribute departure specifies a scheduled departure time at the start point of the fixed route segment (a transfer node):

```
MM_ScheduleInfo :: departure : TM_Primitive
```

6.2.14.4 Attribute: description : CharacterString

The attribute description is a natural language description of the schedule:

```
MM_ScheduleInfo :: description : CharacterString
```

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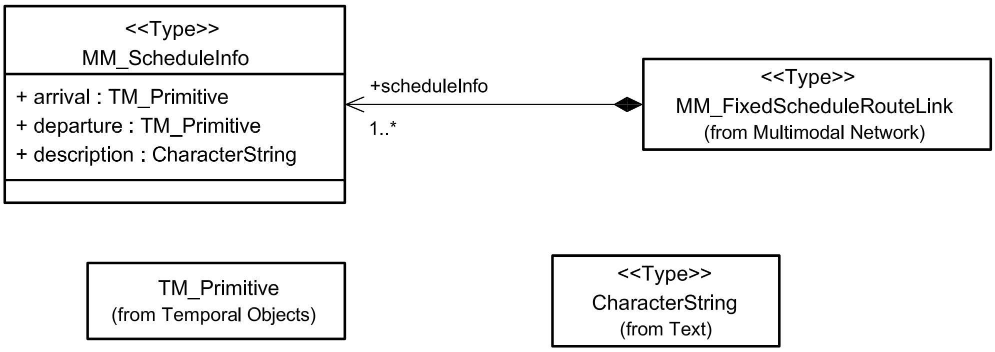

Figure 17 — Context Diagram: MM_ScheduleInfo

6.3 Multimodal Routing

6.3.1 Semantics

The leaf package Routing contains classes for specifying a route within a multimodal network.

6.3.2 MM_Route

6.3.2.1 Semantics

The type MM_Route describes routes defined by a geometric object (a composite curve), and starts and stops positions on the geometry. MM_Route is a subtype of NT_Route in ISO 19133:2005. The UML diagram for MM_Route is given in Figure 18.

6.3.2.2 Attribute: summary : MM_RouteSummary

The attribute summary overrides the inherited attribute of NT_Route and contains general information about the multimodal route:

```
MM_Route :: summary : MM_RouteSummary
```

6.3.2.3 Role: tripScheme : MM_TripScheme

The association role tripScheme aggregates an ordered set of trip schemes:

```
MM_Route :: tripScheme : MM_TripScheme
```

6.3.2.4 Role: routeSegment : MM_RouteSegment

The association role routeSegment aggregates set of route segments which are components of the whole multimodal route:

```
MM_Route :: routeSegment : MM_RouteSegment
```

6.3.2.5 Operation: recalculate

The operation recalculate overrides the inherited operation of NT_Route and causes the multimodal route to be recalculated from some point along it (given by a waypoint). The return value of the function is the new multimodal route. The returned route follows the original at least up through and to the passed waypoints:

```
MM_Route :: recalculate(NT_WayPoint from, NS_CostFunction cost) : MM_Route
```


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6.3.2.6 Operation: asRouteSegments

The operation asRouteSegments returns a version of the route as a sequence of route segments:

```
MM_Route :: asRouteSegments() : Sequence<MM_RouteSegment>
```

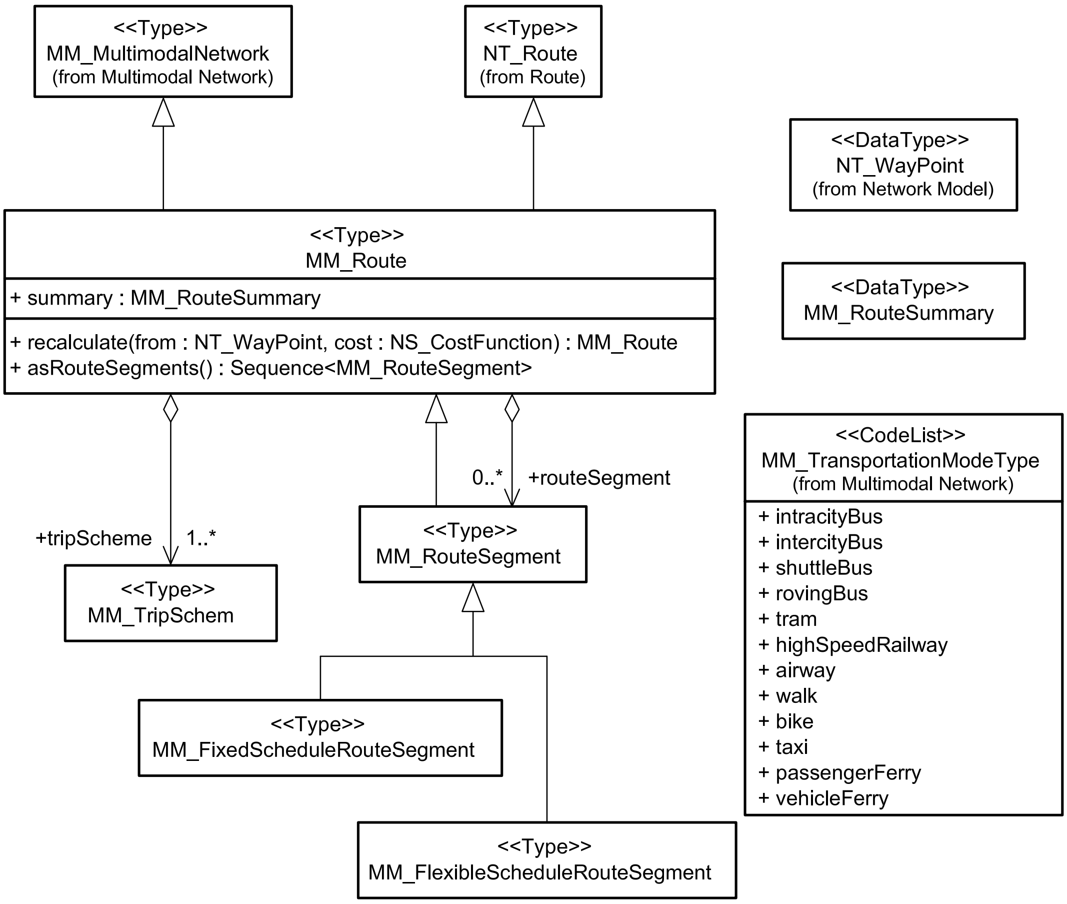

Figure 18 — Context Diagram: MM_Route

6.3.3 MM_RouteSummary

6.3.3.1 Semantics

The data type MM_RouteSummary contains route summary information which is inherited from NT_RouteSummary in ISO 19133:2005. MM_RouteSummary contains an additional attribute to provide appropriate multimodal routing services. The UML diagram for MM_RouteSummary is given in Figure 19.

6.3.3.2 Attribute: numberOfTransfers : Integer

The attribute numberOfTransfers returns the number of transfers required for execution of the route:

```
MM_RouteSummary :: numberOfTransfers : Integer
```


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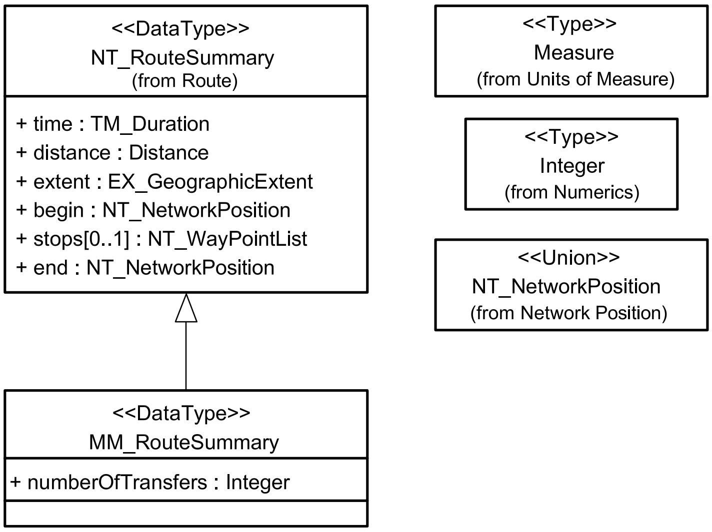

Figure 19 — Context Diagram: MM_RouteSummary

6.3.4 MM_RouteSegment

6.3.4.1 Semantics

The type MM_RouteSegment is used to delineate any route segments between two transfer nodes, or between a transfer node and either the start or end of the parent MM_Route. The type MM_RouteSegment is a subtype of both MM_Route and MM_SingleModeNetwork. The route segment may have two subtypes: a fixed route segment and a non-fixed route segment. The UML diagram for MM_RouteSegment is given in Figure 20.

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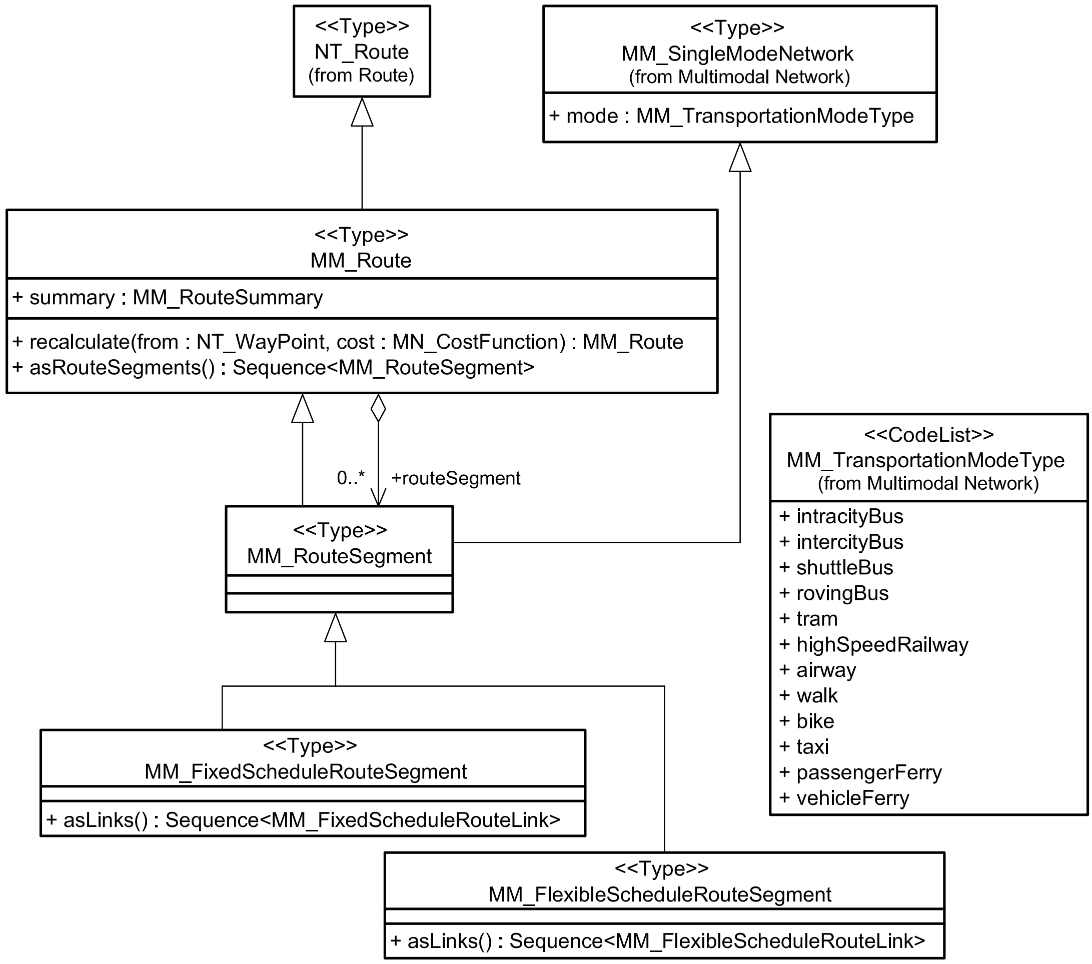

Figure 20 — Context Diagram: MM_RouteSegment

6.3.5 MM_FixedScheduleRouteSegment

6.3.5.1 Semantics

The type MM_FixedScheduleRouteSegment is a subtype of MM_RouteSegment, which delineates a fixed route segment such as transit route segments with a set of MM_FixedScheduleRouteLink. The UML diagram for MM_FixedScheduleRouteSegment is given in Figure 21.

6.3.5.2 Operation: asLinks

The operation asLinks overrides the inherited operation from NT_Route in ISO 19133:2005 and returns fixed route segments as a sequence of MM_FixedScheduleRouteLink:

```
MM_FixedScheduleRouteSegment :: asLinks() :
Sequence<MM_FixedScheduleRouteLink>
```

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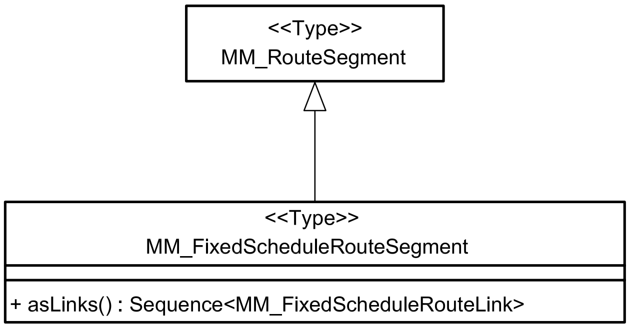

Figure 21 — Context Diagram: MM_FixedScheduleRouteSegment

6.3.6 MM_FlexibleScheduleRouteSegment

6.3.6.1 Semantics

The type MM_FlexibleScheduleRouteSegment is a subtype of MM_RouteSegment, which delineates a non-fixed route segment such as taxi route segments with a set of MM_FlexibleScheduleRouteLink. The UML diagram for MM_FlexibleScheduleRouteSegment is given in Figure 22.

6.3.6.2 Operation: asLinks

The operation asLinks overrides the inherited operation from NT_Route in ISO 19133:2005 and returns non-fixed route segments as a sequence of MM_FlexibleScheduleRouteLink.

```
MM_FlexibleScheduleRouteSegment :: asLinks() :
Sequence<MM_FlexibleScheduleRouteLink>
```

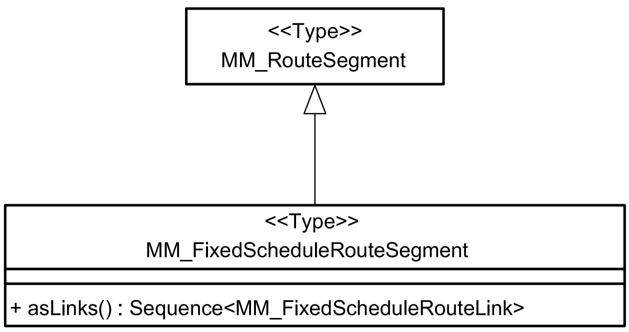

Figure 22 — Context Diagram: MM_FlexibleScheduleRouteSegment

6.3.7 MM_TripScheme

6.3.7.1 Semantics

The type MM_TripScheme, a subtype of NT_Maneuver from ISO 19133:2005, is used to describe a trip for a traveller or an operator on the multimodal network. A trip scheme is a valid sequence of actions given by a sequence of either turns or transfers. The UML diagram for MM_TripScheme is given in Figure 23.

6.3.7.2 Attribute: disabledAccessible : Boolean

The attribute disabledAccessible indicates if this trip scheme is usable for the disabled:

```
MM_TripScheme :: disabledAccessible : Boolean
```


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6.3.7.3 Role: turns : MM_Transfer

The association role turns aggregates the ordered set of transfers involved in this trip:

```
MM_TripScheme :: turns : MM_Transfer
```

6.3.7.4 Operation: startTransfer

The operation startTransfer returns the first transfer of this trip:

```
MM_TripScheme :: startTransfer() : MM_Transfer
```

6.3.7.5 Operation: endTransfer

The operation endTransfer returns the last transfer of this trip:

```
MM_TripScheme :: endTransfer() : MM_Transfer
```

6.3.7.6 Operation: startRouteSegment

The operation startRouteSegment returns the first route segment of this trip:

```
MM_TripScheme :: startRouteSegment() : MM_RouteSegment
```

6.3.7.7 Operation: endRouteSegment

The operation endRouteSegment returns the last route segment of this trip:

```
MM_TripScheme :: endRouteSegment() : MM_RouteSegment
```

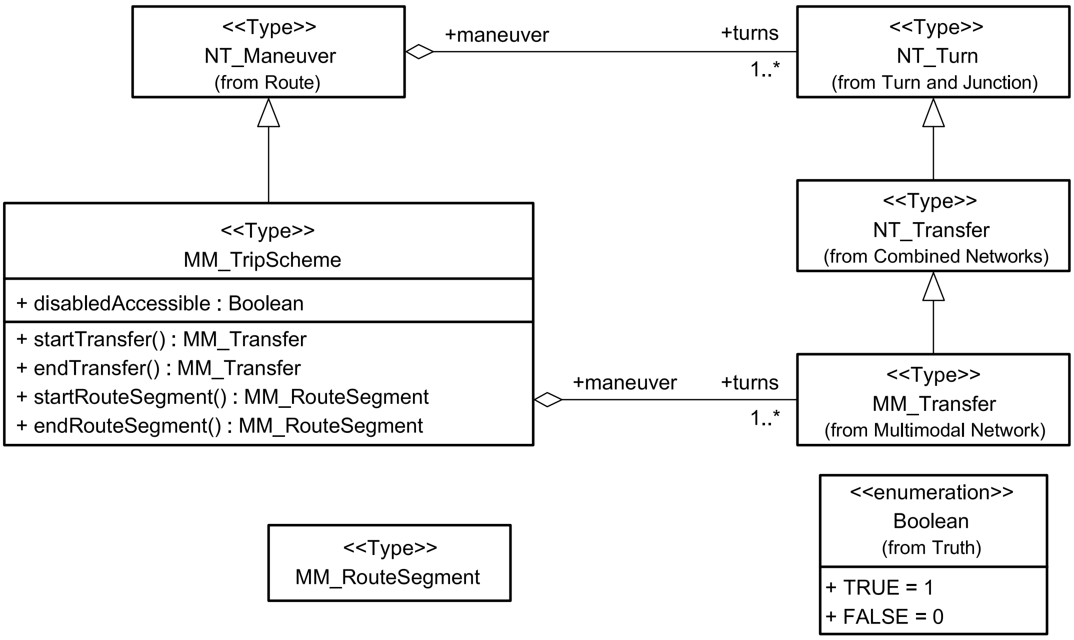

Figure 23 — Context Diagram: MM_TripScheme

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6.4 Multimodal Constraint and Advisory

6.4.1 Semantics

The leaf package Multimodal Constraint and Advisory shown in Figure 1 contains classes and types useful for associating constraints, and a multimodal advisory category to objects, usually transfers, travels and route segments. Basically, this International Standard expands the constraint elements of NT_Constraint from ISO 19133:2005 with the mode constraint. The UML diagram for the multimodal constraints elements is given in Figure 24.

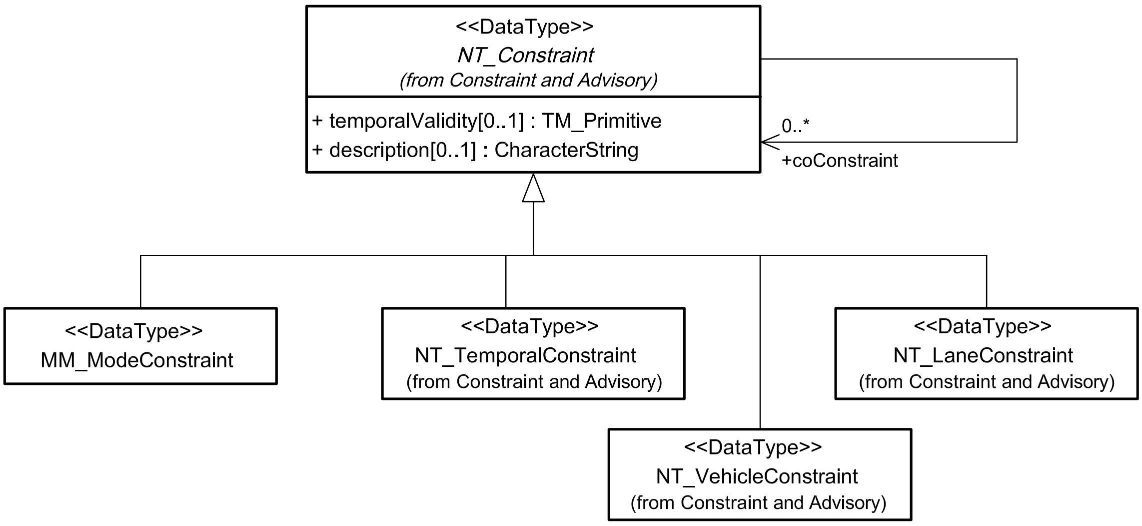

Figure 24 — Multimodal Constraints Elements

To provide a free text information to guide a multimodal trip, this International Standard uses the type NT_Advisory from ISO 19133:2005 with an expanded code list MM_AdvisoryCategory, which is a subtype of the code list NT_AdvisoryCategory from ISO 19133:2005.

6.4.2 MM_AdvisoryCategory

For multimodal routing and navigation purposes, the code list MM_AdvisoryCategory extends the corresponding code list NT_AdvisoryCategory from ISO 19133:2005 by adding the potential values takeTransferPoint and dropoffTransferPoint. Each value specifies an appropriate type of advisory to reach a destination point via potential waypoints, using multimodal transportation. The UML diagram for MM_AdvisoryCategory is given in Figure 25.

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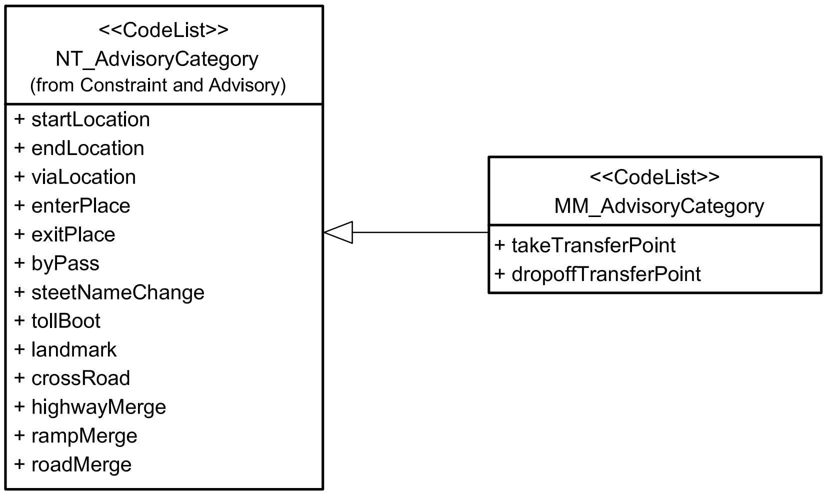

Figure 25 — Context Diagram: MM_AdvisoryCategory

6.4.3 MM_ModeConstraint

6.4.3.1 Semantics

The data type MM_ModeConstraint is used to specify mode preference by a traveller for the type of a mode. The UML diagram for MM_ModeConstraint is given in Figure 26.

6.4.3.2 Attribute: preferredMode [1..*] : MM_TransportationModeType

The attribute preferredMode is used to specify mode preference by a traveller for the type of a mode:

```
MM_ModeConstraint :: preferredMode[1..*] : MM_TransportationModeType
```

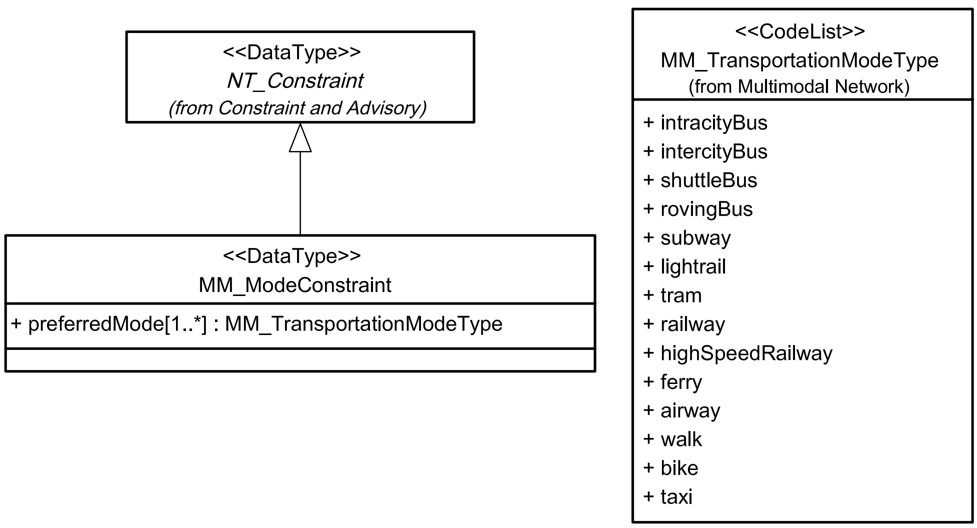

Figure 26 — Context Diagram: MM_ModeConstraint

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6.5 Multimodal Navigation Service

6.5.1 Semantics

The leaf package Multimodal Navigation provides classes that describe request and response pairs, using two basic services, NS_NavigationService and NS_RenderingService, from ISO 19133:2005 as the interfaces for multimodal navigation services. The services in the multimodal case substitute a type in ISO 19133:2005 with its subtype defined below, e.g. MN_RouteRequest instead of NS_RouteRequest.

6.5.2 MN_RouteRequest

6.5.2.1 Semantics

The data type MN_RouteRequest is the itinerary request specifying the origin (starting point), waypoints and destination (ending point) of the requested route. This data type is a variant subtype of NS_RouteRequest from ISO 19133:2005. The UML diagram for MN_RouteRequest is given in Figure 27.

6.5.2.2 Attribute: costFunction [0..1] : MN_CostFunctionCode = "time"

The attribute costFunction identifies the type of cost function used to choose among the candidate routes. This attribute overrides the inherited attribute costFunction of NS_RouteRequest:

```
MN_RouteRequest :: costFunction[0..1] : MN_CostFunctionCode = "time"
```

6.5.2.3 Attribute: transportationMode [0..*] : MM_TransportationModeType

The attribute transportationMode enumerates the transportation modes which a user wants to take for the requested route:

```
MN_RouteRequest :: transportationMode[0..*] : MM_TransportationModeType
```

6.5.2.4 Attribute: avoidMode [0..*] : MM_TransportationModeType

The attribute avoidMode enumerates the transportation modes which a user wants to avoid for the requested route:

```
MN_RouteRequest :: avoidMode[0..*] : MM_TransportationModeType
```


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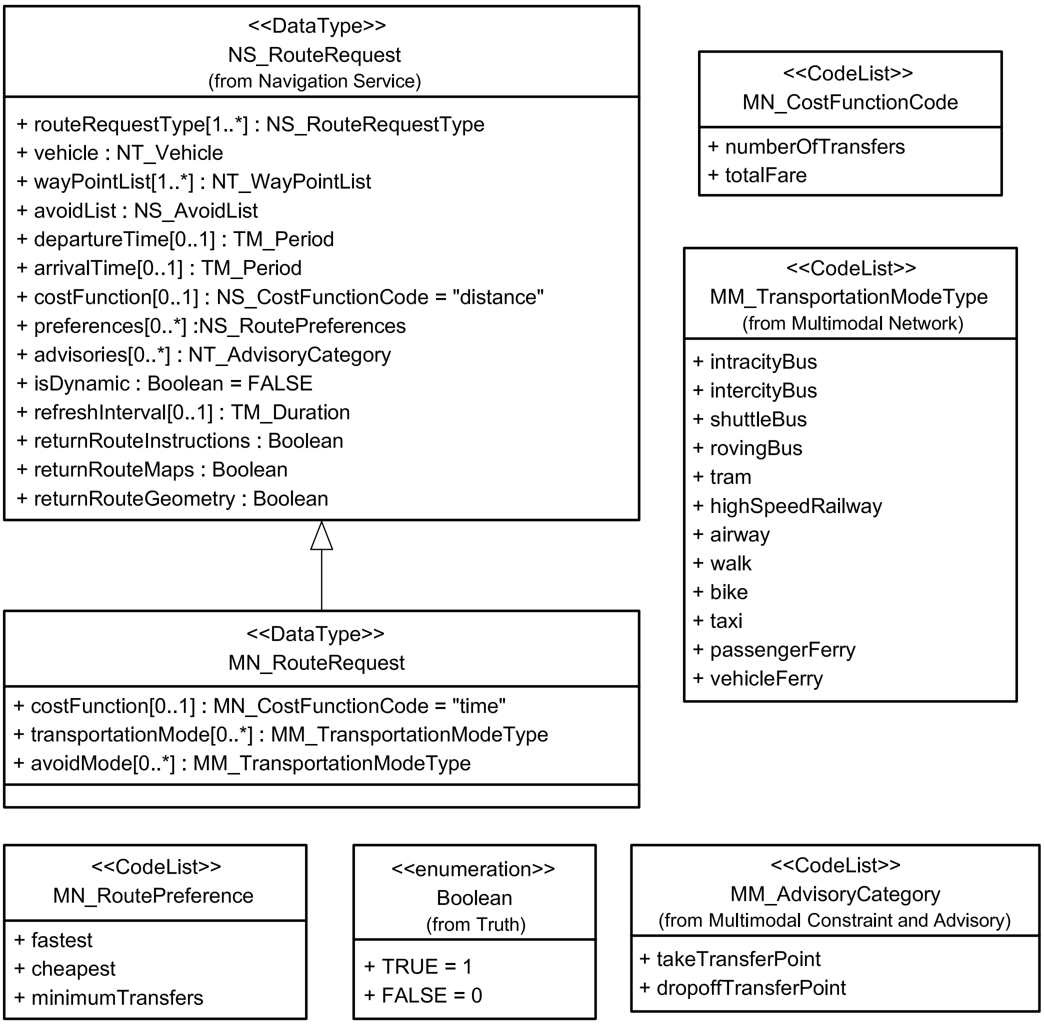

Figure 27 — Context Diagram: MN_RouteRequest

6.5.3 MN_RoutePreference

6.5.3.1 Semantics

The code list MN_RoutePreference is a subtype of NS_RoutePreferences from ISO 19133:2005, which supplies the types of route segment that the traveller prefers. In addition to the values of NS_RoutePreferences, MN_RoutePreference includes fastest, cheapest, and minimumTransfers. The UML diagram for MN_RoutePreference is given in Figure 28.

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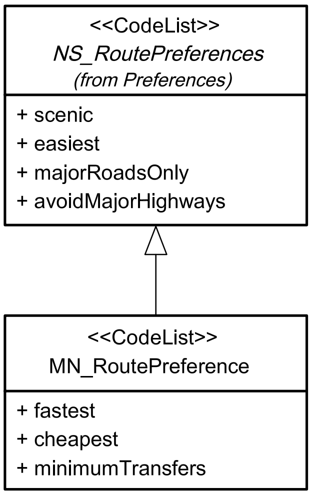

Figure 28 — Context Diagram: MN_RoutePreference

6.5.4 MN_Instruction

6.5.4.1 Semantics

The data type MN_Instruction is a subtype of NS_Instruction in ISO 19133:2005. MN_Instruction describes a single route instruction or advisory. A multimodal route can be navigated by executing a sequence of instructions. The UML diagram for MN_Instruction is given in Figure 29.

6.5.4.2 Role: tripScheme : MM_TripScheme

The role tripScheme is the trip scheme being executed by this instruction:

```
MN_Instruction :: tripScheme : MM_TripScheme
```

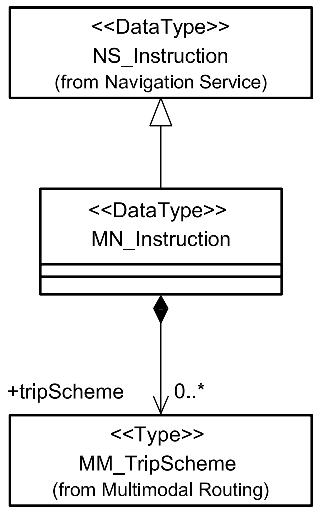

Figure 29 — Context Diagram: MN_Instruction

6.5.5 MN_CostFunctionCode

For multimodal routing and navigation purposes, the code list MN_CostFunctionCode extends the corresponding code list NS_CostFunctionCode from ISO 19133:2005 by adding the potential values numberOfTransfers and totalFare. The UML diagram for MN_CostFunctionCode is given in Figure 30.

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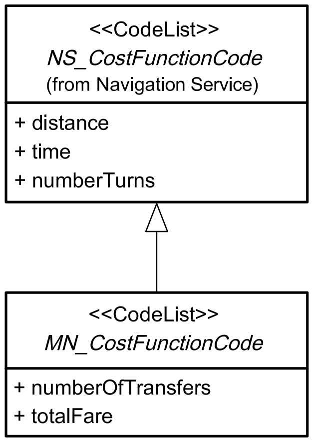

Figure 30 — Context Diagram: MN_CostFunctionCode

6.6 Multimodal Cost Function

6.6.1 Semantics

The leaf package Multimodal Cost Function contains classes and types for the description of cost functions for use in multimodal route determination. As a multimodal cost element, basically, this leaf package utilizes all subtypes of NT_CostElement from ISO 19133:2005. In addition to the subtypes of NT_CostElement, this International Standard adds one more cost element: waypoint costs (MN_WaypointsCost). The UML diagram for the multimodal cost elements, including those used from ISO 19133:2005, is given in Figure 31.

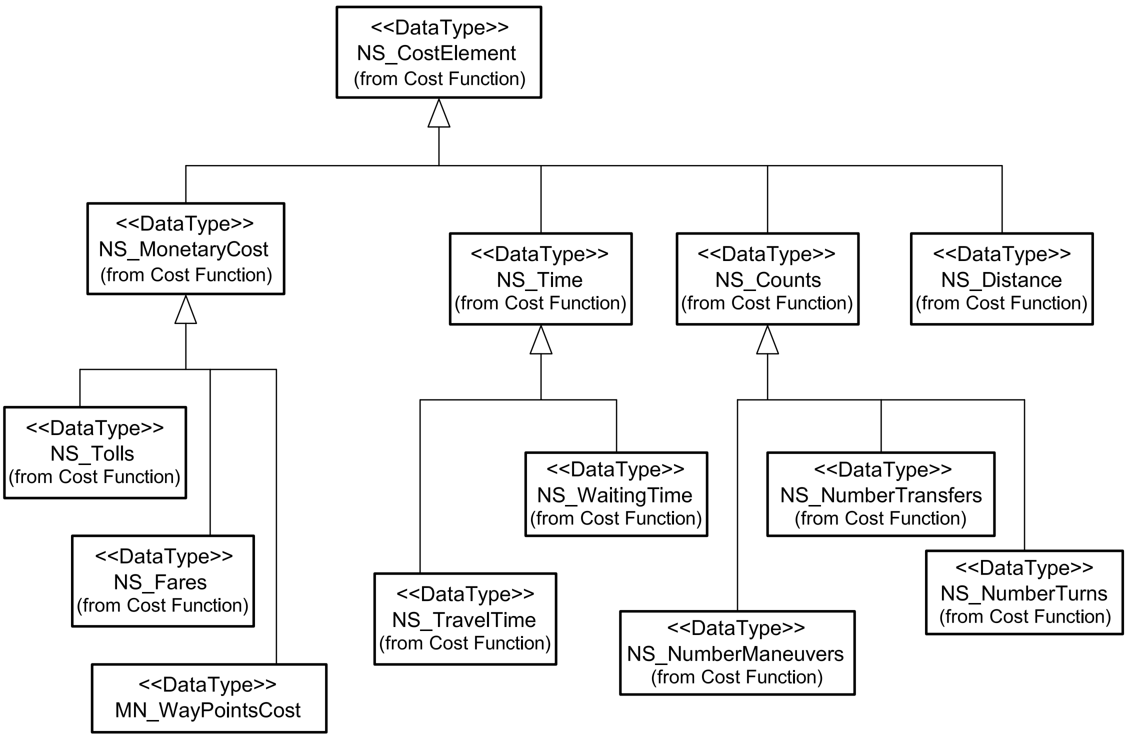

Figure 31 — Multimodal Cost Elements

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6.6.2 MN_WayPointsCost

The data type MN_WayPointsCost is used for describing monetary cost related to waypoint activities such as parking, lodging and meals. The UML diagram for MN_WayPointsCost is given in Figure 32.

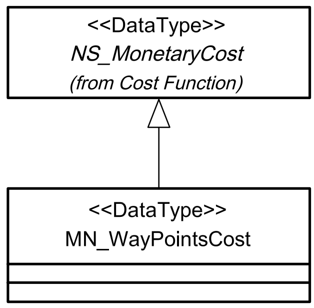

Figure 32 — Context Diagram: MN_WayPointsCost

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Annex A
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Abstract test suite

A.1 Semantics

Conformance to this International Standard shall consist of either service conformance or data conformance.

Data conformance includes the use of data types from application schemas (“application type”) that are mappable into types in this International Standard (“standard type”). In this context, “mappable” means that there is a correspondence between the standard types in the appropriate part of this International Standard, and the application types of the application schema in such a way that each standard type can be considered as a supertype of the application type designated by the correspondence. This means that an application type corresponding to a standard type contains sufficient data to recreate that standard type’s information content.

Service conformance includes both the consistent use of message-based request/response interfaces and data conformance for the message packages used by those interfaces.

A.2 Data Types

A.2.1 Semantics

This abstract test is an extension of the abstract test in ISO 19133:2005, A.2.

A.2.2 Multimodal Network and Route

a) Test Purpose: Verify adequate application classes for the expressions within a multimodal network and route data model.

b) Test Method: Inspect the documentation of the application schema or profile and exhibit the required correspondence.

c) References: ISO 19108, ISO 19133:2005 and the following data types from this International Standard:

1)	Temporal data:	ISO 19108;
2)	Basic network data:	ISO 19133:2005;
3)	MM_MultimodalNetwork	6.2.2;
4)	MM_TransferNode	6.2.3;
5)	MM_TransferNodeType	6.2.4;
6)	MM_Transfer	6.2.5;
7)	MM_TransferLink	6.2.6;
8)	MM_SingleModeNetwork	6.2.7;
9)	MM_SingleModeTurn	6.2.8;

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10) MM_SingleModeJunction 6.2.9;

11) MM_SingleModeLink 6.2.10;

12) MM_FixedScheduleRouteLink 6.2.11;

13) MM_FlexibleScheduleRouteLink 6.2.12;

14) MM_TransportationModeType 6.2.13;

15) MM_ScheduleInfo 6.2.14;

16) MM_Route 6.3.2;

17) MM_RouteSummary 6.3.3;

18) MM_RouteSegment 6.3.4;

19) MM_FixedScheduleRouteSegment 6.3.5;

20) MM_FlexibleScheduleRouteSegment 6.3.6;

21) MM_TripScheme 6.3.7;

22) MM_AdvisoryCategory 6.4.2;

23) MM_ModeConstraint 6.4.3.

A.3 Multimodal navigation services

A.3.1 Semantics

This abstract test is an extension of the abstract test in ISO 19133:2005, A.3.

A.3.2 Multimodal navigation services

a) Test Purpose: to verify the use of the appropriate interfaces for a multimodal navigation service.

b) Test Method: Inspect the documentation of the service interface to verify the use of interfaces defined in the references below.

c) References: ISO 19108, ISO 19133:2005 and 6.5 and 6.6 of this International Standard, including the following subclauses:

1) Temporal Data: ISO 19108;

2) Basic navigation service data: ISO 19133:2005;

3) MN_RouteRequest 6.5.2;

4) MN_RoutePreference 6.5.3;

5) MN_Instruction 6.5.4;

6) MN_CostFunctionCode 6.5.5;

7) MN_WayPointsCost 6.6.2.

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Annex B
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Multimodal Cost Functions for routing and navigation

B.1 Introduction

It is widely believed that about 80 percent of public and private decisions are related to some sort of spatial and locational consideration, leaving only a few areas that are not affected by locational considerations. The Internet puts an unprecedented amount of locational information of all kinds at a user's fingertips, information that can be used for personal production activities in a mind-boggling variety of ways (Østensen, 2001).

The location-based services (LBS) are the new faces of the wireless Internet (Kim, 2004). LBS, sometimes called location-based mobile services (LBMS), are an emerging technology combining information technology, GIS, positioning technology, ITS technology and the Internet. LBS combine hardware devices, wireless communication networks, geographic information and software applications that provide location-related guidance for customers. They differ from mobile position determination systems, such as global positioning systems (GPS), in that LBS provide much broader, application-oriented location services, such as the following:

— "You are about to join a ten-kilometre traffic queue, turn right on Washington Street, 1 km ahead."

— "Help, I'm having a heart attack!" or "Help, my car has broken down!"

— "I need to buy a dozen roses and a birthday cake. Where can I buy the least expensive ones while spending the minimum amount of time on my way home from the office?"

A typical example of LBS for personal navigation can be found in ISO 19132.

B.2 A use case: Request and response for routing and navigation services

B.2.1 Cost model

B.2.1.1 General

Following is an example in LBS for a request for a routing and navigation service: "Find the least costly routes using all available modes of transportation from my current position, stopping at a gas station for 10 gallons of gas, a pharmacy to pick up a prescription medicine, and a flower shop for a dozen roses before arriving home."

In this example, there are three types of costs involved: (1) the purchasing costs for needed items and stopping costs including parking; (2) costs related to the time spent on the road or on transit; and (3) distance-related costs such as gasoline used, wear and tear from the use of a car, and transit fares.

B.2.1.2 Purchasing and stopping costs

There are three items to shop for, called activities, denoted by (B^m), meaning that activity one (B^1=10) is to buy 10 gallons of gas, activity two (B^2=1) is to pick up the prescribed medicine, and activity three (B^3=12) is to buy a dozen roses. Suppose that there are three gas stations, two flower shops and one pharmacy to choose from. Assume that the pharmacy and flower shops can also be reached by subway. The unit cost for a gallon of gas at the three different locations is denoted by (b_j^m), meaning that cost per gallon at location 1 (j=1) is denoted by (b_1^1), at location two is denoted by (b_2^1), and the other as (b_3^1). Likewise, the unit cost for a rose at

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the flower shop at location one is denoted by (b_1^2) and the other as (b_2^2). The unit cost of the medicine at the pharmacy is (b_1^3). If an item "m" is not available at stop "j", then $b_j^m = \infty$ (unbounded). The matrix B_j^m represents the decision to purchase B amount of item m at stop j. Let s_j represent initial stopping costs that include parking costs once decided to stop at j. The marginal costs for stopping at location j for purchasing m are represented by s_j^m which includes walking, waiting, queuing and other added costs to purchase m at location j. The decision to stop at location j is given by $d_j = 1$ if any B_j^m is non-zero. The decision to purchase item m at stop j is d_j^m = 1 for all B_j^m that are non-zeros.

Thus, the total cost of purchasing needed items at all location j (C^j) including stopping costs in this example can be written as:

$$C^j = \sum_j d_j s_j + \sum_m (b_j^m B_j^m + d_j^m s_j^m) \qquad (1)$$

where

$d_j s_j$ is the cost of making an initial stop at j which includes parking cost;

$b_j^m B_j^m$ is the total cost of purchasing m at location j;

$d_j^m s_j^m$ is the marginal cost incurred for purchasing item m including queuing at j.

Once shopping is done, the total items purchased should be at least the same as the original intention to buy (B^m), i.e. 10 gallons of gas, a dozen roses and the medicine.

This is expressed as:

$$\sum_j B_j^m = B^m \qquad (2)$$

B.2.1.3 Time costs

Time spent on the road to go to one of three gasoline stations, on the road or on transit to go to one of two flower shops, and to the pharmacy, will depend on which one at which to shop and in which order.

The road and transit network is represented by two types of elements: a set of points called nodes and a set of line segments connecting these points called links. Figure B.1 depicts a combined road and transit network including five nodes connected by 11 links. It is not important at this point which links are transit and which are roads, since what matters is the travel time in this example. Nodes are numbered by ordinary Arabic numerals, 1 to 5, and links are identified by letters of the alphabet, from a to n. The link travel time in minutes is given within parenthesis, right after the link number.

It is possible to reach node (5) from node (1) by several routes (or paths) through the network. In fact, there are (n-1)! possible routes if none of the links are one way. A route is a sequence of directed links leading from one node to another. For example, in the above network, to get from node 1 to node 5, the following routes are available, excluding those routes that require stopping at the same node more than once.

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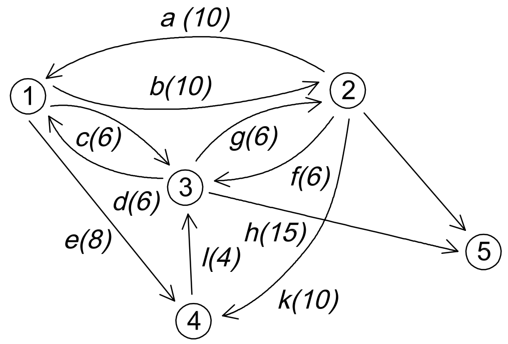

Figure B.1 — Sample Combined Network with Fixed Link Travel Time

Route 1: 1→b→2→n→5 (total time ($\sum_a t_a$) on roads: 20 minutes);

Route 2: 1→b→2→f→3→h→5 ($\sum_a t_a$ is 31 minutes);

Route 3: 1→b→2→k→4→l→3→h→5 ($\sum_a t_a$ is 39 minutes);

Route 4: 1→c→3→h→5 ($\sum_a t_a$ is 21 minutes);

Route 5: 1→c→3→g→2→n→5 ($\sum_a t_a$ is 22 minutes);

Route 6: 1→e→4→l→3→h→5 ($\sum_a t_a$ is 27 minutes);

Route 7: 1→e→4→l→3→g→2→n→5 ($\sum_a t_a$ is 28 minutes).

This is not all of the possible routes with stops. Several possible routes pass through two gas stations and would therefore give alternative routes. The ones not listed are not optimal, but that is not obvious a priori.

Assuming one knows each traveller's unit cost of time per hour and denotes it as (α^{w}) for a traveller of the occupation type w, then the total travel cost for traveller type w (C^{w}) is the unit cost of time (α^{w}) multiplied by the total time spent on all links a on mode k $\sum_a t_a^k$, if link a is in route r of mode k between the origin (O) and destination (D) pair denoted by i and j. That is:

$$C^{w} = \alpha^{w} \sum_{k} \sum_{a \in r_{ij}^{k}} t_a^k \qquad (3)$$

where a$\in r_{ij}^{k}$: link a is in route r of mode k between the origin (O) and destination (D) pair denoted by i and j.

Mode k includes walking and link travel time t_a^k includes transfer time connecting the two modes on foot if link a is a connecting link.

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Assuming that a traveller's unit time cost (α^{w}) is \$ 20/hour or 33 cents per minute, the total cost for taking route 1 is 33 cents times 20 minutes, i.e. \$6.60. If route 2 is the minimum route and thus is chosen, then the total costs for taking route 2 is 33 cents times 31 minutes, i.e. \$10.23.

B.2.1.4 Distance-related costs

Unit cost per mile for distance-related costs such as gasoline used, and the wear and tear from using a car and/or transit fare is denoted by d^{k}, and the total distance travelled by mode k is denoted by (d_{a}^{k}), then the total distance related costs (C^{d}):

$$C^{d} = \sum_{k} d^{k} \sum_{a \in r_{ij}^{k}} d_{a}^{k} \tag{4}$$

where $a \in r_{ij}^{k}$: link a is in route r of mode k between the origin (O) and destination (D) pair denoted by i and j.

B.2.1.5 Total costs for shopping, routing and navigation

The total cost for traveller type w for stopping at a gas station for 10 gallons of gas, a pharmacy to pick up a prescribed medicine, and a flower shop for a dozen roses before reaching home now can be calculated by summing up the minimum purchasing costs (C_{j}) over all location j, the minimum routing and navigation costs (C^{w}) and the minimum distance costs (C^{d}), subject to that all items are successfully purchased.

The solution of the problem for type w traveller can be found by minimizing the total costs, such as:

$$W = C^{j} + C^{w} + C^{d}$$

or

$$W = \sum_{j} d_{j} s_{j} + \sum_{m} (b_{j}^{m} B_{j}^{m} + d_{j}^{m} s_{j}^{m}) \quad + \alpha^{w} \sum_{k} \sum_{a \in r_{ij}^{k}} t_{a}^{k} + \sum_{k} d^{k} \sum_{a \in r_{ij}^{k}} d_{a}^{k} \tag{5}$$

subject to equation (2).

This is a typical Linear Programming (LP) problem; however, solving an LP with tens of thousands of links and nodes is not a trivial issue. Many scholars have found efficient algorithms for solving it differently than solving it as an LP problem (see Boyce, Lee and Janson, 1998; Lee, Boyce and Janson 2002 for a detailed discussion of formulating and solving dynamic route choice problems).

The next question is how to obtain the link travel time (t_{a}).

B.2.2 Estimating link travel time, t_{a}

B.2.2.1 General

Estimating link travel time depends on whether or not real-time traffic data, including volume and speed, can be obtained and be made available for service brokers/users.

B.2.2.2 When real-time link speed is available

When real-time speed data is available for each link, then one can easily estimate the link travel time by the following equation:

$$t_{a} = (60 \text{ minutes x link distance in km}) / [\text{speed (km/hour)}] \tag{6}$$

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For example, if the current speed on link a is 30 km/hour and the link length is 2 km, the current link travel time is (60 min × 2 km) / 30 km/h = 4 minutes.

B.2.2.3 When real-time link traffic volume is available

Many cities now have installed devices such as loop detectors to obtain real-time traffic volume on certain links. In such a case, real-time link speed may not be usually obtainable from loop detectors, but real-time link traffic volume can be. One can convert real-time link volume to link travel time by using a function such as the BPR function shown below:

$$t_a = t_a^0 \; [1+ \eta(v_a/(c_a)^{\lambda}] \quad (7)$$

where

t_a is the current link travel time;

t_a^0 is the uncongested free flow travel time on link a;

v_a is the real-time traffic volume on link a;

c_a is the capacity of link a in number of vehicles per lane (*Highway Capacity Manual by the Bureau of Transportation Statistics*, 1998);

η is a coefficient to be calibrated (the usual value used for US city roads is 0,88 as can be seen in Bureau of Transportation Statistics (1998) and Horowitz (1991));

λ is a coefficient to be calibrated (the usual value used for US city roads is 5,5 as can be seen in Bureau of Transportation Statistics (1998)).

For example, assume that there is a link on which uncongested link travel time (t_a^0) is 40 miles/hour for a 2-mile link (or 3 minute link travel time), and which has two lanes with the capacity of handling 1 600 passenger car-equivalent units (PCU) per lane. Further assume that loop detectors indicate that there are 4 000 PCUs passing by in that link now, then the estimated link travel time is:

t_a = 3 minutes [1 + 0,88 (4 000/3 200)^{5,5}] = 12 minutes.

If there are only 1 000 PCUs travelling, then link travel time is:

t_a = 3 minutes [1 + 0,88 (1 000/3 200)^{5,5}] = 3 minutes.

For detailed descriptions on the other type of link travel time functions, see Suh, Park and Kim (1990).

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