An Evaluation of Context–Aware Infomobility Systems

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ABSTRACT
The delivery of real-time, context-aware and personalized information to end users for mobility support is a high-priority objective in improving mobility services efficiency and effectiveness. This chapter aims at providing an analysis of existing studies in the field of context awareness research targeted to the infomobility application domain. We propose an evaluation framework for infomobility services based on the elicitation of context information items and high-level requirements. The framework is applied to some relevant state-of-the-art research works among personal navigation systems, infomobility service integration frameworks and context-aware location-based communication platforms. Evaluation results are discussed in order to highlight open research challenges in the infomobility application domain.

KEYWORDS
Context awareness, mobility, multimodal transport, location-based systems, Intelligent Transport Systems

1 INTRODUCTION
The mobility of people and goods and the efficiency of transport systems are calling for requirements which are more and more critical in our society in terms of social, economical and individual issues. Traffic congestion and related environment problems represent serious threats to citizens’ quality of life and economic development. According to a study for the European Commission, it is estimated that congestion costs will represent 1% of the gross domestic product of the European Union in 2010 (European Commission, 2001).

In order to face these problems, national and local governments are promoting several efforts to make mobility more efficient and sustainable. Sustainable mobility relies on the capabilities of optimizing each transport mode with respect to safety, environmental friendliness and energy efficiency.

Obviously, proper actions for transport services and infrastructure enhancement are needed in order to improve the efficiency and effectiveness of mobility services. Nonetheless, providing valuable on-time information services to end-users can strongly contribute to more efficient mobility. Thus, the delivery of real-time and personalized information services to end users for mobility support (i.e. “infomobility services”) is a high-priority objective. At present most commercially available infomobility services are conceived as static information delivery. They are usually targeted to drivers and rarely to pedestrians and often focus on a single transportation mode (e.g. either private, pedestrian or public transport) (Rehrl et al., 2007). As a consequence, the burden of managing different transportation modes when planning travel
and modifying travel plans according to up-to-date information about traffic events (e.g. accidents and congestion, parking places availability, delays in public transportation) is mainly placed on end-users.

Infomobility services typically include a wide range of services: navigation, route planning and re-planning, geo-referenced content delivery (e.g. Points of Interest descriptions, localization of nearest shops, railway and bus stations, parking facilities, etc.), alerts about critical events (incidents, congestion, public transport delays, etc.), payment services and facilities booking (e.g. parking and seat reservation). Infomobility services for mobility of persons can also be named as Traveler Information Services (U. S. Department of Transportation, 1998).

Research on context-awareness can provide significant progress in the infomobility application domain with respect to the systems and applications state of the art. As a matter of fact, information delivery for user mobility support (infomobility) is a domain that is especially challenging for research activities in the field of context awareness. This is due to several reasons, but mainly because application focus is on user location, which is a first-level context attribute. Not surprisingly, initial research studies on context awareness have focused on location-aware applications, such as the Active Badge Location System (Want et al., 1992) and location-aware tour guides (Abowd et al., 1997; Cheverst et al., 2000). In the infomobility domain, location strongly influences user information and service requirements, as well as other contextual attributes (especially those related to the environment surrounding the user). User requirements for infomobility services’ content and delivery channel adaptation may be influenced by context events, such as incidents, traffic congestion and public transport delays that may require assisting users with appropriate navigation services and re-planning trip schedules.

A relevant challenge is also determined by the fact that in this application domain, context knowledge should include a large amount and a variety of information (ex. user location, current transport mode, traffic and public transport events, weather conditions, etc.) to be appropriately acquired and managed in order to provide users with up-to-date, reliable and complete information for navigation and mobility assistance.

**Aim of the Chapter**

Our objective is to investigate how research on context-aware and mobile communication and computing might provide significant progress in the infomobility domain, with special focus on persons’ mobility.

This chapter aims at providing an analysis of existing research studies and trends in the field of context awareness research targeted to the infomobility application domain. Several surveys and state-of-the-art analyses exist in the field of context-aware mobile computing and applications (Baldauf et al., 2007; Bernard, 2006; Saha & Mukherjee, 2003; Anagnostopoulos et al., 2007; Henricksen et al., 2005). Some studies have also focused on the delivery of location-based services (D’Roza & Bilchev, 2003; Dao et al., 2002; Barnes, 2006). We argue that a special analysis should be devoted to the infomobility application domain, due to its own specific features and requirements which distinguish it from the wider “location-based services” application domain.

This paper is organized as follows: Section II clarifies what we mean with the term “context-awareness” in the infomobility domain. In Section III we discuss main high-level requirements in designing information services for more efficient mobility. The result of this analysis is a set of criteria used for evaluating some state of the art studies in Section IV and V. Section VI briefly presents related studies which have not been selected for evaluation but have provided relevant results. Section VII concludes the paper by highlighting open research issues for infomobility service design and motivating our future research activities.

**II CONTEXT AWARENESS FOR INFOMOBILITY**
Context awareness is a concept which can be applied to several application domains (e.g. smart homes, e-health, emergency management) with the objective of designing applications which should be responsive to specific contexts and situations, helping end users in their activities and improving their quality of life.

A definition that has been widely accepted in the international research community is the one provided by Abowd et al. (1999): “Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves.”

According to this definition, a designer can define what context is according to the target application domain requirements. As a general approach, context information should describe the “who”, “what”, “why”, “where” and “when” attributes influencing the interaction between a user and the application.

Based on the five coordinates “who”, “what”, “why”, “where” and “when” we try to define basic context items for context-aware infomobility services (see Figure 1).

**Who?** This may consist of all the information concerning the user with respect to mobility, for instance his/her preference for public or private transport means or walking, and his/her habits (e.g. going to work at the same time every day). It may also include the fact that the user is travelling alone or in a group. The value of these context items could be exploited to adapt system decisions for proposing transport means and itineraries optimized according to time, costs and other user-dependent parameters.

**What?** This dimension may refer to “what the user is doing” and “what mobility and transport services are available”. Some examples of user activity and mobility status are: planning and/or re-planning his/her route; driving his/her own vehicle; being a passenger of public transport; walking in transfer sites; in-door visiting or staying at a specific place; controlled-gate access (highway, parking areas, tunnels, local buses, etc.). Knowledge of this kind of information should be properly exploited in order to minimize the required level of user attention with respect to what the user is doing (e.g. driving a vehicle) by choosing the appropriate interaction channel (e.g. text-based or voice based interface).

Information about available mobility and transport services may include planned mobility and transport services information (road networks, public transport itineraries), as well as unexpected events related to mobility and transport services (e.g., road incidents, traffic congestions, etc.), which may influence user mobility and planned services. Infomobility services should adapt to such information by accordingly planning and/or re-planning user itineraries in order to offer up-to-date and reliable information and assistance.

**Why?** The purpose of the user’s journey can be exploited in order to appropriately adapt content delivery. For instance, users moving for holiday might appreciate a proactive delivery of the Points of Interests’ description, while users moving for work might be more interested in information such as available network connectivity and facilities in transit places (e.g. meeting and conference rooms in airports and railway stations).

The Where and When dimensions of context information are extremely important for providing effective infomobility services. Firstly, infomobility services should provide up-to-date location-based content. Secondly, also context items pertaining to the above-mentioned categories (who, what and why) may be enriched with geographical and time references. For instance, geographical and time references may be needed to properly exploit and correlate information about mobility and transport services (what?) and to adapt services according to user location at a certain instant of time (who?).

**Where?** A “location” context item may refer to user current location, as well as to intermediate locations in the user itinerary. Moreover, as mentioned above, other context items may also be associated to location information (i.e. geo-referentiation). Location may be represented in terms of physical or logical information. Physical location is represented in terms of geographical coordinates according to
standard reference systems; logical location is usually represented in terms of symbolic information, such as “at home” or “at work” (Hightower & Borriello, 2001).

When? A timing reference can be used to characterize user current location and consequently to determine the progress with respect to a planned itinerary. Timing information can also be associated to a planned, monitored or estimated timetable of public transport vehicles and road network events.

III REQUIREMENTS FOR CONTEXT-AWARE INFOMOBILITY SERVICES

Several reviews on general-purpose context-aware computing exist (Baldauf et al., 2007; Henricksen et al., 2005, Chen & Kotz, 2000; Strang & Linnhoff-Popien, 2004). The evaluation methodology proposed by Baldauf et al. (2007) is based on a conceptually layered framework that includes the following functions: architecture, sensing, context model, context processing, resource discovery, historical context data, security and privacy. Henricksen et al. (2005) have distinguished the following requirements for middleware in context-aware systems: support for heterogeneity, support for mobility, scalability, support of privacy, traceability and control, tolerance for component failures, ease of deployment and configuration.

The above-mentioned studies provide comprehensive reference frameworks for the evaluation of context-aware systems, but they are not specifically targeted to the infomobility application domain. Moving from these previous studies on context-awareness, we attempt to provide an evaluation

Figure 1. Context Items for infomobility services
framework targeted to the infomobility domain. In the following we describe a set of requirements that should be satisfied in planning and deploying context-aware infomobility services for tourists. The analysis is based on our previous work (Paganelli et al., 2006; Paganelli et al., 2007) and on some available studies, such as the analysis of end user needs concerning infomobility (Infopolis2 Project, 1999), expert evaluations of technological challenges (Safety Forum – Working Group RTD, 2006), as well as the above-mentioned reviews on context-aware systems.

We have elicited a set of seven requirements. Five requirements are general and could be applied to evaluate also other kinds of context-aware distributed systems: seamless service continuity, compliance with standards for interoperability and dynamic integration of information sources, personalization and user interaction adaptation, information reliability, security and privacy. Hereafter these requirements are discussed with the aim of highlighting issues specifically related to the infomobility application domain, and thus eliciting attributes which are used in evaluating state-of-the-art infomobility projects in the following sections.

We also considered two requirements that are more specific to the infomobility application domain, as they are related to managing mobility and transport information: awareness of real-time situations about mobility and support for transport multimodality.

In this discussion we did not consider other requirements, even if relevant for the design and evaluation of context-aware distributed systems. Some of these requirements are, for example:

- Ease of deployment and configuration: the easiness for users to deploy and configure a context-aware system (Henricksen et al., 2005).
- Traceability and control: the state of the system components and information flows between components should be traceable in order to provide adequate understanding and control of the system, in order to enable mechanisms for estimating the occurrence of possible system malfunctioning and/or management of system faults.
- Scalability: the system should continue to function well as it is changed in size, for instance if the number of users increases or new mobility-related information sources (i.e. sensors, weather services, mobility servers, etc.) are used in the system.
- Dependability: a property of a computer system such that reliance can justifiably be placed on the service it delivers (Randell, 1998). Such a requirement is especially challenging for pervasive and context-aware systems, as they should dynamically adapt to changing situations, inferred on the basis of information acquired from heterogeneous distributed sources.

Such requirements have not been taken into account in this evaluation as they can be discussed in terms of architectural patterns and technological implementation details, but they do not represent specific issues of the infomobility domain.

R1) Seamless service continuity
End user’s access to infomobility services should be “always-on”. This requirement is relevant for several application domains, but it is especially challenging for the infomobility application domain. As a matter of fact, while the user is moving, service access may be compromised, mainly due to possible changes in the communication infrastructure. End user mobility within short (e.g. urban environment) as well as long distances (e.g. driving on the highways) may strongly influence user capability in accessing infomobility services. Changeable factors that can compromise such capability may include: user device features (e.g. PC, PDA, vehicle on-board device), different access networks (e.g. Wi-Fi, WiMax, cellular networks, etc.) and heterogeneous network operators, as well as related network characteristics such as billing and available bandwidth. Providing seamless always-on access to information requires proper mechanisms to mask these discontinuities.
An extended analysis of communication requirements of the Intelligent Transport System (ITS) is provided in (Fiedler et al., 2005). In this study, ITS services are classified in five categories (i.e. public streaming service, individual messaging service, backwards streaming service, selective streaming service, personal interactive service), and their communication needs in terms of availability, performance, security and cost are represented in a format which is suitable to be matched with network parameters.

In the field of ubiquitous communication these research challenges are specifically addressed with the term “Seamless mobility”. Seamless mobility can be intended as uninterrupted service access, independently from available networks and user devices, thus enabling the users to move across different access networks and change computing devices. As specified by the International Telecommunication Union (2006), seamless mobility can include:

- **Terminal mobility**: the ability of a terminal to change location and still be able to communicate;
- **Personal mobility**: the ability of a user to maintain the same user identity irrespective of the terminal used and its network point of attachment.
- **Service mobility**: the ability of a user to use the particular service irrespective of the location of the user and the terminal that is used for that purpose.

All-IP communication platforms are now seen as potential candidates for providing seamless mobility. An approach based on Mobile IP for handling terminal mobility at the IP layer is described in (Morand & Tessier, 2002). SIP is an application-layer protocol that inherently supports personal mobility and can be extended to support service and terminal mobility (Schulzrinne & Wedlund, 2000). Multilayered approaches are also being discussed in (Wang & Abu-Rgheff, 2003; Zeadally et al., 2004).

One further aspect, which can be included in the “seamless continuity” requirement, is the capability of an infomobility system to provide assistance both in the pre-trip and on-trip phases and in different mobility statuses (e.g. walking, driving a private vehicle, being passenger in public transport means). The concept of seamlessness may also include the system’s capability to continuously support user needs by providing both push- and pull-based information delivery. The proper delivery modality should be chosen according to different parameters, such as user preferences, interests and current activity (e.g. “visiting a cultural heritage site” or “driving a vehicle”) as well as technological requirements.

**R2) Awareness of real-time situations about mobility**

Infomobility services should be managed and delivered by exploiting awareness of real-time situations about mobility in order to provide users with complete and updated information. Such awareness should include both static (e.g. cartographic data, public transport scheduled routes) and dynamic information (e.g. traffic status, public transport real-time schedules, weather forecasts). This information might be exploited in order to adapt infomobility services’ content (e.g., for dynamic route re-planning), delivery paradigms and channels (e.g. push/pull, audio/text) to changing mobility conditions and traffic events. Context data sources needed to acquire information about mobility situations usually include heterogeneous sensors and monitoring applications. Moreover, different context data providers, such as traffic monitoring centers, public transport operators and municipalities may be required to interoperate. Nowadays the capability of organizing and exploiting user-generated content is being experimented (Holone et al., 2007). This approach based on user communities can potentially enrich awareness of mobility situations, but is likely to highlight information reliability requirements (see below).

**R3) Support for transport multimodality**

Transport multimodality (e.g. bus/railways/boat, public/private transport) is a key approach towards more sustainable and safe mobility. The objective of achieving an optimal exploitation of current transport and
road infrastructure in order to decrease current congestion rates may be facilitated by delivering accurate and real-time multimodality information (Safety Forum – Working Group RTD, 2006). Nowadays, information about public transport-based itineraries can be obtained via pre-trip web-based research, while most personal and mobile navigation systems are conceived for car driving. At present, in-car navigation systems and multi-modal trip planning systems are non-interoperating domains (Rehrl et al., 2007). Completeness, freshness and validity of information delivered to end users are essential requisites to effectively support transport multimodality. Support for this requirement is thus strictly tied to the previous one, in terms of the integration of heterogeneous information for both private and public transport.

R4) Compliance with standards for interoperability and the dynamic integration of information sources
Delivering real-time and reliable mobility services requires the integration of heterogeneous, geo-referenced, static and/or dynamic information coming from different and autonomous sources, such as transport operators, public institutions and traffic management centers. Interoperability and the integration of such heterogeneous information require a wide agreement on common rules and models for information exchange. At present, some standard specifications for exchange of infomobility information exist. Examples of European standards based on XML and Web Services technologies include DATEX, a specification for traffic event information exchange (European Commission - DG for Transport and Energy, 2006), SIRI, a standard specification for public transport information exchange (CEN TC 278, 2006) and TRANSMODEL, a conceptual data model for public transport operation and management (CEN TC278, 1997). The Open Geospatial Consortium (2007) has published international specifications for location-based services, such as route planning and geo-referencing. Nonetheless, most available route planners, navigation and map services do not offer open and standard interfaces for third party service integration. Semantic-based service-oriented architectural design is a promising approach towards semantic interoperability and service integration offered by heterogeneous providers, but research is still at an early stage (Vetere & Lenzerini, 2005).

R5) Personalization and user interaction adaptation
Personalization concerns how information services should adapt to user profile and preferences. In the infomobility application domain this approach should be focused on user preferences and profile explicitly related to mobility (e.g. physical disabilities or preference for private transport). Service delivery and user interaction should be adapted according to several parameters, such as different user devices (e.g. mobile phones, PC, in-car navigation systems), preferences, profiles and current contexts. For instance, navigation and assistance services should adapt to a user’s current mobility status, as a user’s spatial behavior is different in walking or car-driving situations. Different techniques can be used for user profiling (individual or group profiling): manual input or more sophisticated techniques (learning technologies, collaborative filtering). Moreover, several techniques can be adopted for application adaptation to user profiles and contexts (e.g. rule-based adaptation, machine learning algorithms, etc.). An evaluation of existing predictive algorithms for personalizing a mobile application is proposed by Nurmi et al. (2007).

R6) Information reliability
Information delivered to end-users should be reliable or, should at least respect specific service levels agreed upon with the end-users. Imprecise, incomplete, or wrong information could compromise attaining the final objective (supporting users in their mobility) and thus cause the users’ disaffection with
infomobility services. This problem may arise as infomobility services have to be based on the integration of different information sources, usually managed by different providers (for instance, user-generated content can also be exploited for updated information about mobility). Analogously, context data can be acquired by heterogeneous sensors with different precision and reliability characteristics and managed by different subjects. As a consequence, a huge amount of heterogeneous, probably redundant and incoherent information has to be properly processed and managed in order to provide reliable information to end-users. Information modeling and management techniques for assuring information quality and reliability are required to guarantee a wide acceptance of infomobility services. A method for measuring context information quality in ubiquitous environments has been proposed by Younghee & Keumsuk (2006). The method is based on the following quality dimensions: accuracy, completeness, representation consistency, access security and up-to-dateness. Furthermore, trust and reputation systems can be applied to estimate the reliability of user-generated content (Jøsang et al., 2007).

R7) Privacy and Security
The effectiveness of context-aware infomobility services strongly depends on the continuous and distributed acquisition and processing of user-sensitive data, such as current position, activity, physical disabilities and health status. Thus, achieving a wide user acceptance of infomobility services requires the adoption of techniques for privacy protection and user perception on personal data control. Techniques for protecting privacy of the user’s identity and location may include anonymity, pseudonymity, cryptography, policy-based privacy systems, etc. Cardoso and Issarny (2007) proposes a taxonomy for privacy invasion attacks and classification of existing privacy enhancing technologies according to the protection provided for those attacks.

When dealing with context-aware and pervasive systems, traditional approaches to security may be not satisfactory. This is mainly due to the strong relevance that user interaction with the physical environment and with related contextual attributes plays in context-aware applications. This scenario may require security techniques to be flexible enough for providing different levels of security services based on system policy, context information, environmental situations, temporal circumstances and available resources (Campbell et al., 2002).

IV INFOMOBILITY SERVICES: STATE OF THE ART SHORT ANALYSIS
This section provides an analysis of some relevant state of the art research and experimental activities in the infomobility application domain. At present, the term “infomobility” is widely adopted by European research communities and industries (European Commission, 1999), but it is not widely diffused at international level. Nonetheless, a huge amount of research projects may be related to this application domain. As already mentioned in the introductory section, infomobility deals with providing users with information useful for their mobility and may include navigation, multimodal route planning and replanning (including services for booking transport facilities), location-based content delivery, alerts about events which can have an impact on user mobility in the pre-trip, on-trip and post-trip phases. To summarize, infomobility includes these main issues: navigation information targeted to personal user mobility plan, integration of information about multimodal transport, location-based content delivery and multi-modal communication channels.

To the state of our knowledge, research studies covering the whole infomobility domain do not exist. Nonetheless, many research activities and projects have tried addressing some of the above-mentioned issues. Hereafter we propose a categorization schema, where each category represents one or more of the
above-mentioned issues. In choosing the following categories, we have also tried to represent the most diffused patterns in collected research studies.

- **personal navigation systems**: services for navigating pedestrian routes, public transport or private vehicles (related to the issue “navigation information targeted to personal user mobility plan”);
- **infomobility integration frameworks**: systems designed to allow the integration of different information repositories about mobility (related to the issue: integration of information about multimodal transport);
- **context-aware location-based communication platforms** towards Next Generation Networks (related to the issues: location-based content delivery and multi-modal communication channels).

We collected research studies in the area of context awareness and infomobility by searching in major electronic research databases (IEEE Explore, ACM Digital Library, Science Direct) as well as web search engines (e.g. Google and Google Scholar). We also identified and collected studies from main international conferences in the domain. Among the rich amount of research papers that we found we chose a set of nine papers for evaluation using the following selection criteria (in order of priority): originality of methodology and novelty of research results, specific focus on one or more of the above mentioned categories, most recent publication date.

Many valuable research papers have thus not been selected, but many of them are worth mentioning. The section “Related work” provides a brief overview of relevant contributions which could no be taken into account in this study.

**Personal navigation systems**

**Personal Travel Companion**

Rehrl et al. (2007) have designed and implemented a prototype, named Personal Travel Companion, aiming at providing users with continuous assistance services including personalized multimodal trip planning in the pre-trip phase as well as mobile multi-modal trip management in the on-trip phase. They have realized a smart-phone based application for orientation and guidance in complex public transport buildings.

The prototype provides door-to-door multimodal route planning accessible from a desktop PC or a mobile device. The route is calculated on integrated public transport, road and pedestrian networks. User preferences (e.g. preferred transport modes, mobility requirements, options and time constraints) are taken into account by the system for calculating personalized routes. Personalized routes can be stored in order to keep a personal history of planned routes, frequent itineraries, etc.

On-trip assistance services are delivered by means of multimodal extensions to in-car navigation systems or a mobile personal travel companion on smart phones. Continuity and seamlessness of guidance and assistance are approached by means of mobile multimodal trip management on different devices and navigation and orientation to the destination address (included pedestrian navigation inside transfer buildings). As a matter of fact, the system integrates services for both the pre-trip and on-trip phase. Moreover, navigation help is also provided in transfer buildings (e.g. a parking where travelers change from car to public transport). Real-time awareness of the mobility situation is not guaranteed and context awareness is conceived only in terms of service content adaptation according to user location, preferences and transport means. Service access relies on GPRS connectivity, thus seamless always on access supported by converged communication platforms is not specifically addressed in this work. The
prototype does not include mechanisms and techniques aiming at coping with information reliability, privacy and security requirements.

**Smart Travel Information Service (STIS)**

STIS is a system that offers travelers a multimodal journey planning service aimed at bridging the coordination gap between the available transport systems (Brennan & Meier, 2007). Journey plans are created based on the preferences expressed by end-users and integrate static and dynamic information about traffic and public transport.

The STIS is a middleware platform that uses transport data made available by a data layer, named iTransit Framework, and uses an HTTP interface to provide users with personalized journey plans. The service can be accessed by PCs or mobile phones and it is implemented by means of an XML message exchange over an HTTP connection. The iTransit framework (discussed below) integrates information coming from different legacy systems based on a common spatial data model. Context is here conceived in terms of updated traffic and public transport information, while user context awareness (e.g. location) is not an object of the application. Moreover, the focus of the application is on journey planning rather than on navigation help during the on-trip phase. Real-time information on mobility conditions may be acquired by integrating traffic and transport monitoring centers via the iTransit Framework, but the system does not support dynamic re-planning on user routes based on real-time information, such as public transport delays and traffic congestions.

**Navitime**

Navitime is a mobile navigation service that is offered in Japan and used by a large number of users (1.82 million of user were estimated in January 2007) (Arikawa et al., 2007). Navitime provides users with itinerary calculations and on-route guidance services combining several types of transportation: walking, driving and riding trains, taxis and airplanes.

Navitime is a distributed system: servers compute routes and generate maps, mobile phone clients capture location information, handle user input, download data, visualize maps, and handle interruptions through incoming email messages and phone calls. Routes are selected based on a set of criteria, including fastest route, minimized travel expense, transfer and walking distance. Contextual information which is managed by the system includes user location, acquired through GPS-enabled devices or manually specified by end users and used to adapt navigation and assistance services to current location, mobility and transport information and other geo-referenced information used to annotate maps and routes (e.g. additional weather information, amount of carbon dioxide emitted for each route).

Navitime integrates mobility information coming from heterogeneous data suppliers by converting them into four common formats: Dformat for timetable data, Mformat for road network data, Vformat for 2D map data representation and V3Dformat for 3D map data representation. Publicly available documentation does not make any explicit reference to Navitime’s compliance with existing standards for mobility-related information exchange and storage.

Further considerations about personalization, real-time mobility information availability, seamless mobility access and information reliability cannot be provided due to lack of publicly available documentation.

**Evaluation of presented personal navigation systems**

In this paragraph we discuss how the above mentioned personal navigation systems address the set of requirements proposed for the infomobility application domain.

Seamless mobility is tackled in different ways by these systems. The Personal Travel Companion focuses on uninterrupted navigation help, even inside transfer buildings, thus addressing seamless
mobility at the information level. In STIS and Navitime, seamless service access is demanded for cellular network communication, but no special focus is dedicated to terminal, service or personal mobility.

All research projects provide a minimal level of awareness of the real-time mobility situation by providing basic features in user location detection and location-based content delivery based. System knowledge-based dynamic information services of real-time mobility situations (e.g. delays, congestions, etc.) are not explicitly supported by any of the analyzed studies. Nonetheless, such services would be extremely useful especially in enhancing multimodal travel planning services, as those delivered by STIS, Personal Travel Companion and Navitime, with additional features for dynamically adapting and re-planning user multimodal routes.

Personalization is realized in the Personal Travel Companion and STIS by adapting multimodal trip planning to user preferences, whereas Navitime puts more concerns on managing privacy-sensitive information. More precisely, with Navitime, privacy-protection is managed by detaching and encrypting personally identifiable information before forwarding service requests; also, stored location-search queries are not linked to user identifiers.

Differences between Navitime and the other two systems with respect to privacy and personalization are probably due to the fact that Navitime is a commercial service, with a wide user basin (almost 2 million users in Japan), and thus is more concerned with respecting regulations on user sensitive data, rather than providing advanced personalization features.

None of the analyzed personal navigation systems seem to adopt international standards for mobility data exchange.

Infomobility integration frameworks

iTransit

iTransit is the framework for a multi-layered Intelligent Transport System (ITS) architecture designed for integrating novel as well as legacy-intelligent transport systems (Meier et al., 2005). The framework is based on a multi-layered object data model. Interoperability is achieved by specifying this common data model as the basis of a federated architecture of heterogeneous and legacy ITS systems. The model contains spatial and temporal aspects of transport and traffic data and represents a unified mechanism for querying and processing information coming from heterogeneous ITS system. It also includes global data layers (i.e. data of general interest), containing the physical and political geography and transport network of a region. Global layers can be extended through system view layers, which represent information generated or used by a specific system (e.g., public transport schedules, weather information, etc.). Interoperability between different data layers is ensured by a set of high-level concepts (named “context abstractions”) representing main abstractions for global and system layers: Real World, System, Data, Location and Identification Objects.

An application-programming interface has been designed on this data model. Data exchange among systems composing the iTransit architecture is based on CORBA and Web Services. The data model is compliant with OpenGIS specifications (Open Geospatial Consortium, 1999), but, to the state of our knowledge, European standard specifications specifically addressing the mobility domain, such as DATEX and SIRI, have not been taken into account.

Built on the above-mentioned data model, the iTransit architecture is made of three tiers, each implementing a different interoperability layer: a legacy tier that includes legacy systems implementing their own data model; iTransit tier integrating transportation systems that natively implement the iTransit data model, and an application tier including value added services built upon the iTransit system.
Highway Traveler Information System in the Jiangsu Province of China

Xiang et al. (2007) describe guidelines and design principles that have been adopted for the implementation of the Highway Traveler Information System (HTIS) in the Jiangsu Province of China. In China, the specifications for defining a national ITS architecture have been published. Nonetheless, the Jiangsu province is one of the few Chinese provinces that have planned HTIS development within research projects promoted by the Jiangsu provincial Highway Bureau.

The HTIS architecture aims at providing a framework that enable the interaction among distributed heterogeneous systems. It is organized into seven logical levels that represent different political geographical organizations, responsibility for data sharing and network routing and legacy systems. These levels include: a provincial hub level, hosting provincial hubs which represent the central data collection and distribution points and connect to various regional hubs; a regional hub level populated by 14 regional hubs interfacing with data sources and providing users with information within each region; a hub interface level which supports integration with ITS legacy systems by converting legacy protocols and data formats into HTIS specifications; HTIS subsystem level, including all the subsystems which acquire data from field devices and connect to their regional hub (directly or through hub interfaces); a field device level including field devices (e.g. sensors, detectors, etc.) acquiring raw data for traffic monitoring; an Information service provider level including information-based agencies that connect to the provincial hub and use HTIS data for disseminating to end users (via kiosks, users’ personal devices, etc.) and analysis purposes; an Internet level, which includes services providing end users with HTIS data via the internet.

The focus is on context information concerning highway monitoring and control, while context items centered on end users (e.g. location, activity, etc.) seem not to be taken into account. Emphasis is on a model for integrating heterogeneous and distributed information systems, based on a layered architecture, shared protocols and data formats.

Arktrans

Arktrans (Natvig & Westerheim, 2007) is the Norwegian national framework architecture for multimodal Intelligent Transportation Systems (ITS). Its aim is to establish a common view of the transport domain for all transport modes (road, sea, rail and air) in terms of standard functionalities and interfaces for interoperability among heterogeneous ITSes.

At present, Arktrans specifications define information needed by users travelling on public transport means, such as timetables, real-time information about delays and services provided on board and at stops. This information is defined by a conceptual model that represents concepts and logical relationships defined on UML diagrams and XML syntax. Existing European standards, such as TRANSMODEL, have been analyzed but not implemented, as they do not completely address some basic Arktrans requirements (e.g. multimodality with special emphasis on waterborne transport). Several related pilot projects are now being developed for the creating a door-to-door multimodal travel planner, combining scheduled planning (public transport via road, sea and rail) and non-scheduled (car, bike, walk) transport means. Route calculation personalization is made by considering user preferences.

According to publicly available documentation (Natvig et al. 2007), pilot implementation activities focus on supporting users in pre-trip and on-trip travel planning, whereas navigation service integration seems not to be foreseen.

Evaluation of presented Infomobility Integration Frameworks

The above-mentioned integration frameworks do not consider seamless mobility as a primary objective, as they focus on the issue of integrating back-end systems rather than on providing information services
to end-users. They provide potentially full support of real-time mobility information delivery, as they are specifically designed to integrate static and dynamic information about traffic and multimodal transport coming from different providers and sensor systems. Nonetheless, limited support is provided for dynamic adaptation with respect to real-time information about mobility and traffic status, as they are not targeted to deliver end-user information. As a consequence, also personalization, user interaction adaptation and privacy concerns do not specifically apply to these studies. The Arktrans program also includes the development of a multimodal planning service in the near future, which would consider user preferences. Presently, all these systems provide an integrated information layer on top of which advanced information services could be designed.

Interoperability among heterogeneous systems is mostly addressed through layered architecture models. As a matter of fact, a layered model approach promotes interoperability by defining layers characterized by specific functions and interfaces between layers. Compliance with existing standard specifications for data representation and exchange is not supported, or well-documented. In the Arktrans design case, existing standard specifications were judged as not appropriate for fulfilling project goals.

Information reliability is partially achieved by almost all systems by involving transport operators and public governments as authoritative information providers. However, to the state of our knowledge, no data management techniques have been systematically applied in order to manage data quality.

**Context-aware location-based communication platforms**

**LoL@**

LoL@, the Local Location Assistant, is a UMTS tourist guide prototype that has been developed within a collaborative project between a company and a university at the ForschungsZentrum Telekommunikations Wien (Umlauft et al., 2003). LoL@ is a guided tour service developed on an architecture for location-based services implementing SIP and OSA/Parlay standards. It provides tourists with a navigation service along predefined routes including Points of Interest and multimedia content delivery related to sights.

The application is based on a client/server architecture and has been implemented using Java Applets and Java Servlets together with XML-technology for content representation. Communication with the server is based on the HTTP protocol over a GPRS or UMTS connection.

LoL@ provides navigation and routing functionalities in the Wien city centre. A central concept for user interaction is the “map” metaphor. POIs and itineraries are shown over a map and users can interact with the application by clicking on icons and hypertext links and through spoken commands. Users may choose among textual, graphical and voice-based navigation and routing.

Context is modeled in terms of user location. LoL@ can use different positioning techniques: GPS, cell-based positioning, and users’ manual input. A location server assures location information quality by acquiring location information from the GPS or cellular network operator infrastructure and calculating accurate location information. It has been planned to extend the context model with a date and time reference (for instance opening hours for museums).

**MapWeb**

MapWeb is a location-based service platform built on top of the IP Multimedia Subsystem (IMS) architecture (Huang et al., 2006). The MapWeb architecture includes three layers: the Application layer, the Control layer and the Media and End-point layer. The Application layer hosts the MapWeb server which provides location-based information and communication services by integrating different Application Servers (AS), e.g. a Location AS, Presence AS, and other external servers (e.g. map servers).
The Control layer provides session and routing management. The Media and End-point layer includes terminals that initiate and terminate signaling for session establishment.

For instance, the MapWeb application can show a map-based interface on the user device. Through map-based interaction, the user can view his/her own position, locate buddies and contact them via phone call or instant messaging and locate POIs. The system can adapt services and communication channels according to user preferences and profile. Moreover, the user can specify some rules for adapting services according to context. In MapWeb, context is conceived in terms of location, current time, user presence and activity (obtained from a user calendar). MapWeb does not specifically aim at providing infomobility services; rather it provides a platform enabling the development of such services based on integrated communication, personalization and context management services.

**IMS-based location-aware services**

The IP Multimedia Subsystem (IMS) is an international standard for advanced multimedia service delivery in next generation converged networks. Several research studies are investigating how to extend IMS with support for location-based services. The advantage of such an approach is to enhance location-based services with value-added features provided by the IMS architecture, such as Quality of Service support, standard-based service integration over an IP-based infrastructure and charging facilities. Mosmondor et al. (2006) propose an extension of the IMS architecture by designing and implementing an IMS Location Server that provides IMS and IMS application servers with location information obtained from different positioning systems. The IMS Location Server is a generic SIP Application Server that can obtain location information from network-based positioning systems via Mobile Location Protocol (MLP) (Open Mobile Alliance, 2007). Complementary to this network-centric view, a terminal-centric location system has been proposed by Fabini et al. (2006) to provide the IMS core and IMS services with location information obtained by client devices equipped with positioning systems (e.g. GPS or Galileo receivers). The proposed technique also interoperates with network-centric location mechanisms and aims at improving location information accuracy. User information privacy protection can be assured by SIP-based privacy mechanisms (Jennings et al., 2002; Peterson, 2002).

**Evaluation of Context-aware location-based communication platforms**

The systems analyzed in this section address seamless mobility in terms of communication services. In Lol@ service access is guaranteed only if there is cellular network availability (GPRS and UMTS network). A minimal level of seamless service delivery is provided by means of a resume functionality that is provided when connection is lost (e.g. by network loss or simply because of an dead battery).

Systems relying on SIP signaling, such as MapWeb and IMS-based location services, can leverage on personal mobility features. None of the analyzed systems (Lol@, MapWeb and IMS-based location services) support multimodal planning services.

Regarding personalization, Lol@ and MapWeb implement personalization techniques for adapting interface and user interaction paradigms to user preferences, but do not implement techniques for privacy protection. Privacy-sensitive information management is addressed by IMS-based systems (Mosmondor et al., 2006; Fabini et al., 2006) and other research studies related to mobile communication (Arikawa et al., 2007; Umlauft et al., 2003).

**V DISCUSSION**
In this section we comment on the results of the state-of-the-art studies analysis shown in the previous section. Our findings are summarized in Table I, where each system is evaluated according to the context items and high-level requirements discussed in Section II and III, respectively.

Seamless service continuity is a critical aspect, partially addressed only by a few solutions with focus on different issues. Personal navigation systems focus on providing contents for uninterrupted navigation assistance aimed at managing transitions (such as outdoor/indoor, transportation means changes), whereas location-based communication platforms address the seamless service continuity requirement in terms of uninterrupted service access, or “seamless mobility”. This difference is due to the fact the studies belonging to these categories usually pertain to different research areas: human computer interaction, graphical user interfaces, geographic information management and mobile application development (personal navigation systems) and communication protocols and platforms (location-based communication platforms).

Awareness of real-time situations concerning mobility and (partial) support for transport multimodality are usually guaranteed by infomobility integration platforms. This is a straightforward consequence due to the fact that these platforms provide mechanisms and models for integrating both static and dynamic data that come from different providers. These platforms could be used to develop personal navigation systems and location-based communication platforms enriched with real-time information. This has not yet happened for several reasons. First, infomobility integration platforms are not widely available. As a matter of fact, developing an infomobility integration platform requires a strong effort in terms of standardization, agreements with different transport operators, costs and resources. Usually this implies the intervention of public administrations, as in the cases of Arktrans, HTIS and iTransit. Second, these frameworks rarely present open and standard interfaces that enable the development of added value services. This is also a consequence of the poor adoption of standards in interoperability and dynamic information sources integration.

At present, limited support is provided for dynamic real-time information adaptation for mobility and traffic status. To the state of our knowledge, existing systems do not provide both dynamic planning and navigation systems integrating multimodal mobility information and automatic adaptation to context events (e.g. congestions and public transport delays).

Personalization is usually intended as adaptation of multimodal trip planning to user preferences and disabilities or adaptations of interfaces and user interaction paradigms to user preferences.

Information reliability is a requirement that has not yet been widely addressed. Only iTransit, HTIS and Arktrans partially face this issue by involving transport operators and public governments as authoritative information providers. However, to our knowledge, no data management techniques have been systematically applied in order to manage data quality in the infomobility domain.

Most analyzed works do not implement techniques for privacy protection, except for Navitime, Map-web and the IMS-based location-aware services. As already discussed, major attention for privacy protection is shown in commercial products (e.g. Navitime) and prototypes for commercial products (MapWeb).

Regarding context information management, the results in Table I show how similar patterns can be found for systems in the same category (personal navigation systems, infomobility integration frameworks, context-aware location-based communication platforms). This is due to the high-level objectives that such studies may have in common (see the description of categories’ main objectives in Section IV). As a matter of fact, infomobility integration frameworks manage context information that is mainly related to planned and real-time mobility and transport services as well as to other geo-referenced content. Context-aware communication platforms focus on information characterizing the end user (e.g., preferences, activity, location and time). Personal navigation systems manage information describing
planned and real-time transport services, but do not extensively manage user location and time. None of the analyzed systems manage information characterizing the trip in terms of user habits and social context (e.g. being alone/in group). Nonetheless, this contextual information could be exploited in order to properly adapt navigation and information services in order to optimize trip planning and management according to factors such as travel duration in specific day times (e.g. peak hours) and costs.

**TABLE I. Evaluation Results.** The table shows whether state-of-the-art works address high-level requirements for infomobility: yes (y), partially (p), no (n). In some cases, required information was not publicly available (n.a.), or the requirement was not a specific design objective (-).

<table>
<thead>
<tr>
<th>High-level Requirements</th>
<th>Personal Travel Companion</th>
<th>STIS</th>
<th>Navitime</th>
<th>iTransit</th>
<th>HTIS</th>
<th>Arktrans</th>
<th>Lol@</th>
<th>MapWeb</th>
<th>IMS-based location aware services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seamless service continuity</td>
<td>p</td>
<td>p</td>
<td>p</td>
<td>-</td>
<td>-</td>
<td>n</td>
<td>p</td>
<td>p</td>
<td>p</td>
</tr>
<tr>
<td>Awareness of real-time situations about mobility</td>
<td>n</td>
<td>p</td>
<td>p</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>p</td>
<td>p</td>
<td>-</td>
</tr>
<tr>
<td>Support for transport multimodality</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>y</td>
<td>n</td>
<td>y</td>
<td>n</td>
<td>n</td>
<td>-</td>
</tr>
<tr>
<td>Personalization and user interaction adaptation</td>
<td>y</td>
<td>y</td>
<td>n.a</td>
<td>-</td>
<td>-</td>
<td>p</td>
<td>y</td>
<td>y</td>
<td>-</td>
</tr>
<tr>
<td>Compliance with standards for Interoperability and dynamic integration of information sources</td>
<td>p</td>
<td>n.a</td>
<td>n.a</td>
<td>n.a</td>
<td>p</td>
<td>p</td>
<td>n</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Information reliability</td>
<td>n</td>
<td>n</td>
<td>n.a</td>
<td>p</td>
<td>p</td>
<td>p</td>
<td>n.a</td>
<td>n.a</td>
<td></td>
</tr>
<tr>
<td>Privacy and Security</td>
<td>n</td>
<td>n.a</td>
<td>y</td>
<td>-</td>
<td>-</td>
<td>n.a</td>
<td>n.a</td>
<td>y</td>
<td>y</td>
</tr>
</tbody>
</table>

**Context Information**

| Who? | User preferences | y | y | y | n | n | y | y | y | n |
| User habits | n | n | n | n | n | n | n | n | n |
| Alone/in group | n | n | n | n | n | n | n | n | n |
| What? | User activity and mobility status | p | n | n | n | n | y | y | y | n |
| Planned mobility and transport services | y | y | y | y | y | y | n | n | n |
| Real-time mobility and transport services | n | y | y | y | y | y | n | n | n |
| Why? | Purpose of user journey | n | n | n | n | n | y | y | n | n |
| Where? | User location | n | n | y | n | n | n | y | y | y |
| Geo-referenced content | y | y | y | y | y | y | y | y | n |
| When? | Timing reference for user location | n | n | n | n | n | n | n | y | y |
| Timing reference for mobility and transport services | y | y | n | y | y | y | n | n | n | n |
VI RELATED WORK

Several research systems have addressed issues related to the infomobility domain. For sake of completeness, we mention also other relevant research contributions beyond those more deeply discussed in the previous paragraphs.

A pioneer work is the GUIDE system (Cheverst et al., 2000), which provides tourists with location-based information by accessing a PDA. COMPASS (Van Setten et al., 2004) is an application providing tourists with context-aware recommendations and services. Gulliver Genie (O’Grady et al., 2004) is a prototype of a context-aware application delivering proactive information services to tourists based on their location and preferences. Another example of a city guide is Sightseeing4U (Scherp & Boll, 2004), which delivers location-based information via a multimodal user interface on a mobile device. These studies were not selected as they especially focus on tourism, a restricted area of the infomobility domain.

A more recent research trend concerns the exploitation of user-generated content to enrich navigation and geo-referenced content delivery. Some examples are CityFlocks (Bilandzic et al., 2008) and OurWay (Holone et al., 2007). The former is a mobile system enabling visitors and new residents in a city to access knowledge and experiences of local residents, thus facilitating “social navigation” in urban places. The latter is a prototype system for mobile pedestrian navigation that uses user-generated maps and annotations to provide accurate information services adapted to users’ physical abilities and personal preferences. We did not analyze these studies in detail as they exploit a specific information source (end-users).

The Im@gine IT system is an agent-based service network architecture proposed for a real world applications in the infomobility sector (Spanoudakis & Moraitis, 2006). The Im@gine IT system is configured as a federation of agents distributed across different geographical areas, each of them serviced by one service integrator (named broker agent), one or more service providers (agents acting as service providers and events handlers) and other operators. Canali and Ancellotti (2006) propose a distributed architecture to support next generation infomobility services that provide interaction and collaboration among mobile users.

These systems have not been selected for evaluation as the available documentation focused more on illustrating the underlying system infrastructure rather than on describing the actual infomobility services developed, which are instead the focus of our analysis.

VII CONCLUSIONS

In this paper we have discussed high-level requirements and related technological challenges that should guide infomobility services innovation and evolution. We have also presented existing works in the field on infomobility, including personal navigation systems, infomobility service integration frameworks and context-aware location-based communication platforms. From the analysis of these works, with respect to the selected evaluation criteria, we found that at present most existing systems do not fully address infomobility requirements (i.e. seamless service continuity, awareness of real time mobility situations, multimodality support, personalization, information reliability and privacy protection) in a holistic way. Moreover, existing context models do not fully cover the information items that could be profitably exploited to improve the effectiveness of adaptive infomobility services.

Of course, it is not feasible to address the whole set of requirements through separate research and development projects, due to the amount of information bases, expertise and resources needed. Rather, it is required to adopt modular architectures based on standard interfaces in order to be able to build scalable, flexible and extensible products by combining results of different projects, maximizing reuse of
existing building blocks and minimizing the need for new code. Future research activities could be profitably directed towards combining context-aware semantic-based service frameworks for dynamically adapting and orchestrating infomobility services that come from heterogeneous providers, with results of research activities in All-IP communication platforms for seamless mobility. A primary requirement for that is the adoption of standards, as already discussed in the previous sections. Research on converged communication platforms and the design of multi-protocol devices (PDA, RFID readers etc.) are paving the way towards effective seamless mobility.

An aspect that could influence future research and development activities is the support by public authorities and stakeholders (such as transport operators, highway and railways infrastructures’ managers). This support is required in order to promote standardization activities and the adoption of the same standard specifications in a wide geographical area and to facilitate the collaboration among different stakeholders in terms of information sharing, communicating critical events and creating synergies for facing emergencies and abnormal conditions.

At present, our research work is oriented towards the development of a flexible and scalable service-oriented architecture, aimed at addressing infomobility requirements. This research activity is based on our results of previous research projects on the following topics:

- the development of a context-aware mobile tourist guide, providing tourists with geo-referenced and community services, such as reputation services and instant messaging (Paganelli et al., 2006; Paganelli et al., 2007). The system, developed in the framework of the KAMER research project, is a context-aware application integrating in a novel way location-based content delivery with communication and knowledge exchange services. Context awareness is conceived in terms of user location, but also in user preferences awareness, current activities, closeness to points of interest and physical proximity to other tourists, especially those with similar preferences and itineraries. The KAMER prototype includes a context management middleware that supports context data acquisition, processing, storage and delivery to applications.

- The development of an architectural framework for Semantics-Driven Integration of heterogeneous systems, implementing Service oriented Architecture principles (SOA) (OASIS, 2006). The framework is built over Sun’s Java Business Integration (JBI) specification (JSR-208) and it has been enhanced with a special Knowledge-Base Module service integration framework, based on semantic web technologies that promote interoperability among heterogeneous systems. A first proof-of-concept has been developed for a specific application domain: trust intermediation for eTourism (Parlanti et al., 2006).

These previous works constitute the basis for the development of an infomobility service platform, built on the above-mentioned service integration framework enriched with context management modules. The system will also include a Java-based client side application for delivering navigation and information services to travelers and tourists via mobile devices. Thanks to its modular and standard-based architecture, the framework will ease the progressive integration of heterogeneous information providers (traffic monitoring centers, public transport operators, geo-referenced content providers, etc.) in order to provide users with complete, reliable and updated information about mobility. This work aims at directly addressing requirements for awareness in real time mobility situations, multimodality support, personalization and information reliability. The adoption of an SOA approach facilitates the integration with third-party added value services that are coping with other requirements.

Results of this research and development activities will be integrated in a test-bed for infomobility services promoted by the Regione Toscana Public Authority, also in participation with regional public transport operators, “Autostrade per l’Italia”, the leading Italian Concessionaire for toll motorway
management and for related transport services, and other companies specialized in vehicular technologies and mobile information services.

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