DEPENDABILITY OF LOCATION-BASED SERVICES: A LARGELY OVERLOOKED ASPECT

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Abstract: There is obvious lack of attention to the dependability issues in literature on location-based services (LBS). Both researchers and practitioners were so far too much concerned with the questions about what useful features an LBS should have, while almost completely leaving out the questions about how to assure such basic properties as reliability or response accuracy. However, LBSs are applications that require high dependability, as we argue in this paper, so assuring those is both more critical and more difficult than usually. We discuss the existence of this disagreement between the actual importance of LBS dependability and the level of attention towards it among practitioners and researchers. We also identify and briefly discuss the major factors influencing dependability of LBSs, namely the quality of content, software reliability, algorithms appropriateness, interface quality, and communication quality.

PROLOGUE

Let us start with an anecdote.

> In a hospital, a nurse is writing down a mail from the dictation of the man, who is completely covered by plaster, with arms and legs broken: Dear editor, I would like to inform you that on the page 14 of your manual "How to handle a helicopter" I discovered a minor misprint...

At this point, we wanted only to tell this "horror story". We will return to it later, in Section 2.

1 WHY ARE LBSs STILL IN AN EARLY STAGE?

According to the latest statistics published by the GSM Association (GSM Association, 2003), in May 2003 there were 863 million GSM subscribers worldwide and 1218 millions wireless subscribers in total. In May 2002, the numbers were 692 and 1008 millions, correspondingly. As can be seen, the market is already huge yet still growing at fast pace. Although being saturated in some developed countries, such as Japan and many countries belonging to the European Union, it is still expanding rapidly in developing countries, such as China and Russia.

This presents a huge customer potential for commercial activities. The rapid growth of wireless mobile networks, coupled with advances in Internet and network technology, results in a fast development of Mobile E-Commerce, or M-Commerce, i.e. the activity of conducting E-commerce transactions over a wireless network using mobile terminals. The high-end mobile terminals have already reached the complexity and performance of the personal computers of mid 1990's, and the development continues at fast pace. Most new mobile phones are Java-enabled and can run, in principle, any application with reasonable resource needs. The small and light, yet powerful, mobile terminals are carried by their owners almost all the time.

In addition, the location of a mobile terminal can be determined within mobile networks, by using satellite navigation systems, or by some other available means. Recent developments in these areas seamlessly extend the positioning of wireless devices into all the environments where they can be used for voice and data communication. Thus, *location-based services* (LBSs) have become possible. We view an LBS as a special case of M-commerce, where the actual position of the terminal is used in the service provision.

There are many obvious needs that location-based services could fulfill. When people are in an unfamiliar place or have some unusual problem, they may need information about their surroundings. They might like to receive some guidance about how to reach a specific place, find a place to park the car, eat, spend a night and so forth. Traditionally, people solve

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these problems with the help of printed maps and various handbooks and guides. Today, LBSs could enable people to solve them in a more effective way. Studies of potential location-aware applications can be found in literature (Schilit et al., 1994; Dommety and Jain, 1996; Beadle et al., 1997), as well as recent discussions of business opportunities in LBS and customer value proposition (Rao and Minakakis, 2003; Barnes, 2003). The most basic LBS types are location-based yellow pages (information on restaurants, hotels and other points of interest) and route guidance (a map with the current location of the user, route finding). In addition to these services for personal information and navigation, LBSs are considered to include also such services as finding and tracking (friends, children, property), functional services (e.g. calling a taxi, roadside assistance) and some other. Ideas and opinions expressed in this paper apply to all types of LBSs to some extent; however, we have in mind those informational and navigational services mainly when speaking about "location-based services". Overviews of LBS enabling technologies and technical issues can be found in books devoted to LBSs, e.g. (Hjelm, 2002; Jagoe, 2003), or numerous journal and conference papers, e.g. (Dao et al., 2002; D'Roza and Bilchev, 2003; Tsalgatidou et al., 2003).

Therefore, location-based services seem to have all the prerequisites to become a very successful business — the demand, the huge (and growing) market and the good technological infrastructure, which is still developing further. LBSs have been a hot topic for both researchers and practitioners for a decade already, pushed forward by various players including mobile operators expecting LBSs to form an important revenue-generating class of mobile services, mobile phone manufacturers, Geographic Information Systems (GIS) community searching for possibilities to sell their data, algorithms and software, and other content providers (e.g. publishers of yellow-pages directories). According to the forecasts made in 2001, the LBSs should have over 300 million users by the end of the year 2004 (Singhal et al., 2001).

However, the reality we see is quite different. Despite all the opportunities and despite being a hot topic for a decade, LBSs are still, in 2004, in a very early stage. At least in Europe, location-based services are rare, provided mainly by the mobile operators themselves, and rather simple. There are some barriers delaying deployment of LBSs (Mitchell and Whitmore, 2003): operator debt levels, waiting for UMTS, limited LBS standards, pre-occupation with precision of available positioning solutions, privacy concerns (operators are vulnerable to public criticism), and business model paralysis (indecision by operators on whether to keep location for themselves or release to others). Nevertheless, many LBSs have been launched in recent years – so, according to (The Research Room, 2003), a total of 133 location-based services from 38 cellular networks were commercially available within Europe's top 15 cellular markets at the end of 4Q 2002.

However, many of those existing services do not seem to be well adopted and heavily used by customers, and this creates one more key barrier hindering development of new and more advanced LBSs. This lack of user adoption is often a surprise for mobile operators, who usually think that just providing some relevant information at the appropriate place and time means money. The lack of user adoption seems to be a surprise for the research community as well. Only recently, after a decade of discussing business opportunities and developing prototype LBSs, researchers have begun to investigate what requirements an LBS must fulfill in order to be successful.

Obviously, users must have a perceived need for the LBS provided. Many authors proclaim the huge business potential of location-based services; however, as summarized in (Dao et al., 2002), the market for LBS is currently very speculative while there is no definite answer to the questions whether consumers are really interested in LBS and whether they are willing to pay for them. Also, there may often be a discrepancy between what services users really want and what services the providers imagine them to want. The existence of such a phenomenon for mobile Internet services in general was demonstrated in the study (Chae et al., 2000). We believe, however, that even the simplest and the most prevalent of the location-based services available at present, namely of the yellow-pages type, have a clear demand for them.

In some cases, potential users might also be totally ignorant about some service that could be useful to them. This is because *visibility* (the degree to which the potential adopters are aware about existence of the innovation), *trialability* (the degree to which one can experiment with the innovation), and *result demonstrability* (the degree to which the results of using the innovation are observable and communicable to others) are important factors influencing an innovation adoption process (Karahanna et al., 1999). LBSs, however, are advertised well (achieving visibility), and delivered often on pay-per-request basis (leading to considerable trialability); they provide information or service that immediately applies to user's life (good result demonstrability).

We conclude, therefore, that existing location-based services should have been adopted by users unless they had some considerable defects, i.e. their perceived usefulness of perceived ease of use were insufficient. As we said above, in recent few years publications started to appear supporting this conclusion.

Some researchers consider the technological imperfection of present LBSs to be the main factor. So, (Grajski and Kirk, 2003) discuss that in Japan

location-based services seem to be more successful than in Europe, and associate this with the fact that in Japan 3G networks and precise Assisted-GPS positioning are already deployed. Other researchers concentrate on requirements for LBSs themselves. (Bisdikian et al., 2001) list the concern of privacy, the need to consider context beyond location, the need for service personalization, and usability of user interfaces as the main success factors. (Unni and Harmon, 2003) concentrate on the requirement that the price users pay for using the LBS must correspond well to the perceived value of the service, and also on the privacy concern. (Kaasinen, 2003) made an evaluation of a few LBSs by interviewing their users, and among users' concerns she listed appropriate and comprehensive contents, effective interaction with the service, possibility of more detailed search options than currently available, seamlessness, privacy, and personalization. (Köhne et al., 2003), based on discussion in student focus groups, list service price and content quality as the main (even knock-out) attributes of LBS, followed by technical aspects (device properties, positioning accuracy, convenience of use, configuration possibilities), privacy concerns, level of consumer activity (e.g. push vs. pull), and uniqueness of features as compared to competitors.

Surprisingly, content quality is rarely discussed. While agreeing with the importance of all the other requirements; we share the view of (Köhne et al., 2003) that content quality is a knock-out criteria. One aspect of this problem was noticed in the above-mentioned study (Kaasinen, 2003): the author reported that the limited content of the services (missing information) was one of the main reasons why users considered the services not useful. We "played" recently with a few currently available yellow-pages LBSs. Reporting on these experiments is outside the scope of this paper. However, we also discovered that data provided by these services is often outdated and incomplete. We believe that it should be obvious that with a low content quality an LBS would not be adopted by users no matter how well it is technologically advanced (e.g., with very precise positioning), how usable the interface is, how well it is personalized, and how well the privacy is protected. Content is what the users pay for. Actually, a low content quality LBS would hardly be adopted even if it cost no money to use it (for arguments see Sections 2 and 3).

In this paper, we extend this view and hypothesize that one of the major factors hindering user adoption of existing LBSs is their low dependability. *Dependability* is the trustworthiness of a computing system which allows reliance to be justifiably placed on the service it delivers (the definition by IFIP WG10.4). In other words, low dependability implies that the users just do not feel that they can rely on those services. Content quality is obviously one of the constituents, LBS dependability is affected by other factors as well (we will discuss them in Section 4).

We cannot provide sufficient empirical evidence (besides mentioned above) supporting this hypothesis, neither indicating that dependability of existing services is low, nor that this is a major factor leading to a lack of user adoption. The hypothesis is based on our interpretation of the experience of about four years of doing research in LBS and following development of the field. It is supported also by the obvious lack of attention to the dependability issues in literature, including both practically oriented and scientific sources. The talk is always about opportunities, enabling technologies, at best also about privacy and interface usability concerns, but never about the dependability. Even books devoted to location-based services, such as (Hjelm, 2002), trying to discuss all the possible related topics do not spend a single page on content quality or dependability requirements. As we said above, so far we seen only two papers (Kaasinen, 2003; Köhne et al., 2003) that (very briefly) mention even the most obvious concern of content quality. (There were, however, also a few publications which tried to apply theory from the information quality research field in the context of general mobile services (Chae and Kim, 2001; Landor, 2003) - therefore showing recognition of the problem.)

For us, it is quite obvious that both LBS researchers and practitioners were so far too much concerned with the questions about what useful features an LBS should have (i.e. utility), while almost completely leaving out the questions about how to assure a sufficient level of such basic properties as reliability or response accuracy (i.e. dependability). It seems that it is just not recognized that the dependability requirements for LBSs are quite high, higher than for most of conventional end-user applications, web or mobile services (the reasons for this we will discuss in Section 2), and that it may be insufficient to rely on common practices and methods of assuring it. Moreover, LBSs are usually developed as prototypes or pilots, and thus receive even less quality control than conventional software systems do.

We believe that in order to make LBSs a success, the situation has to be changed. More attention should be paid by LBS developers to the dependability issues. Also, some specific LBS dependability oriented research should probably be conducted in the scientific community.

2 WHAT IS DIFFERENT ABOUT LBSs?

In Section 1, we made a claim that location-based services are more sensitive to dependability problems

than most conventional end-user applications (including web and mobile services). Let us explain why we think so.

LBSs evolved from desktop applications. This evolution proceeds mainly by adding new technologies. Adding Internet support to desktop applications gave birth to web services. Adding wireless networks turned web services into mobile services. Adding location support turned mobile services into LBSs. Thinking this way hides the problem — there seems to be nothing really different about LBSs.

However, this is a case where quantitative changes lead to qualitative ones. LBSs are in fact philosophically very different from any of their predecessors. Any location-based service is an *augmented reality* application. Any information or functionality an LBS provides does not have much value per se, but assists in performing a primary user task, i.e. navigation through a city, making some immediate decisions, etc. If the user relies on the service, a failure of the service very likely leads to a failure of the user.

Recall that anecdote from the prologue to this paper. Small misprint in the manual leads to the helicopter crash. This is a joke, of course — no manual is assumed to be used like that, during the flight, but must be studied beforehand. Responsibility lies with that pilot completely. However, this is a nice example of that a "small" error in data may turn out to be very big if this data is used real-time, for making immediate decisions. Imagine also that instead of that printed manual, the helicopter had a software adviser system that depending on the situation gave tips to the pilot. Similar "small" error in it may lead to similar consequences — however, responsibility would lie now with software vendor, because this system is assumed to be used real-time, and it is assumed that the user may rely on it.

> Providing relevant data at right place and time is a great business opportunity; however, it comes with a great responsibility as well.

Any location-based service is assumed to be used in the course of the activity it supports, not before starting it. This significantly raises the dependability requirements for LBSs, as compared to similar purpose but offline applications and data sources.

Consider the most common LBSs at present, of the yellow-pages type. They are often developed as just offering a location-based real-time access to data sets collected for the purpose of printing phone books. However, the quality requirements for such an LBS are higher than for a printed phone book. LBS is intended mainly for traveling people as a tool providing support in making decisions about where to go. Therefore, wrong information may mean wrong decisions, lost time and, as a result, anger of the client (and losing him) in the best case and a lawsuit in a worse case. We can imagine, for example, an emergency situation where an LBS gives a wrong address for a pharmacy and the user therefore does not get the required medicine in time. But even if we do not consider such worst-case scenarios, it must be obvious that if a service provider plans to collect any revenues from his LBSs he should consider the dependability aspect very seriously. Clients are lost very quickly if they feel that they cannot trust the service.

A few more reasons for raised dependability requirements in LBSs are the following. First, once you have a printed phone book, using it is free. In contrast, the payment for using a commercial LBS is usually based on how much you actually use it. For many services, the client pays a fixed fee for every query made. Already a few erroneous answers may thus easily lead to losing the client. Second, phone books are published usually once in a year; the customers are therefore prepared to encounter some outdated information. A user requesting information from a "new technology" source and paying for this information expects it to be always up-to-date. Third, an LBS usually presents only a few short records to the client as the result of a query. This makes flaws in data noticeable easier even if they do not lead to critical failures.

One more reason for why location-based services require better dependability than most of other mobile applications is the following. Compare LBS, for example, to an application providing mobile access to e-mail. Mobile e-mail service offers a new information channel to the user. If a user does not have this service, he just cannot read his mails while traveling. Therefore, he is probably ready to use the service even if it has some flaws. In contrast, an LBS aims for *replacing* an information channel. If a user does not have an LBS helping him in finding a nearest hotel, he will solve this problem anyway using a travel guide or just asking people. Having an LBS might be better; however, getting an erroneous answer even once the user can easily give up on the service and return to a traditional way of solving this kind of problems. In other words, an LBS usually needs to compete with other sources of information; dependability is therefore very important.

3 WHY IS DEPENDABILITY FORGOTTEN?

Let us briefly discuss why there is a lack of attention to dependability of LBSs.

Imagine walking on an airplane for your next flight and you notice the following product warranty next to the entry (we borrow this joke from (Carpenter, 1999)):

> The software programs on this aircraft are sold

> "as is" without warranty of any kind, either expressed or implied. The entire risk as to the quality and performance of the software is with you. The developer does not warrant that the functions contained in the programs will meet your requirements or that the operation of the software will be uninterrupted or error free.

That is really a joke. Nobody will be willing to get on an airplane like this. Everybody knows that airplanes software is safety-critical and must be subject to a rigorous quality control.

In contrast, LBSs seem to be sold to users exactly under this kind of product warranty. They are therefore assumed to be something that should make users happy just because it exists, even if it has flaws — "something is better than nothing". Actually, it is quite common when introducing an innovation to concentrate first on demonstrating its utility and then gradually improve its dependability. This is often approapriate; however, based on arguments presented in Section 2 we should conclude that LBSs are not a case – they should be dependable from the very beginning. (Discussing LBS content incompleteness problem, (Kaasinen, 2003) makes a similar conclusion: that it should be considered carefully how much content a pilot service should include to be at all worth releasing.) Lack of recognition of this is probably the main reason for low attention to the dependability aspect in LBSs.

As we mentioned in Section 2, it is common to consider location-based services to be a subset of mobile services that are in turn a subset of web services. So, in addition to traditional concerns about web services and mobility only the obvious question of user's privacy is treated as a rule. Most of mobile services provide some additional value to their users; they are *useful* in the best case and *useless* in the worst case – they cannot be *harmful*. But LBSs can. However, location-awareness is commonly considered as a way to personalize mobile applications in this way improving their usability and therefore value (LBSs are presented in this way, e.g. in (Kaasinen, 2003) and (Unni and Harmon, 2003)). An LBS therefore inherits the appearance of a service that always has a positive value, and in the worst case is just a waste of money with zero value. That fact is forgotten that an LBSs, as any decision support system, may have a negative impact if it is of a bad quality, i.e. there is not only some value but also some risks associated with use of the service. In other words, the responsibility that comes along with the business opportunity of providing relevant information at right place and time is usually not recognized.

In addition, software systems quality assurance has never been a popular topic, especially among practitioners. Quality is not taught much in universities, many of developers had no quality and testing education in their formal studies or even training provided by the employer, quality assurance is seen as a tedious and non-creative activity, see e.g. (Ahonen et al., 2003). This attitude leads to the phenomenon that a creative developer and a developer caring about the quality are always two different persons, see e.g. (Yamaura, 1998). As any innovation, LBSs are developed inside research labs, i.e. by creative people. Therefore, this intensifies the problem.

4 FACTORS INFLUENCING LBS DEPENDABILITY

In this section, we identify and briefly discuss the main factors influencing dependability of location-based services. They are *content quality*, *software reliability*, *algorithms appropriateness*, *interface quality*, and *communication quality*.

Content quality

Since LBSs are all about providing relevant information at appropriate place and time, most services are built around a dataset that is of interest for users. Therefore, the first dependability concern is about this dataset quality.

The problem comes from the fact that this dataset is usually *repurposed* for the LBS, i.e. it was created for another reason. However, the quality requirements on it in the LBS may be higher than in the original use. In Section 2, we argued that the quality requirements on data provided through a yellow-pages LBS are higher than on information on the yellow pages of a phone book. This means that a dataset that is good enough as the source for a phone book may turn out to be of insufficient quality for using in the LBS.

Therefore, the quality of a repurposed dataset should be verified. This is not a trivial task in most cases, since the work of checking the entire dataset may be equal to creating a new one. Consequently, a statistical evaluation procedure should be applied. The goal is to guarantee that the quality of the dataset is not worse than required in the LBS (i.e. not worse than the estimated level of clients' tolerance). One such procedure for evaluating the data quality in a yellow-pages LBS was developed by us and presented in (Katasonov and Sakkinen, 2003).

In many cases, the LBS developer, even while being able to verify the quality of the dataset used, can hardly improve it. Then, a strategy for reducing data quality requirements may be considered. For example, changing the business model to one where user pays a monthly fee for using the service should lead to higher tolerance to service failures compared to a case when the user pays for every individual query made.

Also, providing more data in response to a query (say, data on 4 nearest restaurants instead of 2) should also reduce the criticality of individual flaws. Another way is to reformulate the utility of the service – there is a big difference between claims "the service reports on the two nearest restaurants" and "the service reports on two restaurants in close vicinity of the user".

Software reliability

Quality of software, both on the server and on the client side (if any), is another major concern. We are not ready no say much beyond the triviality that software, of course, should be reliable and therefore should be rigorously tested. A good testing approach is "horror-based testing" (Beizer, 1990). The worst-case scenarios are identified, i.e. the worst things that may happen because of software failures, and testing then aims for guaranteeing that those situations will not occur in practice.

The basic techniques for software testing and quality assurance apply to any kind of software-based systems including LBSs, of course. However, already web and mobile technologies require new testing and bug analysis methods (Nguyen et al., 2003), making it worth writing special books on testing internet-based and mobile systems. Probably, the LBS context will also require development of new or adaptation of existing methods.

Algorithms appropriateness

Similar to repurposing existing datasets, LBS developers tend to build their services around already implemented (or easily implementable) algorithms and technological solutions. Therefore, LBSs are often do "what is possible" instead of "what is required". However, the task in hand should be analyzed first, the requirements elicited, and appropriate algorithms selected. A few examples follow.

- Positioning precision. For a yellow-pages LBS, cell-based positioning would probably (but not always) be enough. However, for a route-finding LBS this will obviously be insufficient.
- Calculation of distances. For some tasks, straight-line distance is appropriate measure. For some other tasks, the road network must be taken into account (e.g. the user may be frustrated when getting a response that the nearest restaurant is only one hundred meters away while it actually across the river).
- Taking user's movement into account. For some tasks, it may be insufficient to provide data related to the location from which the user has sent the query, but rather needed to provide data related to the location where s(he) will receive the service response.

In some situations, a cheaper alternative might be sufficient given just that the service provider keeps it fair. So in the case of a simple yellow-pages LBS, cell-based positioning and straight-line distance calculation would be enough if it is claimed that the service reports on two facilities in close vicinity of the user. However, it is common to claim that the service reports on the nearest facilities. This is hardly required by a user from such a service; however, if the claim is not met, this obviously creates a negative impression. In other words, claiming such an unachievable utility, the service provider deliberately reduces the dependability of the service. Existence of the phenomenon of such claims about location-based services provides additional support for the point that very little attention is actually paid to the LBS dependability.

Interface quality

This and the following factor are rather well known since they are relevant for all the types of mobile services and applications.

Mobile terminals have small and low-resolution displays and limited input capabilities. This makes it more difficult to interact with a mobile terminal as compared to interaction with a PC. In addition, the practical conditions, when and where the mobile devices are used, cannot be expected to be constant, as it is usually in the case of a "desktop" application. The mobile users are typically in very unstable environment in varying conditions, where their cognitive capacity is demanded for other tasks as well. The mobile users have less "mental bandwidth" - capacity for absorbing and processing content - than a stationary user in front of a PC since the interaction with the mobile phone often is reduced to a secondary task that must not interfere with their primary task (e.g., driving or walking) (Chincholle et al., 2002).

All these peculiarities have to be taken very carefully into account when designing a new mobile service. The basic implied requirement is that the user interface should be very simple and user friendly and the amount of presented information content limited and well specified. The mobile users tend to use services that allow both quick manipulations of the interface and reduction in number of steps to access information (Chincholle et al., 2002).

Usability issues of mobile interfaces are actively studied by researchers from the Human-Computer Interaction (HCI) field. An example of investigated area is use of audio feedback in order to reduce the required visual attention, see e.g. (Brewster, 2002; Holland et al., 2002).

Communication quality

The properties of mobile networks are: (relatively) low bandwidth, high latency and unpredictable disconnections. These properties impose restrictions on mobile services and must therefore be addressed in the design of a new service. Some of the implied requirements are: not very intensive use of the mobile network and minimal volume of transmitted data, and possibility of offline operation.

5 CONCLUSIONS

Most of the major mobile phone operators in Europe already provide at least one location-based service to their subscribers. However, on the background of a decade of being a hot topic and very promising forecasts, LBSs are still in a surprisingly embryonic stage of development. While there are obvious barriers delaying deployment of new LBSs, such as operator debts and lack of standards, another problem is that those existing services seem to experience a lack of user acceptance. This should be surprising as well – if one shares common beliefs about high utility of LBSs (as we do).

One of the possible reasons for low adoption of LBSs that is often mentioned is a lack of trust to the service provider caused by user's privacy concerns. In this paper, we expressed our opinion that there is another reason also – low dependability of existing services.

There is obvious lack of attention to the dependability issues in LBS literature. Both researchers and practitioners were so far too much concerned with the questions about what useful features an LBS should have, while almost completely leaving out the questions about how to assure a sufficient level of such basic properties as reliability or response accuracy. However, because of the LBS specifics, assuring it is both more critical and more difficult than for most of conventional end-user applications, web or mobile services, requiring therefore increased attention in practice and probably even some research work done.

LBSs are applications requiring high dependability. Under some worst-case scenarios, a failure of even the simplest yellow-pages LBS may lead to serious consequences. But even if we do not consider these worst-case scenarios, it must be obvious that if a service provider plans to collect any revenues from his LBSs he should consider the dependability question very seriously. Because of the specifics of LBSs, clients are lost very quickly if they feel that they cannot trust the service. And dislike many other innovations, LBSs must be dependable enough already upon releasing. However, until this is recognized, LBSs are mainly developed under mottoes like "let's do what is possible today" and "something is better than nothing".

As we mentioned in Section 1, the paper (Grajski and Kirk, 2003) discusses that in Japan location-based services seem to be more successful than in Europe. The authors associate this with the fact that in Japan more advanced technologies than in Europe are in use. However, it must be obvious that an LBS with a low dependability will not be accepted by users no matter how well it is technologically advanced. On the other hand, it is generally believed that Japanese companies in general and Japanese software engineers in particular care much more about quality than Europeans or Americans, see e.g. (Yamaura, 1998). Therefore, we could expect that their LBSs are of better quality that those available in Europe. This is very probably one of their main success factors.

In this paper, we also identified a few major factors influencing dependability of LBSs, namely content quality, software reliability, algorithms appropriateness, interface quality, and communication quality. A defect in the service with respect to any of these factors may lead to the service failure. Data flaw, software failure or inappropriate algorithm may lead to an incorrect (or of insufficient precision) answer. Bad interface may lead to user's inability to comprehend the answer in time-critical circumstances. Not taking into account the latency and bandwidth of the mobile network may lead to the situation when the answer fails to arrive to the user in time.

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