34

DEFRAGMENTING INTELLIGENT TRANSPORTATION: A PRACTICAL CASE STUDY

ALAN CARLTON[1], RAFAEL CEPEDA[1] AND TIM GAMMONS[2]

[1] *InterDigital Europe Ltd, London, UK*
[2] *ARUP, London, UK*

The authors acknowledge the support of Innovate UK by providing funding for the oneTRANSPORT project and the oneTRANSPORT partners for their input and insightful discussions.

34.1 INTRODUCTION

The Transport industry is at a crossroads: embrace the future or try to preserve a status quo. Today, many industries are on a journey from closed data silos to the open possibilities of the Internet of Things (IoT). This legacy of silos has resulted from many decades of highly custom projects, protocols, and integration efforts, which have created a world of isolated islands of functionality. This approach is not sustainable in a world where increasingly profits and perceived value are moving to services and data.

The Transport industry has made good strides in the right direction. However, transport sector initiatives are not directed to opening data. Instead, to date it has been about defining protocols and technology to support the management of closed transport data and *control center* applications. Likewise, opening up existing data without addressing opening up the systems and the market will limit the use of that data in a geographically scalable and sustainable fashion. The value of the IoT lies in moving away from this single-purpose-asset paradigm to a multiuse disruptive one. Furthermore, it is not good enough if just one party opens up data for their own

Internet of Things and Data Analytics Handbook, First Edition. Edited by Hwaiyu Geng.

Companion website: www.wiley.com/go/Geng/iot_data_analytics_handbook/

benefit and ends up creating yet another silo. Instead, what is needed is a truly *open marketplace for data*, where a multitude of stakeholders can play, innovate, and benefit.

34.2 THE TRANSPORT INDUSTRY AND SOME LESSONS FROM THE PAST

The Transport industry of today parallels the telecommunication industry 30 years ago. In the 1980s, the telecom industry was characterized by national monopolies (or oligopolies) of local champions and manufacturers. This strangled innovation and growth due to separate national standards, small markets, poor economies of scale, and high prices. This did not ebb until after progressive acts of deregulation and the advent of standardized global technologies—like Global System for Mobile Communications (GSM) digital mobile phones—and prior to the consolidation, and massive growth, of the telecom industry.

Two key factors triggered change in the telecom industry: one of technological and one of regulatory nature. Technological change allowed the advent of affordable mobile phones, providing new capabilities that found a latent mass-market demand. Later on, many of the traditional telecom manufacturers struggled in accepting the need for change when Apple and Google introduced their new operating systems, iOS and Android, and their App stores. Long-standing industry leaders, such as Nokia and Motorola, blindsided and convinced of their traditional long-held views could not compete. Both companies are no more.

Regarding regulation, European integration and the emergence of the Single Market in 1992 were the key drivers for the GSM digital mobile phone standard. Europe-wide market opportunity encouraged the industry investment that drove the necessary technological advances. Countries that embraced this change by deregulating its telecom industry, 5 years or more ahead of other nations, emerged as the winners. With the United Kingdom as the change leader in Europe, the combination of early deregulation and support of this technology change resulted in many major telecom companies from Japan and the United States, making very substantial research and development (R&D) and manufacturing investments in the United Kingdom in the 1990s.

A key difference between the transport management and the telecom industry is that while both started as state-owned regulated industries, one has seen privatization and deregulation across the world and the other has remained state owned and managed. This, in part, reflects the slow and growing importance of transport management as an essential public service and the historic delegation of this to multiple disparate Local Authorities. As a consequence, and as summarized in Table 34.1, there is a stark contrast between transport and telecom industries today.

The transport sector is also facing technological and regulatory issues that today are leading to multiple proprietary solutions to common needs. For instance, a local authority transport manager, seeking a solution for parking, is faced with a choice of over a dozen different solutions. All these solutions offer similar capabilities, but are

TABLE 34.1 Comparison of Transport and Telecom Industries Today

Issue	Transport	Telecom
Market nature	Geographically fragmented (regional, not even national)	Global
Overall market size	Low volume	High volume, massive
New service development	Slow, costly	Very fast, third-party developer markets
Product types	Proprietary, bespoke, niche solutions	Standardized solutions
Pricing	High price	Low price, economies of scale
Competition	Low competition	High competition

Courtesy of InterDigital. Use with Permission.

implemented in different ways, with different benefits, costs, and, perhaps most importantly, incompatible systems across vendors and even across same-company products.

With this in mind, the next logical step is to explore the evolution of the transport industry and apply lessons from the telecom industry to revolutionize the transport experience for its users. A novel and innovative solution using the emerging global IoT standard oneM2M [1] is later presented in this chapter as the tangible creation of an open marketplace for data to benefit citizens, cities, and stakeholders.

34.3 THE TRANSPORT INDUSTRY: A LONG ROAD TRAVELED

The earliest forms of automated traffic systems were deployed in the 1920s in New York and Detroit. These were isolated traffic signals deployed at intersections to improve road safety. Over the years, these isolated traffic control systems were enhanced with the use of microprocessors in the 1950s and early system integration in 1970s. These emerging coordinated traffic control systems were known as Urban Traffic Control (UTC) in the northern hemisphere and Area Traffic Control (ATC) in Asia and the southern hemisphere. In the 1980s, the Transport and Road Research Laboratory (TRRL), then part of UK Government, independently developed traffic responsive coordinated systems in cooperation with other governmental and industry players. The main objective of this system was adjusting the traffic signal settings (cycles, green splits, and offsets) by real-time optimization of an objective function, such as minimizing travel time or stops, based upon estimates of traffic conditions. This system later morphed into two competing proprietary solutions known as Split Cycle Offset Optimization Technique (SCOOT) in the United Kingdom and Sydney Coordinated Adaptive Traffic System (SCATS) in Australia.

SCOOT and SCATS have been successfully deployed in many cities around the world. The SCATS was developed to deal with corridor management and capacity problems along routes radiating out from a central core—a feature typical of many Asia-Pacific road networks. SCOOT, on the other hand, is a real-time modeling-based system, which manages a network as a whole and distributes "green time" to optimize overall queue lengths and congestion—a feature typical of European cities, especially in the United Kingdom. Both systems, however, can be adapted to function in different environments.

Also in the 1980s, Japan developed a coordinated traffic system with responsive capability. Although the United States had a number of R&D projects, it was generally accepted by the US traffic engineers that fixed-time plan systems were adequate. Thus, transport control products were developed by Japanese and US firms independently using national technology norms with very little global cooperation or standardization.

Through the 1990s, only a handful of traffic system suppliers survived worldwide due to the limited market size and the high up-front cost for new entrants. By the mid-1990s, there were only about 400 traffic systems deployed worldwide. With a life cycle of 10–15 years, the demand for new systems was also limited. Meanwhile, SCOOT and SCATS systems continued to be highly proprietary and fiercely defended by suppliers (e.g., Siemens) and government organizations (e.g., Roads and Maritime Services, NSW). This proprietary model was also common with Japanese suppliers, while in the United States some transport authorities had more success integrating products from different suppliers. The Chinese traffic industry followed the lead of international manufacturers' products, which enabled them to circumvent some integration issues. However, many of the more sophisticated features of international products did not fully function with the Chinese equipment.

By the mid-1990s, the urban traffic systems market was in a "technical cul-de-sac." The technology was outdated and traffic data was not accessible outside of the proprietary systems. Having invested over many years, the major suppliers saw little benefit in opening their systems and were therefore reluctant to embrace change. At around this time, the urban traffic management and control (UTMC) concept was developed in the United Kingdom. With sponsorship from the Department for Transport (DfT), UTMC aimed to provide a way forward for the UTC market to meet current needs and to provide a platform for future competitive development.

The development of UTMC brought about a much needed change and moved the traffic industry forward with benefits such as the introduction of IP communications, rich data mapping, geographic information system (GIS) interfaces, and interoperability. This also led to some competition among peripheral device manufacturers such as those for CCTV cameras. Other suppliers also developed new functionality such as journey time measurement and interfaces with interurban systems. Nowadays, however, UTMC remains a capital-intensive facility funded entirely by Transport Authorities forced to purchase additional enabling features from a closed set of traffic equipment suppliers.

DATEX II has also been developed in Europe to offer a framework that defines an open and standardized data format and a model for transport data exchange between traffic centers, traffic operators, and media partners. Most UTMC systems deployed today support DATEX II adaptors.

While transport systems have moved to some open interfaces, it is still the Traffic Authority that remains referred to as the "end user" in deployed systems. Hence, they determine what the consumer or "citizen end user" actually requires. In contrast, other industries such as the mobile communication sector have seen tremendous growth through the globalization of standards, opening up of data, and the enablement of market forces (e.g., application stores) in driving the definition of end-user needs.

The intelligent transportation systems (ITS) industry is similarly trying to respond and adapt to the emerging market for open transport data. Yet, the proposed mechanisms for the release of data tend to follow traditional models (e.g., a licensed one-way data stream and selected data sets rather than full release). Suppliers are also understandably protective of their systems since they charge for the ongoing support, product enhancements, and other services.

While traditional industry suppliers had viewed their own customers, the Local Authorities, as the end user, the early 2000s saw other players outside of the traditional traffic industry recognize the opportunity to empower the traveling public—the era of user-driven transport applications had begun. The challenge that now needs to be addressed is a wider integration across the whole transport sector for the benefit of the complete citizen end-user experience.

The first steps in this journey came with the arrival of commercial satellite navigation devices. This was fundamentally enabled by the US government decision to allow access to the higher-precision GPS satellite codes previously restricted to military use only. The potential of a mobile phone to evolve into a handheld mobile Internet device, or smartphone, was pioneered by Nokia with the incorporation of GPS chips in their high-end phones along with map functionality. Unfortunately, small screens and poor user interfaces rendered them a poor competitor for GPS devices. Shortly after though, Google recognized that mobile Internet access could enable a new level of local search capabilities, serving a real customer need, while also enhancing the value of their existing product offering. This marked the advent of real-time mapping services. The subsequent introduction of the iPhone presented a much easier-to-use interface replacing the traditional layered menus used by Nokia and other phone manufacturers at the time. The second-generation iPhone, launched in 2008 and complemented with the Apple's App Store, enabled easily downloadable applications starting a full revolution in the telecom industry. This chronologic timeline is illustrated in Figure 34.1.

The new App store paradigm opened the door for empowerment of end users. Early applications were simple downloadable city guides, transport timetables, and navigation. Over time, transport applications became more sophisticated evolving from the use of static to dynamic data. Within the United Kingdom, government support for the opening up of publicly owned data has been an important factor in facilitating this movement. The launch of data.gov.uk in 2010, which included access to the National Public Transport Access Nodes (NaPTAN) database, was perhaps one of the earliest steps. Availability of such data enabled public transport apps to quickly evolve from simple timetables to delivery of real-time service updates (e.g., location) to users for specific buses and trains. Combination of multiple data sources enabled real-time comparison of different mixed transport modalities, for example, Citymapper. Mass usage navigation apps, such as Google Maps, have also evolved to

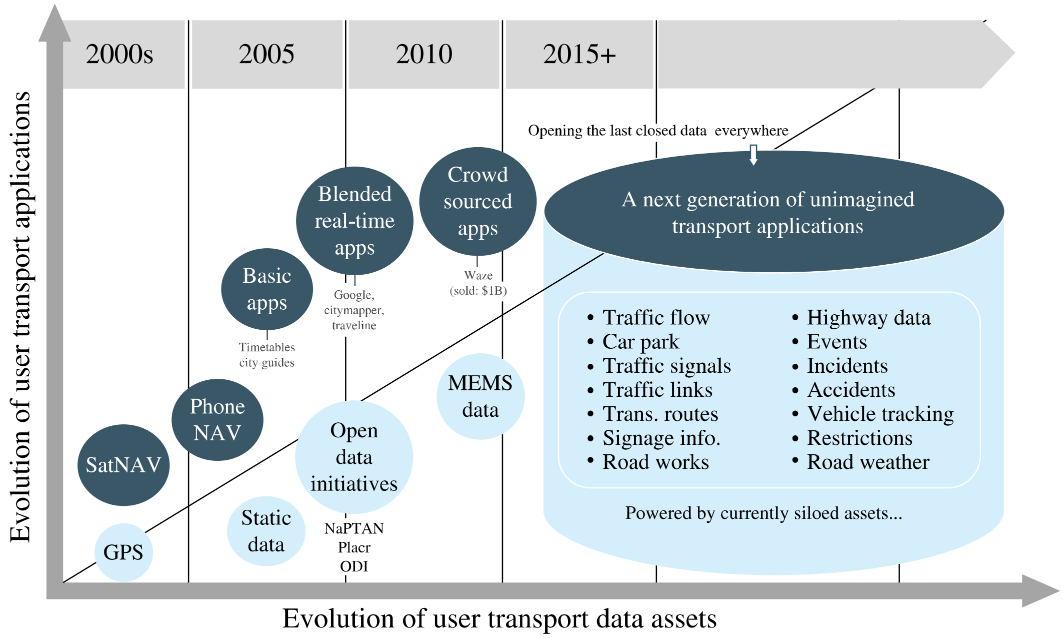


FIGURE 34.1 Evolution of transport applications and transport data assets. Courtesy of InterDigital.

incorporate such capabilities. Another major advance was the launch of the London Datastore (LDS) later in 2010, making much of the new transport data available free of charge to developers for commercial use. This was followed by the creation of the Open Data Institute (ODI) in 2012.

In parallel, with the emergence of Open Data and new applications, smartphone hardware continued to evolve. This included more sophisticated sensor capabilities—compass, gyroscopes, accelerometers, magnetometers, multiaxis inertial measurement units, and others. This evolution enabled devices to measure location, movement, and other factors more precisely, which effectively provided GPS-like performance even when outside of the GPS coverage range. Crowdsourcing of location data, speed, and traffic incidents has leveraged such capabilities notably led by the Israeli start-up company Waze, acquired by Google in 2013.

34.4 THE TRANSPORT INDUSTRY: CURRENT STATUS AND OUTLOOK

While much of the transport data has been unlocked in the UK's largest cities, much more still remains closed and inaccessible. The LDS, for example, offers access to a wide range of historical data as well as live feeds of traffic cameras, traffic disruptions, etc. Live access to detailed raw data on individual traffic signals (e.g., SCOOT data), and many other UTMC input data, remains problematic in large part due to closed system design. Moves toward a more open and integrated approach are starting to take off. However, without an integrated approach, there remains a large risk of maintaining the status quo, where individual Transport Authorities adopt different technology paths, an approach that puts dominant suppliers in a strong position to exploit this fragmentation. Currently, given trends in Local Authority funding, such approaches are just not sustainable in most countries across the globe.

In summary, there are two clear stories emerging:

1. The first driven by geographically fragmented Local Authorities' legislated responsibility to manage traffic—which has resulted in an industry cul-de-sac of high-priced, customized systems in an era of diminishing financial budgets
2. The other driven by the telecommunication and IT industries and by the Government-sponsored trend toward Open Data, which has resulted in a mass market for smartphone applications that end users want and for which many are willing to pay

At first glance, one might envision that these two stories perfectly complement each other, with the second being the solution to the problem of the first. While in one sense this is true, real challenges remain in large part due to conflicting cultural perspectives, experiences, and goals of different industries and communities. Some important transport-specific and time-specific requirements need to be highlighted:

- *Local responsibility and accountability* for Transport Management needs to be retained in order to account for the specific local needs when undertaking transport planning. However, the activities within adjacent counties and authorities and mutual impacts are not to be ignored. Furthermore, other local nontransport-related activities are becoming increasingly relevant. For example, the emergence of the Smart Cities concept and the opportunity to harness data across different conventional silos to deliver local benefits and improvements.
- *Local authority trends* related to funding in all areas including transport. Together these have contributed to a constrained market and deployment of ITS products in the United Kingdom and other countries.
- *The role of data* in creating new economic value and the subsequent adoption of a proactive policy in regard to Open Data are important. Local Authorities are being encouraged, at least in the United Kingdom, to make data publicly available [2]. Thus, Authorities are increasingly recognizing the market potential of the data assets they have in their possession.
- *The challenge of opening up data* as some authorities have been approached by major Web players wishing to acquire access to their transport data. For a Local Authority this is both an opportunity and a challenge. It represents an opportunity to secure new income, but it is a major challenge as well for at least three reasons:
  - Valuing the data—Quantifying the value of data is difficult as in many cases the true value is not yet known by a seller or purchaser.[1]

[1] A similar situation arose when Technology Transfer Offices (TTOs) were introduced at Universities to increase research commercialization. Many TTOs initially hugely overvalued IPR, with very limited University income generated as a result—the opposite of the intention of their establishment.

- Skilled staff—Local Authorities have limited staff resources capable of drafting appropriate contracts, as exemplified in Partridge Report [3], which revealed how poorly managed licensing contracts had resulted in both inappropriate control and release of personal health data through lack of understanding.
- Commercial staff—Multiple users are emerging for Local Authority data. Even if the skills were there, the time taken to negotiate multiple low-value contracts will require more commercial resource than are available.

These issues will be even further magnified when considering that Local Authorities face similar issues regarding their data assets from other public sectors.

"Open Once, License to Many" inherently offers a simple solution to these issues. The platform model in the real use case discussed in the next section is one of Publish/Subscribe, whereby standard contracts can be developed with suppliers and with consumers of data to enable significant savings both in staff resources and proper control of data assets. This model will also offer benefits to larger Web players who also prefer to negotiate a single contract with platform providers for all the available data. For example, this was the case in the deal between Google and ITO World [4].

It is clear that time is running out for the existing outdated business models. The reduction in public funding and the desire for independent Application Developers to solve the problems in the transport industry are two strong factors in driving this forward. The traditional assumption that governments have no alternative but to pour more money into the management of transport solutions may continue to hold true to a degree, but this is simply a recipe for survival, not for growth—which is what is needed to address the challenges of more increasing population densities and increased traffic. A novel and innovative solution that encourages such growth is discussed next.

34.5 USE CASE: oneTRANSPORT—A SOLUTION TO TODAY'S TRANSPORT FRAGMENTATION

oneTRANSPORT is an Innovate UK-supported [5] project initiative in the area of "Integrated Transport–In-Field Solutions." The project addresses both immediate and anticipated future challenges facing the transport industry (e.g., congestion, shrinking Local Authority budgets, end of subsidies, etc.). These challenges are complex and interdependent. Today, oneTRANSPORT involves 11 cross-sector partners including five Transport Authorities (data owners and use case providers), a technology platform provider, a transport industry specialist, and four transport sensor/device manufacturers and transport analytics providers.

The oneTRANSPORT solution is based on oneM2M, an international standard to truly enable the IoT revolution (Figure 34.2). This standard was created with the singular intention of breaking down industry and data and technology silos and enabling the possibilities of the IoT. oneM2M is a *Service Enablement Layer* standard whose core functionality is to provide a set of service capabilities that enable manageable data sharing for new services and application development from multiple parties.

FIGURE 34.2 oneM2M service enablement layer international standard. Courtesy of InterDigital. Use with Permission.

oneM2M is based on a "store and share" paradigm. Hence, interested applications are notified about resources and relevant changes by means of subscription. Access rights, usage, and privacy are ensured through the defined service capabilities.

oneTRANSPORT is unique and complementary to existing transport technologies (e.g., UTMC, DATEX II). It enables new layers of functionality to address challenges from the transport industry by opening up the data, on a multicity scale, that many Local Authorities have locked behind existing systems. The data is made accessible to the innovative power of the application development community in a fair and equitable manner for all stakeholders. oneTRANSPORT will enable new transport applications to be highly transferable, delivering both local and interregional impact. The challenge here is doing this in an economically attractive manner to Local Authorities. To this end, oneTRANSPORT defines an innovative cloud-based model of brokers that enable an "open once, sell to many" vision.

oneTRANSPORT, by virtue of its approach, offers the opportunity to trigger a transition in the transport management industry to a standard-based ITS market with associated economies of scale. The oneM2M standard defines a set of RESTful[2] APIs[3] and protocol interface spanning devices (e.g., traffic sensors, actuators), gateways, oneM2M servers, and application servers. As a service enablement standard, oneM2M is agnostic to the underlying connectivity and can operate over wired or wireless systems, standards-based or proprietary, as would be found in different geographical regions. The oneM2M standard has been in development for several years. There are currently more than 300 participating partners and member organizations from all around the world. Much of oneM2M core definition was derived from previous work in European Telecommunications Standards Institute (ETSI). In 2012, the standard transitioned into a joint[4] activity involving all of ETSI's regional

[2] Representational state transfer (REST) is a standardized way to create, read, update, or delete information on a server using simple HTTP calls (the foundation of data communication for the World Wide Web).

[3] APIs = Application Programming Interfaces, standardized ways in which software entities interact/communicate.

[4] The bodies involved in standardizing oneM2M are ETSI (EU), ATIS and TIA (America), ARIB and TTC (Japan), CCSA (China), and TTA (South Korea). These same bodies collaborated to create the mobile broadband 3G and 4G standards, which today have greater than two billion users, 30% of the global population (cf. 22% in 2012), and a 75% penetration in the developed world.

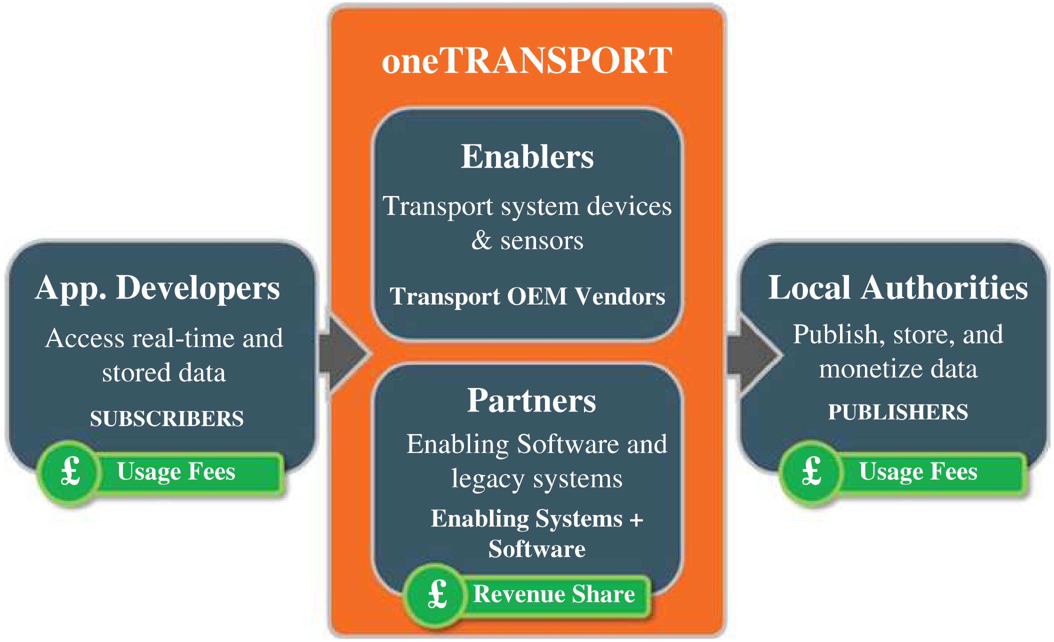


FIGURE 34.3 oneTRANSPORT platform vision. Courtesy of InterDigital. Use with Permission.

counterparts across the United States, Japan, China, and South Korea. The first formal release of the standard was in February 2015.

The oneTRANSPORT platform vision is illustrated in Figure 34.3. This vision is simple: to create an open marketplace for data, analytics, and software enablers through the power of the oneM2M open interfacing. oneTRANSPORT defines a platform that allows Local Authorities as well as third-party software vendors to monetize the array of data assets that their technologies provide. The open interface approach implicitly avoids vendor lock-in issues—hence allowing the proliferation of an open ecosystem that in time is expected to expand well beyond transport.

The *oneM2M Service Layer* provides the "core system services" of oneTRANSPORT and full-featured M2M Service Delivery Platform (SDP) functionality. This includes interworking of transport data assets from other systems, event management, gateway services, device management and discovery, configurable charging, filtering and semantic services, and so on. All data that is made available to higher-layer entities flows through, and is exposed by, the oneM2M API. This layer supports a RESTful architecture, allowing higher-layer entities to register for event notifications and other supported services. *oneTRANSPORT* offers new "premium data service capabilities" to Application Developers. There may be multiple embodiments of software services, from different vendors, designed for the same or similar purposes in this layer. Two categories of premium service capabilities are currently anticipated:

1. *Transport data analytics* that are predictive and/or simple analytics functions. There is no inherent limit to the number of analytics engines and providers that can be hosted by oneTRANSPORT.

2. *Transport application enablers* that provide core application enablement software and API support to higher-layer applications. These software entities typically encompass functionality to more than one higher-layer application.

oneTRANSPORT may be used to enhance and expand the value of current applications such as Citymapper or Waze through integration at the oneTRANSPORT API. It should be noted that today's applications such as Waze are *smartphone data*-centric applications (i.e., relatively simple). oneTRANSPORT will open up a new world of *machine data available everywhere*, enabling a whole new category of possibilities and expansions.

The following use case exemplifies the "predictive" experience that will be possible when this world of fluid data and competitive analytics is realized. Below is an excerpt of a future day in the life of the oneTRANSPORT end user:

> *The Travel Avatar Experience*—Joe woke to the usual sound of his smartphone alarm. After grabbing his phone from his bedside table, he smiled at the message that greeted him. "Turn over Joe, the way things look right now you might be better leaving about 15-minutes later." Joe really like this new application—it really worked! Over the years, he had crowded his phone with countless travel apps that never really delivered. This app did and it made a difference. It brought everything together in a uniquely personal experience: buses, trains, cars, incident delays, car shares, and even parking information near his usual destinations. He had challenged it a few times, but had long since learned not to waste his time because it was always right. Most days he would take his car and the app would guide him to the cheapest (and available!) parking spots near his office. Other times, it would recommend that he take the bus or a train. As long as he never forgot his phone, the app just seemed to know what he was doing and the awards system provided him free trips on regular occasions. Furthermore, the longer he used this app, the adverts in the background just got better and more useful. He had actually seized on some of the ideas suggested to him for lunches, coffees and even a new gym that had opened close to his work.

34.6 oneTRANSPORT: BUSINESS MODEL

Today, there are numerous physical and virtual data sources that might be leveraged in any number of ways to drive intelligent transport decisions. However, the highly fragmented nature of these data sources makes it nearly impossible for an open application ecosystem, with all its benefits, to emerge in any meaningful way. oneM2M provides a solution to this problem in its core value proposition by defining a standardized horizontal service layer. This common service layer allows the exposure of data sources via a standardized API, which enables easier application creation, ecosystem proliferation, and high scalability.

By introducing a new "layer" of functionality to complement traditional and existent technologies, oneTRANSPORT will open up transport data assets in a monetizable manner going beyond simply Open Data. The impact of oneTRANSPORT will be nothing less than the completion of the value chain up to the "citizen end user."

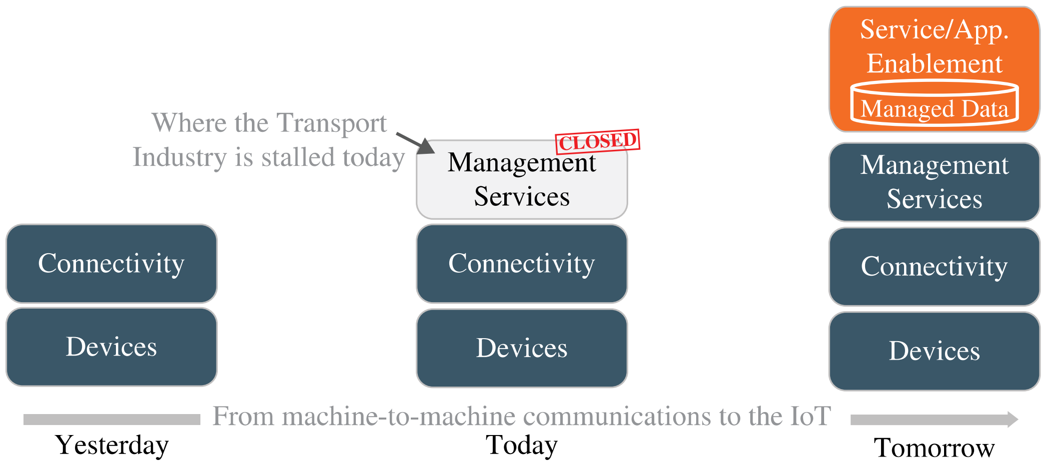


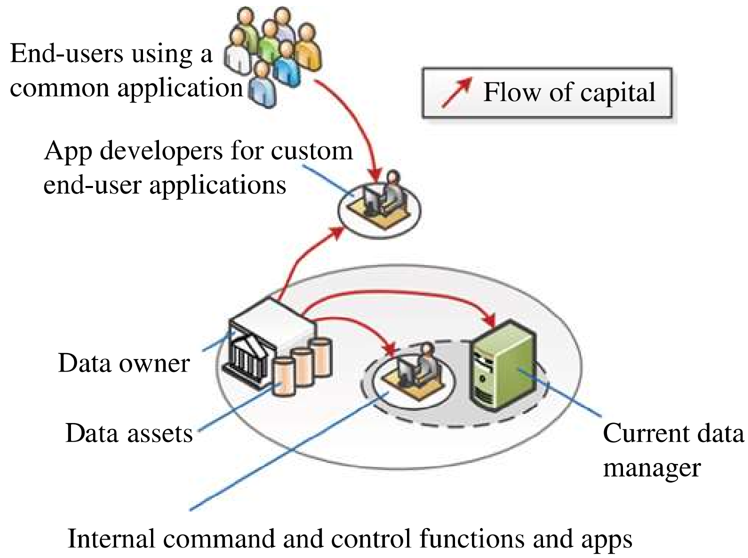
FIGURE 34.4 oneTRANSPORT opens data assets once to many users. Courtesy of InterDigital. Use with Permission.

This will open up a new level of possibilities in transport application experience following the structure in Figure 34.4.

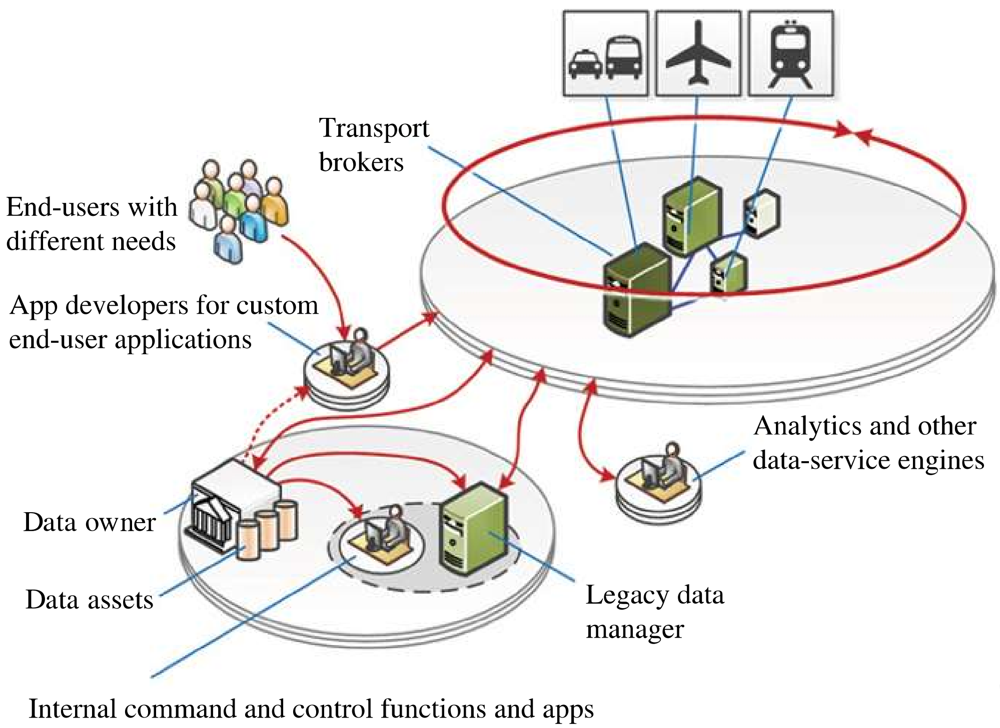
The evaluation of oneTRANSPORT as a business proposition requires a thorough analysis of what costs are actually involved and what strategies can be used to deliver revenues and long-term profitability. While some technology propositions may have the potential to deliver integrated transport and reduce congestion, if they cannot deliver this in a practical and profitable way for Transport Authorities, it has no value.

The proposed business model of oneTRANSPORT is envisioned in three evolutionary phases. These phases have a central player, a *oneTRANSPORT Broker*, orchestrating the services offered by the solution. The oneTRANSPORT broker role can be occupied by anybody: a Local Authority, a technological provider of the platform, or an appointed third-party manager as a business expert in the area. This central player may change from phase to phase depending on exploitation agreements and the competitive environment that develops. Figure 34.5 outlines the evolution from today's status quo, with Local Authorities solely supporting all their transport solutions, to a oneTRANSPORT-based system with multiple data brokers, IoT platform providers, app and analytic vendors, and data owners. This transition is enabled by the three phases described as follows:

Phase 1: In-field trials—This initial phase is a 2-year trial starting in late 2015 and characterized by Local Authorities opening up their data assets to the software development community through a oneTRANSPORT broker. This phase is also characterized by the integration of data assets, installation of new sensors, development and testing of mechanisms for usage and charging, development of embedded analytics, creation of an exemplary software application, and the deployment of initial data filtering tools. Since the revenue stream is expected to be low during this phase, the initial system development will be covered by funding from a private–public partnership.



Status Quo



oneTRANSPORT-based system

FIGURE 34.5 Business model evolution of oneTRANSPORT. Courtesy of InterDigital. Use with Permission.

Phase 2: Initial commercial stage—During the second phase, or a 1-year initial commercial rollout, a more comprehensive Data-as-a-Service (DaaS) scheme will be offered to Application Developers with both enhanced analytics and premium data offerings. This phase will create an open marketplace for data, which will allow different mobile Apps to be offered to users from a large number of software developers. At this point, Local Authorities will see profits from users accessing their data assets via mobile software applications subject to very modest data access fees. In turn, an appointed *local* oneTRANSPORT broker will start deriving profits through licensing fees. A portion of these fees will be used to recruit other partners and grow the ecosystem.

Phase 3: Full commercial stage—This third and last phase is characterized by a tighter integration between local oneTRANSPORT service proxies and service offerings from oneTRANSPORT brokers to additional Local Authorities and application developers. Revenues will increase progressively due to more data users accessing the platform, more software Apps being offered, external data users joining the ecosystem, and a large variety of analytics and premium data services. This phase is envisioned as a fully scalable business solution with an extensive rollout as a result of low expected investment from counties and a competitive market.

Additional direct benefits to the Local Authorities will increase over time coming from, for instance, savings in transport subsidies and reduction in health services for pollution-related illnesses. Indirect benefits will result from reduced journey time of commuters, a reduction in pollution-related expenditure, and increased interest in local investments and thriving job market for small and medium businesses.

34.7 CONCLUSION

oneTRANSPORT, based on the oneM2M standard, is the next step-up for the transport industry. This solution takes the transport industry to the next level and into the deep realm of possibilities envisioned for the IoT.

Transport is not a level playing field today. Large cities, like London and New York, are able to autonomously drive change on a large scale in their own systems by using large budgets and offering a potentially large user base. This story is not the same across the vast majority of Local Authorities, of different sizes and budgets, who are facing ever-increasing budget constraints and "do-more-with-less" challenges. Even within the larger city economies, there are limits to what can be achieved in a truly scalable fashion. Time and time again, history has shown us that in order to achieve great change and impact, scale and standards are required.

The Transport industry needs to change in order to address the range of challenges that it currently faces in a holistic manner. The benefits of such changes could be enormous and may include: much needed new revenue streams for Local Authorities, significant socioenvironmental improvements, and the realization of a truly internationally integrated transport system enabled by a fair and ubiquitous open data environment.

To realize these benefits, oneTRANSPORT is delivering the next generation of integrated transport solutions building on the following principles to ensure readiness (and a winning position) for the inevitable IoT future:

- *Avoid proprietary systems*—to reduce the risk of downstream vendor lock-in.
- *Use globally standardized technology*—to open up the global market.
- *Support multiple existing infrastructures, rather than being "clean slate" solutions*—to ensure operation across diverse systems and multiple geographies.
- *Involve multiple Transport Authorities and ecosystem players*—to achieve and demonstrate the preceding points.
- *Deliver new sources of revenue into the transport ecosystem*—so that Local and Transport Authorities find the solution (at a minimum) cash neutral and hence create rapid global adoption.
- *Encourage solutions that facilitate new, open, competitive markets*—to create opportunities for both the existing transport industry players and new entrants.
- *Encourage Authorities to open up their transport data*—by creating new possibilities and revenue streams for them.
- *Employ an open, standardized, interface for new transport sensors*—to support and make use of data from future IoT sensors, which will be deployed outside of transport (future proofing), and to encourage interface standardization (lower costs) among transport sensor and system suppliers.
- *Support services and applications from other emerging systems*—to maximize value and interoperability of solutions.
- *Provide measures of the modal shift effectiveness of services*—to allow their comparison.
- *Enable Local Authority services beyond transport*—to support the next moves to smart counties and to the future "smart world."

oneTRANSPORT is not another industry, data, or technology silo. A fundamental premise of this solution is the integration and discoverability of multiple data assets, platforms, vendors, and systems. This integration process will be established through multiple open events to share knowledge and resources among interested stakeholders, which include Transport Authorities in any country, other platform providers, analytics and device vendors, software developers, universities, citizens, and so on. This integrative project is thus a real opportunity to unleash the true value of the IoT.

ACKNOWLEDGMENT

With special thanks to Vanja Subotic, InterDigital, for her leadership and many useful editorial inputs.

REFERENCES

[1] oneM2M is a trademark of the Partner Type 1 of oneM2M. See http://www.oneM2M.org (accessed August 31, 2016).

[2] "Release of Data Fund"—see https://www.gov.uk/government/news/15-million-funding-to-open-up-public-data (accessed August 31, 2016).

[3] "Review of data releases by the NHS Information Centre." Sir Nick Partridge, June 17, 2014. http://www.hscic.gov.uk/datareview (accessed August 31, 2016).

[4] http://www.bbc.co.uk/news/technology-27394691 (accessed August 31, 2016).

[5] connect.innovateuk.org (accessed August 31, 2016).

35

CONNECTED AND AUTONOMOUS VEHICLES

LEVENT GUVENC, BILIN AKSUN GUVENC
AND MUMIN TOLGA EMIRLER

Ohio State University, Columbus, OH, USA

35.1 BRIEF HISTORY OF AUTOMATED AND CONNECTED DRIVING

Early work on autonomous vehicles can be traced back to work on autonomous operation of mobile robots motivated by the need to use such devices in unmanned space exploration. An autonomous mobile robot is a completely independent unit with its own power source, actuation system, an array of sensors to perceive the environment, and a computing system used for decision making. Research on mobile robotics has, thus, been inspirational for autonomous road vehicles and automated driving. However, it is not possible to directly jump from autonomous mobile robot technology to automated vehicles operating on roads. There are several reasons for this. First of all, a mobile robotic platform is not designed to operate on roads, especially on highways. Any vehicle that is operated on roads has to pass rigorous certification tests called homologation which no mobile robotic platform will be able to satisfy. Secondly, while mobile robotic platforms can stop and wait to assess the current situation, this is not possible in the case of an automated vehicle which cannot arbitrarily stop in the middle of the road, thus obstructing traffic. Early researchers working in the area of autonomous road vehicles have concentrated on low-speed driving in closed test areas for this reason. This is a very significant issue which has been a differentiating factor in successful implementations. Those research groups that were able to implement their automated driving algorithms at speeds up to highway driving speeds have been successful, while others who were not able to do

Internet of Things and Data Analytics Handbook, First Edition. Edited by Hwaiyu Geng.

Companion website: www.wiley.com/go/Geng/iot_data_analytics_handbook/

this have failed. Unlike mobile robotics, automated driving vehicles are constrained to follow and share the road and obey all rules of traffic.

There have also been early research efforts that were concurrent with the work in autonomous mobile robots. One significant example is the pioneering research work on autonomous vehicles at the Ohio State University during the 1960s and 1970s led by Prof. Fenton of its Electrical Engineering Department [1]. The cars used in this pioneering work had a sensor in front that sensed the current inside a wire carefully taped to the road and served as the path to be followed. This work had to stop in 1980s due to lack of funding. The California Partners for Advanced Transportation Technology (PATH) program was one of the well-known succeeding programs on automated highway systems in the United States originating in 1986 [2]. The California PATH program was funded by the State of California and also used guided wires embedded in the road initially, followed later by the use of magnetic markers embedded in the road for autonomous trajectory following.

The well-known and well-publicized Defense Advanced Research Projects Agency (DARPA) Grand Challenge autonomous vehicle races of 2004 [3] and 2005 [4] and the subsequent DARPA Urban Challenge of 2007 [5] were more recent demonstrations of the feasibility of autonomous vehicles. While the feasibility of autonomous driving was demonstrated in the DARPA challenges, the solution approach of bulky actuators, an excessive amount of redundant sensors surrounding the vehicle and the large computers used with insufficient computing power based on today's standards, meant that the developed technology was nowhere close to implementation in a series production road vehicle. In those days, consumers also did not demand cars with automated driving capability as the technology was considered to be expensive and not able to cope with the large variety of highly demanding real-world situations.

Some drastic changes took place in recent years in both the automated driving and the connected vehicle (CV) areas that changed both the consumer and federal and state government acceptance of these new technologies. In the automated driving area, the success of the Google self-driving cars [6] that were actually built based on DARPA Challenge experience of winning teams for obtaining lidar-based maps in the United States and around the world was a big game changer. The public opinion changed to a much more favorable view of autonomous vehicles and their prospect of being available soon. A similar event took place in vehicle connectivity around 2009–2010 as modems based on the new IEEE 802.11p communication standard for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication became available. A wide variety of alternatives had been tried in the past for V2V and V2I communication without much success. With the new standard in place and with the newly available modems, automotive Original Equipment Manufacturer (OEMs) and suppliers were immediately interested in the possibilities offered by CV technologies. The presence of major automotive OEMs and research labs backing most of the teams that took part in the Grand Cooperative Driving Challenge (GCDC 2011) [7] was a clear indication of this interest. In the GCDC 2011, connected automated driving based on the new communication standard was demonstrated by multiple runs by two platoons of vehicles from different vendors in a highway, at regular highway speeds. Research in the CV area has progressed tremendously since then, as is evidenced by the highly successful CV Pilots program of the US Department of Transportation (DOT) [8]. As a result of this success, automotive OEMs will soon be asked to manufacture their vehicles with onboard units that have modems with V2V, V2I, and vehicle-to-everything (V2X) communication capability.

While not taking a direct interest in the autonomous vehicle results of the DARPA challenges, automotive OEMs and suppliers took a different approach of building vehicle automation piece by piece, starting with active safety systems like the Electronic Stability Control (ESC) [9] system and continuing with Advanced Driver Assistance Systems (ADAS) like Adaptive Cruise Control (ACC) [10], Lane Departure Warning and Keeping [11], Collision Risk Warning and Avoidance [12] using emergency braking, and so on. Their approach was to build automated driving functionality incrementally and first offer the new technology in higher-end models. As a result, it is possible to have technologies like automatic car following (ACC), lane centering control, and automatic parking even in the lower-priced models today. Based on this success and on public acceptance and also based on nontraditional competition from the likes of Google and Apple, automotive OEMs are preparing to make automated driving available in their series production vehicles as early as 2020. These automated vehicles will also be connected to other vehicles, the road infrastructure, and to other road users like pedestrians and bicyclists through smartphone apps.

35.2 AUTOMATED DRIVING TECHNOLOGY

Automated driving has been categorized into six categories [13] displayed in Figure 35.1 by the Society of Automotive Engineers (SAE). Currently available automated driving technology falls under level 2 and level 3 which are partial and conditional automation, respectively. Level 2 partial automation is available in series production vehicles with lane centering control for steering automation and ACC and collision avoidance for longitudinal direction automation. Partial automation is characterized by all driving actuators being automated and the presence of a driver who can intervene when necessary. Recently introduced autopilot systems for cars are examples of conditional automation where the car takes care of driving in some driving modes (like highway driving), but the human operator is always in the driver seat to take over control if necessary. In level 4 highly automated driving, the human driver is available to intervene, but the driving tasks are taken care of autonomously even if no intervention takes place. There are a lot of research vehicles with level 4 automation. The goal, of course, is to reach the highest of them all, that is, level 5 automation, which is characterized by all driving modes being executed autonomously without the need for someone in the driver seat. This means that all driving tasks except for the entry of the final destination should be planned and executed autonomously by the car. While some example applications exist in the case of predefined missions, no vehicle with that level of autonomy currently exists.

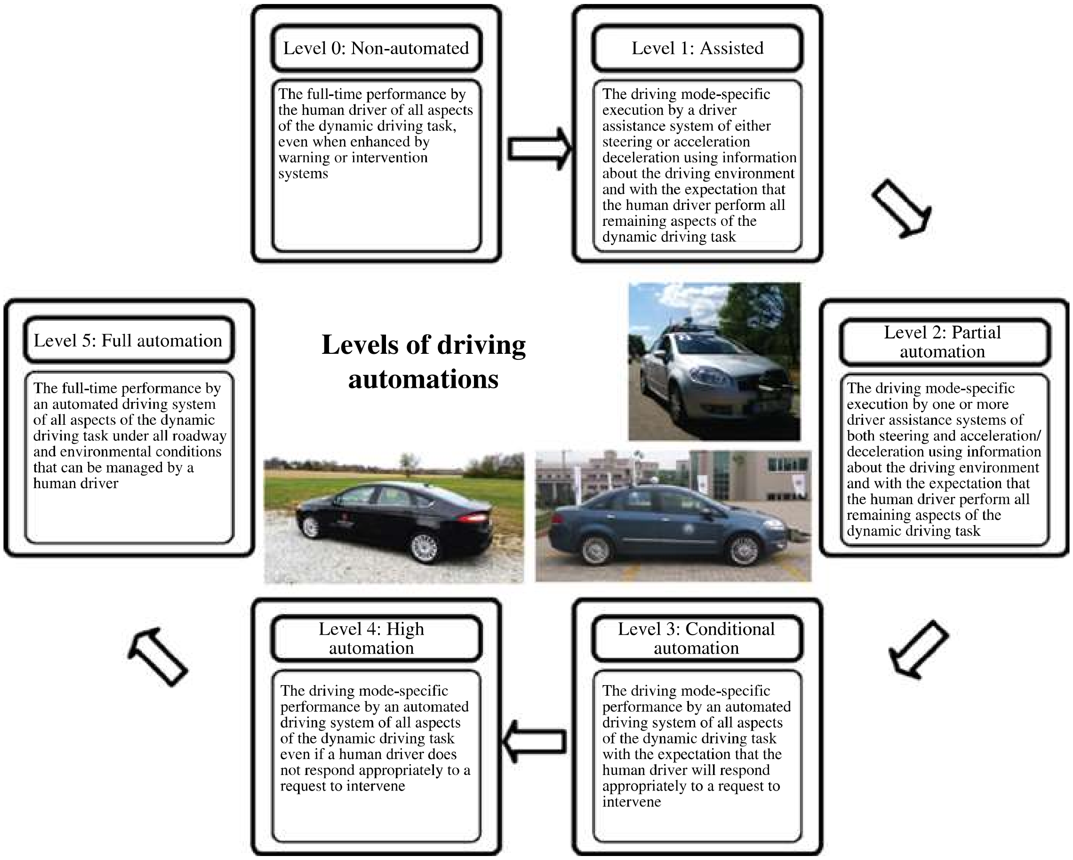


FIGURE 35.1 Categories of automated driving as defined in SAE J3016 are illustrated noting that level 5 full automation is the final goal. © Copyright by Levent Guvenc. Use with permission.

Regardless of the level of automation desired, all automated driving systems need to possess similar underlying features. Firstly, the actuators of the vehicle in the longitudinal and lateral directions have to be automated. These include the throttle, brake, and gear shifting in the longitudinal direction and steering actuation control in the lateral direction. Current road vehicles use electronic throttle control (ETC), so it is relatively straightforward to automate throttle commands. Use of electronic commands for automated braking is possible in road vehicles that have electronic brake-force distribution (EBD). Even though EBD intervention is the preferred method, braking automation can also be achieved by interfacing to the brake pedal sensor in a hybrid electric vehicle. The electronic transmission controller needs to be accessible by software for automating gear shifting. As the automatic transmission will take care of power shifting automatically, it needs to be accessed by the automated driving controller for higher performance. The automated driving controller in level 4 and level 5 automation will also need to shift to reverse gear autonomously. Finally, the electric power-assisted steering (EPAS) electric motor can be used for autonomous steering in current road vehicles through its torque overlay function.

Access to all these actuators is available on the controller area network (CAN) bus in current road vehicles, meaning that implementing the actuators needed for driving

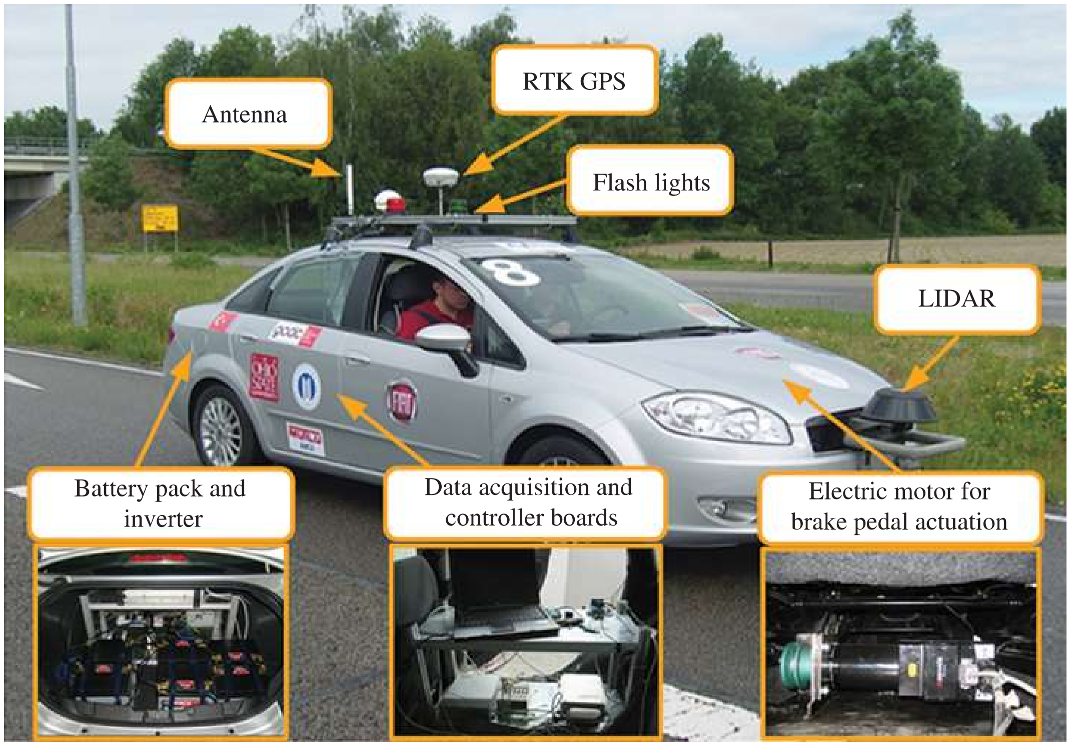


FIGURE 35.2 An interesting example of a level 2 partially automated driving vehicle from 2011 is illustrated here. The vehicle automation hardware is completely add-on with no additional holes drilled in the car. All the add-on hardware was easily removed completely in about 2 hours by two people. This platform was extended in 2012 to a level 3 conditional automation of the same brand of vehicle and demonstrated in autonomous driving. © Copyright by Levent Guvenc. Use with permission.

automation is a matter of interfacing and sending the correct CAN bus signals. The actuators needed for vehicle automation already exist in the car for an automotive OEM. This should be compared with the bulky actuators that were used in the past as is shown in Figure 35.2. A state-of-the-art series production road vehicle also has several sensors like the speed, longitudinal and lateral accelerations, yaw rate, steering wheel position/velocity, and wheel speed sensors that can be used as part of the sensor suite needed for vehicle automation.

One of the most important sensors needed in automated driving is the Global Positioning System (GPS) sensor which is needed for positioning. The GPS sensor is actually just a receiver of GPS satellite signals. A differential antenna real-time kinematic (RTK) GPS sensor and an inertial measurement unit (IMU) with at least a 10 Hz update rate and 1–2 cm of accuracy is currently needed for level 3–5 automated driving. Inertial navigation system calculations are used with the IMU readings to obtain correct position information during short GPS outages [14]. IMU readings occur at much higher frequency of 100 Hz or more and can be combined with the less frequent GPS signals in a Kalman filter to obtain smooth, higher-frequency position updates.

Intelligent cameras are used for cheap but reliable environment sensing under optimal dry road and lighting conditions. Intelligent cameras have their built-in microprocessor which detects and tracks several objects like other vehicles, pedestrians, and bicyclists in real time. Radar sensors with built-in microprocessor and signal processing have been traditionally used in the automotive industry as part of ADAS like ACC and emergency braking. These radar sensors can also detect and track several objects and have a CAN bus interface to the corresponding electronic control unit (ECU). New-generation radar sensors can also be used to do mapping of the environment. When one is interested in mapping the environment, however, the most powerful sensor is a lidar. Lidars that are built for use in automobiles have decreased significantly in size and also have a built-in microprocessor and signal processing software. They typically scan four different planes to be able to differentiate between an actual object and changes in road slope [15]. To increase the covered field of view, several of these lidars are placed around the vehicle. Another approach is to use a scanning lidar like the 64 plane ones that were used in the DARPA challenges. The Google driverless vehicles also use such scanning lidars placed on top of the vehicle for environmental sensing. Much smaller 32 and 16 plane scanning versions of these lidars are currently available at much lower cost. However, these types of lidars are still not packaged compactly enough for use in series production vehicles. Furthermore, they do not have a CAN interface or a built-in microprocessor with signal processing. They only provide raw data and, therefore, require the presence of a powerful, real-time operating computer on board the vehicle. Successful series production-level automated driving will require all automation actuators and sensors to have CAN bus interfaces and all sensors to have built-in intelligence. All of these vehicles will necessarily have a navigation system which will have a high-resolution digital map providing electronic horizon information in real time. This map which will have very accurate representations of lane positions will function like an extra sensor (map as sensor) in the vehicle. The GPS and V2V modem will be integrated as part of the navigation system. As an illustrative example, a level 4 automated driving vehicle under preparation is shown in Figure 35.3.

Success of future series production of automated driving vehicles will require either considerable reductions in the cost of high-performance sensors used in automated driving or improved sensor signal processing, fusion, and control methods to be used with low-cost, low-performance sensors. The currently used approach of different suppliers providing different ADAS functions has resulted in separate ECUs for each main function like ACC or lane centering control. A new hardware architecture comprising of a smaller number of more powerful ECUs has to be adapted and utilized in the future. Different suppliers should be provided space in one of these smaller numbers of ECUs for their functions.

As compared to the big automotive OEMs, the smaller high-technology companies that currently want to concentrate on low-speed automated driving are facing significant cost-related challenges as they cannot use the benefits of series production. Down the road toward widespread acceptance and production of automated driving vehicles, a major breakthrough in approach similar to the PC revolution or similar to the one that partially took part in the robotics area is expected to take place.

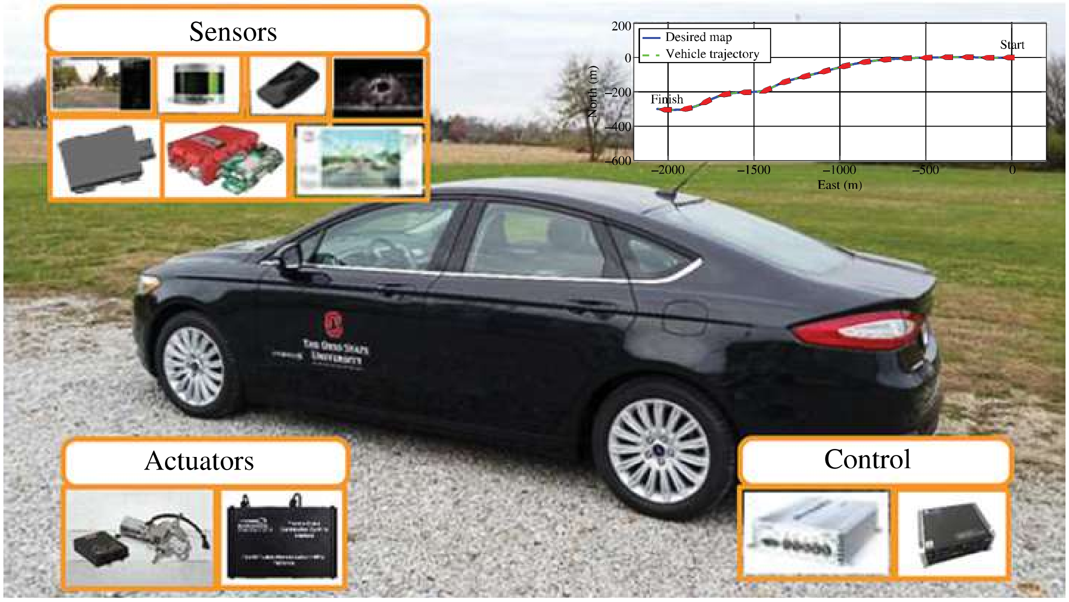


FIGURE 35.3 A level 4 highly automated driving vehicle under construction is displayed here. The actuators, sensors, and electronic control units used for automation have a very low footprint in this type of automation where driving is taken care of by the autonomous system with the driver taking control only if there is a need. © Copyright by Levent Guvenc. Use with permission.

First of all, the highest benefit from automated driving will be achieved when using a fully electric vehicle. This fully electric vehicle will have electromechanical brake-by-wire and steer-by-wire actuation. Its hardware and software architecture will be open source, modular, and plug and play. This will initiate new actors which will be small start-up companies to easily enter this market with their innovative, alternate solutions. New nontraditional manufacturers will be able to easily assemble and configure these vehicles just like assembling and configuring a PC. Pretested and certified vehicle chassis frame and body combinations will be readily available. Highly accurate digital modeling tools will be used for highly realistic virtual testing of the car before it is manufactured.

35.3 CONNECTED VEHICLE TECHNOLOGY AND THE CV PILOTS

It is expected that CV technologies will be present in series production cars before higher levels of automated driving. Cars will be equipped with a modem capable of V2V, V2I, and V2X connectivity. This modem is just an extra sensor with endless possibilities for application development and enhancement from the perspective of automated driving. For safety critical applications that are typical of automated driving, these modems use the wireless access in vehicular environments (WAVE) protocol based on the IEEE 802.11p standard and use the intelligent transportation systems (ITS) band of 5.9 GHz. In the future, with faster communication rates, your smartphone may actually be used as the main communication device in your car

(V2X) as well as the awareness device when you are walking as a pedestrian or using a bicycle. In a smart city, your smartphone may also be used to connect you to your home and office among other applications.

A CV demo from the GCDC 2011 is shown in Figure 35.4. A more demanding version of this demo combining both automated driving and vehicle connectivity will take place in 2016 as the GCDC 2016 [16]. Cooperative ACC is used in the longitudinal direction to reduce the time gap between vehicles in a platoon. Infrastructure-to-Vehicle (I2V) modems broadcast speed limits and traffic-related events to the vehicles. Vehicles on the same lane send requests to each other before forming a convoy. Vehicles in the convoy receive a recommended speed profile which they all follow. The lead vehicle broadcasts this speed information which is broadcast from each preceding vehicle to the one following it. Other information like vehicle characteristics, GPS position and velocity, and vehicle intent and acceleration are also sent to the following vehicle. The acceleration information is critical in Cooperative Adaptive Cruise Control (CACC) as it helps reduce the time gap between vehicles. A properly tuned and executed CACC will allow platoons of vehicles to damp shockwaves that they will be faced with in traffic, thereby improving mobility. A coordinated combination of CACC with lateral control and decision making results in the most basic form of cooperative automated driving in highways.

FIGURE 35.4 An example of connected driving is seen here with two platoons of connected vehicles following a speed profile communicated to them by the lead vehicle. The vehicles use CACC in the longitudinal direction. Traffic light SPAT information and speed limits are communicated by roadside units to the vehicles. © Copyright by Levent Guvenc. Use with permission.

A low-cost longitudinal cooperative driving system that uses communicated position/velocity/acceleration information with a low-cost GPS has been implemented and tested successfully [17] in the GCDC 2011 and later and is a good starting point for low-cost highway driving automation when used together with an intelligent camera for lane keeping and collision avoidance.

Along with improved mobility in the form of avoiding congestion during traffic shockwaves, CV applications also have safety and environmental benefits. Intersection safety is the most important use of CV safety applications as CV technology allows nonvisible vehicles to be seen through the communication link. Other safety applications include collision warning and curve speed warning. Vehicles are also warned of pedestrians and bicyclists who are nearby. Environmental benefits are obtained indirectly through the use of optimal speeds for fuel minimization and through avoiding congested traffic.

Research on CV has advanced significantly in Europe, Japan, and the United States. The current approach in the United States is the most advanced due to the fact that real deployments of CV technology are already taking place. The DOT in the United States has been funding CV test sites, CV application development efforts, and now large-scale CV deployments on real roads. The CV applications and hardware and software architecture have been standardized. Three large-scale CV deployments were recently funded. Along with the incorporation of roadside units, weather information sensors, and traffic lights with signal phase and timing (SPAT) information, large traffic processing centers that collect information from the equipped vehicles and use it dynamically for ecorouting purposes are also used in the deployments. The deployments use tens of thousands of vehicles equipped with V2V modems or simpler awareness systems. The ecospeed regulation, ecolanes management, and Eco-Cooperative Adaptive Cruise Control (eco-CACC) are the latest CV applications that automated driving vehicles will definitely benefit from.

35.4 AUTOMATED TRUCK CONVOYS

User demand dictates which new technology ends up in series production vehicles. Automotive OEMs will not develop new technological features unless there is a demand from the buyers or a mandate by the regulating authorities. Interestingly, the biggest need and demand for driving automation comes from the logistics sector due to many reasons. The logistics sector wants their trucks to be able to drive fully or semiautonomously as this will reduce the driver workload considerably. It is very difficult to find expert truck drivers who need to spend long hours of driving which is a very tiring and boring task. Drivers are also mandated by law to rest after a certain period of driving. Some driving tasks like those in ports or loading/unloading situations are very slow paced, with the driver being forced to waiting for hours in the truck without traveling a significant distance. These types of situations make automated driving very attractive for trucks. This is the reason why truck manufacturers and suppliers are working on highway automated driving systems for trucks. These systems are currently very basic in nature and use a camera and radar as the

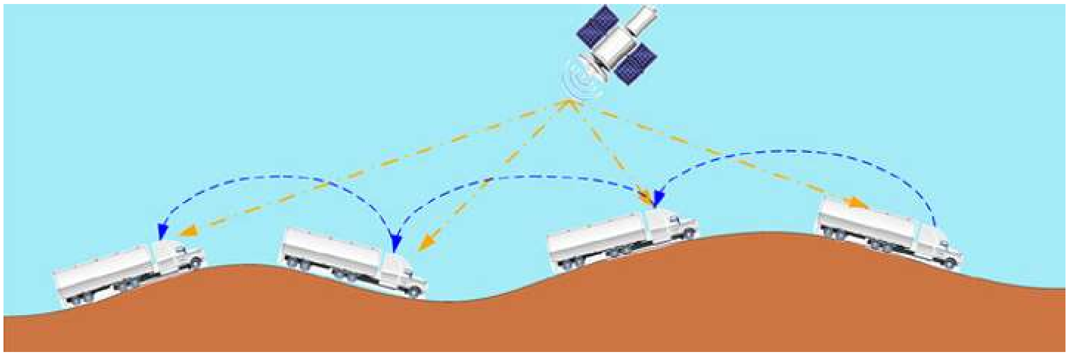


FIGURE 35.5 Predictive cruise control of a platoon of trucks is shown. Predictive cruise control systems for trucks are currently available from manufacturers. Current research on predictive cruise control focuses on incorporating traffic speed and traffic light information to the cruise speed profile optimization. The highest fuel economy benefits will be obtained if the trucks are also equipped with regenerative braking. © Copyright by Levent Guvenc. Use with permission.

main sensors. The camera is used for lane keeping control and the radar is used for longitudinal control. A currently available technology for trucks that is illustrated in Figure 35.5 is predictive cruise control where the slope data in the electronic horizon coming from a digital map is used to find the optimal speed profile for fuel efficiency. It is expected that these predictive cruise control systems will find widespread use in the truck industry and will form an integral part of the automated driving truck. Work on truck platooning has been going on for decades with a large number of successful research implementations. All trucks in a truck platoon will follow the optimal speed trajectory. The following trucks will also benefit from a reduced aerodynamic drag due to the presence of the truck in front of them, resulting in further fuel savings. We should soon be expecting to see automated convoys of trucks on the roads with possibly only one driver operating the leading truck.

35.5 ON-DEMAND AUTOMATED SHUTTLES FOR A SMART CITY

In recent years, the notion of a smart city has gained popularity around the globe. We are actually already living in relatively smart cities. Important aspects of smart cities are that they are green, connected, and automated. Automated driving technologies are, thus, a very important part of smart cities. Small, fully electric automated vehicles are expected to solve mobility problems in smart cities on an on-demand basis [17]. This on-demand usage will reduce the total number of vehicles. The smaller fleet of vehicles will move both people and goods and will be connected to all other aspects of the smart city. While their main function will be to pick people up and transport them to their desired destination, it will also be possible for them to deliver online orders to your doorsteps. These automated shuttles will also be integrated with public transportation systems and solve the first mile, last mile problem. They will also solve the mobility problems of an aging population.

35.6 A UNIFIED DESIGN APPROACH

Research and development work on automated driving trucks and automated driving cars currently concentrates on high-speed highway driving as that is where the biggest benefits lie. These vehicles can currently use relatively expensive sensors and actuators due to the final cost reductions made possible by series production. On the contrary, on-demand automated shuttles usually use low-speed vehicles and do not benefit from series production as their production volumes are relatively small. Widespread use of such automated low-speed shuttles will only be possible upon the use of low-cost sensors, actuators, and ECUs. Currently, the design of high-speed and low-speed driving automation uses two different approaches, with low-speed automation being similar to mobile robotics. In the long run, however, both the high-speed and low-speed automated driving worlds have to converge as we reach full level 5 automation of driving. The converged design procedure will look like the V-diagram shown in Figure 35.6. A highly realistic and validated model of the vehicle will be used in model-in-the-loop (MIL) simulations first. This will be followed by software-in-the-loop (SIL) simulations. Actuators, sensors, controllers, and modems of the vehicles will be networked together in a hardware-in-the-loop (HIL) simulation setting for final lab testing with real hardware. The rest of the vehicles and traffic situations will be virtually generated using real-time capable simulation computers. The last step will be road testing with the actual vehicle in a proving ground. It is possible to do vehicle-in-the-loop (VIL) simulation at this stage. One interesting example of VIL testing is platooning with a convoy of virtual vehicles [18].

It is clear that a unified design approach that handles both low- and high-speed driving automation will be necessary in the future. This unified design approach will benefit greatly from the future possibility of an open-source, modular, and plug-and-play software and hardware architecture for automated driving vehicles.

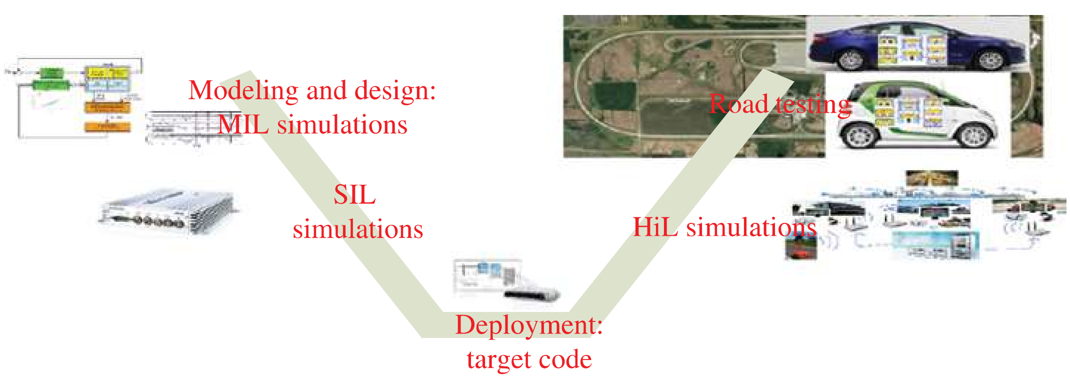


FIGURE 35.6 The V-diagram of a unified approach for developing connected and automated driving systems starting with model-in-the-loop simulations and ending in road testing. © Copyright by Levent Guvenc. Use with permission.

35.7 ACRONYM AND DESCRIPTION

ACC *Adaptive Cruise Control:* Cruise control systems maintain a constant speed set by the driver, with the driver being required to apply the brakes when a slower preceding vehicle is encountered. In contrast, a vehicle equipped with ACC adjusts its speed automatically, to safely follow other vehicles with possibly varying speeds. In doing so, the ACC system uses a sensor to detect the presence of the vehicle being followed while measuring relative distance and relative speed. Using this data in its control system, a vehicle with ACC adapts to changes in the speed of the vehicle that precedes it [10].

ADAS *Advanced Driver Assistance Systems:* The general name of driver support systems in order to increase the safety and comfort of the driver and the passengers such as ACC, automatic parking system, collision avoidance systems, lane departure warning system, lane keeping assistance, hill descent control, etc.

CACC *Cooperative Adaptive Cruise Control:* CACC system extends the capability of ACC system using the information of the state of the preceding vehicle obtained via wireless communication. Using this extra information, the time gap in standard ACC systems can be reduced [18].

CAN *Controller Area Network:* CAN is a serial bus system, developed to be used in vehicles to exchange information between different electronic components. The CAN protocol is standardized by the International Standards Organization [19].

EBD *Electronic Brakeforce Distribution:* EBD system is a braking technology that automatically varies the amount of force applied to each wheel based on road conditions, speed, loading, etc. in order to maximize stopping power while maintaining vehicle control [20].

Eco-CACC *Eco-Cooperative Adaptive Cruise Control:* Eco-CACC is a kind of CACC. Eco-CACC includes longitudinal automated vehicle control while considering ecodriving strategies (minimization of fuel consumption and emissions). The Eco-CACC application incorporates information such as road grade, roadway geometry, and road weather information in order to determine the most environmentally efficient speed trajectory for the following vehicle [21].

EPAS *Electric Power-Assisted Steering:* EPAS supplements the required torque that the driver applies to the steering wheel. It eliminates many hydraulic power system components such as the pump, hoses, fluid, drive, belt, and pulley. EPAS has variable power assist, which provides more assistance at lower vehicle speeds and less assistance at higher speeds [22].

ESC *Electronic Stability Control:* ESC is an active safety system, which is used to improve the handling performance of the vehicle and prevent possible accidents during severe driving maneuvers. These systems stabilize the vehicle motion by generating corrective yaw moment using individual wheel braking and engine torque reduction. The corrective yaw moment is calculated based on a comparison between the desired and measured vehicle yaw rate and/or vehicle sideslip angle [23].

ETC *Electronic Throttle Control:* ETC establishes the essential connection between the acceleration pedal and the throttle valve using electronic signals instead of a mechanical link. The desired throttle position is calculated based on the information from both the acceleration pedal and other systems such as engine controller, ESC, etc. The control unit compares the desired throttle position with the actual throttle position and sends the appropriate signal to the motor to drive the throttle to the desired position [24].

GPS *Global Positioning System:* The GPS is a space-based navigation system that provides location and time information in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to at least three or more GPS satellites [25]. In practice, however, information from at least five satellites should be used. High-end GPS systems can use information from hundreds of satellites.

HIL *Hardware-in-the-Loop:* The actual control hardware is tested in a real-time simulation environment, which contains the plant model as real-time software. It is useful for testing interactions between the control hardware and the plant [26]. Since the plant exists as software, effects of changes in the plant and disturbances are very easily tested in a lab setting.

IMU *Inertial Measurement Unit:* The IMU is a sensor to measure acceleration and angular velocities along a body's three main axes. It consists of accelerometers and gyroscopes. An internal navigation system is the combination of the IMU sensor with mechanization equations. These equations convert IMU data to vehicle position, velocity, and rotations [27].

MIL *Model-in-the-Loop:* The controller and the plant are represented entirely as models in a simulation environment. This is also called offline simulation. MIL simulation is useful for initial controller development [26].

RTK *Real-Time Kinematics:* The RTK satellite navigation is a technique used to enhance the precision of position data derived from satellite-based positioning systems such as GPS in real time, that is, with low computational latency such that it can be used instantaneously in a moving vehicle. It uses measurements of the phase of the signal's carrier wave, rather than the information content of the signal, and relies on a single Earth-fixed reference station(s) or interpolated virtual station to provide real-time corrections, providing up to centimeter-level accuracy [28].

SIL *Software-in-the-Loop:* The control algorithm is represented as executable code, and the plant is represented as a model in a simulation environment. It is useful for testing the executable control code for possible errors before controller implementation [26].

SPAT *Signal Phase and Timing:* SPAT is a message type that describes the current state of a traffic light signal system and its phases and relates this to the specific lanes (and therefore to movements and approaches) in the intersection [29]. The signal phase is green, yellow, or red and the timing is the time to change phase.

V2I *Vehicle-to-Infrastructure:* V2I communication is the wireless exchange of critical safety and operational data between vehicles and the roadway infrastructure, intended primarily to avoid motor vehicle crashes [30]. V2I communication is also used to collect data from vehicles passing by. This data is sent to a traffic control center for further processing.

V2V *Vehicle-to-Vehicle:* It is a dedicated wireless communication system handling high data rate, low latency, low probability of error, line-of-sight communications between vehicles [31]. V2V communication is necessary for CV platooning and emergency braking.

VIL *Vehicle-in-the-Loop:* The VIL test setup combines the test vehicle with a synthetic test environment such as a traffic simulation. The actual vehicle is made to believe that it is in traffic by supplying it with artificially generated sensor signals. Therefore, repeatable and safe tests are realized using the real hardware and dynamics of the vehicle. This setup combines the advantages of driving simulators and a real test vehicle [32]. The vehicle may be stationary or moving.

REFERENCES

[1] http://researchnews.osu.edu/archive/naefenton.htm (accessed December 25, 2015).

[2] http://www.path.berkeley.edu/about (accessed December 25, 2015).

[3] http://archive.darpa.mil/grandchallenge04/ (accessed December 25, 2015).

[4] http://archive.darpa.mil/grandchallenge05/ (accessed December 25, 2015).

[5] http://archive.darpa.mil/grandchallenge/ (accessed December 25, 2015).

[6] https://www.google.com/selfdrivingcar/ (accessed December 25, 2015).

[7] http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=6266747 (accessed December 25, 2015).

[8] http://www.its.dot.gov/safety_pilot/ (accessed December 25, 2015).

[9] Aksun Güvenç, B., Güvenç, L., Karaman, S., Robust Yaw Stability Controller Design and Hardware in the Loop Testing for a Road Vehicle. *IEEE Transactions on Vehicular Technology*, **58**: 555–571, 2009.

[10] Aksun Güvenç, B., Kural, E., Adaptive Cruise Control Simulator, a Low-Cost Multiple-Driver-in-the-Loop Simulator. *IEEE Control Systems Magazine*, **26**: 42–55, 2006.

[11] Emirler, M.T., Wang, H., Aksun Güvenç, B., Güvenç, L., Automated Robust Path Following Control based on Calculation of Lateral Deviation and Yaw Angle Error. *Dynamic Systems and Control Conference*, ASME, Columbus, OH, October 28–30, 2015.

[12] Ararat, Ö., Aksun Güvenç, B., Development of a Collision Avoidance Algorithm Using Elastic Band Theory. *17th IFAC World Congress*, IFAC, Seoul, July 6–11, 2008.

[13] http://www.sae.org/misc/pdfs/automated_driving.pdf (accessed December 25, 2015).

[14] Altay, I., Aksun Güvenç, B., Güvenç, L., A Simulation Study of GPS/INS Integration for Use in ACC/CACC and HAD. *9th Asian Control Conference*, Istanbul, June 23–26, 2013.

[15] Sankaranarayanan, V., Güvenç, L., Laser Scanners for Driver-Assistance Systems in Intelligent Vehicles. *IEEE Control Systems Magazine*, **29**: 17–19, 2009.

[16] http://www.gcdc.net (accessed December 25, 2015).

[17] https://engineering.osu.edu/news/2015/08/smart-ride-ohio-state-researchers-develop-automated-demand-transportation (accessed December 25, 2015).

[18] Güvenç, L., Uygan, I.M.C., Kahraman, K., Karaahmetoğlu, R., Altay, I., Şentürk, M., Emirler, M.T., Hartavi Karcı, A.E., Aksun Güvenç, B., Altuğ, E., Turan, M.C., Taş, Ö.Ş., Bozkurt, E., Özgüner, Ü., Redmill, K., Kurt, A., Efendioğlu, B., Cooperative Adaptive

Cruise Control Implementation of Team Mekar at the Grand Cooperative Driving Challenge. *IEEE Transactions on Intelligent Transportation Systems*, **13**: 1062–1074, 2012.

[19] http://www.can-wiki.info/doku.php (accessed January 1, 2016).

[20] https://en.wikipedia.org/wiki/Electronic_brakeforce_distribution (accessed January 1, 2016).

[21] http://www.iteris.com/cvria/html/applications/app101.html (accessed January 1, 2016).

[22] http://www.cvel.clemson.edu/auto/systems/ep_steering.html (accessed January 1, 2016).

[23] http://www.cvel.clemson.edu/auto/systems/stability_control.html (accessed January 1, 2016).

[24] http://www.cvel.clemson.edu/auto/systems/throttle_control_demo.html (accessed January 1, 2016).

[25] https://en.wikipedia.org/wiki/Global_Positioning_System (accessed January 1, 2016).

[26] https://www.youtube.com/watch?v=dzgMYGWXpUc (accessed January 1, 2016).

[27] Emirler, M.T., Uygan, I.M.C., Altay, I., Acar, O.U., Keles, T., Aksun Guvenc, B., Guvenc, L., A Cooperating Autonomous Road Vehicle Platform. *Workshop on Advances in Control and Automation Theory for Transportation Applications*, IFAC, Istanbul, September 16–17, 2013.

[28] https://en.wikipedia.org/wiki/Real_Time_Kinematic (accessed January 1, 2016).

[29] http://www.iteris.com/cvria/html/glossary/glossary-s.html (accessed January 1, 2016).

[30] http://www.its.dot.gov/factsheets/v2isafety_factsheet.htm (accessed January 1, 2016).

[31] http://www.iteris.com/cvria/html/glossary/glossary-v.html (accessed January 1, 2016).

[32] Bock, T., Maurer, M., Farber, G., Validation of the Vehicle-in-the-Loop—A Milestone for the Simulation of Driver Assistance Systems. *Proceedings of the IEEE Intelligent Vehicles Symposium*, Istanbul, Turkey, June 13–15, 2007, pp. 612–617.

36

TRANSIT HUB: A SMART DECISION SUPPORT SYSTEM FOR PUBLIC TRANSIT OPERATIONS

Shashank Shekhar[1], Fangzhou Sun[1], Abhishek Dubey[1], Aniruddha Gokhale[1], Himanshu Neema[1], Martin Lehofer[2] and Dan Freudberg[3]

[1] *Institute for Software Integrated Systems, Vanderbilt University, Nashville, TN, USA*
[2] *Siemens Corporate Technology, Princeton, NJ, USA*
[3] *Nashville Metropolitan Transport Authority, Nashville, TN, USA*

36.1 INTRODUCTION

The allure of smart city technologies lies in its promise to enrich the lives of residents by empowering the stakeholders to make efficient and informed decisions and help alleviate complex issues. One such issue that is universally faced by large cities of the world is the problem of commuter traffic. Solutions are difficult, partly because so much of our physical infrastructure was designed for a different era—when no one could imagine just how many cars would hit the streets each day—and partly because options like mass transit and adopting car shares, biking, and walking are seen by many as "trading down" making their commute less convenient. The irony is that very often, a short walk or bus ride would be far faster, easier, and cheaper than driving. Unfortunately, there is a general lack of awareness among people about the effectiveness of these options.

For example, consider the city of Nashville, TN. The traffic congestion in the city has nearly doubled over the last decade and is expected to grow at an even faster rate in future—a recent study found it to be the top 25 congested cities in

Internet of Things and Data Analytics Handbook, First Edition. Edited by Hwaiyu Geng.

Companion website: www.wiley.com/go/Geng/iot_data_analytics_handbook/

the United States [1]. Therefore, there is an urgent need to act now. Given that adding infrastructure is difficult and slow, we are focusing on increasing the use of shared mobility options like public transit. Nashville ranks as 74 out of 100 in the number of passengers per capita [2]. Improving transit services and increasing their efficiency and usage are strategic priorities of the Nashville Metropolitan Transport Authority (MTA). Key to attracting new users, in addition to providing services that are competitive with personal automobiles and that can meet basic service needs, is to make public transit easier to use and to improve the image of the services. For those who seldom use public transportation, it can be difficult to figure out how to interpret schedules and how to pay the fare, for example. Potential new customers have to be convinced that riding transit will be a pleasant experience, and people like themselves use transit. However, without the ability to model, it is almost impossible to efficiently design, configure, and deploy such a system.

This lack of understanding is an impediment to improving and deploying of smart city technologies at large scale. To that end, researchers from the Institute for Software Integrated Systems at Vanderbilt University have teamed up with the Nashville MTA and Siemens Corporate Technology to work on the Transit Hub [3] project (Figure 36.1). This project aims to put accurate, real-time information about potential travel options into citizens' hands as soon as they choose their desired destination from their current or a specified location.

Static schedule information for transit has been available in Nashville for a number of years through tools such as Google Transit. However, vehicles do not always exactly follow the schedule, making real-time vehicle locations and bus stop ETAs valuable pieces of information for the customer. In order to provide this type of real-time information, Nashville MTA has partnered with Trapeze Group to design and install a fleet-wide vehicle tracking system called Automated Vehicle Location (AVL). Transit Hub makes use of transit schedules in combination with real-time vehicle location and service alert information from the AVL system, as well as data from rider smartphones and dozens of other sources. Among other analysis, anyone with our free app[1] can compare travel times using all available options—biking, walking, public transit, driving, and more.

As part of the larger smart city movement, we are implementing the Transit Hub project as a large-scale distributed human cyber–physical system (CPS) [4], wherein the human and the sensors in the physical environment provide the information, which is analyzed by computational services to provide contextual decision support to the commuters. The data collected by the system also helps us create predictive analytical models that help the MTA better understand the transit network bottlenecks and areas for future improvements. This article focuses on the technical underpinnings of the Transit Hub application and the backend data services.

[1] The application is currently undergoing tests and is not yet available for wider dissemination.

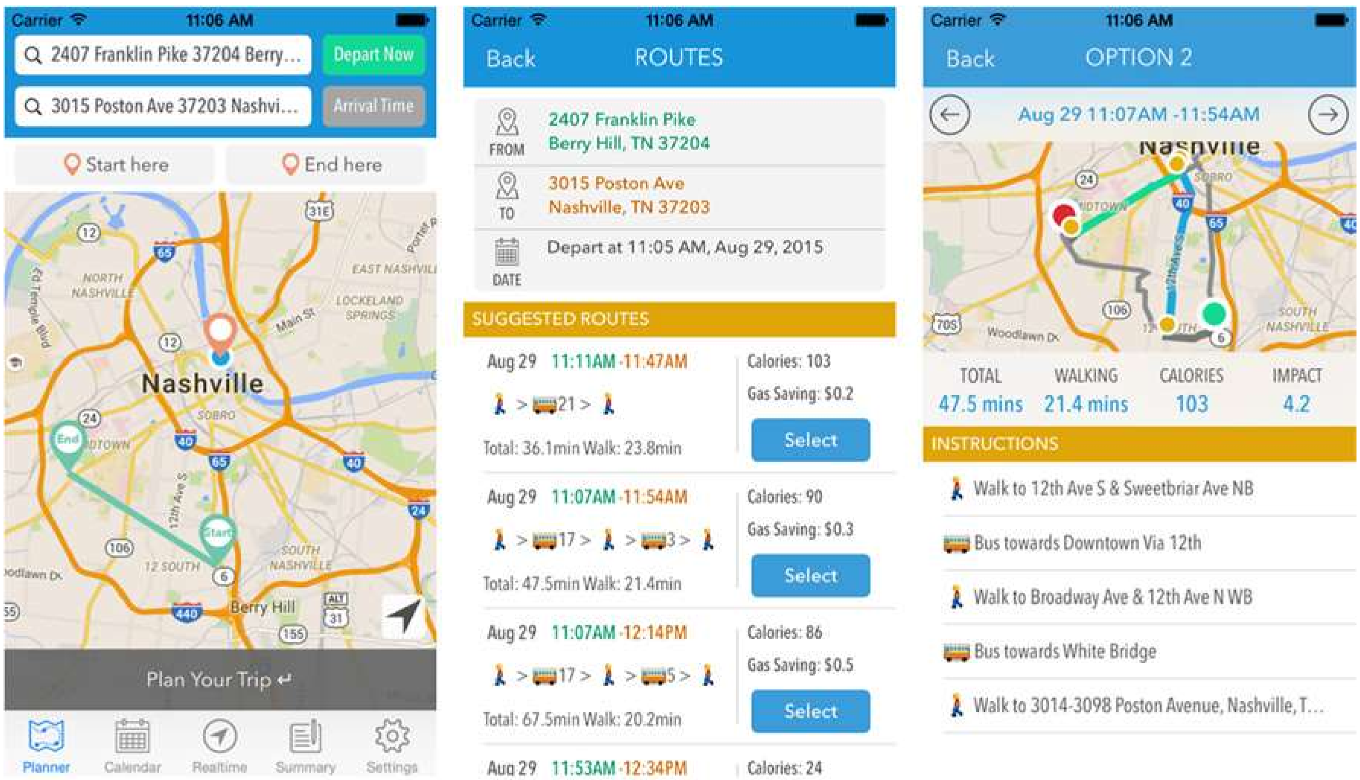


FIGURE 36.1 Trip planner, route comparison view, and details view. Reproduced with permission from Abhishek Dubey.

36.2 CHALLENGES

One of the key challenges in enabling smart city applications such as Transit Hub is the ability to collect and disseminate sensor data from the selected element of the city infrastructure and then analyzing the data in almost real time. However, this is difficult because of scale and network heterogeneity. While we can mostly depend on the availability of cellular (e.g., 3G/4G and LTE) networks, we also have to contend with Wi-Fi LAN (e.g., DSRC/802.11p), WirelessHART, and Bluetooth technologies. Furthermore, all actionable information delivered to a nearby hub has a useful lifetime and must be disseminated prior to its temporal bound.

Our approach for solving the data dissemination problem relies on using modern middleware technology that can seamlessly allow configuration and management of distributed application across heterogeneous networks. We are currently investigating the application of a middleware developed by our lab—Android Mobile Middleware Objects (AMMO) [5], a novel middleware developed for tactical applications on mobile devices by Vanderbilt University for the DARPA Transformative Apps program. The goals of AMMO were to support multiple communication/data distribution paradigms over a diverse suite of networking technologies—from low-bandwidth tactical radios to cellular technology and Wi-Fi. Communications paradigms, such as broadcast publish–subscribe with content filtering, and client–server are supported. While developed primarily for tactical applications, the capabilities of AMMO are an excellent match for resource-constrained dynamic networks typical of a city-wide deployment. For example, smartphones with AMMO middleware were used for situational awareness during the presidential inauguration in January 2013 by first responders with the National Guard, Washington DC Metro Police, National Park Service, and the local Fire Department.

Another challenge that requires attention is the architectural framework for the decision support system. A practical solution is to use a multimodel simulation approach that facilitates the precise integration of heterogeneous, multimodel simulations. Simulation integration frameworks, such as High-Level Architecture (HLA), address the integration of distributed heterogeneous simulators using distributed discrete-event semantics. In this regard, we are building upon our prior work on Command and Control Wind Tunnel (C2WT) [6] a simulation integration framework that facilitates assessment of command and control systems performance in the presence of adversarial network disruptions.

36.3 INTEGRATED SENSORS

The Nashville MTA AVL system includes a number of integrated components and sensors to aid in the tracking, monitoring, and operating of transit buses. The primary sensor supporting vehicle tracking is a GPS antenna and receiver located onboard each vehicle. The GPS coordinates are sent to an onboard computer where the location information is then correlated with schedule and stop location data to determine where the bus is on the current route and trip. This location information is also used to calculate schedule adherence (minutes ahead of or behind schedule) for the bus.

In addition to the GPS receiver, there are additional integrated sensors to aid in the tracking of vehicles. For example, vehicle odometer readings are used to supplement GPS information in areas where signals are weak or unreliable. At Music City Center (MCC), the downtown transit hub for MTA, radio-frequency identification (RFID) transmitters have been installed at each bus bay. Every vehicle has an RFID tag that reads the signal from the MCC bay tags to determine when the bus arrives and departs the transit center. This equipment also allows transit supervisors to monitor the location of buses within the facility down to the individual bay level.

Other in-vehicle components are also integrated with the AVL system. The farebox receives route and location information from the AVL, enabling the correlation of fare payment activity by bus stop. Engine alarms are sent directly to the AVL by the Engine Controller Module to enable real-time vehicle health monitoring and historical data analysis. Infrared-based Automated Passenger Counter (APC) sensors installed at each bus door provide passenger boarding and alighting activity data to the AVL which then correlates the data with schedule information to determine passenger activity by stop, trip, route, and direction. Even the vehicle destination sign is integrated with the AVL to enable the sign to change automatically and without driver intervention when switching between routes.

36.4 TRANSIT HUB SYSTEM WITH MOBILE APPS AND SMART KIOSKS

The Transit Hub system is accessed by a mobile application that can be deployed on individual user's smartphones. It features smart trip planning, service-alert integration, personal transit schedule management and notification, and real-time transit tracking and navigation. The Trip Planner utilizes origin and destination address and departure and arrival time to search for the future transit trips that meet the user's requirements.

The Trip Planner offers a user-friendly interface (Figure 36.1) for users to enter the information for route searching. For people who are not familiar with the Nashville area, for example, first-time visitors, they can enter the start and end address in the search bar. For the local residents, they can just drag the map view to pinpoint the start and end locations.

The app's real-time view (Figure 36.2) displays a map of the scheduled trip with lines indicating the walking/bus route and markers indicating the bus stops to transfer as well as original and destination locations. Users can tap the Go button at the very bottom to start real-time navigation. If real-time data is available for the trip, the exact bus that the user is supposed to get on/off for the next step will be shown in the map, with time label indicating the remaining time. If there is no real-time data for the scheduled bus, time left to get on/off the next bus will be calculated and displayed based on the static schedule time.

The application not only aggregates the real-time transit data that is already available from local transit authorities, but it also provides a crowd-sourced alternative to official transit tracking feed. When a user is using the mobile application, they can choose to provide their anonymous location and the data about when they are on the bus to the backend server. The server uses anonymous data to protect user's privacy.

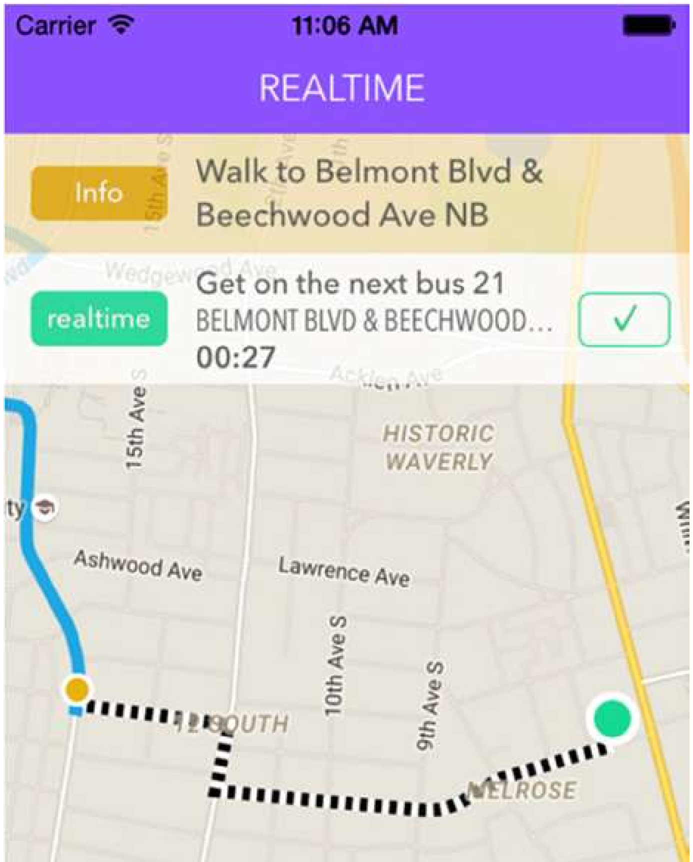


FIGURE 36.2 Real-time view. Reproduced with permission from Abhishek Dubey.

As the data accumulates over time, techniques like transit simulation and machine learning can be utilized to process the huge database of collected data, predict transit delay with more accuracy, and make the transit service more reliable by adjusting transit schedules. Furthermore, it could even provide potential bus stops to add and remove to better meet the evolving demand patterns.

Notification is usually an important part of any transit application. Without proper notifications, users can still miss the buses if they forget to keep an eye on the departure time after searching the suggested routes and planning the ideal trips to destinations. In the Transit Hub application, users can enable push notifications easily from the app and customize how long they want to leave alerts to be pushed ahead of time. When a user schedules a trip into the future and adds it to the Calendar, the notification is set to be pushed to the user's device when it is time to leave to catch the scheduled bus. Moreover, if the backend server predicts that the scheduled trip might be delayed for some reason, the user is notified accordingly.

36.4.1 Transit Hub Information Architecture

Figure 36.3 illustrates the technical design of the overall Transit Hub decision support system which enables the smartphone application. At the center lies the hub middleware responsible for coordinating all the Transit Hub activities. Its roles include

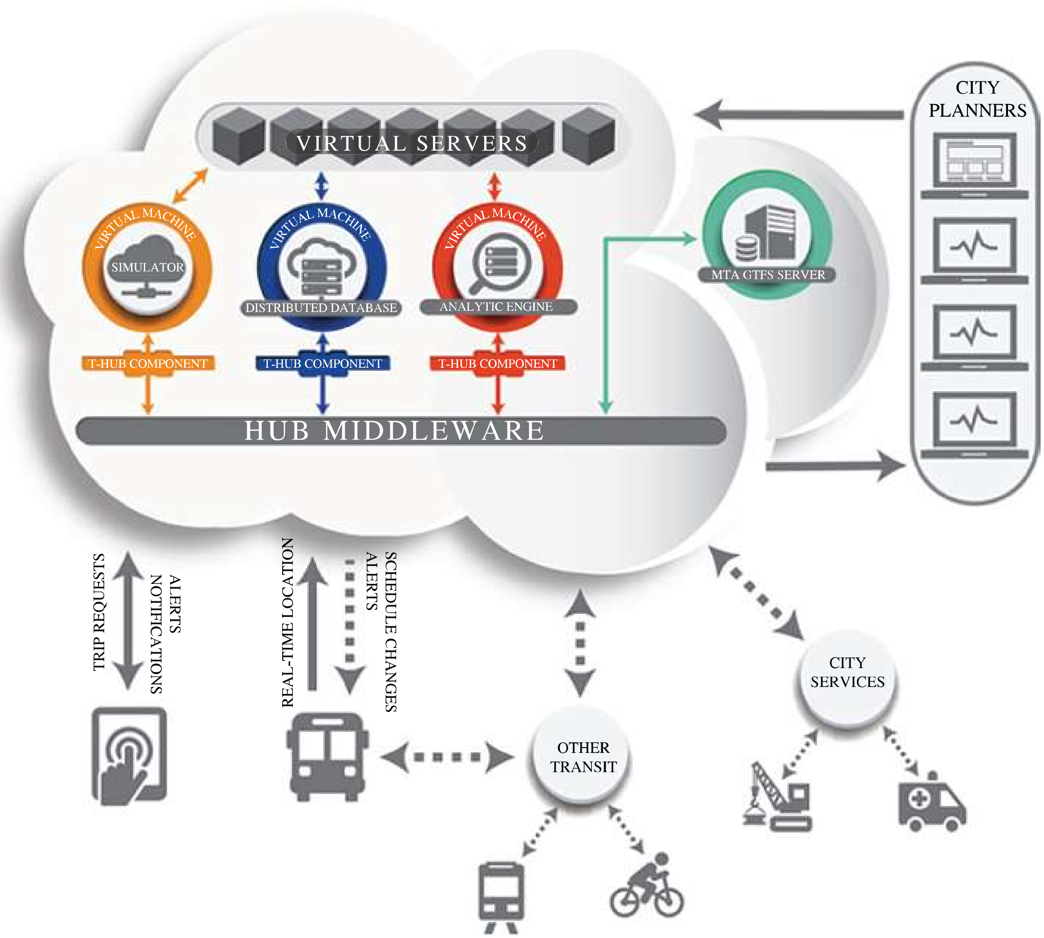


FIGURE 36.3 Transit Hub design. Reproduced with permission from Abhishek Dubey.

running data collection service, analyzing the collected feed, running simulations to provide a decision support framework in response to client requests. The data collection service is responsible for collating data from different sources and persisting into the Transit Hub's distributed database for consumption by the decision support system and its clients. The service adheres to the timeliness and data quality guarantees needed by the decision support system. The service is also replicated across multiple servers in master–slave architecture such that one of the slaves take over the data collection role in case the master service fails. There are three types of data being collected:

1. Real-time feeds from Nashville MTA—Google has defined the General Transit Feed Specification (GTFS) [7] for transit authorities to release transit data feeds. The Nashville MTA publishes real-time feeds using the GTFS format. Transit Hub collects this data for supporting mobile applications and performing historical analysis for the city-level decision support system.
2. Traffic-related feeds—There are several sources of traffic-related information in Nashville city. The Tennessee Department of Transportation (TDOT)

publishes traffic-related feeds. HERE API [8] is another source for traffic congestion information. In the current iteration of the Transit Hub framework, we have used the HERE APIs as the data source. In the future, we will also include weather data and event details from social media channels.

3. Trip information from Transit Hub mobile application—The Transit Hub mobile application is another source of data for the decision support system. Based on user permissions, it can transmit the GPS coordinates of the rider's bus trip, as well as the path traversed by foot. This is valuable information that can be utilized to plan future bus routes and their frequency to better utilize the available resources. Presently, we are only logging the searches performed by the users while planning their itinerary and their selection.

The multisource data is collected and persisted into different data stores in the Transit Hub backend for later retrieval. We employ MongoDB, a distributed NoSQL database to manage and store the data which is accumulating rapidly over time:

1. Real-time transit data from Nashville MTA: Our backend server repeatedly requests and stores the data from the trip updates feed, vehicle position feed, and service alerts feed every minute. The size of the data being stored in the database is about 3 GB per day.
2. Real-time traffic flow information from HERE API: We are recording the traffic flow data for road segments of all bus routes in Nashville for analysis and prediction purposes. Without optimization, the scale of the raw data is about 2.8 GB per day, which is extremely space consuming. To optimize performance and save storage space, we remove the static fields from original data such as road segment, physical layout information, and speed limits. Furthermore, since the traffic condition typically remains the same in a short term, we adopt a time series format that only stores the traffic condition which changes since last update. The optimized traffic data for storing is reduced to nearly 10% of its original size, about 0.27 GB per day.
3. Static bus schedule dataset: This dataset is updated only when Nashville MTA releases new bus schedules to the public.
4. Crowd-sourced data from Transit Hub app: Our backend server collects these data anonymously upon user permissions when users plan for bus routes or track their trips in the app. The size of the data depends on the quantity of mobile app users and how frequently they use the app.

36.4.2 Decision Support Framework for Transit Hub

The Transit Hub mobile application helps users in trip planning and real-time tracking. It relies on the Transit Hub middleware for supplying optimal trip plan options and better trip tracking than what is provided by the MTA feeds. To achieve this, Transit Hub performs analysis and provides decisions at two levels. At the global level, it integrates historically collected data with simulations to provide augmented feeds to the mobile application and trip recommendations that helps MTA to optimize the load (future work). At the user level, the user's travel history and current information, such as planned trip, location, time, and cost constraints are utilized to provide best recommendations for the user—this is part of the ongoing work.

36.4.2.1 Analyzing the Collected Data Feed In the current version of Transit Hub, we provide augmented feeds to external entities and the Transit Hub mobile applications containing predicted time for different bus routes. The analytical engine of Transit Hub consists of a simulation-based predictive model, a data-driven statistical model, and a real-time prediction model.

The simulation-based model works with the real-time feed and current traffic delay information to simulate bus movement on various routes and predict delays. This model uses the Simulation of Urban MObility (SUMO) [9] microscopic simulator for simulating city traffic. We use an OpenStreetMap (OSM) [10] of Nashville and convert it in the format that SUMO understands. The static routes for buses from MTA GTFS feeds are mapped to SUMO format for simulating. We maintain a pool of virtual machines to run simulations for different buses from their current locations. The real-time traffic conditions are obtained using HERE APIs. Going forward, we will also take into account the historical data from traffic congestion at different times of the day. The traffic congestion information contains a "jam factor" that provides information about congestion level at all road segments within the queried region. Based on the jam factor, we configure the simulator for lane speeds and periodically run multiple simulations to collect the result to augment the feeds with delay results produced in the simulation.

The statistical model applies long-term analytics methods on historical transit data to explore persistent delay patterns in route segments and bus stops. This model utilizes K-means clustering algorithm to group the historical delay data into different clusters according to the time in the day and performs normality test on each clusters. The analytics results, including the mean value with confidence interval of each cluster, are then provided to the analytics dashboard and Transit Hub mobile app. The model also helps to identify the outliers in real time. By investigating the bus trips with severe delay, we can understand better what factors cause bus delay and how to optimize the system. Our backend server runs the statistical methods for all the route segments at the end of each month when a new monthly historical dataset is ready.

The real-time prediction model utilizes the real-time transit feeds such as trip updates and vehicle locations to provide short-term delay prediction. Since the data rate of the original real-time vehicle location feed is not stable and there may be errors and delay in hardware and communication, we developed a Kalman filter to reduce the noise when estimating the arrival time at each bus stop. To predict the delay in a route segment, we utilize not only the predicted route's data but also the data from multiple other routes that share the same route segments. Another Kalman filter is applied on the preceding trips' delay data to predict the delay for the requested route. We will integrate more data sources into the system, such as weather conditions, traffic congestions, special events, and so on.

36.4.2.2 Dashboard and Recommendation Engine for City Planners The Transit Hub decision support system will also cater to the needs of MTA engineers and city planners. The current implementation of the Transit Hub analytics dashboard is shown in Figure 36.4. Choosing the options from different routes, directions, weekdays, and time period in the day, the analysts from MTA and the city can utilize the information provided by the dashboard to check the historical delay patterns and outliers in each route segment, identify which parts are the bottle necks in the routes, and come up with solutions to modify the bus schedules and optimize the performance of the transit system.

It will enable what-if analysis based on simulations and historical traffic and demand data and help in answering questions like how do the riders get affected if the number of buses are reduced or increased, buses get rerouted or a traffic accident occurs? It will also assist in simulating cascaded delays due to congestion. Designing incentives for passengers to take buses from particular stops and routes based on simulated results is another goal.

36.4.2.3 Infrastructure Requirements for Transit Hub The Transit Hub has been designed to form the backbone of Nashville MTA's scheduling and planning services. This imposes strict requirements on the system that needs to be fault tolerant and provide timeliness guarantees. The users of Transit Hub application also expect availability and timeliness bases service level agreements (SLAs). The scale of the system brings its own challenges.

The real-time feeds accumulated by the data collection service are at the scale of several gigabytes per day. This number will keep increasing as MTA expands its services and we introduce new data sources. This requires us to design infrastructure that can efficiently persist and query data at terabyte scale and handle petabyte scale data in the longer run. We also need data replication to withstand failures. To fulfill these requirements, we use a distributed NoSQL database, MongoDB residing on a cluster of servers. However, going forward, we need a database which can support even larger datasets.

Another resource-intensive component of Transit Hub is the Analytical Engine that periodically or on demand runs simulations to predict delays on different routes. However, maintaining a huge pool of virtual machines to perform simulations is expensive. We need efficient resource management algorithms so that the service is viable. To that end, we are developing algorithms utilizing Linux container-based virtualization technology [11].

36.4.3 Kiosk Systems for Human–CPS Interaction

Today's platforms have evolved from being simply technical innovations to also focus on realizing powerful, socioeconomic platforms affecting the daily lives of millions of users. These socioeconomic platforms enable a new class of applications and services to emerge at an unprecedented speed, quality, and cost. These trends can help cities and urban areas to increase their pace of innovation, while the effort expended in planning and implementation can be reduced from time spans ranging

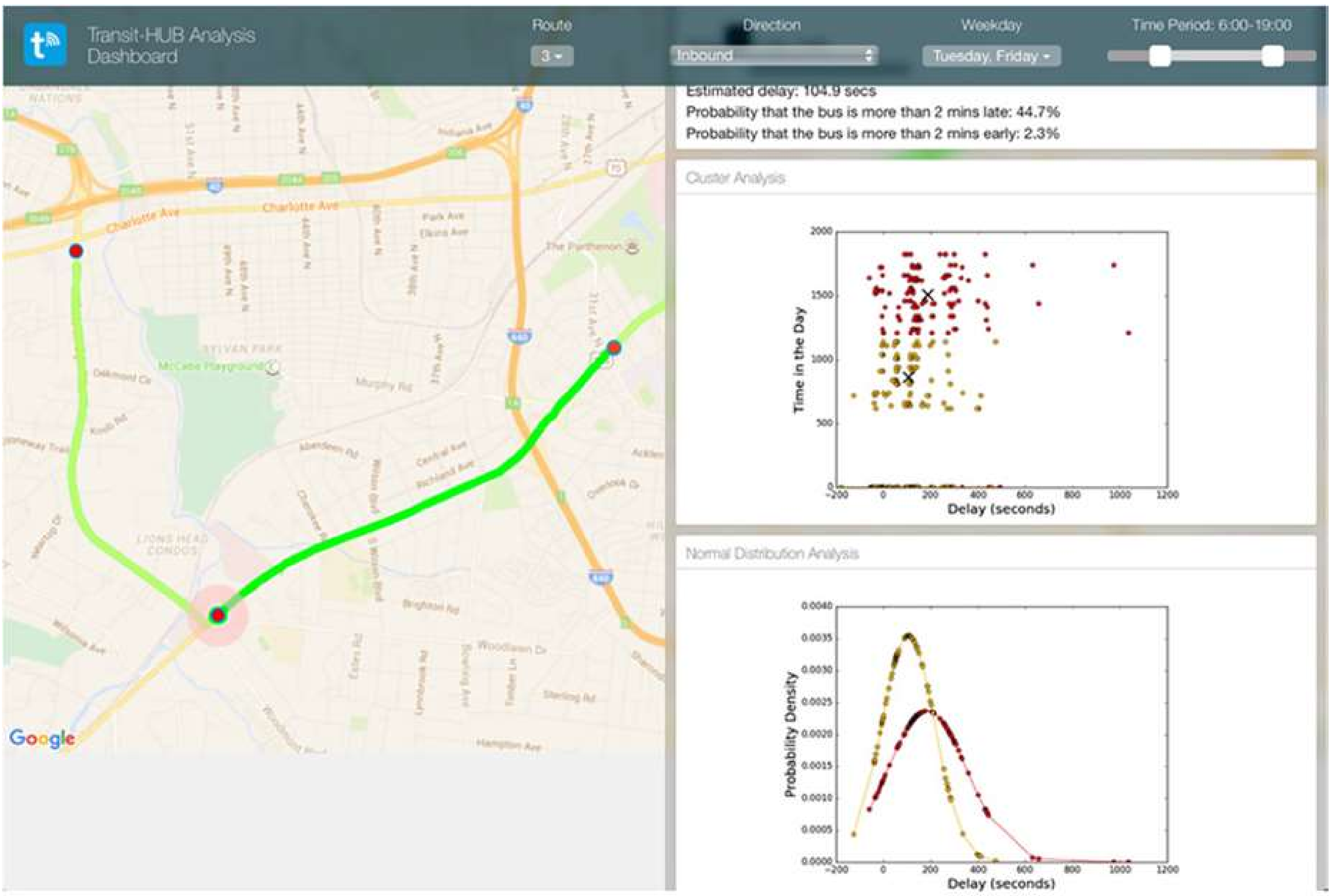


FIGURE 36.4 Transit Hub analytics dashboard. Reproduced with permission from Abhishek Dubey.

from years or even a decade to just months. As an example, consider the state of art for user interfaces or wearable interfaces: the smartphone is the common denominator.

Despite the proliferation of smartphones, both socioeconomically backward and senior citizens are unlikely to afford today's sophisticated smartphones or be able to use them effectively. Consider public transportation as a basic civic amenity provided by a city. People having difficulties using smartphones are often the most reliant on public transportation, for example, elderly or disabled people. Often they need to rely on information from station personnel, security personnel, police officers, or fellow citizens. Despite several new mobile apps that help plan for transportation, people with lower socioeconomic status often lack the resources to access those services. Access to public transportation, including the information to plan trips has even been named a civil rights issue. These socioeconomic issues demonstrate that communities and transportation providers cannot rely solely on smartphones for providing transportation-related information to citizens. This is where the notion of a smart kiosk device comes into the picture.

Kiosk Systems enable new ways of interaction between humans and CPS. Touch-based computers and terminals have been placed in public settings for more than 20 years, but the advancements of hardware and software as well as novel architectural approaches such as CPS enable a completely new class of system. Kiosks are envisioned to be strategically placed in cities and urban communities to provide riders access to transportation-related information. Barrier-free access, both in terms of placement of the Kiosk and design of Kiosk hardware and software, is a key consideration. All users benefit from the additional effort spent on designing an accessible system. In this section, we will introduce Kiosk Systems and their benefits for cities as well as their citizens, visitors, and local business. We will also show how Kiosk Systems can complement apps such as the Transit Hub.

Kiosk Systems offer direct and barrier-free access to city-life-related information and services. They integrate real-time, contextual, event-aware, and localized content from various domains. They can themselves serve as an information source using modular extendable sensors and usage feedback. Figure 36.5 highlights one such Kiosk System, and Figure 36.6 summarizes the key benefits of Kiosk Systems and illustrates how they help in making smarter decisions.

36.4.3.1 Benefits for Cities Due to the advent of social media and the decline of traditional media, many cities and public agencies have adopted new means of communication with their citizens, visitors, and customers. However, cities and transportation agencies do not control when and where the information gets displayed. So, often this information drowns in a stream of tweets, emails, or posts. Also, often the information may not reach the intended audience in a timely manner. Even regular users of public transportation are not interested in service updates of routes they are not using or are not affecting their commute. Casual users will not subscribe to those updates at all, because the information might be relevant to them only a few times per year. All these challenges can be resolved by having the kiosks display the right information at the right time.

FIGURE 36.5 Example of a Kiosk System—Siemens smart city hub. Reproduced with permission from Abhishek Dubey.

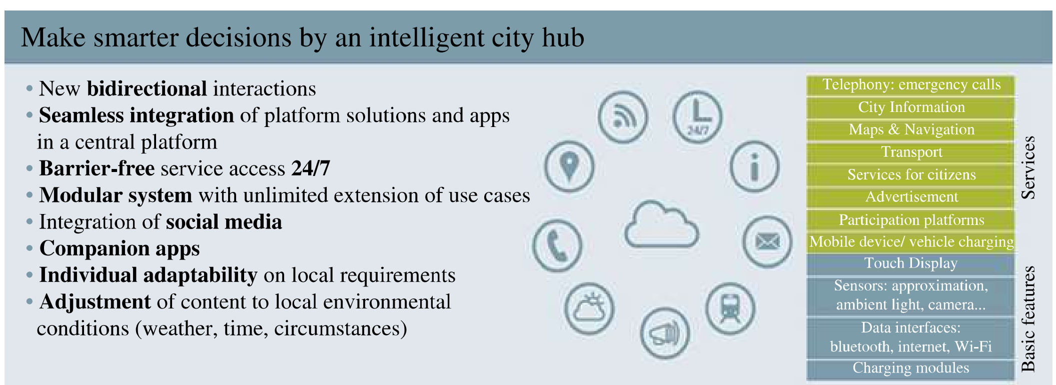


FIGURE 36.6 Decision support by a Kiosk System. Reproduced with permission from Abhishek Dubey.

Additional benefits accrue from the ability of the kiosks to provide instant feedback to city officials because the kiosks can track and report on the likes and dislikes of citizens who utilize the services of the kiosks thereby enabling the officials to refine their offering. A prominent capability of the kiosk is the fact that it can be customized for the needs of the city. This capability stems from the understanding that cities have different needs, they face different challenges, they have different geographical features, and they may have different historical past. Having a kiosk be tailored to the needs of the city is a significant benefit for the city.

36.4.3.2 Benefits for Citizens Kiosk Systems enable quick access to services such as public transport, bike sharing, parking, games, and navigation integrated into one interactive platform. The reason why this is more attractive is because this approach does not incur the same impediments as those incurred in traditional communication mechanisms, such as mass mailings or local newspapers. These latter approaches cannot convey real-time information and updates. The Kiosk System enables information on and booking of such services. The hardware platform itself facilitates easy information consumption by using large multitouch screens. Free (wireless) Internet access and charging facilities for smartphones or tablets are additional benefits for citizens. Charging facilities can also be extended to electric bicycles and cars. Many more capabilities can be included in a kiosk. For example, it can be equipped with medical equipment ranging from simple first-aid kits all the way to lifesaving defibrillators. They can also be used to track localized crime, such as an assault, and help dispatch security personnel to the scene in a timely manner.

36.4.3.3 Benefits for Entrepreneurs and Local Businesses Kiosk System enable winning new customers by means of advertising that are not considered as such. If a traveler is looking for a small, independent café that is not located at a nearby location, a Kiosk can provide him or her directions to the café. Incentives such as coupons can also be targeted effectively, for example, limiting them to a certain period of time when the business is slow or showing them to customers who have not visited a business yet. Thus, kiosks have the potential to boost local economy. In turn, the customer service in these businesses is bound to improve further improving the reputation of the city.

36.5 CONCLUSION

As the urban sprawl increases across the world, the cities of the world are facing unprecedented challenges stemming from traffic congestion, housing costs, environmental pollution, water and sanitation issues among many others. Often many of these challenges cannot be effectively addressed due to the bureaucratic structuring of the city government and the lack of interoperability across various departments. Beyond these limitations, however, many of these challenges remain unresolved also because technology has not been harnessed to its fullest potential despite significant advances in wireless and mobile connectivity, proliferation of smart end devices such as smartphones and other IoT technologies, and powerful computational platforms such as cloud data centers.

This chapter described our efforts in harnessing these technological advances in the context of smart cities. Specifically, we have focused our efforts on the Transit Hub project being designed and deployed for the city of Nashville, Tennessee, USA. The Transit Hub is a multitier architecture comprising the Nashville MTA's buses which act as the sensors of our IoT architecture and providing their location information, a trip planning mobile app running on smartphones that enables travelers to plan their trips, and a cloud-based decision support system that analyzes real-time traffic and bus location data to serve the trip planning requests made by smartphone users. Complementing the smartphone-based app is also the Smart Kiosk system, which can be deployed at strategic locations within the city to guide visitors and also city residents, particularly those from socioeconomically backward strata who cannot afford smartphones or the elderly who cannot operate the smartphones, in guiding them to their destinations.

Preliminary ideas and working artifacts from our Transit Hub project were demonstrated at the 2015 Global City Teams Challenge program [12] hosted by the US National Institute for Standards and Technology (NIST). Our team is now partnering with the Nashville city government addressing multiple additional challenges beyond just the bus trip planning. We aim to make further progress in the future and demonstrate our ideas at venues such as GCTC 2016, as well as evaluate the efficacy of our technology and its benefits to Nashville. Based on these outcomes, we plan to reach out to other cities providing them insights gained from our work and make our technology available to them.

ACKNOWLEDGMENTS

This project uses derivatives from work funded in part by the US National Science Foundation and Siemens Corporate Technology.

REFERENCES

[1] Report: Nashville's traffic congestion 33rd worst in the Western Hemisphere. http://www.bizjournals.com/nashville/blog/2014/06/report-nashvilles-traffic-congestion-33rd-worst-in.html (Accessed September 28, 2015).

[2] Comparison of Nashville MTA with Peers. http://www.nashville.gov/portals/0/SiteContent/MTA/docs/StrategicTransitMasterPlan/06Ch4PeerReview.pdf (Accessed September 28, 2015).

[3] TRANSIT-HUB. https://thub.isis.vanderbilt.edu (Accessed September 28, 2015).

[4] Cyber Physical Systems. http://www.nsf.gov/news/special_reports/cyber-physical/ and http://www.nist.gov/cps/ (Accessed September 28, 2015).

[5] AMMO – Android Mobile Middleware Objects. http://www.isis.vanderbilt.edu/sites/default/files/u352/Sandeep-ammo_poster.pdf (Accessed September 28, 2015).

[6] Graham Hemingway, Himanshu Neema, Harmon Nine, Janos Sztipanovits, and Gabor Karsai. 2012. Rapid synthesis of high-level architecture-based heterogeneous simulation: a model-based integration approach. *Simulation*, **88**, 2, 217–232 (Sage Publications).

[7] General Transit Feed Specification Reference. https://developers.google.com/transit/gtfs/reference?hl=en (Accessed September 28, 2015).

[8] Here: Maps for Developers. https://developer.here.com/ (Accessed September 28, 2015).

[9] "Simulation of Urban MObility" (SUMO). http://sumo.dlr.de/wiki/Main_Page (Accessed September 28, 2015).

[10] OpenStreetMap. https://www.openstreetmap.org/ (Accessed September 28, 2015).

[11] Shashank Shekhar, Hamzah Abdel-Aziz, Michael Walker, Faruk Caglar, Aniruddha Gokhale, and Xenofon Koutsoukos. 2016. A simulation as a service cloud middleware. *Annals of Telecommunications*, **71**, 3, 93–108 (Springer).

[12] Global City Teams Challenge. https://www.us-ignite.org/globalcityteams/ (Accessed September 28, 2015).

37

SMART HOME SERVICES USING THE INTERNET OF THINGS

Gene Wang[1] and Danielle Song[2]

[1] *People Power Company, Redwood City, CA, USA*

[2] *University of California, Berkeley, CA, USA*

37.1 INTRODUCTION

Smartphones are the most popular consumer electronics device on the planet. We carry little supercomputers around in our pockets or purses every day. And we use them for all kinds of purposes, not just making calls. In fact, when you talk to your friends about something you're trying to do, they're likely to say, "Well, there's an app for that." At People Power, we have been researching how smartphone control can extend to the Internet of Things (IoT). There are infinite possibilities, but we are targeting the areas in your life where you'll get the most out of connected devices. We are building smart home services running on smartphones that connect users to the people and things they love most.

The service starts free. You can download our app Presence to turn your old smartphone into a free webcam or security camera with motion detection and video alerts. In addition to this, you can scale up and begin forming an ecosystem of connected and cooperating devices in your home.

37.2 WHAT MATTERS?

Homes are expensive, and people want to protect them.

Internet of Things and Data Analytics Handbook, First Edition. Edited by Hwaiyu Geng.

Companion website: www.wiley.com/go/Geng/iot_data_analytics_handbook/

As IoT has taken off, people have come up with all kinds of new innovations, from remote-controlled home appliances and smart baby monitors to smart wristbands that track your activity level. The tech world as we know it is expanding to reach every part of our lives, and each added function brings another level of control and possibility.

Although IoT is multidirectionally expanding by leaps and bounds, the innovations that will be most impactful relate to what people care about the most: family, close friends, pets, and valuable belongings. The value is clear; the IoT services that have caught on and become part of people's daily lives are the ones that deal with security, healthcare, and saving money. IoT devices that do things like help you fix your posture or improve your golf swing will surely bring a positive change to your life, but to make the most positive impact and do the most good, our innovations must be driven by what people prioritize.

The home is the locus of these values. Not only is a home expensive, but it is also invaluable for the things it protects: family, pets, and your valued belongings. People's lives are centered around their home, which is why smart home services will be adopted into our daily patterns and lifestyles. So you can spend less time worrying and more time living and doing the things that are important to you with the ones who are important to you.

37.3 IoT FOR THE MASSES

How do you bring IoT to the masses? There are a number of technologies through which you could attempt to build the most far-reaching solution, but the ideal solution is an end user sticky app. We have already discussed that IoT services will be the most impactful when they relate to what people care about the most—but they will also catch on the best when the services are easily accessible and able to support all of an end user's needs. Smartphones have replaced computers as the main hub from which people connect to IoT, so they will be the hub through which we reach the masses.

We need a solution that can support many different kinds of devices and protocols so that you can do things like reduce your energy usage, secure your home, and check up on your loved ones from the palm of your hand. To support such a system requires powerful analytics, and to empower users to build a secure community, there must be a social networking aspect.

An IoT solution for the masses must allow large-scale deployments of IoT networks to be supported. In order to achieve this, the software must be able to weave together disparate platforms, devices, and protocols to create an ecosystem of smart devices in your home.

The great thing about smartphones is that not only can you use it as a hub, but every smartphone is already equipped with a number of sensors. Most people do not return or donate their old smartphones when they upgrade, so those unused phones can be used as free IoT sensors.

37.4 LIFESTYLE SECURITY EXAMPLES

Lifestyle security is the term that acknowledges the varied and dynamic nature of your unique lifestyle and offers the solution of a home security system that matches your every need. It's not your grandfather's security system. Gone are the days of installation fees and expensive hardware for a security system that leaves much to be desired and has rigid constraints. Lifestyle security becomes integrated into your daily routine and is optimized for your smartphone to meet your daily needs.

37.4.1 Smartphones as Internet of Things Devices

The smartphone is not only a controller but also a sensor. Utilizing the sensors in the phone as IoT end points, you can repurpose any old, unused smartphone into an IoT device. Here is a collection of case studies using a repurposed smartphone as a motion-detecting security camera.

Our first case study involves catching burglars. One family had set up their motion-detecting security camera to keep an eye on their kitchen area while they were on vacation. When their dog sitter came into the kitchen, opened their cabinets, and began stuffing the family's prescription medication into her shirt, the motion-detecting webcam was prompted to capture the act and notify the family with a video alert. As it turns out, this particular dog walker had done this many times in the past. She was arrested for stealing type 2 narcotics.

When the Ryu family was out of town, they had a house sitter care for their house and make sure their cat was fed and doing well. The resourceful house sitter wanted to keep track of the cat and set up a camera to watch for any irregular activity but ended up catching armed burglars on video stealing the family's computer.

The security webcam has been used to supplement regular security systems as well. A user—Chris—cleverly installed a security camera in a vending machine. There was already a regular security system in place, but the camera placed inside the vending machine captured the three people breaking into the machine from a clearer angle, joking around as they use a small knife to work at the machine, with faces in plain sight. The video was blasted on local news to aid in finding the people.

We know many parents who work long days for the sake of their families and so aren't able to be at home when their kids finish a day at school. A camera installed in the entranceway as a front door camera can be used to check whether your kid has come home (or not!) from school. It'll give you that extra bit of security being able to see for yourself that Johnny has made it home unscathed from his third grade classroom.

These are also great for watching pets. People have used them to make sure their sick or lonely dog is doing okay when they are left at home alone. These have also been used for sneakier purposes like checking to see which of the neighbor's dogs is pooping on your lawn. Another use has been veterinary care. If you bring your dog to the veterinarian for surgery, you can watch your dog in its cage as it receives aftercare. You don't have to change your work schedule or leave your other responsibilities behind to be assured that your pet is recovering safely.

Video recordings also open up a whole new world in being able to observe wildlife that you would normally miss. It has been used to observe owls at zoos, and people have caught giant herds of deer or a couple of skunks going through their yard. Users who care for chickens have also used the motion-detecting cameras inside their chicken coops to make sure no suspicious characters, be they burglars or foxes, were making off with eggs. This way, you can also be aware of all of your home's visitors; maybe it was a bird—and not the mailman—that was tampering with the contents of your mailbox!

37.4.2 Entry Sensors as Internet of Things Devices

The door sensor can be affixed to your front doors and windows. Now you can know when your teenager comes home at night, and when you are away from home or on vacation, you can be alerted when someone opens your front door or your child's bedroom window.

37.4.3 Water Sensors as Internet of Things Devices

If your house floods due to old water pipes breaking, that's thousands of dollars of damage. I've had neighbors who have had old pipes burst in their house—twice! But what if you were able to catch the leak sooner? This goes for people who have vacation homes as well. Keep your mountain cabin secure so that you are alerted right away when pipes freeze, thaw, and burst. That's a lot of damage and expense avoided.

37.4.4 Touch Sensors as Internet of Things Devices

The touch sensor alerts you if it moves. This allows you to see if your babysitter has been stealing from your liquor cabinet or if your children have been reaching into the cookie jar. Simply attach the touch sensor to the lid of the jar or your bottle of expensive whiskey and it will go off if someone moves it or lifts the lid.

37.4.5 Motion Sensors as Internet of Things Devices

The motion sensor lets you detect motion—day or night. It is infrared so it can see in the dark, meaning you can have coverage around the clock. You can mount the motion sensor onto a wall or near the ceiling so that it can look down into the room you want to monitor, and it will be able to tell if anyone is moving.

37.4.6 Smart Plugs as Internet of Things Devices

Smart plugs can be installed at critical points throughout the house so that energy use is shut down after everyone is asleep. With commands that repeat themselves daily, you can be sure your TV and entertainment station are turned off every night so that you save money every night you go to bed and do your part in conserving energy.

37.4.7 Robots as Internet of Things Devices

Robots can help give you more control. You can mount your motion-detecting iPhone onto a main motorized iPhone mount, and then from your smartphone, remotely control the direction and angle of your camera's field of vision.

37.4.8 Ecosystem of Devices

One of the true benefits to having a smart home system is having an ecosystem of devices working in concert with one another (Figure 37.1). A natural language rules engine lets your connected devices cooperate for you. Not only can we connect to any device easily, but we can also make your devices work together with simple "if, then" commands. For example, if I detect someone opening the front door and it's after 9 pm and before 8 am, then I will beep the alarm, take a picture, and turn on the light.

You can also switch your entire entertainment system off every night after you finish using it or set your system to turn the lights on every evening when you are away on vacation to deter burglars from targeting your home… the possibilities are there at your fingertips!

37.5 MARKET SIZE

The market for smart home services is growing rapidly as it becomes clear that the future for home security must be accessible, easy to install, and affordable. By 2020, five billion people will depend on 50 billion connected devices surrounding them. By

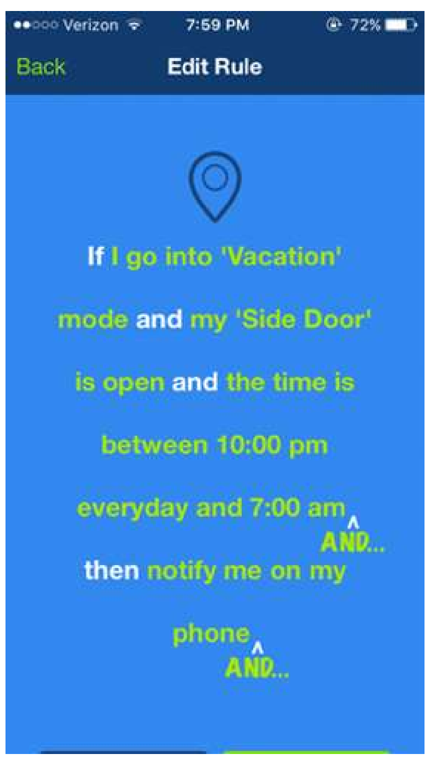


FIGURE 37.1 This screenshot is an example from the app Presence. It depicts the screen of an end user coordinating connected devices to work together for their benefit.

2022, an affluent home in the developed world will have over 500 smart devices of all types. By 2025, 50% of our homes in the United States will be "smart" homes, mostly populated by Do-It-Yourself (DIY) systems that the end users install themselves.

37.5.1 Homes and Home Security

To give you an idea of the scale of this market, we will first look at the housing market. The United States has 133 million housing units, and China had almost 456 million households in 2012. The United States and China are among the biggest markets for home security, with 61% of the market share of home security concentrated in the Americas and around 21% in Asia and Pacific.

The global market is growing. According to a report from MarketsandMarkets, the global home security market was valued at $28.3 billion in 2014 and is predicted to reach $47.5 billion by 2020.

37.5.2 Home Security Market Challenges

The home security market has plateaued at 25% penetration and traditionally consists of middle- and upper-income groups. This leaves lower-income populations completely unprotected by home security firms. This is paradoxical as lower-income people tend to live in neighborhoods with higher rates of crime and thus have a higher need for security measures.

Those who live in multifamily buildings and rent their homes are also disadvantaged by a system that targets wealthy homeowners. According to the chief analyst at NextMarket Insights, one in three US households rent their homes, and younger consumers, who tend to be more mobile, are less likely to consider purchasing a traditional home security system because they are not easily transferable to new homes. There is a need for a more flexible security service that targets those who are priced out of expensive traditional security alternatives.

37.5.3 The IoT Solution and IoT Market

The demand for flexible and low-cost home security is being met through the smart home and IoT, which includes all internet-connected devices that can be controlled remotely through a smartphone or remote.

The IoT market is blooming. Business Insider says that IoT will become the largest device market in the world by 2019, double the size of the smartphone, PC, tablet, connected car, and wearable markets combined.

This coincides with a trend in home security toward DIY solutions as an emerging alternative to traditional security solutions. According to a report from NextMarket Insights, the DIY self-installed home security solution will account for $1.5 billion in equipment and services by 2020.

37.5.4 IoT Challenges

Despite the huge potential for growth, there remains a general lack of adoption of IoT solutions. Sixteen percent of households currently have at least one smart home device, including things like smart sensors, lights, and door locks. Of those households that do not have a security system, 20–40% of US households express willingness to adopt home security with smart aspects. The lack of awareness of smart home solutions is to be expected, given that the market for smart home solutions is still relatively new. In order to take advantage of the market, social media and word of mouth will be important factors in spreading awareness.

37.5.5 A Future of Success

There are opportunities for implementation in other nations like China, which has a huge market with more people. China has recently become the greatest iOS app-downloading country. iOS downloads grew 30% from Q1 2014 to Q1 2015, surpassing the United States and making China now the largest market for quarterly iOS downloads. China will be a large market for IoT home security, with a growing tech sphere and a prevalence of apartment homes, which will benefit from a cheaper security system.

In addition to the national growth, it appears that apps in China related to lifestyle are growing at a faster rate than apps for entertainment and photo and video. This indicates that people are downloading an increasing number of apps that concern their lifestyle relative to fun apps or photo and video apps. As we have mentioned before, the apps and technology that impact the areas people care about most will succeed—and it seems that lifestyle apps are the types of apps that are being integrated into people's daily lives.

37.6 CHARACTERISTICS OF AN IDEAL SYSTEM

37.6.1 Characteristics for End Users

The ideal system will fit your mobile lifestyle, be managed from the palm of your hand, set up swiftly and easily, have the potential to expand to cover whatever you need, and connect you to your community.

37.6.1.1 Mobile Lifestyle The ideal system suits you and fits with your mobile lifestyle. In the increasingly mobile lifestyle of the twenty-first century, it is necessary to find new and innovative ways to integrate the things you value into your mobile device. This is what we call lifestyle security. This could mean anything from being able to ensure that your house is secured while you are away on vacation to checking whether your child came home from school while you are at work or at the grocery store.

The ideal smart home security system would target the safety of the house. It combines industry-leading sensors and motion detectors with the mobile app to monitor doors and windows, detect motion, and receive updates on temperature and water detection through your smartphone. This is the ultimate use of your smartphone as the hub and "remote control" from which you have the power to ensure your home's security and your freedom from worry.

The ideal energy management system on the other hand would deliver real-time, whole-home energy monitoring and smart plug control, giving you the ability to manage electricity use from a smartphone or tablet. This is perfect for residential and small business users to save money every month with just an app and some plugs.

37.6.1.2 Managed from the Palm of Your Hand The ideal system can be managed from the palm of your hand. This means you should be able to do everything from one app instead of needing multiple apps to control multiple devices (Figure 37.2). Whether you are managing your energy or keeping track of your home security, both tools should be controlled and monitored from the same app.

37.6.1.3 Out-of-Box Experience An ideal system sets up in minutes and doesn't require advanced knowledge of technology or electronics in order to begin using it expertly. Out-of-Box Experience is a key component of product design and should be easy enough for end users to do without help.

The ideal out-of-box experience is as easy as placing the sensors where you want them and deciding on rules and actions in your app. It would be a simple, clean process that has the system up and running in minutes, with an in-app video to tell you what to do so that you don't need to rely on technicians. The ideal Out-of-Box Experience allows you to set up your own smart home system independently (Figure 37.3).

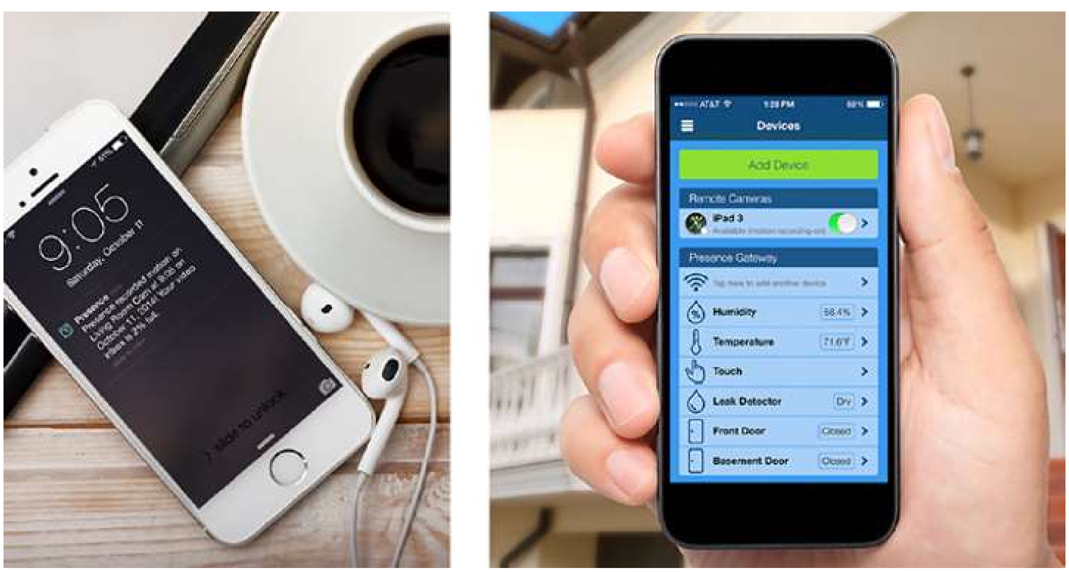


FIGURE 37.2 We are increasingly utilizing mobile devices to keep up with our increasingly mobile lifestyles.

FIGURE 37.3 This is an example of a security pack with a clean, elegant design and a vast array of sensors so that users don't need to go out of their way to purchase their own sensors.

37.6.1.4 Framework of Innovation The ultimate component of a solution that adapts to your life is one that expands as your needs grow (Figure 37.4). The ideal solution evolves as you and your ideas evolve, expanding to add more sensors or outlets under your command or downsizing as you see fit. You should be able to custom-make new commands and actions as you require from within your app, and the system should expand or collapse with just a few changes in the app, switching the desired sensor off.

37.6.1.5 Social Networking The ideal system is about more than just you and your belongings. A social aspect would work with your family and friends, creating a connective community aspect both on social media and in the neighborhood.

An ideal system lets you share with your friends on social media and involve your family and friends in your community or neighborhood who you trust to help you watch over your house. This proves useful if you are leaving for vacation. Instead of relying on a call center, you can have someone receive alerts from your home for you so that they can check up on your home or help as needed. This is all about integrating the system with your life, as part of the connections you already have with people (Figure 37.5).

FIGURE 37.4 This screenshot shows an example of an app that is customizable to the end user's needs. The user can add or delete devices at the touch of a button.

37.6.2 Characteristics for Partners

For partners, there are other factors on the back end to ensure that the solution is ideal for each service provider or manufacturer. An ideal system is customizable, able to be translated into different languages, and offers a framework for innovation.

37.6.2.1 A Customizable System Customizable systems would allow partners to allow partners to easily add new capabilities, applications, and analytics that allow them to build new systems in the future that they haven't even imagined today. This makes for a flexible solution that allows the company to concentrate on what they think is most important now for their customers while allowing the service to evolve into the future.

The ideal software stack offers our partners the chance to become part of the growing IoT world without having to build the infrastructure on their own. Regardless of the suite of programs the company wants to build, a good software stack will

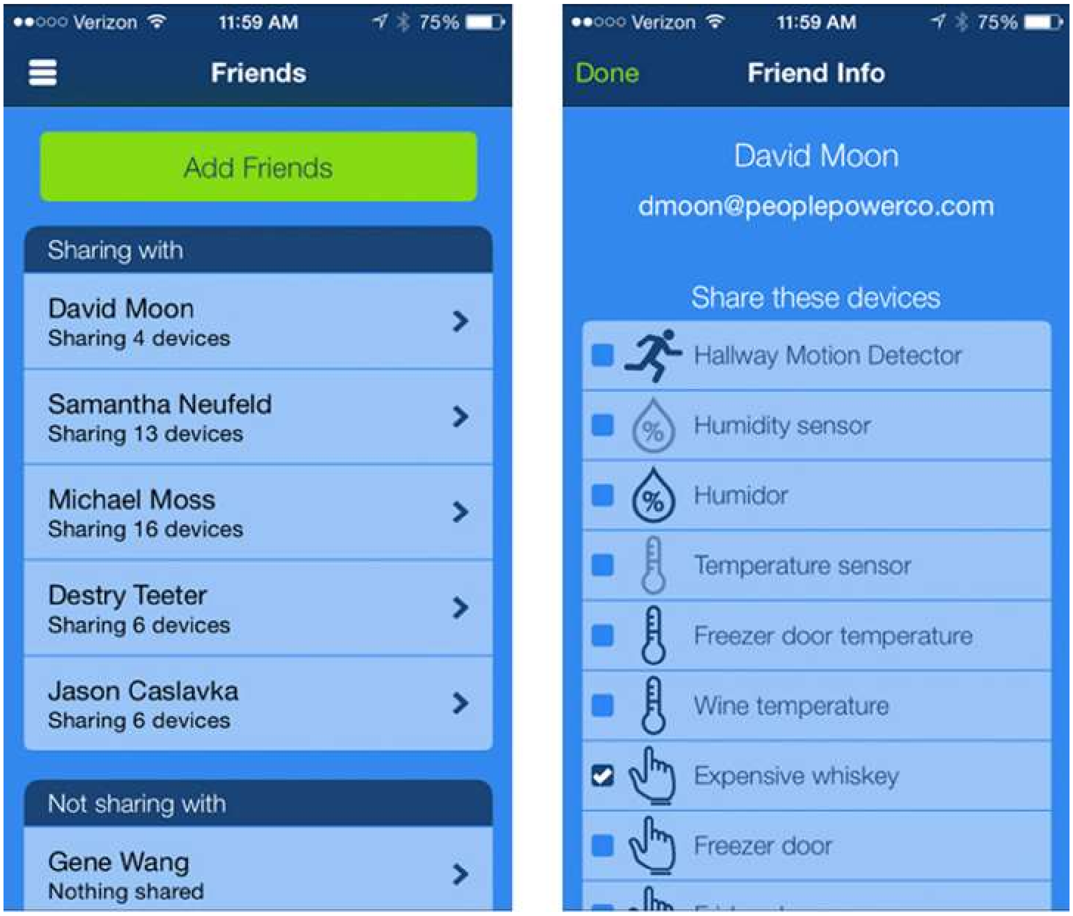


FIGURE 37.5 This figure displays a friend's list on the first screen and on the second screen, an example of how you can have your friend David Moon receive alerts about your "expensive whiskey" for you.

weave in easily with what products a company already has, or become the platform on its own. This will allow companies to offer life-changing services in areas like home security, energy management, and elderly care with ease.

37.6.2.2 Localizable for Other Languages A system that can be localizable for other languages allows us to come out with a French or Chinese version of an app, creating more opportunities in the global market for expansion.

37.6.2.3 Framework for Innovation The ideal system offers a framework for innovation. It grows and evolves to support new connected devices and powerful new analytics, providing a constant innovative outlook for future services and use cases and allowing your company's visions and dreams to be seen to completion. Not every company has the time or resources to scale up to match and beat their competitors. An ideal system helps take care of that job for them.

37.6.3 Administrative Console

One great use of IoT has been for service providers to utilize IoT software to have an administrative role-based web console for device management, user management, user communication, and engagement. In order to do this well and comprehensively, you would need a dashboard for basic reporting, a way to monitor and manage users and groups, a communication method to send messages, a way to engage the community via challenges, and points and rewards to reinforce positive behavior and form habits.

In order to give great technical support to end users, it will be useful to log user activity and statistics and diagnose problems. To support this, you will want to sort users into groups, track various metrics from those groups, and send targeted, customized messages to groups and individuals. This gives the administrator the knowledge and power to manage every phase of your program.

For diagnostics and support, you will want to log all API calls and track user activity and statistics. There should be features to proactively identify devices that have issues so that you can manage devices across your campus. Service providers will want to manage users, take notes on their activity, understand them, and form Groups of users, manually or automatically, to control them for specific purposes or better manage your actions.

Communication must be enabled in various forms such as in-app messaging, e-mail, and text message. Another way to engage your user base is through challenges and games. Challenges are part of the user engagement experience, and you can reward habit-forming behaviors with points, driving sticky engagement programs.

37.7 IoT TECHNOLOGY

In order to carry out all of the requirements of an ideal system as discussed earlier, you need a fully developed software stack. The example we will use is People Power Company's answer to the demand for IoT technology.

People Power's IoT Suite includes Presto, which connects IoT devices to the Cloud for free (Figure 37.6); Symphony, which provides social engagement, data analytics, and a blazingly fast mobile rules engine; Virtuoso, which allows telcos and utilities to offer compelling apps for home security, energy, healthcare, and more, under their own brand; and Maestro, which enables service providers to technically support end users; engage them with challenges, points, and rewards; and upsell high-potential users to new devices and services.

37.7.1 Connectivity Layer

The fastest and most cost-effective way to cloud-enable any product Presto is free for products with up to 2048-bit SSL, optional bidirectional authentication, up to 12 measurements and status updates on average per hour, and near-instantaneous command delivery.

FIGURE 37.6 IoT software architecture.

Presto is the fastest and most open connectivity layer available today for IoT. It is also free for manufacturers to Internet-enable any device, and with open APIs and an open developer console, it's extremely easy to get connected. It also connects to other clouds through cloud-to-cloud integrations and OAuth 2.0 and can even connect with devices that are already shipping in market by teaching Presto how to speak that device's language. Once connected, manufacturers can take advantage of the upper layers in IoT stack, including Composer, Harmony, Virtuoso, and Maestro.

Presto's Key Features:

- HTTP GET and POST to send measurements and receive commands.
- Both JSON and XML support, it's the developer's choice.
- Bidirectional data streams, usually less than 50 bytes per minute.
- NAT and firewall penetration.

- Synchronization in 0.25–0.50 second latency
- Online and offline recognition of devices and people
- Automatic data correction and filters
- Vector measurements for maximum database efficiency
- 2048-bit SSL encryption and optional bidirectional authentication
- Manage dropped connections, reliably deliver missed messages
- Marshal message delivery to low-capability devices
- Broadcast and unicast messaging, sharing a single pipe
- RTMPS and RTSP video streaming available but not free

37.7.2 Cloud Server

A carrier-grade cloud server includes family and community social networks, e-commerce, and a rules engine which can all be deployed into any data center.

Why is Symphony important?

- Harmony delivers an engaging customer experience that encourages sharing, competition, cooperation, and social commerce.
- Composer future-proofs organizations by enabling smart learning, data analytics, and a new service creation environment.

37.7.2.1 Harmony: Social Engagement Layer Harmony implements the social and behavioral psychology mechanisms required to deliver an extremely powerful and engaging customer experience (Figure 37.7). Harmony enables customer interaction, sharing, competition, cooperation, and social commerce. Harmony

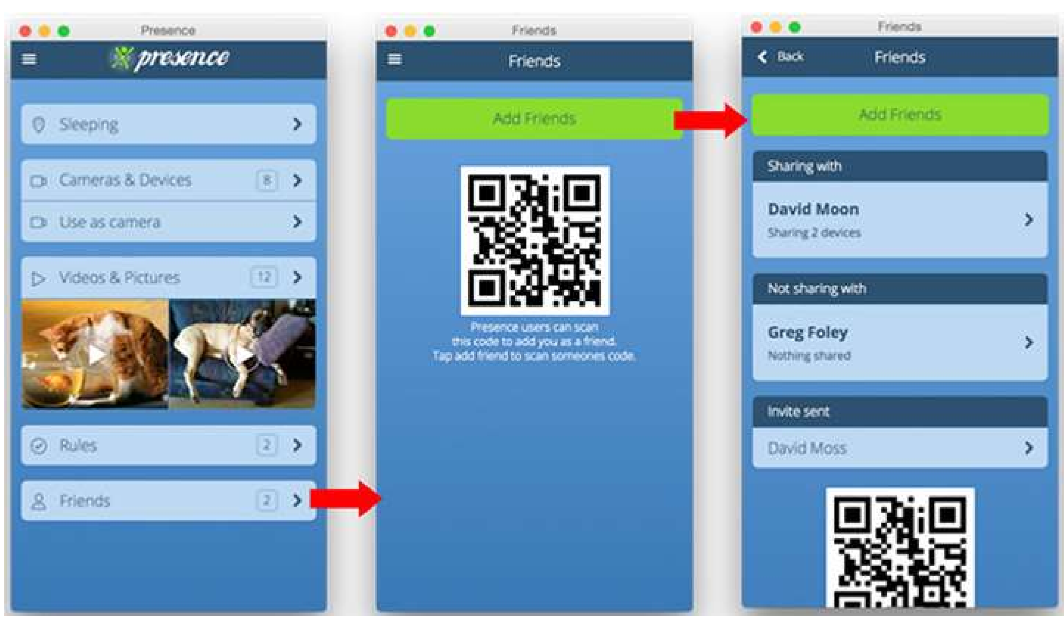


FIGURE 37.7 Harmony social engagement layer.

enables Trusted Social Networks and Community Social Networks and shifts the user experience from individual smart homes to collective smart communities. Uniquely, Harmony also bridges IoT with popular social networks, such as Twitter and Facebook (Figure 37.7).

Trusted Social Network is like a neighborhood watch program, enabling users to share events from their home from specific devices with people they trust, typically while they're away or on vacation. Another form of a Trusted Social Network enables caregivers to all participate in taking care of a loved one and receive alerts if that person falls or hasn't taken their medicine.

Community Social Networks are for communities and neighborhoods. We connect people who may be physically nearby each other but may not necessarily know each other directly. There are many benefits to doing so, including the powerful behavior-modification strategies that can be employed across a population. For example, an energy engagement program employs the following psychology strategies based on the formation of a Community Social Network:

Social proof—People want to do what others like them are doing. Harmony enables groups of users to see what others are doing, as well as share their own experiences.

Motivational bridges—Motivational bridges reward good habit-forming behaviors and word-of-mouth advertising with points, which translates into meaningful rewards.

Goal setting and public commitment—Setting attainable goals that are worthy enough is proven to motivate people to make lifestyle changes. Making goals public, rather than private, increases the likelihood they will be achieved. Accountability is key and a fun way to merge community and goal setting together.

Incentives and competition—Winning a competition is a prize unto itself—status—and competitions inherently incorporate aspects of social proof and goal setting. Competitions can range from living healthier lives or being in touch with your home environment to being an active promoter of smart home service to others.

37.7.2.2 Composer: Smart Learning Analytics and Automation Composer is a real-time big data and smart learning services engine. Simply put, this is the foundation for an application development and soon app stores for IoT—which will add new value and features for residential and business customers. The power of Composer lies in its ability to enable data scientists and developers to creatively develop apps on top of any Internet-connected device. Unlike a mobile app, apps for IoT run 24/7 in the background of user's lives. The app store of the future will not be in your face on a mobile screen but operate silently in the background to automate tasks, notify users of important events, generate monthly reports, learn a user's or appliance's patterns and behaviors, and connect service providers with their customer base without being overalerted.

Today, Composer enables developers to create apps for connected devices in the very popular scripting language Python. With appropriate user permissions, apps have the ability to listen to data streams from devices, control devices, generate alerts and emails, and learn. In the near future, apps will be able to ask users questions to gain additional context around the data.

To ensure app quality, our Composer SDK and app store have been designed to enable users to rate and provide feedback on apps, just like the Apple App Store.

Analytics services add new value and features and/or open new markets for residential and business customers.

Features can be added to connected products beyond what the manufacturer intended, enabling clients to differentiate themselves from other smart home services.

Composer enables developers to create and customize apps and allows end users to provide immediate app feedback and rankings.

37.7.3 Mobile App Framework

An app framework for iOS, Android, and Web enable the rapid deployment of compelling IoT services featuring your brand.

37.7.3.1 Why Virtuoso? It's all about the user experience—their connection and their trust. Powerful cloud servers, intelligent analytics, and the smartest devices in the world are all useless if the interface isn't simple and easy to use.

37.7.3.2 How Does It Work? We've done the heavy lifting for you. Thanks to Virtuoso, you can offer mobile-first services that easily expand with add-on products and features. Specifically built to support IoT, Virtuoso will jump-start your interface to your users by allowing easy integration with third-party devices, cloud services, and apps.

Businesses large and small are struggling with how to quickly roll out IoT services. But end users don't want to have to use multiple apps to manage their devices. In a mobile world, Virtuoso solves these issues by combining heterogeneous device services into a single, unified app framework, empowering enterprises to deliver mobile app services that truly matter.

37.7.3.3 What Is It? Virtuoso is a customizable app framework for iOS, Android, and Web that allows enterprises and others to get a head start on new revenue streams leveraging IoT. The framework enables the control of connected devices and develops solutions such as security, care, and energy management. People Power's own award-winning Presence app is built with Virtuoso and is the first and only "freemium" model for IoT:
The Virtuoso's key features include:

- A white-label framework with proven user appeal
- Offers a time-to-market advantage
- Ease of deployment and integration with third-party devices

- Incorporates a behavioral-design approach to the user experience
- Provides for better engagement and more satisfied customers
- Enables higher average revenue per user (ARPU) and greater retention

37.7.4 Command Center

A command center enables device management and services across a large user base. Sign up users, support their needs, issue challenges, and offer rewards to keep them engaged.

37.7.4.1 Why Maestro? When deployed in large scale, IoT can be daunting. Maestro takes the anxiety out of the equation by providing you with the administrative tools you need to tend your flock of users and devices.

37.7.4.2 How Does It Work? Monitor millions of devices and control them remotely. You can onboard new users with ease and run customer engagement programs to keep them connected. Diagnostics, dashboards, and predictive analytics simplify your life.

The social engagement tools within Maestro help service providers connect with users and ensure they leverage IoT services effectively. Gamification rewards higher user engagement, leading to higher ARPU for the service provider.

Maestro can facilitate large-scale population behavior change, realizing the true value of IoT across homes, businesses, and communities alike.

37.7.4.3 What Is It? Maestro is a unique management platform for businesses to easily administer their IoT devices, services, and customer programs remotely. Our web-based management tool includes onboarding, monitoring, messaging, engagement, analytics, and reporting. Think of it as Customer Relationship Management (CRM) for your devices.

Maestro collects user, device, and program data for key insights into device monitoring and customer activity and lower administrative costs. It enables the management of multiple deployments and sites from an easy-to-use interface with big-data reporting that provides the actionable intelligence needed by service providers to keep things running smoothly and their customers engaged.

Maestro's Key Features Include:

- IoT service recruiting and device fulfillment
- Device status monitoring and troubleshooting
- In-app messaging to groups or individuals
- Gamification with Points and Rewards

37.7.5 Geofencing

A lot of people take their smartphone around with them wherever they go, so we can use the location of your smartphone to register whether you are at home or away. Geofencing lets you create a virtual fence around your home so that when you leave the range and go into “away” mode, any protocols you have set to activate when you are “away” will be triggered. This becomes useful when you are in a rush, because all you have to do is leave home and when your phone registers as “away” from home, all of your lights turn off. Geofencing is also useful for when you are on vacation. If you live in Silicon Valley but your smartphone is now in the East Coast, the system can infer that you are traveling and continue to turn your lights on and off to make it appear that you are at home and deter burglars from targeting your home.

37.7.6 IoT Services for Anybody with a Smartphone

The Presence app from People Power is leading a whole new model for IoT. For both our hardware and the total cost of our service, there is little to no cost. This puts us in a strong market position to reach those who would be deterred by expensive hardware and high recurring fees. As Tom Kerber, the Director of Research at Parks Associates said, “as consumer awareness of smart home products and services increases, the smart home market will shift to lower cost channels. People Power Presence is the lowest cost entry point for the smart home.”

Our freemium model allows those who were previously priced out of traditional security alternatives to get the benefits of an award-winning app that can give them a sense of security over their lives.

37.8 CONCLUSION

In order to bring IoT to the masses, solutions must be developed that improve lifestyles in the areas people care about the most, in a way that people can easily access and use, at an affordable price.

An end user app solution empowers users to take their home security and energy management into their own hands. Powerful software that allows platforms, devices, and protocols to be woven together allows manufacturers and service providers to coordinate and manage a comprehensive ecosystem of smart devices. A powerful user management console will let you do anything from find and diagnose problems to engage communities in games that will change their behavior and begin real social change across an entire building or campus.

The Internet of Things offers endless possibilities for innovation, and the market is growing rapidly for smart home solutions on smartphones.