Deloitte.

Smart Cities
The importance of a smart ICT infrastructure for smart cities

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Contents

This report is an English translation by Stokab of the original Deloitte report in Swedish.

Summary

Europe, like much of the rest of the world, is facing a number of profound changes in several social areas, driven by factors including demography and climate. These challenges are putting huge demands on the public sector in many of its areas of responsibility, such as education, elder care, health care and environmental protection. New structures, solutions and public-private co-operations in various forms, as well as a large element of digitalisation, are necessary for Europe to remain competitive and overcome the challenges society is confronting. Several of these issues have already begun to be addressed within the framework of various projects and programmes aimed at creating smart cities and smart services. One success factor in the work with smart cities and services will be to expand the discussion beyond IT and telecommunications and see the big picture from a societal perspective, including issues of quality for citizens and development in key social areas.

The technical development of smart cities, services and applications is proceeding apace, based on areas such as IoT (Internet of Things), cloud services and big data. However, in many respects we lack a cohesive understanding of the public perspective on the creation of a smart city. For a city, with its myriad and complex units and operations, creating good opportunities for interoperability among applications and technologies and ensuring synergies and economies of scale across them all, is a major challenge. An important key to success is to avoid vertical solutions at risk of functioning as silos. This requires a horizontal approach in which shared, horizontal layers are created that contain clear standards and guidelines for applications and technologies. It will be a key task for every city to define a "game plan" for its evolution towards becoming a smart city, i.e., what conceptual model for development is chosen and how to best create an open environment that fosters competition, diversity and innovation.

Increasingly, the services provided by cities - everything from traffic control to elderly care - are moving into a digital environment and are taking on digital components or ancillary services. In this context, it is vital that a city assumes responsibility for the digital infrastructure, just as it previously assumed responsibility for analogue services and infrastructures and ensured that they worked efficiently together. In doing so, the city will assure its strategic governance and development of the areas for which it is responsible, now and also in the future.

The reference model developed within the framework of this report may serve as a basis for defining the conceptual model that every city needs to establish and which may provide assessment and decision support. Based on the reference model and five strategic assessment criteria – flexibility, finances, innovation, knowledge and security – the report highlights three specific market models, i.e. practical applications of the reference model. The market models – the Operator Model, the Specialist Model and the Collaboration Model – have different properties and characteristics and thus generate different effects and consequences for each individual city.

One central issue in the choice of market model is the view on the city's role and responsibility for creating open solutions and fostering competition and innovation. In many respects, the choice of market model is critical to a city's opportunities to actively shape its evolution as a smart city.

Based on the assessment through the reference model, the following it can be observed that the Specialist Model and the Operator Model have weaknesses compared to the Collaboration Model. The distinguishing characteristic of the Operator Model is that a smart city choses to have an external actor assuming overall responsibility, inter alia resulting in lock-in effects. The distinguishing characteristic of the Specialist Model is multiple actors that develop vertical solutions for various areas, which risks resulting in fragmentation. The Collaboration Model, where the city assumes main responsibility for the infrastructure, is the most effective model, as it generates the following positive effects:

- It gives the city's own operations and external actors access to an open and operator-neutral fibre infrastructure, which provides opportunities for competition and diversity to the benefit of consumers, reduces the risk of verticalisation and lock-in effects and gives the city possibility to efficient and competitive public procurements and supplier contracts.
- It gives the city an opportunity to drive horizontal solutions that facilitate a higher degree of interoperability among applications and technologies while providing greater potential for synergy effects and ensuring economies of scale.
- The city can develop a specifying organisation in which procurement and development do not occur in silos and key skills can be retained. This makes it possible to more efficiently link internal needs to external actors and suppliers. The Collaboration Model also gives the city the opportunity to maintain control over central data, privacy and security aspects.

The table below shows an overall assessment of each market model based on the strategic decision criteria.

Table 1: Assessment of the market models

	Operator Model	Specialist Model	Collaboration Model
Flexibility	◑	◑	●
Finances (long-term)	◑	◑	◕
Innovation	◑	●	●
Knowledge	◑	●	◕
Security	◕	◑	●
Total	◑	◕	●

The positive effects of the city assuming main responsibility for the infrastructure have been highlighted in several Deloitte studies on the significance of the communications infrastructure to the broadband market. These studies have shown, for example, that access to open and operator-neutral fibre infrastructure, as provided by municipal networks for example, promotes competition and diversity.

The capacity of operators and service providers to drive and improve service development and innovation is also facilitated, thus creating greater diversity and competition, which leads to a broader range of services for consumers.[1] Providing and ensuring access to an open and operator-neutral fibre infrastructure thus creates a platform for developing products and services in both the consumer and business markets. This report shows that this will become even more important in the forthcoming development of the smart city in which many of the city's areas of responsibility are digitalised. The Collaboration Model builds a platform for developing the city's own smart services as well as commercial services and communications, such as 5G. On this platform, the city can competitively procure its smart services in order to leverage the specialist expertise found in private firms. Overall, this model stimulates innovation and service development in the cohesive ecosystem of the future digital society while avoiding vertical lock-ins, which can potentially be very costly and inefficient for a city from the long-term perspective.

[1] Deloitte (2014): *Communication infrastructure and its importance for broadband markets*.

Introduction

Background

While there is no clear-cut definition of "smart cities", they are often described as cities that utilise ICT and other technologies to increase public benefit and improve the standard of living (further discussed in section below). Smart cities are highly dependent upon greater cooperation among citizens, business and the city, as well as other actors in the public sector.

In an environment characterised by cooperation and partnership among various actors, a city can take on different roles, ranging from a passive role to a more active, facilitating role in which the city establishes the right conditions for all actors to operate within the smart city area. A city needs to choose its role based on how it can optimally promote the development into a smart city while ensuring good strategic flexibility going forward. With a long-term approach, a city can issue clear targets and guidelines for operations while ensuring favourable conditions for competition, innovation and scope for action over time. Every city needs to establish structures and collaboration models in order to be equipped to meet the changing expectations and preferences of citizens, business, city operations, colleagues and collaborative partners while maintaining control over the agenda and direction of the city in the future.

The communications infrastructure is a key component in smart city development. Every city needs to ensure that communications platforms are established and accessible in order to achieve the smart city concept in an open and resource-efficient manner. Access to a modern, basic infrastructure for data communications in the form of, for example, fixed networks, mobile networks and dedicated networks for IoT-applications will be critical to cities aiming to become "smart."

Deloitte has previously conducted several studies of the impact of the communications infrastructure on the broadband market. These have shown, inter alia, that open and operator-neutral access to fibre infrastructure promotes competition and diversity. The capacity of operators and service providers to drive and improve service development and innovation is facilitated, thus creating a wider array of service providers and a broader range of services for consumers.[2]

The importance of access to a good broadband infrastructure for economic development, growth and innovation was also highlighted in a recently published OECD report, which shows that high speed broadband networks foster economic growth.[3] The study makes it clear that fibre infrastructure coverage is an important investment in innovation and growth. The OECD report also highlights the importance of "municipal networks" to investments and roll-outs of fibre networks in particular. According to the report, investments by municipal networks also drive higher investments by other actors and stimulate competition.

[2] Deloitte (2014): *Communication infrastructure and its importance for broadband markets*.
[3] Mölleryd, B. (2015): *Development of High-speed Networks and the Role of Municipal Networks*.

The choice of market model, i.e., how the broadband market value chain (see Figure 1 below) is structured and organised, has proven critical to the degree of openness, competition and innovation performance of a specific broadband market.

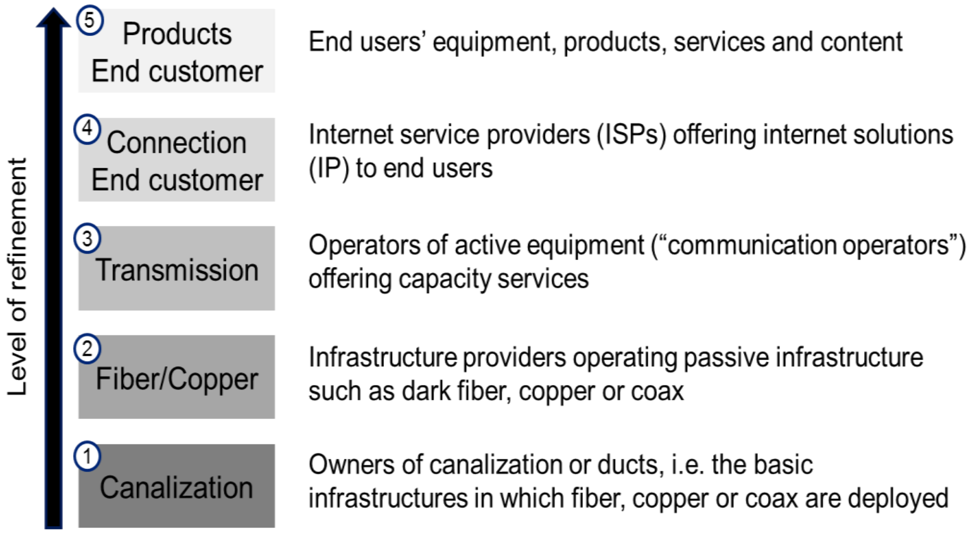

Figure 1: Value chain for the broadband market. Source: Swedish Post and Telecom Authority

A broadband market dominated by a vertically integrated actor – i.e. one that owns infrastructure and simultaneously operates at all levels of the value chain - has a tendency to underperform with regard to innovation, competition and diversity for the end user. The reason for this is that such actors often compete with their customers and/or co-operation partners at one or more layers in the value chain, which implies potential conflicts of interest. A vertically integrated actor, for example, has limited incentive to invest in and design open multi-fibre networks that can offer dark fibre to other actors, since this would stimulate competition higher up in the value chain. Meanwhile, fully parallel infrastructures of the same type are a less likely scenario due to the high investments required combined with the risk of failing to achieve adequate return because customer penetration is too low.

From the competition perspective, an operator-neutral fibre provider with a network designed and built for multiple operators is thus a very efficient solution. It is, however, also critical to ensure that at least one market actor does not have the incentive or the option to move up in the value chain. The municipal network model in Stockholm, for example, demonstrates that it is possible to establish open and operator-neutral networks, which is essential to fostering competition at the retail level and diversity in the range of services offered to end users.

Defining the smart city

As mentioned above, there is no clear-cut definition of "smart city" and in many respects there is no cohesive public perspective on the establishment of a smart city. In common for most definitions, including the one used in this report, is that "Smart City" is the term for the use of ICT and other new technologies to improve the sustainability, efficiency and quality of public services and improve the standard of living for citizens. A Smart City thus constitutes a cohesive ecosystem in which various smart services can effectively interact and do not constitute separate vertical solutions.

A few examples of definitions of a Smart City follow:

EU:
"*A smart city has three priorities: energy, transport and ICT. The aim of technology application in these areas is to increase efficiency, reduce energy consumption and reduce emissions of greenhouse gases.*"[4]

City of Stockholm:
"*A smart city is a city that uses innovations and new technology to improve customer service and city services that make life easier and better for everyone who lives, works and operates here. It is also a city that develops and offers sustainable, climate-smart services made possible through connectivity and open data, integrated platforms, sensors and other technology.*"[5]

Telefonica:
"*A smart city is a city that utilises information technology to make their central infrastructure and public services more interactive and efficient.*"[6]

A city can play a key role by creating avenues to openness for the basic infrastructure and access to data, as well as the prerequisites for the competitive procurement of public services. In other words, the city can work actively to create an ecosystem that benefits citizens, business and society. The three sample definitions also show that various actors have different views on what makes a city a Smart City. Telefonica, for example, takes a more technical perspective, while Stockholm sees the city as a platform for innovations that make life easier for the people who live and work there.

Aim

Like the broadband market, a city's choice of market model for a Smart City will create the conditions for the city's opportunities to foster openness, competition and innovation capacity. It will thus be highly important from the strategic point of view to understand the effects of a city's choice of model with regard to both openness of the infrastructure and forms of public procurement of public services.

In order to illustrate the importance of the communications infrastructure for Stockholm and other cities that have ambitions to become smart cities, and in particular the critical issue of access to open and operator-neutral fibre, Deloitte has been commissioned by Stokab to highlight trends and developments in the smart cities market and to design a reference model that can act as support for strategic choices and decisions regarding market models for smart cities.

[4] EU (2016): Smart Cities.
[5] City of Stockholm (2016): *How can Stockholm become the smartest city in the world?* (*Sw*. Hur kan Stockholm bli världens smartaste stad?)
[6] Telefónica (2016): *Smart Cities – Leading the IoT pathway*.

Trends affecting the development of a Smart City

A Smart City is constantly influenced by new trends. As a result, the city must be flexible and adaptable in order to keep up with rapid developments. The trends also have direct impact on specific areas within a Smart City, where larger amounts of data, for example, impose higher demands on data storage and the underlying communications infrastructure.

Trends that have impact on the infrastructure of a Smart City are described in the following section. The section has been divided up into technical trends, application trends and market model trends. The three trends are defined as follows:

- **Technical trends:** Refers to trends in communications technology and other related technical advances such as 5G, big data and cloud services. These trends will make smart cities possible, but will also put higher demands on the underlying communications infrastructure, among else.

- **Application trends:** Refers to applications or tools that help citizens, businesses and city administrations develop services in new and existing areas. There are many different application areas in a Smart City, including health care and transport.

- **Market model trends:** Refers to how a city chooses to organise and procure its solutions and how these affect the city's role as the facilitator of an efficient Smart City.

Technical trends

The technical trends described in this section were arrived at by identifying and assessing a large number of trends according to three criteria – relevance, timing and magnitude – in order to identify the trends most important to the infrastructure of a Smart City.

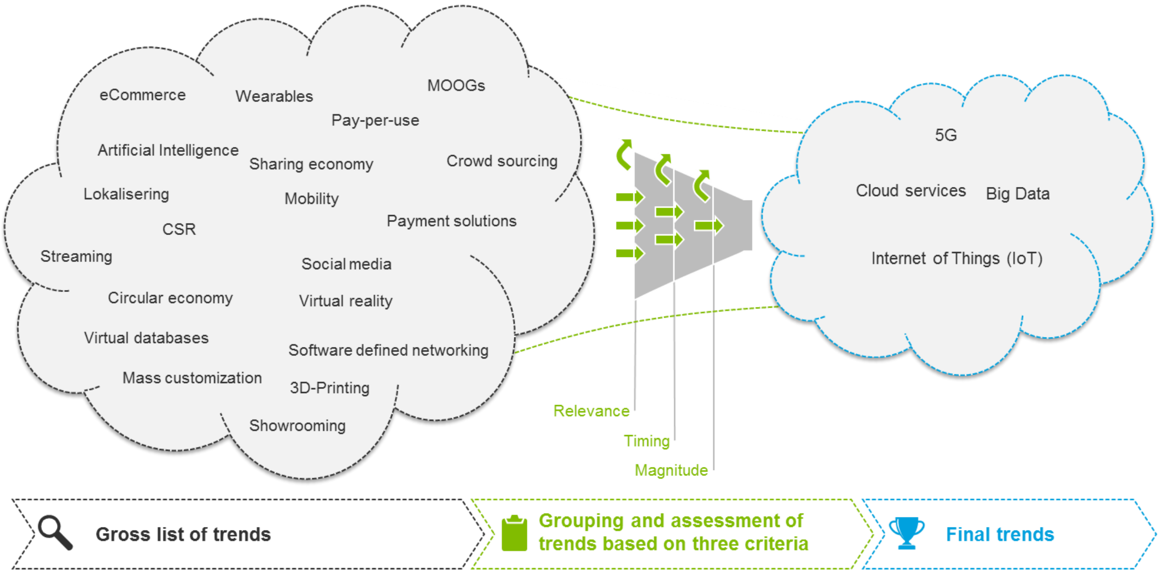

Figure 1: Identification of the technical trends most important to the infrastructure of a Smart City

The trends assessed as most relevant are the Internet of Things (IoT), 5G, big data and cloud services.

Internet of Things (IoT)

IoT refers to the use of sensors – small devices that can record various types of data, such as heat, light, speed and weight – and wireless communication in various types of physical products on a large scale, where devices are connected to the internet and work without human interaction. When many sensors are connected, this creates big data, allowing the physical world to be analysed in detail and, in many cases, in real time. The information can be used for purposes including optimising a city's infrastructure and using its resources more efficiently. Some IoT services put demands on capacity, others on access, and it is therefore important to have an infrastructure that can manage both parts.

There are several general trends in the IoT area that put demands on the infrastructure of a Smart City.

- **Multiple applications:** In the future, IoT solutions will be found in virtually all areas and a vast number of physical devices, such as street lights and buildings, will have to be fibre-connected.
- **Powerful growth in IoT:** The number of IoT devices is estimated to grow by about 30% every year until 2020.[7]
- **Industry is the primary driver:** The development of IoT will be driven primarily by industry.

Assessment

In addition to the general trends, several factors are facilitating rapid development of IoT:

- **Price pressure on sensors:** The price of sensors has fallen for the last five years and estimates indicate that it will continue to drop by about 5% per year over the next few years.[8] The price drop is going to make it cheaper to install sensors on a large scale, which is often required to connect a large number of devices in a city.
- **Fibre infrastructure:** If a city has an expansive fibre infrastructure, it will power faster expansion of the sensor network because the infrastructure will be required whether the sensors transmit information directly via the fibre network or via wireless networks.
- **Wireless coverage:** Most sensors require wireless network access to transmit data because other connections, such as fibre, are not available in all locations. Access to wireless networks will be made possible through increased development, expansion and availability of 5G, WiFi and LoRa, for example.
- **IPv6:** The newest internet protocol allows an almost infinite number of unique IP addresses, making it possible to identify more IoT devices.
- **Better processors and storage:** The big data generated by sensors has to be stored and processed, which was not formerly possible to the same extent as now due to insufficient storage capacity and processor speed.

In spite of rapid development in the IoT area, a number of challenges remain, which are going to require large investments.

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[7] Deloitte Estimate (2015)
[8] Deloitte (2015): *Smart Cities Point-of-View*.

- **Privacy and security:** The big data produced and specific data (or combinations of data) can entail sensitive matters of privacy and constitute a vulnerability for society and citizens. Consequently, a clear strategy surrounding security and data secrecy is essential.
- **Electricity supply:** Large numbers of sensors are going to be installed in locations where there is currently no electricity. Either the electricity grid is going to have to be expanded or the usage of batteries and/or solar cells will have to be increased.
- **Obsolete platforms and sensors:** It will be difficult for older platforms to manage the amount and type of data and information created by IoT devices and investments in new platforms are required. Already installed sensors, in industry for example, also have their limitations, as many of these cannot act autonomously as IoT devices and are dependent upon human input and interaction.
- **Fibre density:** To enable sensor connection, adequate fibre density will be required in the street space, which will entail large investments for cities where fibre is not currently installed.

5G

The next generation mobile network – 5G – is often called the network that will be able to connect and "share data anywhere, anytime by anyone and anything." That which is going to make 5G possible is most likely not a single, revolutionary new technology, but rather a combination of expanding and increasing the number of mobile masts and phased upgrading of existing technologies in mobile communications.

Industry groups and institutions have identified a set of eight requirements for 5G:[9]

- 1-10 Gbps connections to end points in the field
- 1 millisecond end-to-end round trip delay (latency)
- 1000X bandwidth per unit area
- 10-100X number of connected devices
- (Perception of) 99.999% availability
- (Perception of) 100% coverage
- 90% reduction in network energy usage
- Up to ten-year battery life for low power, machine-type devices.

The 5G network is going to require a much higher number of base stations per unit area, i.e., denser placement of masts and sites than is the case for today's mobile network. This will require an expansion of the fibre infrastructure in the street space. The development of 5G will be driven largely by commercial actors and global research collaborations. The first 5G network is expected to be commercially available in 2020.[10]

Assessment

It will be another two to four years before the first 5G networks are expected to be installed for commercial use, which means that it is not one of the trends with the greatest impact in the near term. However, 5G will have major impact in the future when commercial 5G networks become more widely available.

5G will make a large number of smart city applications possible. A few examples:

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[9] GSMA Intelligence (2014): *Understanding 5G: Perspectives on future technological advancements in mobile*.

[10] GSMA (2016): *Unlocking Commercial Opportunities From 4G Evolution to 5G*.

- **Smart and self-driving cars:** Self-driving cars require a connection with very low latency, which is one of the requirements identified for 5G. For example, if there is an accident, a self-driving and connected car can very quickly warn other cars behind it and make sure that various traffic and weather conditions can be rapidly communicated.
- **The smart home:** Smart devices at home will be able to communicate with each other and the monitor energy consumption of televisions and computers, for example.
- **Emergency services:** Firefighters or emergency response teams, for example, will be able to use helmets that can stream video in real time that can be transmitted instantly to supervisors who can provide advice about how to manage risky situations.
- **Virtual reality health care:** The low latency of 5G can enable remote delivery of health care. It will be possible for a doctor to use new robots and a connection with very low latency to remotely perform examinations or even surgery.

Big data

Big data refers to the vast quantity of data produced and available in the digital society as well as the new opportunities for analysing and using the information. The quantity of data is growing exponentially and more than 90% of all data in the world was generated over only the last two years.[11] Data is often described as structured (e.g., system-generated data) or unstructured (e.g., data from social media or email).

Big data has primarily two applications.

- **Analytical big data:** Analytical big data is aimed at analysing and inputting large quantities of data in order to gain better insight into something. Analytical big data technology can be applied to both structured and unstructured data.
- **Operational big data:** Describes the use of big data in ongoing operations with real-time analysis. This often involves both reading and writing of data, which in most cases requires structured data sources to be possible. Operational big data requires low latency networks.

Assessment:

Big data is a tremendous resource for a city and is estimated to generate huge value. It is therefore important that a city has a strategy for avoiding lock-in effects that might arise when other actors control the city’s data. It will thus be an important task to ensure open access to the city’s data for citizens and other stakeholders.

Used properly, big data can enable a large number of new solutions for Smart Cities. A few examples:

- **Improved traffic services:** With the help of RFID tags or connected cars, road traffic can be more easily monitored and areas that are particularly prone to tailbacks, for example, can be identified and analysed faster. Sensors in the roads can be used to measure traffic and pollution and data can be transmitted to a traffic command centre that can use the data to redirect traffic, for example, to reduce emissions in especially vulnerable areas.

[11] SINTEF (2014): *Big Data, for better or worse: 90% of world's data generated over last two years.*

- **Parking:** Big data can also be used to redirect cars to the nearest available parking spaces. City planners can use data to understand which areas have the greatest need for parking and how this can be streamlined in connection with the building of new car parks.
- **Waste collection:** City planners can also use big data for purposes such as seeing how various areas differ and use the information to further improve the efficiency of waste collection.
- **Smarter, more efficient lighting:** Smart lighting can deactivate itself when no one is in the vicinity and energy consumption in the city can be mapped in order to understand demand. How residents move around the city can also be mapped in order to maximise the use of cycle and footpaths.

Cloud services

“Cloud services” are technologies in which large, scalable resources – such as processing power, storage and features – are provided as online services. Instead of users having to own and be responsible for these resources, they can easily access and use them via the internet, either directly from the web browser or via special software and apps. Examples of commonly used cloud services include web mail (Gmail) online data storage (Dropbox) and CRM systems (Salesforce.com). Today, about half of all firms use cloud services in some form.

Cloud services are usually divided into three categories, depending upon what is provided as a service.

- **SaaS or Software-as-a-Service:** Users gain access to software on the cloud service provider’s network and do not have to administer the underlying infrastructure, such as hardware, operating systems, storage, etc. Examples are web mail and Google Docs.
- **PaaS or Platform-as-a-Service:** Users, usually programmers or system developers, gain access to various development environments to create their own applications and software. Examples are MS Azure and Google App Engine.
- **IaaS or Infrastructure-as-a-Service:** The supplier provides processing power, storage and network components that make it possible for users to install and run any software, including operating systems. Examples are Oracle VirtualBox and VMware.

Cloud services are also generally said to have three different distribution models.

- **Public cloud:** The service is available to the public, owned and administered by the provider and shared by multiple customers and users. The public cloud is what is most often associated with cloud services.
- **Private cloud:** The infrastructure and included services are run exclusively for a single firm or organisation. These may be managed in-house or by an external vendor and be placed in both internal and external computer centres.
- **Hybrid cloud:** A combination of multiple cloud services that enables the integration of these cloud services.

There are several examples of cloud services being used for smart cities today: A few examples[12]:

- **Smarter Sustainable Dubuque Project, Dubuque, Iowa, US:** Cloud services provided by IBM are being used make apps available to residents that help them monitor and control water and electricity consumption, where the cloud services enable coordinated applications to improve efficiency, among else.
- **Smart Santander Project, Santander, Spain:** The telephone operator Telefónica is using cloud services to help the city improve the efficiency of sanitation services, such as waste collection.
- **The ClouT project:** ClouT, co-financed by the EU Commission and Japanese research institutions, is creating special smart city solutions using Internet of Things sensors combined with cloud services.

Assessment:
Cloud services are expected to gain a stronger position, because a Smart City and its actors can use cloud services to avoid initial costs and ensure greater flexibility. When choosing external actors, a city must have clear understanding of the ownership of the city's data, as problems related to personal privacy may arise if unauthorised persons have access to the city's data.

Application trends

Several applications are usually mentioned in connection with the term "Smart City". At present, there is no clear-cut categorisation of applications that all actors use, but several recurring themes usually arise in connection with smart cities. Six of these applications are outlined below.

Smart traffic services

Smart transport systems are services that facilitate the transport of people or goods and which improve the efficiency of the use of various resources by making transport methods more easily managed or more easily available.

Examples of services and functions include various types of smart traffic monitoring, parking systems, traffic planning and systems for pricing transport, for example, during various times and routes. Examples of cities where smart transport systems have been trialled or implemented include:

- **Smart traffic system, Singapore:** Singapore's intelligent traffic system includes electronic payments and sensors on taxis, which generate a large quantity of traffic data. The city analyses this data, making it possible, for example, to map traffic conditions at various times of the day.
- **Smart traffic monitoring, Zaragoza, Spain:** More than 150 sensors were implemented in the city in 2010-2011, which measure about 90% of city traffic. The collected information is sent to the city's command centre where it is used for purposes including calculating drive times for common routes, but also for long-term planning of the road network.

[12] Deloitte (2015): *Omvärldsanalys av tekniktrender*.

Smart energy services

Smart energy services include those that primarily enable more efficient and smarter use of various types of energy. These services may involve, for example, smarter ways to deliver energy, more energy-efficient functions and smarter ways to map energy usage.

One example of a smart energy service is smart lighting, both indoors and outdoors, that is activated or deactivated depending upon whether there are people in the vicinity. Services like smart electricity grids and smart electricity meters that can communicate with each other can also make a significant contribution to more efficient use of energy and are classed as smart energy services. Other examples might include distributed energy generators or more efficient energy storage functions.

Examples of cities where smart energy systems have been trialled or implemented include:

- **Smart street lights, Glasgow, Scotland:** Glasgow has launched a pilot project in which street lights are equipped with sensors that detect any people moving in the vicinity. The aim is to study what energy savings can be achieved by allowing street lights to automatically turn off and on depending upon whether a person is walking past.
- **Smart boroughs, Stockholm Royal Seaport, Sweden:** Stockholm Royal Seaport is one of the biggest urban development projects in Europe. Sustainability issues imbue the entire project, which has been made possible in part through the utilisation of ICT. The city has established Royal Seaport Stockholm Innovation as a meeting place and arena where various actors can meet and interact in order to find inspiration for innovative solutions for sustainable urban development.

Smart administrations and agencies

Smart administrations and agencies are often mentioned in connection with solutions aimed at improving the efficiency of public services. This applies, for example, to various types of digital interactions between government agencies and citizens, businesses or government employees. Smart solutions may increase transparency among administrations and make it easier for various actors to interact with them.

Examples of areas that may benefit significantly might be smart education systems, public security and access to open data.

Examples of cities where smart agency systems have been trialled or implemented include:

- **City-wide sensors, Santander, Spain:** One of the world's most comprehensive pilot projects involving city-wide sensors has been launched in Santander, where more than 120,000 sensors are collecting data on everything from the availability of parking spaces to air quality. The city is sharing its information to make it possible for innovators to create various apps and tools to improve things such as interaction with government agencies.
- **Smart cooperation platforms, Florence, Italy:** In 2012, Florence launched an open data initiative in which public information, data and statistics were made available on a public website. There are more than 200 continuously updated datasets on everything from the most popular baby names to maps of cycle parking areas. The aim of the initiative is to promote the development of digital services.

Smart resources

Smart resources include services that streamline and improve water and waste management through the use of ICT solutions. For example, smart water metering systems, smart solutions for waste management and air quality measurement systems can be classed as "smart resources."

Examples of cities where smart resource systems have been trialled or implemented include:

- **Smart rubbish bins, Barcelona, Spain:** Barcelona has been running a pilot project in which rubbish bins are fitted with sensors that can measure how full the bin is. The information is analysed and used to optimise routes for collection vehicles, which only empty full bins. The city of Barcelona estimates that the system may lead to a 10% reduction in rubbish collection.
- **Resource management system, Cologne, Germany:** The city of Cologne has deployed smart energy meters in more than 30,000 households, which measure consumption of electricity, gas and water. The consumption data is collected by energy companies, which have also developed services that allow residents to see their energy consumption on their phones and give them the ability to control their use of energy-demanding appliances to times during the day when water or electricity prices are lower.

Smart buildings

Smart buildings can be described as systems that make it possible for buildings to learn and predict various needs, such as for lighting, temperature and space availability. Examples of these functions might be smart lighting, predictive heating, water and sanitation systems and building automation.

Examples of cities where smart building systems have been trialled or implemented include:

- **Smart buildings, "The Edge", Amsterdam, Netherlands:** More than 30,000 sensors and 6,000 LEDs of various types have been installed in Deloitte's Amsterdam office, "The Edge". The LEDs are connected via internet cables and each has its own unique IP address and can measure infrared, temperature and humidity. The sensors make it possible to show which parts of the building are used the most, which coffee machines or paper towel dispensers need to be refilled and which rooms need to be cleaned. All functions contribute to reducing energy consumption and make it both easier and safer to use various functions in the building.
- **Micro-infrastructures, Greenwich, London, England:** A local council in London has decided to establish a local network of sensors in the Royal Borough of Greenwich. Thousands of sensors have been deployed in buildings, roads, lamp posts and other places in the city. The collected data is then analysed in an "operating system" for smart cities, built in part to enable M2M functionality between connected devices. The platform can be used by service developers who can develop applications based on collected data.

Smart health care

Smart health care includes services that use ICT solutions to increase access to health care, services that can remotely diagnose or prevent illness and other services that can enable effective health care at lower cost. Examples of these are telemedicine, connected medical devices and various methods to prevent the spread of illness.

Examples of cities where smart health care solutions have been trialled or implemented include:

- **Swedish Association of Local Authorities and Regions (SALAR), the LEDA project:** SALAR has selected ten Swedish cities, including Västerås, to be part of a pilot project for various smart solutions. One example is that instead of staff making rounds of rooms in an elder care home during the night to make sure everything is under control, cameras have been installed for monitoring. Another example is that residents of a care home for people with dementia can be given door alarms that signal staff when they go out, which allows the doors to be opened and eliminates the need to lock residents in. These solutions allow staff at homes for people with dementia and elder care homes to focus on the people who actually need help and support.
- **Sensor network for senior citizens, Oslo, Norway:** Systems are being tested in Oslo that were developed to make it easier for senior citizens to manage on their own at home. The system includes screens on walls that older people can use to communicate with health care staff, reminders of daily tasks that are read aloud and wireless sensors that sound alarms if, for example, the oven is left on too long or a door is opened during the night. The network makes daily living easier for senior citizens and makes it easier for their families to check that everything is as it should be while generating large health care cost savings for public authorities.
- **Telemedicine, Basque Country and Spain:** A telemedicine, or "telehealth", system was introduced in Basque Country in 2013 that made it possible for health care staff to provide effective health care remotely. Each patient was given a pulse oximeter and a spirometer, which are connected to a motion sensor system. Doctors and nurses can use these to hold virtual meetings, check the patient's physical condition and give the patient advice remotely.

Assessment

Application trends are going to enable a large number of new, smart services for a Smart City, of which the following are important:

- The described application trends illustrate that at present we are seeing fragmented development of smart services rather than cohesive Smart City development.
- Development is occurring broadly over applications and geographical areas.

Market model trends

In the context of smart city development, it is important to understand the potential consequences of various choices of market model on a Smart City's conditions for stimulating service development, efficiency, flexibility and innovation. In connection with the rapid development of solutions for smart cities, the importance of the chosen market model is going to significantly increase. Several different models will exist on the market and various actors will support different models. The market model can be said to constitute the foundation upon which a city chooses to build its smart city solutions and will thus define many of the rules of the game that will apply to applications and suppliers. Two distinct market model trends will be described in the following section:

- Vertical integration and lock-in
- Consortia and partnerships

Vertical integration and lock-in

Vertically integrated solutions and services are an ongoing trend in the development of smart cities.[13] Vertical integration entails the development of a solution for a single special purpose and the use of tailor-made technical solutions, which impedes interaction between different solutions. A vertically integrated solution often creates a dependency on a specific supplier and thus causes clear lock-in effects; i.e., difficulty subjecting the supplier to competition and replacing the supplier. A vertical solution is often initially both easier and faster to introduce, but is not necessarily the most efficient solution from a longer-term perspective, as the opportunity to obtain economies of scale and interoperability with other solutions may be blocked. If a city has implemented a number of vertical integrations, it becomes considerably more difficult to integrate them horizontally at a future point because, for example, standards and data definitions may differ.

Consortia and partnerships

Suppliers of smart city solutions and services are increasingly choosing to enter into larger partnerships when they offer smart city solutions and concepts to cities. In the US market, for example, a major telephone operator has joined with sensor manufacturers, cloud services providers and telecommunications companies to offer total solutions to smart cities. The suppliers are choosing to collaborate to a greater extent because tremendous breadth of skills and technologies is required to cover all the areas necessary to deliver the entire value chain of smart city services. In several interviews, suppliers have stated that they have chosen to work in partnership with regard to smart cities because this allows each partner to focus on their core competencies.

An example of a partnership is illustrated in the following graphic. In this case, the telephone operator is the hub and has overall responsibility vis-à-vis the city. The participating firms split up the value chain for a Smart City, where, for example, one firm is responsible for cloud services, another for the platform, and a third provides sensors and other infrastructure.

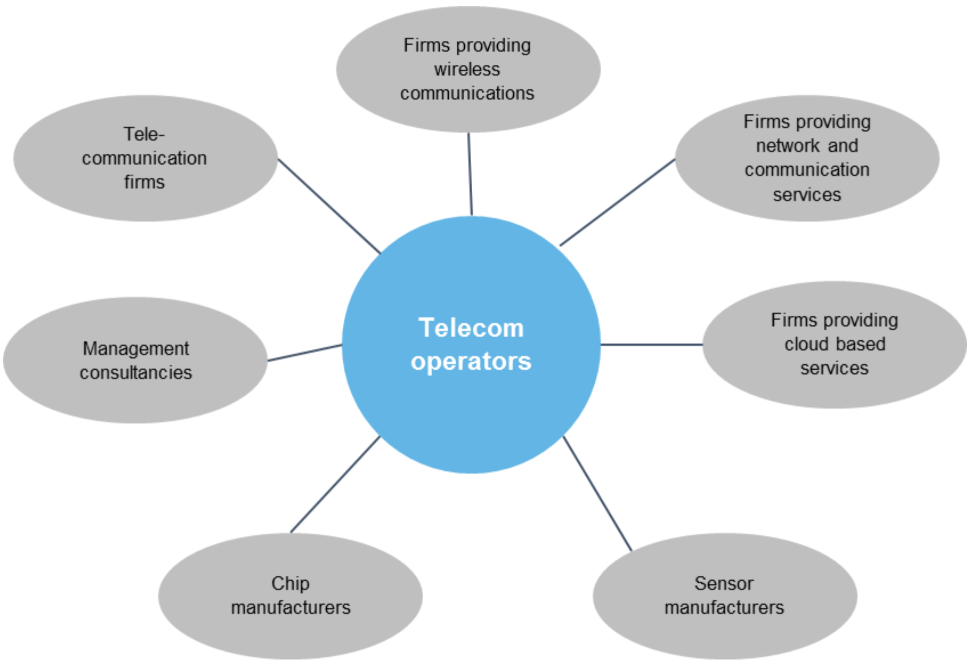

Figure 2: Illustration of a smart cities conglomerate

[13] Interviews with Intel, Ericsson and CGI (2016).

In Sweden, Tele2 has entered into at least 19 partnerships with other firms within IoT to enable the delivery of total solutions to smart cities and businesses. Vodafone has also chosen this route.[14]

Assessment

The market model trends affect actors working in the field of smart cities, where the following areas are important:

- Market model trends are moving towards increasingly vertical solutions intended to lock in customers. Even though market actors form consortia, it limits the number of actors and constrains competition.
- The market is evolving towards an increasingly specialist-oriented digital service sector, which is in itself driving technical development.

The role of a Smart City in the digital social development

For a Smart City to derive benefit from and influence the relevant trends and develop efficient smart services, the following areas are essential to consider:

- As a Smart City, stay focused on being a facilitator that gives firms, residents and administrations the opportunity to innovate and develop services backed up by an open and stable infrastructure.
- Technical trends and smart services are going to create huge opportunities for a Smart City, but it will be critical for the city to have a carefully devised strategy for the underlying infrastructure, such as fibre and wireless networks. It is essential to avoid unaligned standards and to facilitate open and operator-neutral access to the infrastructure, which is a prerequisite for higher innovation performance and flexibility in a Smart City.
- Avoid verticals with the lock-in effects they entail and instead create horizontal solutions. This enables sharing of information and greater flexibility - where a Smart City does not, for example, procure different application in silos, but instead makes sure that the city's various administrations apply a single strategy to public procurements.
- Firms that deliver smart services to a Smart City should focus on specialist expertise rather than delivering total solutions. This focus is essential in connection with procurement of smart services because the lock-in effects are exacerbated when one firm has control over several layers in a Smart City. Lucid thinking in relation to procurement will drive digital service development and innovation in a positive direction.
- The technical trends IoT and 5G are going to increase demands for an expansive and robust fibre and wireless network.

[14] Interview with Tele2 (2016).

Reference model for a Smart City

Reference model

An increasingly complex environment of rapid development of technological fields, market models and applications is generating a need to create an overall view and for the capacity to conceptually structure the various components that together create efficient solutions for cities. A common method for conceptualising a field is to design a "reference model" which, based on simplifications, constitutes a point of departure for building specific, situational models. A reference model is an abstract framework for understanding components and their interrelationships in a particular environment and can therefore be used as a basis for training, as well as to explain patterns and correlations to non-specialists. A reference model is usually not concrete as to the details of implementation, but is instead intended to provide common semantics that can be clearly used across and between specific models and facilitate communication, learning and comparisons of the models.

A general reference model for the main components linked to smart cities is described in the following section. In this case, the "main components" are larger ICT areas that together form the platform of and enable the various applications of a Smart City.

The starting point for the smart cities reference model is a division of the main components into six distinct "layers": infrastructure, communications, sensors, data platform, applications and security.

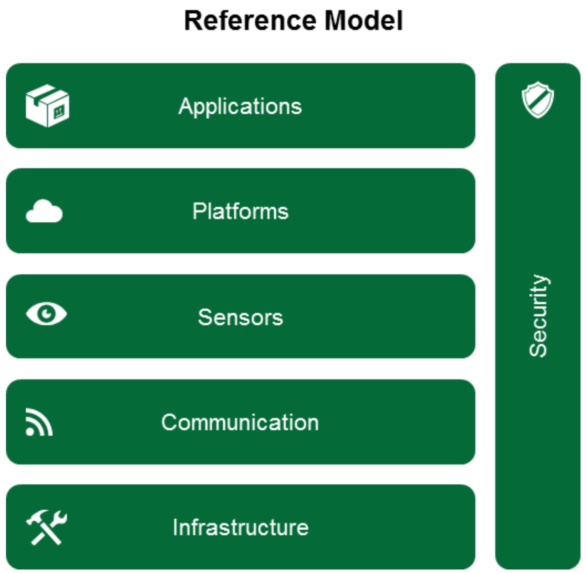

Figure 3: Reference model of a Smart City infrastructure

The relatively simple model provides an opportunity to communicate and compare specific solutions and models across organisations and interest groups, while enabling comparison of the advantages and drawbacks of specific solutions. In more concrete terms, the model provides the following benefits:

- It constitutes a basis for choosing and comparing the advantages and drawbacks of different market models and for determining how a city can influence/stimulate service development.
- It provides an opportunity for better shared understanding and consensus across a city's various units, administrations and firms with joint responsibility for various Smart City solutions and applications.
- It promotes the development of horizontal solutions and elucidates the effects of vertical solutions.
- It creates the conditions and capacity to establish technical standards and specifications for individual solutions.

Horizontal integration is an important key to achieving collaboration among the various units of a city and maximising citizen benefit.[15] Integrating all units within a city is not an easy solution, as a city often consists of thousands of units and systems, but it is important to have a strategy from the outset for horizontally integrating all the layers in a Smart City's infrastructure. This applies all the way from installation of the fundamental fibre infrastructure for broadband and its services to the platforms that collect data.

The layers of the reference model are described in greater detail below.

Infrastructure

Infrastructure refers to the broadband infrastructure, such as fibre, copper, or coax. These three broadband infrastructures enable the delivery of data, which is the basis of the ability to connect a vast number of sensors and deliver huge quantities of data and information within a city.

Fibre is the most frequently applied and future-proof technology. There are no technical limitations and fibre delivers symmetrical – equal up and downstream – speeds that are also considerably higher than provided by the other alternatives. In addition, the bandwidth does not have to be shared by end users, capacity is not distance-dependent, and latency is low.[16] Low latency (delay in the network)- is a very important quality factor for enabling applications such as self-driving cars and various health care applications, such as internet surgery.

A detailed comparison of the characteristics of the three network technologies, copper, coax and fibre, is provided in Appendix III.[17] A summary of these characteristics follows.

VDSL2 is the most common technology for the copper network, which can deliver speeds of about 60 Mbps downstream and 10 Mbps upstream. Newer technologies for the copper network are in trials, where G.Fast, for example, has the potential to deliver up to 500 Mbps when distribution points are used within 100 m of the end-user (FTTdp). Due to the inherent resistance in the copper lines, however, capacity declines rapidly as distances increase, which also means that G.Fast is limited to only shorter distances.

For operators that utilise the coax network, the next development of the technology is the DOCSIS 3.1 protocol. This protocol has demonstrated the ability to deliver speeds of 1-10 Gbps, but the speed has to be shared among end-users. The technology does not deliver symmetrical data transmission and upload speed is generally significantly lower than

[15] IEC (2015): *Orchestrating infrastructure for sustainable Smart Cities*.
[16] Broadband World Forum (2015): *FTTX: Delivering the future of connectivity.*
[17] European Commission (2014): *Guide to High-Speed Broadband Investment*.

download speed. Like the copper network, the capacity of the coax network is sharply limited by the distance between the end-user and the distribution point.

FTTH/B (Fibre) delivers symmetrical and considerably higher speeds that do not have to be shared by end-users and capacity is not distance-dependent. Of the existing infrastructures, FTTH/B is the most complete and future-proof technology.[18]

In addition to an expansive fibre network, a wireless network is required because it is very costly and impossible in practise to link all sensors via a fixed connection. The wireless network needs to be reliable and high-performance to work effectively and manage the data transported. A wireless network also makes it possible for residents to communicate with the city's various systems and applications in real time via phones and tablets. The wireless network can transmit data through, for example, Wi-Fi, 4G/5G, or Bluetooth. However, a Smart City cannot rely solely on wireless connections. An expansive fixed infrastructure is also required for the wireless networks to function effectively. Fibre is the best solution and when it comes to 5G, for example, it is the only infrastructure with adequate technical performance, as it can both transport information over long distances and handle large quantities of data.

In order to realise a Smart City, it is necessary to secure access to fibre not only all the way to buildings, but also into the street space in order to meet the needs of trends such as IoT and 5G. In a Smart City, a wider circle of actors (and not only traditional telecom operators) must be given access to the fibre network with a view to enabling multiple applications on the same platform. A Smart City must also ensure that various actors in closely related layers (communications and sensors) can connect to the infrastructure in an efficient way and on market terms to avoid constraining innovation and development and to provide an opportunity to share the infrastructure. The infrastructure layer is one of the costliest components for a Smart City to deploy. Consequently, the wrong choice of actor can be very costly to rectify at a later date.

Communications

The layer above the passive infrastructure consists of communications equipment that makes it possible for the actors in a Smart City to transmit information in various formats and according to different standards, thus enabling various types of capacity and transmission services such as Wavelength and Ethernet services, which are often performed by a communications operator (free-standing or as part of a larger operator's business). The actors in this layer own the active equipment, i.e., the telecommunications equipment such as switches that enables more advanced communications services and makes it possible to transmit data over the passive infrastructure.

For a Smart City, it is essential that different actors are able to transmit information over the passive infrastructure to provide the prerequisites for innovation. It is in the city's best interests to keep the infrastructure open and available to as many as possible to transmit information over the network. This avoids lock-in effects that can arise if an external actor owns the underlying infrastructure. A Smart City can also separate and manage the communications layer itself. The city's various operations can then procure services on this platform in full competition. In so doing, the city can make optimal use of the specialist expertise found in private firms.

Sensors

Sensors and other scanning tools help smart cities collect information where this was formerly too complex or time-consuming. The sensors also allow the information to be

[18] Broadband World Forum (2015): *FTTX: Delivering the future of connectivity.*

analysed and monitored in real time, which was not feasible in the past. The areas in which sensors can be used include collecting information on energy use, water use, infrastructure and transport by placing them in everything from street lighting to parking meters to waste bins. Many manufacturers of products for public spaces have also begun integrating sensors as standard in their products. The sensor networks generate big data, which puts demands on the infrastructure and the capacity of communications equipment to process the data that is transmitted.

As sensors come in many variations and have a wide range of uses, it is important for a Smart City to have a consistent strategy for standards and protocols so that the infrastructure does not become too complex and to create smooth communication and uniform data.

Data platform

Sensors and other scanning tools are critical components for collecting vast quantities of data and information. A technical platform that is capable of collecting and aggregating data and information is necessary to manage this big data. The role of the data platform is to receive, process and make information available for smart solutions and services.

As sensors generate big data, it is important that the platform is built in such a way that it can communicate with many devices and that there is a clear, embedded structure for storing and managing data using established standards and regulations.

The data platform may be cloud-based or operated and managed by the city itself. The advantages of cloud services are that initial investments are smaller, data storage can be easily scaled up and the city only pays for what it actually uses. The drawback of cloud services is the risk that the city will lose control over the data it collects because actors other than the city often own the cloud infrastructure. For this reason, it is vital to clarify in the specifications and contracts who owns the data, especially with regard to data for which there are potential privacy concerns.

One of the goals for a Smart City is to ensure the openness of data to the city’s stakeholders and citizens. It is therefore important that the city has data platforms capable of collecting information from many different sensor networks and to require interoperability from the actors involved in the smart city. The main goal for the smart city is to create a data storage solution that is as integrated as possible and avoid most parallel data platforms, thereby creating the conditions for a uniform solution and openness of the city’s data. Ownership of data is another central issue, and every city should thoroughly analyse the issue of who owns the data and the consequences of external ownership of the city’s data and information.

Applications

The applications layer is the foundation that makes it possible to use, process and derive value from the data generated. The city’s stakeholders can use collected data to analyse, take decisions and modify it for specific purposes. Ultimately, there is an end user that gains access to the modified information using, for example, an application in the user’s smartphone, tablet or PC. A single data point can thus serve a plethora of uses.

The role of a Smart City in the applications layer is primarily that of specifier rather than applications developer. The city should ensure that the rest of the infrastructure is in place to make it easier for other actors to develop their applications. The development of applications is generally better suited to an external actor rather than the city itself, but the city should prevent the creation of too many vertical applications. Instead, actors should be encouraged to combine various data points to create better horizontal solutions. It is also important that the city has a facilitating role in the applications layer and encourages both private individuals and firms to develop applications that make the city a better place to live, e.g., by conserving the city's resources or reducing environmental impact.

Security

All actors working in the field of smart cities encounter problems related to security and privacy.[19] The increased risk is due to that sensors can be hacked to produce false data or third parties may gain access to information they should not have access to. The main goal of a Smart City is to have more connected devices, which entails more data systems and data flows while the city is supposed to give government agencies, private firms and consumers access to certain parts of the information, which puts higher demands on security.[20] The more people and organisations that have access to the city's data, the harder it is to establish an overall view and control. This implies tremendous demands on the city to safeguard privacy for the city's stakeholders.

In many cities, the big data produced by all the devices and sensors is stored in various cloud services. For these cities, it is important to set up adequate security procedures to prevent confidential data from leaking out to unauthorised parties.[21] Having a combined infrastructure with both cloud services and physical storage sites makes it difficult to gain a clear overview of all parts of the system.[22] Relatively innocent data – such as data on waste collection – can expose the living habits of individuals and vulnerabilities in public infrastructures in a manner that violates privacy. Consequently, control over public data collected by the public sector demands an approach based on considerations of privacy and public security.

The city needs to take an active role in security work at all layers of the reference model, where the city can either take overall responsibility or a supervisory role. The important thing is that the city has resources with security expertise in order to understand and avoid attacks from unauthorised parties and prevent external actors from abusing the city's information.

[19] National Institute of Standards and Technology (2015): *Designed-in Cyber Security for Smart Cities: A Discussion of Unifying Architectures, Standards, Lessons and R&D Strategies*.

[20] DarkReading, InformationWeek (2015): "'Smart Cities' 4 Biggest Security Challenges".

[21] European Network and Information Security Agency, ENISA (2012): *Critical Cloud Computing*.

[22] Cerrudo, C; IOActive Labs (2015): *An Emerging US (and World) Threat: Cities Wide Open to Cyber Attacks*.

The choice of market model and the consequences

The reference model as support for choosing a market model

A reference model does not only support communication and comparison of specific ICT models for smart cities, but can also work as an efficient decision support model for choosing a market model for an individual city. As it is used here, “market model” refers to how a city chooses to organise and manage the various areas described in the reference model. The market model can be said to constitute the foundation upon which a city chooses to build its smart city solutions and will thus define many of the rules of the game that will apply to applications and suppliers. Based on the reference model, the advantages and drawbacks of various market models can be clarified and a number of central areas for smart cities can be discussed, such as:

- How a city chooses to organise its own resources
- What the city chooses to own and operate versus the components and areas for which it chooses to engage external suppliers
- The areas where the city should seek horizontal solutions and standardise interfaces and solutions, etc.
- How the city can establish a clear and efficient model for governance and decision-making
- Which supplier models can be applied and what effects and limitations these may entail

Supported by a reference model, the dialogue between the city’s internal actors and potential external actors can be facilitated and simplified. Strategy and targets for a Smart City can also be clarified based on a reference model, thus providing support for planning and execution of relevant and adequate activities to fulfil the strategy and attain the targets.

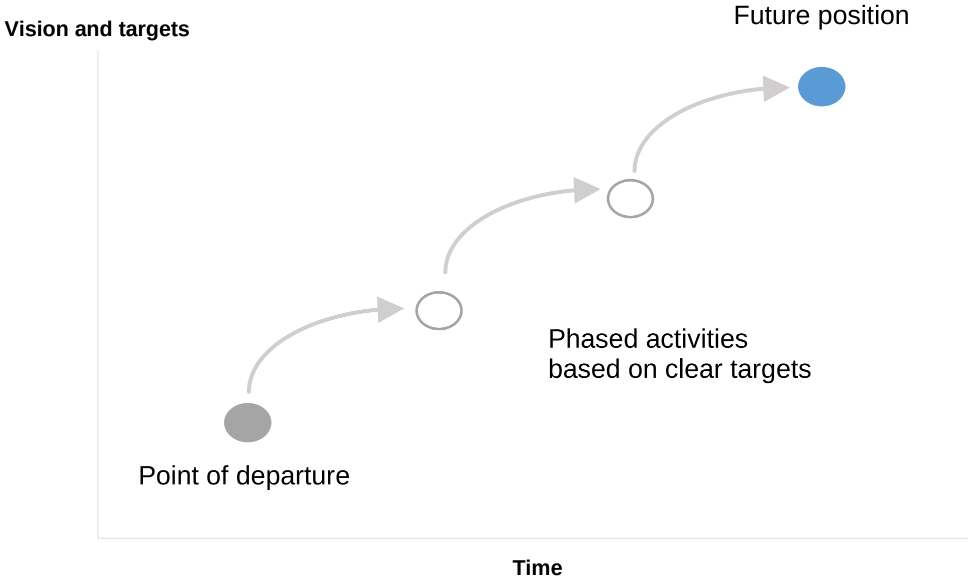

Figure 4: Future vision and targets

In connection with the rapid development of solutions for Smart Cities, the importance of the chosen market model is going to significantly increase. Several different models will exist on the market and various actors will support different models. The ability to clearly assess and communicate the advantages and drawbacks of various models based on key decision criteria will thus be of great strategic importance to an individual city.

Strategic decision criteria

The choice of market model will have both short-term and long-term effects for a city in several areas. It thus becomes extremely important for an individual city to have clear criteria for analysing, understanding and assessing the effects, particularly the long-term effects. Five evaluation criteria are likely to be particularly important: flexibility, finances, innovation, knowledge and security. Each selected criterion is described in more detail below.

Flexibility
Flexibility refers to the opportunities and limitations that a market model gives a city with respect to adapting to external changes and conditions with good planning and at the right time. Key questions include:

- How does the market model affect the city's opportunity and capacity to adapt to and benefit from new technologies and applications?
- What lock-in effects and limitations, if any, might the choice of market model entail?

Finances
The finances criterion refers to the short-term and long-term economic impacts of the choice of market model on a city. Key questions include:

- What costs will arise over the short and long terms?
- What opportunity does the city have to influence and reduce costs?
- What are the effects on cash flow?
- What opportunity does the city have to predict and plan for costs and cash flow?

Innovation
Innovation refers to the impact of the market model on openness and innovation capacity with regard to technology, applications, organisation and processes for a Smart City. Typical key questions include:

- How are opportunities for competition affected with regard to solutions and services?
- How is the city's innovation capacity affected?
- What are the impacts on open innovation and on creating an environment where as many stakeholders as possible can contribute creativity and innovation?
- How is the city's capacity to change affected? That is, what are the impacts on opportunities to implement and manage changes driven by new innovations and suggestions for improvement?

Knowledge
Knowledge refers to the effects of a market model on a city's potential to build knowledge and skills. Key questions include:

- How are knowledge and skills spread and shared?

- What limitations, if any, does the market model impose on the potential to share information and build knowledge and skills?
- To what extent does the market model entail risk of centralisation of knowledge and skills?

Security

The security criterion refers to the impact of a market model on security and privacy aspects such as ownership and control of data and the ability to protect data and information. Typical key questions include:

- Does the market model affect the city's ability to control data and information?
- How are opportunities to analyse big data affected?
- What risks, if any, does the market model entail with regard to data and information security?

The questions under each criterion can be further expanded and should be adapted to the situation and needs of each individual city.

Potential market models

Three possible market models are analysed in this section based on the strategic decision criteria defined above. The chosen models clarify how a city can take a stance on the strategic decision criteria and the long-term consequences of a specific model. The models illustrate possible choices where the city can either take a distinct role of responsibility or choose an external actor to be responsible for the Smart City. The models are general and describe the differences on an overall, simplified level, while in reality there are many different permutations of market models. The following three general models will be discussed and explained:

- Operator Model
- Specialist Model
- Collaboration Model

The three models above were chosen in order to clarify the differences in effects that can arise when different models are applied. For this reason, the models have been deliberately streamlined and stylised.

Operator Model

In the Operator Model, a Smart City chooses an external actor that takes total responsibility for all layers in the reference model. This means that the external actor is responsible for the entire chain, from the passive infrastructure to developing applications, as well as for data and information security. The model is probably not the most common, above all because it is difficult for an actor to be responsible for all layers over time, as this requires a very wide range of knowledge and skills, especially because technical complexity is very high for a Smart City. Theoretically, only operators with their own networks can assume total responsibility, which is why it is called the Operator Model. The model can be likened to the early IT market in which systems were developed in vertical solutions by a single supplier, from hardware to end-user applications. As the IT market matured and common standards, etc., were developed, solutions based on a more modular perspective were made possible, with the option to choose both technical and application solutions.

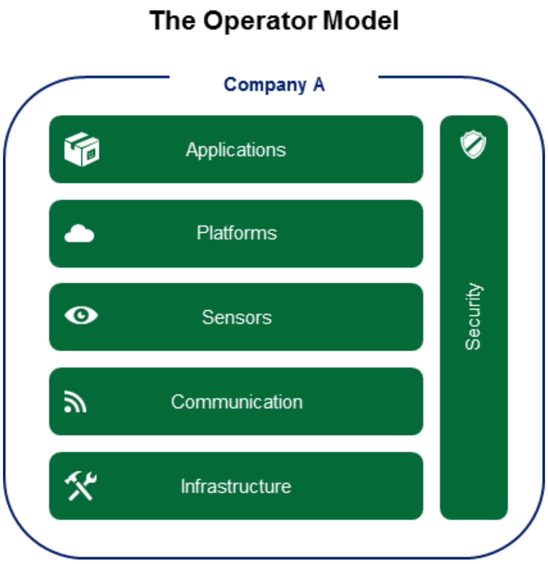

Figure 5: One external actor is responsible for all layers in the reference model

Flexibility

The Operator Model entails high risk of lock-ins because a single actor is responsible for all components of the Smart City. This may make it harder for a Smart City to adapt to new technologies and trends because the implemented standards and solutions will be mainly those of the total supplier, which entails future risk of difficulty in rapidly adapting to new technologies and trends.

The Smart City will also experience difficulties in executing competitive procurement of certain layers, such as fibre infrastructure, in the future because a clear lock-in effect has been created. It can also be problematic to allow a total supplier to take charge of the data platform; in this regard, the city should ensure ownership and control over data and information.

Finances

Short-term, an Operator Model may be an attractive solution for a Smart City, as a single supplier assumes total responsibility and is thus more likely to able, initially, to act faster and more cost efficiently. Long-term, however, the risks may be exacerbated for the Smart City as lock-in effects may ensue, making it difficult for the city to subject the existing supplier to competition. An Operator Model can also entail high costs for the city if it wants, for example, to replace components or layers such as the data platform or to install new sensors if the new technologies and solutions are incompatible with the old ones.

Innovation

Both innovation capacity and the capacity to change tend generally to be affected negatively by the Operator Model because there is risk that lock-ins and monopoly situations may arise when one supplier has control over all layers and can therefore design and build vertical solutions based on its own standards and solutions. Vertical solutions with a single supplier tend to reduce other actors' capacity to drive innovation and development. The negative impact of verticalisation on innovation can be partially mitigated through structured procurements and contract design, but this tends to be more difficult when the external party has total responsibility for the entire vertical.

Knowledge

A Smart City is a complex ecosystem with infrastructure, network and IT components and it is therefore difficult for a single actor to have all the knowledge and skills required to deliver all parts of a solution. The complexity was clarified in the trend section, where it was shown that suppliers often chose to enter into partnerships or larger consortia so that they will have the capacity to offer the best possible solutions for smart cities. There are also long-term risks involved when a city relinquishes control over all layers and components in a Smart City solution, as it may be difficult in a later phase to rebuild knowledge and skills and regain control. For a model like the Operator Model to have any chance of working, the city needs to take a very active role and be well integrated with the firm responsible for the Smart City and ensure that the city has the expertise required to replace a supplier with own personnel or successfully carry out a public procurement and transition to one or more new external actors.

Security

From a security perspective, the Operator Model can provide efficient solutions, provided that the chosen supplier has the right skills and capacity. It may, however, be more difficult for the city to have direct insight into security issues when the external supplier has total responsibility. In particular, ownership of data and information becomes a key issue.

Specialist Model

In the Specialist Model, one or more actors, city administrations and external suppliers design and develop vertical solutions for individual applications. As a result, the market model becomes fragmented because the layers of the reference model are divided into many parts, with verticals for each application area and with one or more actors. Compared to the Operator Model, the risk of verticalisation remains, but with multiple verticals rather than the single vertical of the Operator Model. A division does not, however, necessarily have to be a drawback in all layers, even though horizontal integrations are generally to be preferred in order to obtain economies of scale and interoperability among a city's various applications. There are areas higher up in the value chain where vertical integrations can work, such as within the applications and communications layers. The reason for this is that the risk of lock-ins diminishes the higher up you come in the value chain. Vertical integration comprising the fundamental infrastructure layer, for example, can entail high costs and long-term lock-ins. The Specialist Model can be effective if the individual city chooses to assume responsibility for certain parts or has a clear structure for how the Smart City should be managed and how each layer should be handled to enable economies of scale and interoperability.

The Specialist Model

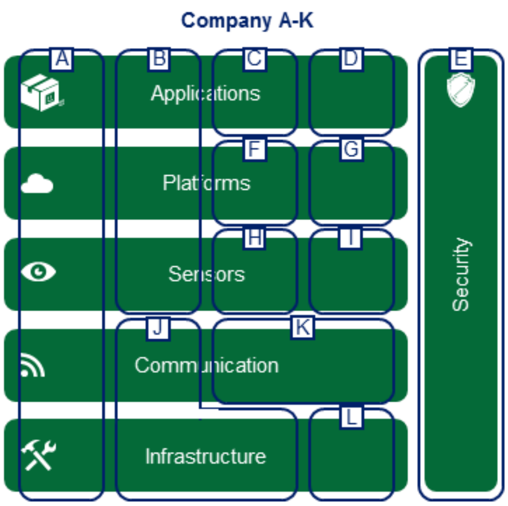

Figure 6: The Specialist Model - one or more actors, administrations and external suppliers design and develop mainly vertical solutions per application. In the illustration, each letter represents one actor.

Flexibility
The Specialist Model is a flexible model in which new technologies and applications can be designed, developed and deployed relatively quickly. The challenge involved in the Specialist Model, however, is that of deploying new technologies or applications across the city's verticals and ensuring interoperability and economies of scale because the applications become more autonomous and independent. There are also difficulties involved in implementing changes on a large scale when the smart city is fragmented into multiple applications verticals with limited overarching management.

Finances
As many specialised actors are involved in the model and develop their own application-specific verticals, the Specialist Model can be more costly than it would be for a single supplier to offer a cohesive total solution. There is also risk that vertical lock-ins will be created per application area, which can, over the long term, constrain the city's opportunities to establish competition and drive costs down, as it becomes difficult to facilitate synergy effects between applications across all layers of the reference model. Generally speaking, however, lock-in effects are smaller with the Specialist Model than with the Operator Model.

Innovation
The Specialist Model is a good model with regard to maintaining innovation capacity within the city because it creates an environment that provides scope to test solutions and suppliers on a small scale. However, it becomes more difficult to implement larger changes because the Smart City becomes fragmented and it becomes harder in a future phase to horizontally integrate verticals and develop new solutions, due to the lack of a common platform.

Knowledge
In terms of knowledge and skills, the Specialist Model has relatively good effects because it gives suitable parties the opportunity to design and develop applications for each area, although this creates vertical lock-ins. In this model, the city also has the option to assume responsibility for various parts of the model if the city is better equipped to do this than the available external suppliers. It is more difficult, however, for the city to gain overall control because the Smart City becomes relatively fragmented in terms of applications.

Security
The Specialist Model makes it considerably more difficult to maintain security and data privacy because multiple actors are involved across the layer. It is also important, as shown in the section on the reference model, that there is an overall function that manages security for the smart city, which is not necessarily aligned with the structure of the Specialist Model.

Collaboration Model
In the Collaboration Model, the city takes main responsibility for the layers in the reference model that are critical to providing the conditions for diversity of actors and services and thus fostering competition in order to avoid negative lock-in or interoperability problems. The Collaboration Model is based on horizontal solutions for the various layers, aimed at driving economies of scale and synergies. Earlier reports from Deloitte have shown that an operator-neutral fibre supplier with a network designed and built for multiple operators and service providers higher up in the value chain is a highly efficient solution for creating diversity and competition. The "municipal network model" found in Stockholm, for example, demonstrates that it is possible to establish open and operator-neutral networks, which is essential to fostering competition at the retail level and diversity in the range of services offered to end users. In addition, the Smart City that applies the Collaboration Model maintains control over the communications layer with regard to procurement and selection of

the actors that manage the communications layers for the city's administrations. As a result, the communications layer is separated and greater competition is enabled in the upper layers because the city's various operations can procure services in the upper layers in full competition and with several potential suppliers. Finally, the city also has an active role in the work with security and data privacy for the entire reference model. This can be done entirely independently or jointly with an external actor, but the city should be closely involved in these aspects, as described in the section on the reference model.

Other parts of the reference model are performed by external actors or by the city, depending upon which is best equipped to do so. If the choice is for an external actor, it is important that the city has a clear specifying organisation with an overall view to prevent vertical lock-ins. The goal for the specifying organisation is to have a horizontal perspective on each layer and to verify that all internal and external actors comply with set standards and procedures so that the city's verticals are able to communicate with each other.

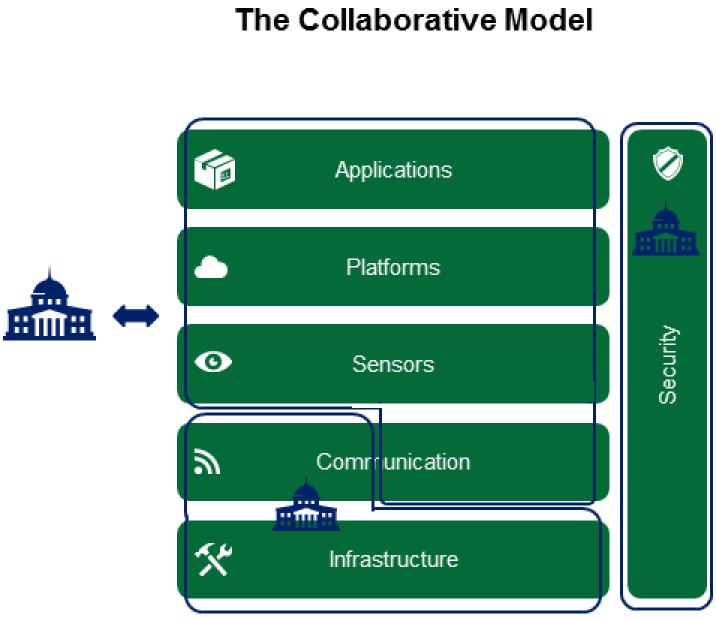

Figure 7: The Collaboration Model - The city is responsible for infrastructure, security and the city's procurement of communications services and works closely with responsible actors for the other parts of the reference model.

Flexibility

As the city is responsible for the infrastructure, which is the layer that can generate the biggest lock-in effect, openness in the other layers increases. The key success factor is that the city can provide other actors with an operator-neutral and service provider-neutral fibre infrastructure, i.e., that the city does not have its own commercial interests to protect in the other layers. The city also gains a clear specifying organisation, which ensures that actors working in the Smart City conform to set standards and procedures for communications and security solutions. This prevents vertical lock-ins and promotes interoperability.

Finances

If the city already owns an expansive fibre and communications infrastructure, the initial investment costs and operating costs will probably be lower than for the other two market models. However, costs may be incurred if further expansion and changes to the underlying infrastructure are needed. Any new establishment will require heavy investment and will probably take several years to carry out. The investments and deployment time must, however, be put in relation to the beneficial effects in terms of fostering competition and greater diversity of suppliers in the other layers and the access to an operator-neutral fibre network. A "build-operate-transfer" arrangement is an alternative to the city making the investment itself. In this arrangement, the initial investment is made by an external actor in exchange for an operating agreement under which the infrastructure is successively transferred to the city and where the city wholly owns the infrastructure after the transition.

Innovation

Access to an open and operator-neutral fibre and communications network fosters competition at the retail level and creates diversity in the range of services offered to end users. The verticalisation that can often arise when an individual actor owns the entire value chain and all layers can be avoided, which allows a platform for innovation to be created in the upper layers, especially the data platform and applications layers, which are central to driving the development of new applications and analytical services.

Knowledge

As the city retains performance responsibility for several of the layers in the reference model according to the Collaboration Model, knowledge and skills can be retained and developed. Through simultaneously opening the upper layers to multiple actors and potential suppliers, an environment is created in which knowledge and skills development can be advanced by a large number of stakeholders. By maintaining its internal expertise, the city also has the ability to effectively act as a link between the city's internal administrations, external suppliers and other actors. In addition to maintaining skills within the city, the model assures the potential for more extensive collaboration at the regional and national levels.

Security

According to the Collaboration Model, the city is responsible for the security level and can thus control and assure the quality of data and information security as well as personal privacy to a greater extent. Through clear ownership of security and ownership of critical data to the greatest possible extent, a city is created in which security is a cornerstone and where technical solutions can be developed in compliance with the city's policies and guidelines for data and information security.

Market models in summary

Based on the previously described reference model, three theoretical market models for a Smart City have been outlined: the Operator Model, the Specialist Model and the Collaboration Model. Each market model was then assessed based on five strategic decision criteria in order to clarify the respective consequences and effects. The assessment shows that the Collaboration Model is an effective model because:

- It gives the city's actors access to an open and operator-neutral fibre infrastructure, which provides an avenue to competition and diversity, which by extension drives innovation as well as knowledge and skills development.
- It gives the city an opportunity to drive horizontal solutions that enable a higher degree of interoperability among applications and technologies while providing greater potential for synergy effects and ensuring economies of scale.
- It reduces the risk of verticalisation and lock-in effects and gives the city a route to efficient, competitive procurements and supplier agreements.
- It gives the city the opportunity to maintain control over the critical security layer in the reference model.

The city can develop a specifying organisation in which procurement and development do not occur in silos and key skills can be retained. This makes it possible to more efficiently link internal needs to external actors and suppliers.

The table below shows an overall assessment of each market model based on the strategic decision criteria.

Table 2: Assessment of the market models

	Operator model	Specialist model	Collaboration model
Flexibility	◑	◑	●
Finances (long-term)	◑	◑	◕
Innovation	◑	●	●
Knowledge	◑	●	◕
Security	◕	◑	●
Total	◑	◕	●

Conclusions and recommendations

Development of smart city solutions and applications is proceeding apace, driven by factors including rapid technical progress in areas such as IoT, cloud services and big data. For a city, with its many different units and operations, creating good opportunities for interoperability among applications and technologies and ensuring synergies and economies of scale across them all is a major challenge. Avoiding vertical solutions that act as silos is an important key to success. This will require a horizontal perspective in which common layers are created for various areas, with clear standards and guidelines for applications and technologies. It will be a key task for every city to define a "game plan" for its development towards becoming a Smart City, i.e., what conceptual model for development is chosen and how the city can create an open environment that fosters competition and diversity and thus innovation and development of new and efficient technologies and applications. Increasingly, the services provided by cities – everything from traffic control to elder care – are moving into a digital environment or are being given digital components or ancillary services. In this context, it is vital that a city assumes responsibility for the digital infrastructure, just as it previously assumed responsibility for analogue services and infrastructures and ensured that they worked efficiently together. In so doing, the city will assure its strategic management and development of the areas for which it is responsible, now and in the future.

The reference model developed within the framework of this report may serve as a good basis for defining the conceptual vision that every city needs to establish and which should be aimed at creating horizontal solutions and platforms that reduce the risk of vertical applications that cannot be integrated. In addition, the reference model may function as a point of departure for discussions of smart services intended to work together for multiple cities and municipalities at the regional and national level. For natural reasons, the focus of this report has been the role of cities in relation to the Smart City. However, the national and EU-level also plays an important role in creating the overarching conditions for a Smart City, both in the form of incentives and clear rules of the game that foster development. In addition, the national and EU level may have an integrative function and contribute with skills and exchange of experience.

The reference model

The reference model we have designed is based on six layers. By necessity, the model is a simplification of reality, but it does give a city a shared picture on which to base discussions, internally and with other stakeholders, of central issues relevant to a Smart City, such as ownership, responsibility, interoperability and standards. The six layers cover:

Infrastructure

- The infrastructure layer includes the fixed infrastructure, where fibre is the best and most future-proof solution. Fibre has no technical limitations and it delivers symmetrical, and considerably higher, data transmission speeds than the other alternatives. Ownership and control of the infrastructure are vitally important to a city that wants an open and operator-neutral market model for its Smart City that enables competition in the upper layers in the reference model.

Communications

- The communications layer includes the active communications solutions that are the basis for end-user services and applications. A Smart City should make a carefully considered decision when it chooses the supplier of the active communications infrastructure in order to avoid lock-in effects. If possible, the chosen supplier should not be active in the upper layers in the model, as this entails a risk of constraining competition and innovation with regard to services and applications.

Sensors

- The sensors layer refers to the various devices (IoT devices, beacons, etc.) that are used to collect data and information within the city. A Smart City should have a consistent strategy for the use of sensors with regard to standards and protocols for facilitating data communications and creating uniform data. The aim here is to avoid costs that may arise in the future when various verticals must be integrated.

Data platform

- The data platform level refers to the aggregate data and information that the city collects and manages. The city must ensure openness to big data for the city's stakeholders so that the stakeholders will be able to combine data points from different verticals in order to create useful and efficient services and applications. It is also important for a Smart City to build a flexible data storage solution in order to avoid unnecessary investments in infrastructure that may rapidly become obsolete.

Applications

- The applications layer refers to the solutions and applications developed for the city's stakeholders and citizens. First and foremost, the city shall act as a specifier for applications, where it shall make sure that the rest of the infrastructure is in place to facilitate for other actors to develop their applications.

Security

- The security layer refers to the technologies, solutions, etc., that will assure data security and privacy across the city's solutions and applications. The city should have a central strategy for security and the orientation should be to have a main actor that is responsible for overall control of the city's various horizontal layers.

Market models

Based upon the reference model, several different market models, i.e., practical applications of the reference model, can be defined. Three models have been discussed and assessed in the report: the Operator Model, the Specialist Model and the Collaboration Model. The models have different properties and characteristics and thus have different effects and consequences. In order to clarify the effects and consequences and to understand the differences between the models, they were assessed and compared in relation to five criteria (flexibility, finances, innovation, knowledge and security).

The conclusion of the assessment is that the Collaboration Model is the most suitable for creating a future-proof, flexible and innovation-enabling model for Smart Cities. According to the Collaboration Model, the city assumes main responsibility for:

- The fibre infrastructure, where the city itself and external suppliers have access to an operator-neutral fibre infrastructure, leading to an open and innovation-friendly Smart City.
- Security and data privacy, as this is going to be one of the most important aspects when a Smart City generates vast quantities of data that may impinge upon the privacy of the city's residents.
- The specifying organisation that sets standards and procedures for the roles of both internal and external actors in the model, and with horizontal solutions as a clear target.

With regard to other parts of the reference model, the actor that is most suitable for the task should be responsible; here, the city can perform these parts itself if it is the most suitable. Regardless of the choice, it is important that horizontal solutions and platforms characterise the smart city, with a view to avoiding vertical lock-ins that can potentially become very costly and inefficient for a city from a long-term perspective.

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Per Gadenius, Global IoT Partners Manager, and Joakim Elmquist, Director IoT Solution Consultants, Tele2.

Appendix II - Acronyms

DOCSIS	Data Over Cable Service Interface Specification
FTTB	Fibre to the Building
FTTC	Fibre to the Curb
FTTH	Fibre to the Home
FTTN	Fibre to the Node
FTTP	Fibre to the Premise
ICT	Information & communications technology
IoT	Internet of Things
IpV6	Internet Protocol version 6
GBPS	Gigabits per second
MBPS	Megabits per second
LoRa	Low Power Wide Area Network
OECD	Organisation for Economic Co-operation and Development
PTS	Swedish Postal and Telecommunications regulator
RFID	Radio-frequency identification
VDSL	Very high data rate Digital Subscriber Line

Appendix III - Broadband solutions

	Fibre (FTTH/B)	Coax	Copper
Top commercial technology	GbE/GPON	DOCSIS 3.0	VDSL2
Data rate (down/up)	1/1 Gbps (or higher)	300/50 Mbps	60/10 Mbps
Transmission reach	Up to 80 km	0.5 - 3 km (high - low speed)	0.2 - 1.5 km (high - low speed)
Infrastructure characteristics	Fibre is installed all the way to the end-user's home (FTTH) or building (FTTB). The fibre network itself has no technical limitations for maximum capacity – the limit is determined by the active equipment used to transmit light through the fibre cables The only broadband infrastructure assessed as future-proof. Low latency and not limited by distance.	Uses fibre to "feeder stations", then coax cables for the "last mile" to reach the end user at the home or building. The speed must be shared among users, which means that a household can rarely reach the top speed a coax cable is able to deliver (because coax cables are almost always shared among several households). The further development of DOCSIS 3.1 should be able to deliver speeds of up to 10 Gbps downstream and 1 Gbps upstream. The first roll-outs are expected within 1-2 years.[23]	In VDSL, data is sent from the operator to a telecoms cabinet on the street and sent from there via copper cables to the end-user's home (FTTC). The resistance of copper imposes serious limitations on the distance over which signals can be transmitted – this applies especially to high-frequency signals. The further development of VDSL, called G.Fast, is supposed to be able to deliver (asymmetrical) speeds of up to 300-500 Mbps downstream. However, transmission reach is sharply limited and G.Fast has been judged to have a reach of less than 100 m.[24] [25] The latest further development, XG.FAST, has reached speeds of 5 Gbps in lab trials. However, this technology has been assessed as having a long way to go before it is commercially viable.[26]

[23] Cable Labs (2015): "Featured Technology – DOCSIS 3.1"
[24] A symmetrical connection means that it has the same data rate, or speed, both downstream and upstream.
[25] Light Reading (2014): "G.fast: The Dawn of Gigabit Copper?"
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