Roads to Smarter Cities

Colin Harrison
IBM Corporation

Abstract

This article describes how IBM's business and technical leadership teams drew insight from the collapse of the Internet bubble in 1999-2000 and came to realize that the Information Technology (IT) industry had shifted to a new conceptual phase. In this new phase, the ready availability of information about many kinds of real-world activities, combined with network access and semantic integration, and on-line, near real-time analytics, leads to a new point of view that IBM came to call Smarter Planet. Within the Smarter Planet point of view, Smarter Cities emerged as a particular case, growing out of earlier work on large-scale sensing and actuator systems. The article explains how IBM's understanding evolved to lead to these end results.

1. INTRODUCTION

The turn of the last century appeared to some as a very dark period for the Information Technology (IT) industry. From 1994 through 1999, the industry had seen enormous growth - growth of the Internet, growth of the Web, growth of mobile, portable devices, growth of networking, and growth in the integration of IT systems within and among enterprises. Then came the rapid collapse of the Internet bubble during 1999-2000. Some observers believed that this was a temporary, cyclical correction, and that things would shortly return to "normal." Others, however, believed the industry was entering a period in which computers and even software had become generic products, more or less impossible to differentiate. To them, this looked like the end of the high-growth Information Age. In IBM's view, neither view was correct. We believed that the conceptual framework that had led the industry during the 1993-2001 period had disappeared, and the industry needed to find a new one.

2. IBM's STRATEGY

At that time IBM's corporate strategy team discussed what was going on with Venezuelan economist Carlota Perez, who was then at Cambridge University. Perez had been studying a phenomenon that has interested economists for many years, which is called "the long cycle." In her 2002 book, *Technological Revolutions and Financial Capital* [1], she had studied cycles of technology development going back to the Industrial Revolution of the late 18^{th} century. There is a classic economic pattern in these cycles related to inventions as exemplified by the steam engine. Initially, there is a small number of early adoptions, and then there is a very rapid period of growth leading to overinvestment in that industry and then collapse. What follows this initial "installation" period, lasting two or three decades, is an era that Perez called "deployment," in which the infrastructure that has been built out – whether canals, railroads, manufacturing capacity or broadband – is leveraged by business and society to create new value and new institutions. Perez identified five major cycles beginning with the Industrial Revolution and continuing to the Age of Information (see Figure 1).

IBM's question to Perez in 2001–2002 was whether the IT industry was at end of a phase or cycle, that is, the end of the Age of Information. Perez replied that what the IT industry had built so far was in fact the platform for continued growth during a coming Deployment phase. IBM's strategy team then focused on what this deployment phase might be, initially naming it "The Age of Collaboration and Advanced Intelligence."

However this insight was only an early part of the conceptual shift. What we did not fully understand at the time were the full implications of this shift. Perez's theories helped explain how Information Technology had emerged from being primarily an engineering discipline, and had become a force that was having a new and more direct impact on society, the economy and people's activities. We were also beginning to see computing increasingly escaping the computer and being infused into all manner of objects, devices and natural systems. We saw that this pervasive instrumentation, linked through global networks, was generating vast new amounts of data. And we knew, from work going on in our own labs, that computing systems and advanced analytics were achieving exponential increases in power – and hence in our capacity to spot patterns in that data. We knew all these facts – but new, inter-disciplinary thinking – a new conceptual framework - was required to understand how this interplay would shape the future of both the IT industry and the global society and global economy.

2.1 Preparing for the Decade of Smart

Figure 2 is a precis of the IBM 2009 Annual Report's account of the prior decade [2]. In the report, Sam Palmisano, IBM's Chairman and CEO, reflected on the period of 1999-2000, which IBM had seen as evidence of broader shifts taking place in the world at that time. One was the end of the PC-centric client/server era and its replacement by a new computing architecture, which came to be known as Cloud computing. This was going to require different capabilities and skills from IT providers. Another was a rebalancing of global economies – sparked in large measure by Internet-enabled global supply chains managed through global logistics. Hundreds of millions of people were moving into the middle class – and they were thus creating global demand for modern, information-centric economic and societal infrastructure. A third was a shift in our clients' focus from productivity to innovation.

Responding to the emerging conceptual framework, IBM changed its mix of businesses, divested commodity products, invested in analytics, built next-generation data centers, embraced Cloud computing, and began to develop green solutions.

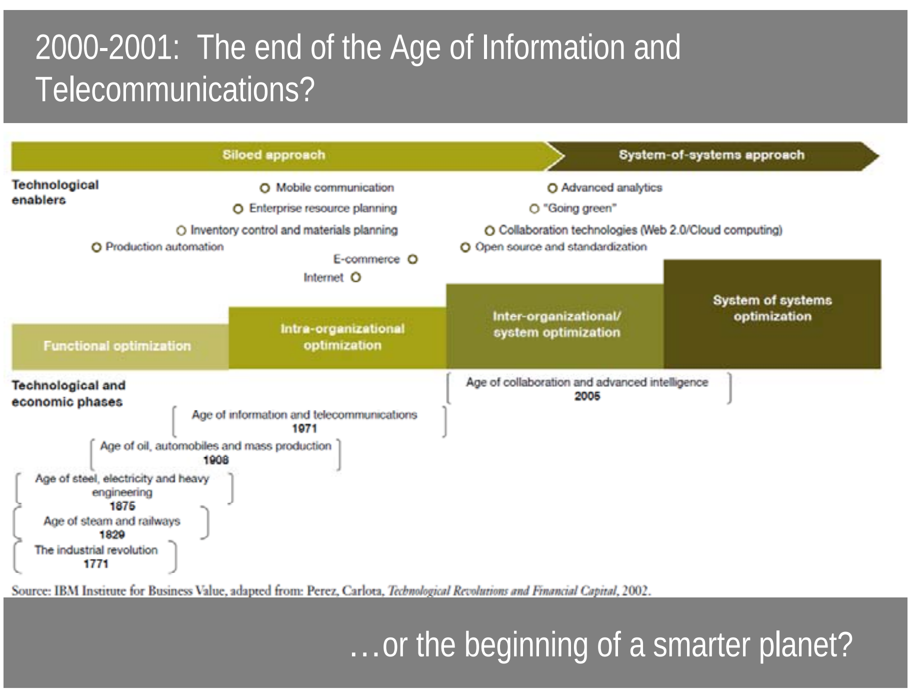

Figure 1 2000–2001: The End of the Age of Information and Telecommunications?[1]

[1] The slides used as figures in this article are actual slides used in period by the IBM

The company used the Internet to implement its own global supply chain. The advent in 2000 of Web Services [3] provided a new way of integrating distributed operations. Whereas IBM's internal focus had been on using computers for efficiency and productivity, it now shifted to the Internet and how to use the globally connected enterprise systems to drive innovation and collaboration. IBM sold off product businesses that were becoming commodities (disk drives, PCs, printers, etc.) and focused on services and software to help its customers deliver innovation.

Figure 2 Preparing for the Decade of Smart.

In this period, IBM also became a globally integrated enterprise. This was a newly emerging organizational form, replacing the "multinational" of the post-war era. Multinational corporations had been an adaptation to the rise of trade barriers and widespread nationalism during the 20th century – leading businesses to create a replica of the parent company in each market, in order to be perceived as local and be permitted to operate there. But with the lowering of trade barriers in the 1980s and the arrival of the World Wide Web in the 1990s, this model became archaic. Corporate functionality could be distributed around the planet, based on economics, access to skills and

teams developing these ideas.

favorable business environments. So, for example, although IBM is a company with its headquarters in New York, its supply chain is managed from China, and other functions are being similarly distributed.

These were some internal impacts of the emergence of the global IT platform, but the biggest changes came from thinking about the rest of the world.

2.2 What important problems should IBM work on?

In 2006 Sam Palmisano held the "InnovationJam," to ask the entire company what important problems IBM should work on going into the 21st century. (IBM's jam platform for large-scale collaboration had been launched in 2001, enabling tens of thousands of people to engage on a moderated set of topics, with results monitored via analytical tools that identified and categorized emerging themes.)

IBM employees and participating family members and business partners came up with a surprising list of answers to Sam's question:

- The Environment
- Energy
- Water
- Transportation
- Carbon Management
- Green Data Centers
- Healthcare
- Business Analytics

At the time, it seemed strange to suggest that a computer company should work on physical infrastructure – such as environment-related issues, energy grids, urban traffic or water management – rather than the traditional domain of IT, managing back-office processes or online collaboration. Today it does not seem so strange, as computing has continued to pervade the physical world and is now infused into things no one would think of as a computer.

The Chairman accepted these responses, and $100 million funding was allocated to conduct ten technical and business experiments based on the InnovationJam results. Not all of these became distinct and successful businesses. Some disappeared completely and others merged into existing activities. But the exercise was valuable in illustrating the kind of future we faced. Our work was increasingly based on, and directed toward, not just the needs and dynamics of particular organizations or operations, but those of planet-scale, complex, emergent systems. Those systems were interdependent with one another. Indeed, we were increasingly seeing the world as a system of systems, in which Information Technology was being closely intertwined with society and individuals' lives. The experiments spawned by InnovationJam were harbingers of our future businesses.

2.3 Applying the new conceptual framework

The next step toward defining and applying this new framework was a new operational approach that emerged from the InnovationJam pilots called the "Instrumented Planet," as illustrated in Figure 2 [4]. IBM realized that there is a great deal more information available about what is going on in the world. This new approach involved the use of sensors, capturing operational data from real-time control systems, and near-real time data processing using enterprise methods and analytics to produce awareness of real-world events. This approach can be used to drive very complex predictive models, enabling simulations to be done in real time so that the outcomes can be used to provide decision support for complex management and optimization processes.

Meanwhile, at the same time that this was going on, the world was changing rapidly. Indeed, the first decade of the new millennium presented a series of globally systemic crises: from security (with the terrorist attacks of 9/11), to energy, to trade (with concerns about supply chains for food, toys and medicine), to climate change, to the global financial crisis. Like everyone else, we saw those crises, and sought to understand their causes and implications. However, these two tracks of perspective and analysis remained distinct from one another. Broadly speaking, the technological and scientific perspectives were not integrated with the business, economic and societal perspectives, except sporadically, and usually in our high-level marketing.

In mid-2008, that changed. The Instrumented Planet approach converged with the view of the Age of Innovation and Advanced Intelligence (Figure 1) and with corporate-level strategy, grounded in the implications of becoming a globally integrated enterprise, to yield the paradigm known as the Smarter Planet [5].

The Instrumented Planet had extended the definition of "sensor" to include "virtual sensors" such as software instrumentation of business processes and even to insights from social communications such as Twitter and Facebook. More broadly, Smarter Planet asserts that, to a large extent, what is going on in the world is knowable and that this information can be subjected to powerful analysis in near real time. The insights gained from this analysis can enable us to improve our use of existing infrastructure and process capacities, to reduce our consumption of resources such as energy and water, and to introduce new flexibilities in how we as individuals exploit these systems. We no longer need to guess about the immediate future; in many domains we can predict it. Often, we have already collected the data.

3. USE OF PLATFORM IN DEPLOYMENT PHASE

As mentioned above, what had been built up through the work of the IT industry by 2000 was a platform for the coming "deployment" phase. Being connected to the real world in near real time and being able to apply complex algorithms to very large amounts of data presented many interesting application areas for such a platform, activities that would use highly complex predictive models. This was the approach IBM adopted for the Smarter Planet initiative.

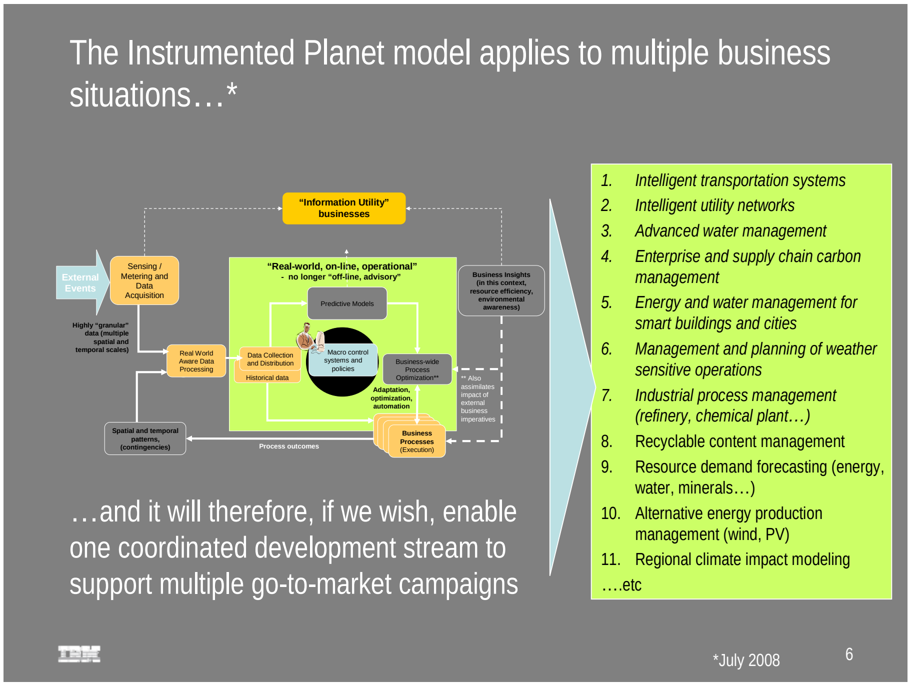

Figure 3. The "Instrumented Planet" Paradigm

3.1 Reference architecture

As shown in Figure 4, the departure point for the Instrumented Planet IT architecture was earlier work from a short-lived IBM business experiment called Sensors & Actuators. This reference architecture decomposes easily into three layers, as shown in Figure 5, and these three layers became the core principles of the Smarter Planet initiative.

The bottom level is called "Instrumented," which means connected to the real world, where there are both physical and virtual sensors and sensing systems. The second layer is called "Interconnected," which means two different things: interconnected through networks, acknowledging the pervasiveness of wireless and wired networks that enable access to the Instrumented layer; and semantically interconnected, the integration of information from very diverse systems, such as transportation and water, into a common information model. The third level is "Intelligent." which means that computational power and efficient algorithms can now be applied to real-world information to perform complex analysis or to drive complex models in near real time, which was unthinkable only a few years ago.

The key to realizing this architecture lay in the Instrumented layer with its sensing and process control, or SCADA, systems, an area in which IBM was not directly involved. IBM realized that it needed to develop a new ecosystem of partners with this expertise. Fortunately IBM had business relationships with many engineering companies that were willing to partner in this area.

3.2 Smarter Planet

At the Interconnected level of the Instrumented Planet Reference Architecture, we can see the processes and choreography of the workflow throughout an organization. We can begin to recognize, out of individual engineering systems, the business processes that are associated with the work flow. Moreover, we can

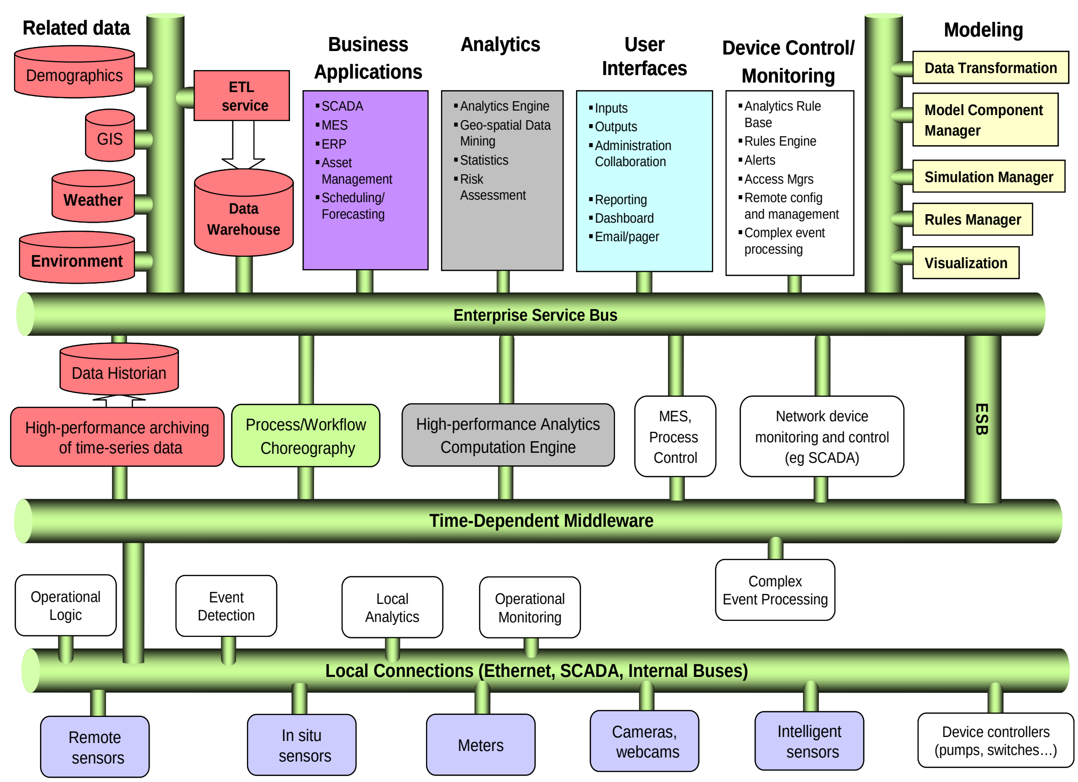

Figure 4. The Instrumented Planet Reference Architecture which was an evolution of earlier work on sensors and actuators.

also begin to aggregate the very large amounts of data coming out of these systems in close to real time. Such systems can produce as much as a 100 TB of data a day. This has led to the creation of very large databases, for historical data, environmental data, geographic data, and so forth.

There are many software tools that can be used to gain insights from the large amounts of data that are flowing upwards. From those insights, under various kinds of policies and various kinds of models, actions can be generated that optimize, for example, the operation of an infrastructure system.

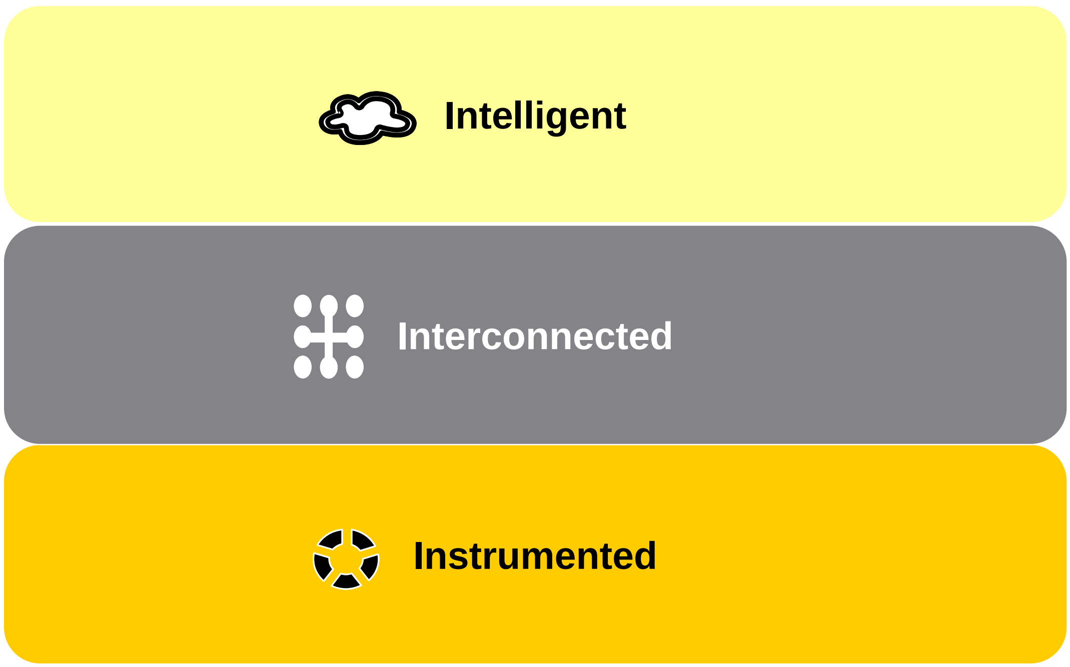

Figure 5. The abstracted Smarter Planet view of the Instrumented Planet Reference Architecture.

4. SMARTER CITIES

The work leading to Smarter Planet and Instrumented Planet provided the general vision and technical plans for an architectural pattern that applied across many domains. But a key step was still missing. This step came during an almost accidental encounter with the MASDAR City [6] project in Abu Dhabi during the summer of 2008.

4.1 MASDAR City

The MASDAR City project had broken ground in early 2008 on a site roughly 2 km square near the Abu Dhabi airport and was at the time extremely visionary (Figure 5). The core technical goal was to be a Carbon Neutral or Net Zero city – that is, a city that produces no net CO_2 emissions by generating all of its power from photovoltaic or solar thermal sources and possibly geothermal sources. This energy would then be used to meet all the energy needs of the city: chilled water for cooling, desalinized seawater, transportation, buildings, light manufacturing, and an innovative, personal, rapid transport system based on small, self-guided, electric vehicles. The challenge that IBM saw was how to allocate available energy dynamically to meet these several needs, which in turn indicated the need to understand how these needs interacted with one another. It was clearly a "system of systems" problem.

IBM had never undertaken such a multi-dimensional, holistic urban project, requiring a platform where one could integrate mobility, energy, and environmental management (see Figure 6). The integrated management of the city's multiple infrastructure systems was important due to their common dependence on a very constrained amount of energy. The city's managers would have to decide minute by minute how to allocate that energy to meet the city's needs. Such allocation problems are considered during the planning and design phases of urban infrastructure systems, but rarely during the operational phase.

The missing step here was that although we had realized that the Reference Architecture could support the individual operational services for many different domains in a city, we had not taken the critical next step of realizing that it could do this for multiple domains simultaneously and therefore enable the passing of information among the various infrastructure domains to support a "system of systems" view. With that one step we moved from considering individual service domains to considering the entire set of city services.

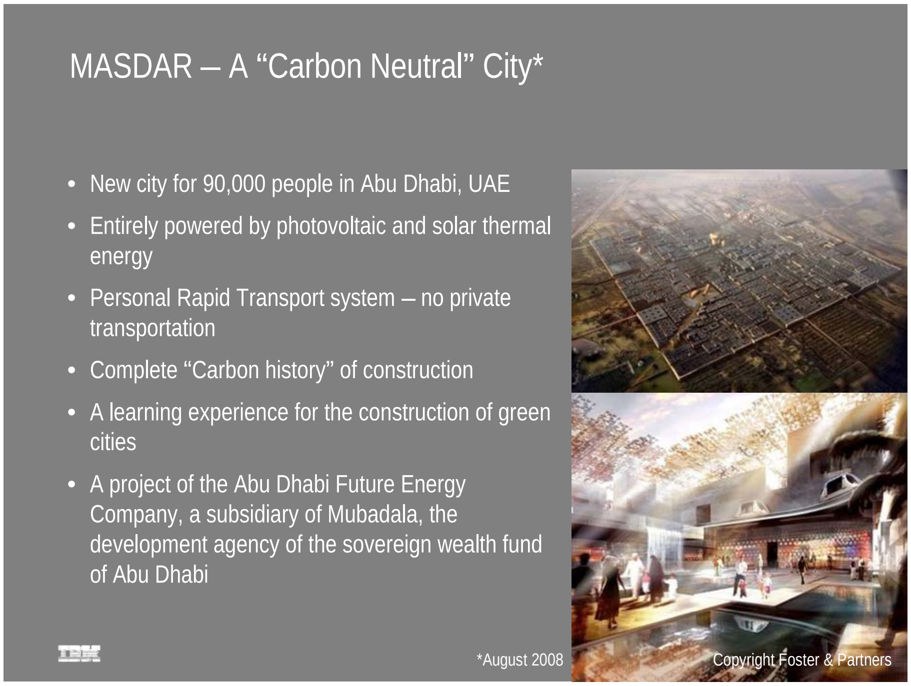

Figure 5. MASDAR City –A "Carbon Neutral" City as planned in 2008.

IBM perceived the need for a "brain," i.e., a nervous system that could look across the needs of different areas of the system and make decisions about how to allocate that energy. We realized that we could use the Reference Architecture to control energy, transportation and water. Moreover, they could all be controlled together. IBM had previously been thinking of smart transportation, smart energy, etc. as isolated systems. Then, in a sudden "Aha!" moment, all of those ideas came together, crystallizing the notion of what the Smart(er)[2] City could be.

4.2 Role of Information Technology

Throughout this period , IBM's view of the relationship between society and information technology was evolving. Grounded in a complex adaptive systems (CAS) understanding of the world. IBM's chairman began to see that Information Technology was going to play a very important role in generating and sharing information among different systems. There was a technical discussion on that point, and the question from business was why is this important, why do we want to do that in a way different from the past?

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[2] The activity was originally called "Smart City", but IBM's marketing team quickly decided that "Smarter" was a better choice of word.

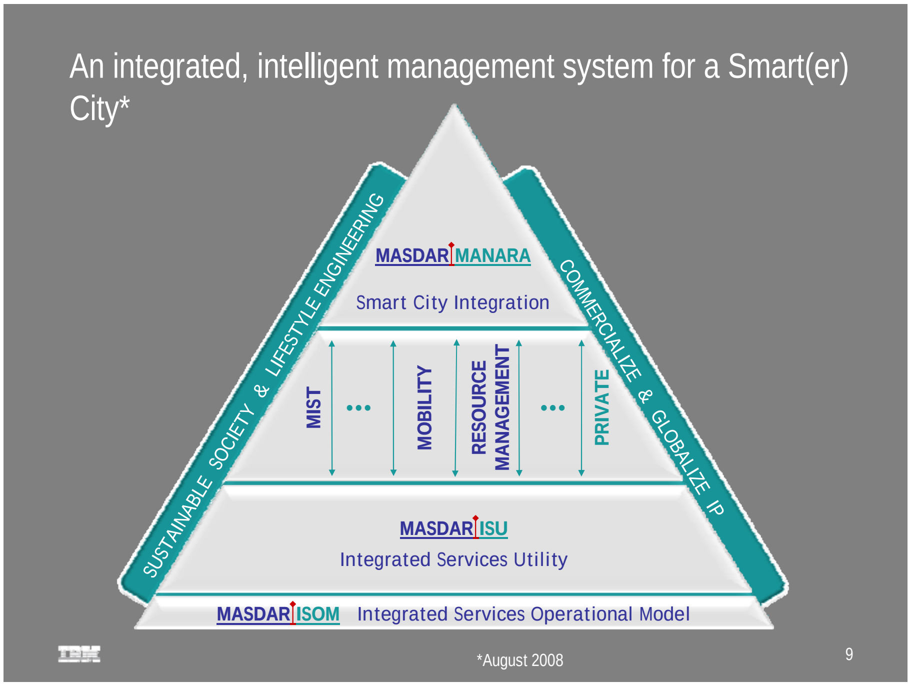

Figure 6. The "Manara" – IBM's first representation of an integrated, intelligent management system for a Smarter City.

The answer was that at the beginning of the 21st century, the development of cities around the world had entered a critical phase. The world's population is expected to peak around 9 billion people during this century and then to decline, so the cities we build or re-build today will play a role in shaping the forms of our society for a long time into the future.

4.3 Global Urban Trends

In 2008, about 50% of the world's population lived in cities; and urbanization was advancing at an amazing pace. The population of the world's cities was increasing by approximately 200,000 people a day. By the end of the century, probably less than 10% of the world's population will live outside the cities. This is a complete reversal of where we were 200–300 years ago. Therefore, in large parts of the world, there is enormous growth of cities and the building of new cities.

In other places though, there are cities that are declining. Cities like Detroit have been suffering a significant population loss over the last several decades as their industrial base has declined. Cities across Eastern Europe are also suffering population declines as people migrate to the West in search of better opportunities. These migrations have created environmental pressures. We will see continued pressure on water, energy, etc. Figure 7, from 2009, captures some reasons why this is a critical time for the development or re-development of cities.

Large cities are now the commercial engines of the planet. We return to the situation of medieval Europe, where cities existed as independent entities before the emergence of national governments. However, these new mega-cities are profoundly different from their ancient or medieval precursors. Bringing 30–40 million people together and concentrating them in one place creates new challenges whose solutions we will have to work out.

Cities are also our major hope for taming growing energy consumption. Agricultural workers have very low resource consumption levels, but consumption rises strongly with rising income [7]. For a given income level, consumption in high density cities is lower than in rural areas. Moderately affluent and affluent people living in dense urban environments living in smaller spaces, share walls, floors and ceiling with their neighbors, have less need to travel long distances, and are less likely to own a car [8]. For these reasons, if some billions of people are to move out of poverty in this century, it is important that they do so in cities and not in rural areas.

4.4 Integrated intelligent management system

IBM recently announced a product for integrated intelligent management of a Smarter City, illustrated in Figure 8. This is the IBM Intelligent Operations Center, which connects external systems with operation centers for transportation, safety, and buildings and pulls information from those systems into a large common information model. This enables intelligent operation centers to have an integrated view of what is going on across an entire city, based on both real-time and historical data. Moreover, through the use of modeling and simulation, it can make predictions. As a result, we can see yesterday and today and have a view of tomorrow.

A system of this type was completed at the end of 2010 for the City of Rio de Janeiro. IBM met with city officials following the heavy rainstorms in Brazil in April of 2010, when many tens of thousands of people in Rio de Janeiro were displaced, and more than 200 people lost their lives. The mayor of Rio de Janeiro came to an innovation workshop IBM was holding with the city and said (paraphrasing), "We have just had this disaster. We know we are not the best organized city in the world, but in 2014 we have the World Cup, and in 2016 we have the Summer Olympics. This must not happen again. Can you build an operation center for us that will enable us to coordinate our emergency response?" IBM built such a center (Figure 7) and handed it over on December 31, 2010. We

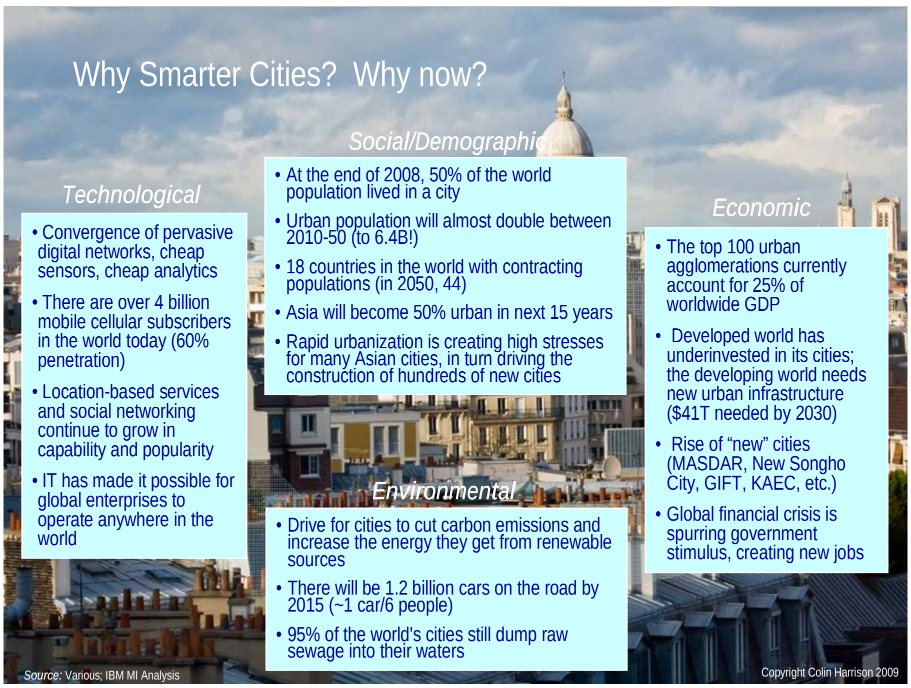

Figure 7. The slide shows reasons drawn from urbanization, from economics, from environmental pressures, and from advances in technology to justify IBM's new interest in Smarter Cities.

are now building similar centers for other cities throughout Brazil.

5. THE FUTURE

The world will continue to change, and information technology will change with it. This goes beyond the respects in which platforms, the Internet, enterprise resource planning systems and other aspects of IT have become critical to the operation of global society. It goes to the ways in which systems of systems such as cities are not only enormously complicated as engineering constructs; they are also complex and emergent because of the inclusion of billions of decision-making, idiosyncratic and adaptive human beings.

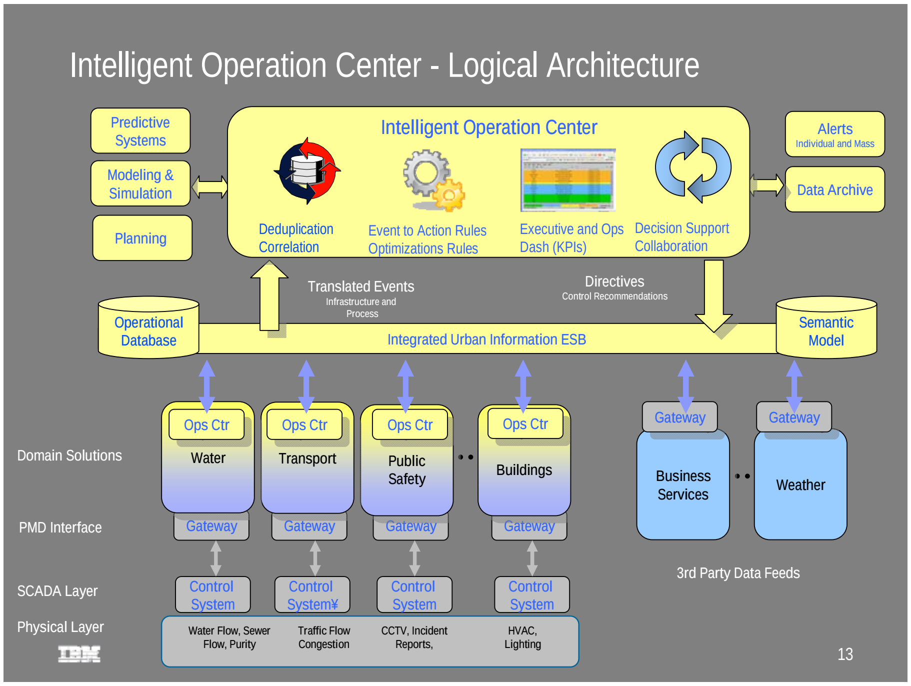

Figure 8. The high-level logical architecture of the IBM Intelligent Operations Center, which implements much of the Instrumented Planet Reference Architecture as an integrated product.

Some implications are clear. For one, systems engineers must extend their concerns to the social consequences of the systems they construct. Engineers must look for ways technology can be used to enable citizens to participate in more of the decision making. And because natural and man-made disasters have become more frequent while population densities have increased, both our systems and our societies must be made more resilient.

So this is what we currently are pursuing. My own interest lies in developing a new theory of cities: that is, how cities operate, why cities have certain "personalities," why some are more attractive than others, and how attractiveness can be improved through changing the way the city operates.

IBM's view is that such complex systems now need to become "aware" of the real-world context in which they are operating. It is no longer sufficient for them to monitor their own process state. They must also be aware in real time of the systems they influence and of events in the wider world that may have an impact on achievable and desirable outcomes. They will also need to deal with a broader range of information sources —not only well-defined infrastructure systems that produce information that is structured, cleansed, reliable, and related to a specific context, but also social systems whose context is often indeterminate and which generate unstructured information that is noisy and unreliable. This will require the development of sense-making systems that can find the needles of relevant information within the haystacks of extraneous information.

3. CONCLUSIONS

Industries mature, including the IT industry, and the focus of attention moves from technology invention, to product innovation, to platform innovation, and eventually to innovative uses of the platform. Although 1999-2000 was a difficult period for the IT industry, it led to a new phase that offered renewed potential for creating economic and societal value – value that comes from understanding and insights available in an integrated, near-real-time view of the world. Indeed, with the benefit of hindsight, we can now see that the crisis the IT industry faced a decade ago was actually the end of an old model – the development of core technologies and the platform - and the dawn of a new paradigm – an era of smarter systems and much closer engagement between society and information technologies.

The Smarter Planet movement has far to go in enabling global society to fulfill its development potential, but it comes at a critical time in the evolution of cities all over the world. As much as anything, this story illustrates the value of having many eyes looking at the state of the world. IBM's chairman saw the chance to leverage the global business platform by probing downwards into the flows of information; and IBM's engineers saw how to build upwards from sensing the real world into an intelligent, integrated operations platform. It also shows that at any time a great step forward may be staring you in the face and you need a special nudge to recognize it.

Acknowledgements

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Biosketch

Colin Harrison is IBM's technical pioneer in Smarter Cities and in the application of the Smarter Principle to helping cities achieve their sustainability goals. Dr. Harrison is a Distinguished Engineer in IBM's Corporate Strategy team leading technical strategy for Smarter Cities. He was the inventor of the Smarter Cities technical architecture, which grew out of 2007 work on Energy & Environment offerings and a technology assessment on the Instrumented Planet. During 2007-9 he was director in the corporate strategy group, leading business strategy development for Smarter Cities. He is also an IBM Master Inventor.