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TEZĂ DE DOCTORAT

Research on online monitoring and intelligent communication management

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ABSTRACT

Currently, according to data provided by various competent governmental or international organizations in the field, the world's population has grown exponentially at an average rate of 1.2% per year for the past 50 years. Although this urbanization process has its advantages, in terms of comfort and living effort, it also presents a number of challenges. Rapid urbanization creates increasing pressure on raw material and energy resources, increasing the demand for water, energy, sanitation supply and distribution services. Also, this urban grouping of the population leads to the increasingly difficult management of health, education, urban mobility services.

Another resulting problem that is a consequence of this urbanization process, but of first order importance for life on Earth, is the pollution generated by urban activities. Cities contribute substantially to environmental degradation, accounting for up to 70% of greenhouse gas emissions and 60%-80% of global energy consumption.

Therefore, to find solutions and ways to make cities smart and sustainable under the given conditions represents one of the emerging challenges is for authorities and decision-makers. One of the possible answers is the adoption of policies to make cities "smart" through an efficient management of infrastructure resources, environmental protection, respectively an intelligent governance with the aim of increasing the quality of life of citizens. Several definitions of smart cities have been given, depending on the field of research.

A definition from the field of telecommunications describes the smart city in terms of the efficiency of urban operations and services, in order to ensure the requirements of present and future generations in relation to economic, social and environmental aspects. Operations in the spirit of this definition cover very wide areas: obtaining multiple information for authorities, businesses and citizens, optimizing the production or consumption of water and energy, traffic management, public safety, response to emergency situations. To adapt to these multi-faceted requirements of smart cities and related fields, the Internet will have to play a fundamental role in communications, information gathering and distribution, data transfer and analysis, and their distributed processing.

In order to develop the ways of designing and implementing Smart City concepts, it is advisable to define a multi-layer architecture as a model for the different fields of application and infrastructures. In the middle of this layered architecture and realizing the informational interconnection of the different levels, the communication support technologies must be located. Therefore, I consider this layer to be of maximum importance, which justifies the choice of this field for the development of doctoral research. This PhD thesis comprises both a theoretical study and a series of experimental researches and the implementation of new solution proposals with the aim of discovering innovative ways to realize the integrated management of services in a smart city.

The main objective of the thesis is the development of an integrated service management platform in a smart city infrastructure, based on the prediction of future states and the analysis of customer satisfaction.

From the period of the pandemic until now, there has been an intense emphasis on the digitization of as many services as possible that the public (citizens) access. Thus, there is fierce

competition between companies to offer customers the opportunity to achieve what they set out to do digitally, online, accessing services from the comfort of their own homes. The criterion that makes the difference and leads to customer loyalty, in this situation, is the desired availability of applications, to be as high as possible. Situations where an application is difficult to respond provide a negative user experience and causes them to reorient to the competition.

Online monitoring involves the surveillance and analysis of activities and data generated in the infrastructure of a smart city, including on citizen communication platforms and other digital channels. This monitoring allows companies and organizations to gain valuable information about the smooth functioning of digital services in such an ecosystem, public perception, customer feedback and market trends.

The research topics related to the thesis are represented by the limitations and shortcomings of all existing methods and solutions to date in the field of online service monitoring. At the same time, the thesis focuses on the study of the current state of online monitoring services to determine the gaps that lead to a low service level; defining integrated analysis strategies based on intelligent agents, for monitoring both equipment and services / applications; research to find algorithms and electronic assistance solutions for the efficient management of maintenance activities, modeling the monitoring process, modeling the impact of malfunctions, implementing an intelligent agent model for assistance in crisis situations and situations of uncertainty, and last but not least, proposals for improving the architecture and management of communication networks used to manage services in smart cities. Different ways of applying artificial intelligence systems in the management and supervision of services were identified and two solutions were proposed for the coordination of several monitoring programs.

The process of transforming a city into a smart one is complex, and involves more than just improving old systems by adding sensors, remote monitoring and controlling essential city services. The process must be thought of as an integrated, multidisciplinary solution, as a strategy that considers all the components of this transformation: technological, standardization, economic, social, legislative. As a result, preliminary studies are required to determine which of the elements of urban infrastructure and services must be subjected to this process and which are the interdependencies, opportunities and threats that may arise during implementation.

In the transition to smart cities, progress is the path to lower resource consumption. According to some authors, the analysis is good to start with the initial assumption formulated by the Sollow-Hartwick solution, according to which sustainability is seen as an investment problem in which the benefits of the use of natural resources must be used to create new opportunities of at least equal value, if not bigger.

In ecological sustainability, the main assumption is that natural capital (fuels, minerals, energy) is not replaced by capital obtained through production (machines, buildings, knowledge). In this case, the area needs to produce the consumed resources and the method of assimilation of the waste generated by the produced capital must be calculated. However, this model suffers from two deficiencies:

- The difficulty of quantifying different resources in territorial units,
- Impossibility to replace all resources.

Further research has shown that the use of both of the previously mentioned models makes each of them individually necessary, but still does not provide sufficient conditions for sustainable development. Mathematical models have even been created to suggest how much should be invested in the final industrial product so as to maintain a balance between consumption and the satisfaction level of the investment. As the rate of technological progress and satisfaction increases, less and less investment is required.

The support for a constant evolution in the urban area is provided by so-called intelligent systems. They represent a method of differentiated development of different types of services in the fields of education, health, transport, energy distribution, public administration, etc. From this range of systems, some are core components, around which services can be built.

The core consists of the subsystems and key technologies that ensure the transparent transmission of information to users in a logical architecture of the smart city. Component satellite systems may include applications as follows:

- Transport system:
    - Integrated traffic management and traffic and travel information systems – increased mobility means facilitating traffic for travelers, not for cars
    - Integrated charging systems – helping reduce carbon emissions
    - Mobility as a Service (MaaS) – information helps people take smart decisions in traveling
- e-Government:
    - Portals for accessing, sending and receiving government documents
    - Electronic payment of taxes
    - Electronic information services for citizens
- Educational systems:
    - Integrated on-line education platforms
    - Cloud-based solutions and products to automate training and learner assessment
    - Solutions for continuing professional training
- Health system:
    - Telemedicine solutions
    - Electronically elaboration, transmission, and validation of medical documents
    - Scheduling visits, employing artificial intelligence in diagnostics, monitoring patients, etc.

For the activity of developing the doctoral thesis, the activities of study, analysis, research and development, data collection, implementation and simulation were structured in such a way as to allow the accumulation of as much knowledge as possible, as well as the achievement of useful results for society scientific and economic environment. The main stages of this period, as well as the results and notable contributions achieved, which can be mentioned, were the following:

- Carrying out elaborate bibliographic studies, both of scientific works in the field or of related fields (mainly, scientific articles from prestigious national and international journals – IEEE, MDPI and others), of invention patents, as well as the pages of some suppliers of services and equipment manufacturers, through which it was identified:

    - the current status of smart city services, concepts, definitions, policies and standards;
    - the results obtained in the most significant cases of good practices; examples of application of smart city concepts in Romania;
    - aspects to be considered in the integrated management of smart cities;
    - architectural classification of smart cities, initial trends in transforming traditional cities into smart ones, and current trends;
    - the niches discovered in these bibliographic studies helped to form the main ideas and find new research directions;
    - proposing new data collection sources, such as crowdsourcing.
- The initial bibliographic studies, carried out in a comparative manner according to certain selected criteria, focused on the discovery of the latest technological advances in the field of services for smart cities, with the analysis of the importance that communication systems have in the management of services:
    - Several data transmission technologies in a super network were analyzed from a technical point of view, starting from the 2^{nd} generation GSM and up to the higher technologies (5G), which consume less energy and have longer-distance transmission capacities;
    - Communications' speed tests were conducted, and the possibility for opportunistic, combined use of these technologies for data transmission and/or collection were compared;
    - The requirements for the implementation of smart type applications, from the level of the smart home to the management of distribution networks, have been studied in detail;
    - Proposals have been made to improve the architecture and management of communication networks used to manage services in smart cities.
- Particular importance was given and an intensive study was devoted to online monitoring tools, through which different ways of applying artificial intelligence systems in the management and supervision of services and communications for smart cities, the algorithms used in data analysis and filtering were identified captured from smart cities and smart transport systems:
    - General concepts regarding online monitoring;
    - Types of monitoring architectures and examples of software tools based on them;
    - Monitoring mechanisms with or without an agent;
    - Evaluation criteria and choice of monitoring tools;
    - The concept of application performance management (Application Performance Management - APM);
- It was proposed a solution for mathematical modeling of the monitoring process;
- The monitoring program Dynatrace and the artificial intelligence algorithms applied by it were also studied, in order to achieve the complex tasks of distributed tracking.
- There was proposed and analyzed a case study for a generic "My Account" application that was malfunctioning and the way how Dynatrace detected the degradation of its response times was analyzed, providing key information to the administrator system, a process that

is very useful in the recovery process. There was also carried out a mathematical modeling of the indicators tracked by monitoring programs, such as Dynatrace, was carried out;

- Modeling of the impact of malfunctions was carried out using Amdahl's law to find the degradation factor in case of incidents;
- Two solutions were proposed for the coordination of several monitoring programs in order to finally have the most efficient, autonomous and exhaustive management of network maintenance:
    - rethinking and reconfiguring dynamic tracing programs with orientation and prioritization on monitoring smart city applications;
    - building a superimposed structure, dedicated exclusively to the control of the trans-network service level of smart city applications, a structure based on monitoring agents, each with very clearly defined and delimited areas of activity, thus leading to a new ecosystem architecture, based on a superior monitoring strategy.
    - A research report was dedicated to the study of artificial intelligence-assisted management of services for the smart city, as follows:
    - A case study was carried out on a selection of sub-components chosen from the architecture of a smart city, in which the development of their integrated management was pursued;
    - A development model of an AI agent for the global management of smart cities was developed;
    - The requirements for the development of a smart city management solution, assisted by artificial intelligence, were analyzed, with the aim of streamlining the processes of the failure management system (Failure Management System - FMS) and reducing the time to restore services and applications;
    - A prototype intelligent agent for assistance in crisis situations was designed, based on Min-Max algorithm with alpha-beta truncation;
    - Another case study was carried out for the management of uncertainty situations.
- An entire chapter was devoted to proposing a platform for integrated preventive maintenance management using software detection, application monitoring, and Markov-based future state prediction to increase the resilience of a complex network. A specific algorithm was developed for monitoring the service level, on the one hand, and a tool to support preventive maintenance management, based on predicting future network states, on the other. A case study is also investigated for smart city applications and further developments are suggested at the end of the chapter.
- The economic-financial opportunity of developing a software application for monitoring the services of a smart city through a business plan was demonstrated.

This PhD thesis was divided into 8 chapters and it has been organized as follows.

In the "**Introduction**" the context of the doctoral thesis is presented and some notions are presented in relation to the current stage of the development of the field of cities and their transformation into smart cities. Also, the strategy for developing the doctoral thesis is presented, the original contributions are listed, and the structure of the doctoral thesis is presented.

Chapter 1 -, “The current state of online monitoring. The need for intelligent management of services and communications” presents, based on data from the specialized literature, definitions, history, policies and standards regarding smart cities, details their components. It also describes current examples of the application of good practices by cities both in Romania and in the world for the transformation from the traditional stage to the intelligent one.

Chapter 2 - "Challenges of the infrastructure management of a smart city" describes the economic-scientific context of the components of smart cities and aspects that must be considered in achieving their integrated management. Based on the specialized literature, the architecture of smart cities is detailed and the weaknesses and shortcomings of the good functioning of such architecture are carefully analyzed, aiming to bring new ideas for improvements.

Chapter 3 - Information and communication technology requirements for cities and intelligent transport systems" - presents a comparative study of the main data communication technologies with applicability in intelligent transport systems (ITS) and intelligent cities (IO), analyzes the technological requirements of these systems and last but not least, it brings proposals to improve the architecture and management of communication networks for SIT and OI.

Chapter 4 - "Communications network monitoring tools with applicability in smart city services" - presents a theoretical study based on numerous technical documentation and specialized literature on online monitoring, software tools that fulfill this functionality, mechanisms different implementation and evaluation criteria and choice of monitoring tools. The concept of Applications Performance Management is introduced, a key practice used by companies that want to ensure that they maintain expected service levels and that customers receive a positive application experience. As an experimental part, in this chapter the mathematical modeling of the monitoring process was carried out and a concrete case study of the benefits of applying the Dynatrace monitoring tool with artificial intelligence algorithms for treating the main reasons for abandoning the use of a web/mobile application by customers. On that case, the impact of dysfunctions was realized using Amdahl’s law and ways of combining the coordinated action of the monitoring programs were proposed.

All these solutions were also materialized through the publication of several scientific articles in ISI WOS (Web of Science) and BDI journals, accepted by CNCSIS.

Chapter 5 - "Artificial intelligence-assisted management of communication networks for smart cities" - presents experimental research and original implementations, materialized through scientific articles published in specialized journals (Sensors, MDPI - Basel, Switzerland, IF=3.9, Ranking Q1-Q2). The requirements of the AI-assisted smart city management solution were determined and a development model of an AI agent for smart city management was designed. An intelligent agent model for assistance in crisis situations, based on min-max algorithm with alpha-beta truncation, was also implemented, and a case study was carried out on the management of uncertainty situations that may arise in a smart city ecosystem.

Chapter 6 - "Integrated platform for assisted service management (based on state matrices, prediction of future states and user satisfaction analysis)" - presents the final goal of the doctoral thesis, namely the development of an integrated platform for assisted service management in a smart city, also materialized in a scientific article in specialized magazines (Sensors, MDPI – Basel, Switzerland, IF=3.9, Ranking Q1-Q2). For this step, concrete performance data was collected from a communication network in Romania over the course of a year, and based on them, the development of the algorithm for evaluating the risks of network and service failures and the algorithm of predicting customer satisfaction.

Having these mechanisms and further using the theory of Markov chains, an algorithm was developed for building the risk assessment matrix, which is the basis of the integrated platform to assist operators in making the best management decisions regarding services in a city intelligent.

Chapter 7 - "Business plan model" presents the economic-financial opportunity of developing a software application for the integrated management of services" - represents a validation of the research results through the development of a new software product, the City Master Companion application. Economic opportunity, applicability and innovativeness were demonstrated through a business plan.

Chapter 8 - "General conclusions and future research directions" presents the conclusions related to theoretical and experimental studies, personal contributions and research perspectives, subsequent to this doctoral thesis.

Starting from the field of the doctoral program – Engineering and Management, the main objective of the doctoral thesis is innovation in the management of smart cities.

The aim of this doctoral thesis was to develop innovative solutions in the process of transforming cities from traditional to smart and facilitating the most efficient management of services within such an ecosystem, so as to ensure a high level of service quality and satisfaction citizens.

According to some definitions in the specialized literature, a smart city represents a region where traditional services and networks are made more flexible, efficient and sustainable with the help of information, digital and telecommunications technologies, in order to improve operations for the benefit of the region's citizens. The transformation of a traditional city into a smart one is achieved through information technology and telecommunications. These two important components provide the technological framework for rapid and large-scale development: the Internet of Things (IoT) and BigData. Apart from these, it is obvious the contribution that the development of some components regarding: infrastructure, renewable energies, etc. should have to achieve these goals. The functional areas on which the analysis was focused and on which several case studies were carried out in this doctoral thesis are: the transport system, electricity distribution, street lighting, the economy, the crowdsourcing component, digital commerce, the environment.

In order to better face the challenges of a smart city infrastructure management, it is necessary to use all the information of the strategic development in order to define an adapted infrastructure. Thus, it was proposed to create a framework architecture of the ICT infrastructure starting from the OSI model, but creating an improved model, better adapted to an integrated development of this infrastructure. The different isolated implementations of the smart city components do not comply with a unified data standard, which is why the addition of the Conversion layer is proposed. This layer is responsible for translating the data format, compatible with the heterogeneous standards of different data providers, into a common agreed format used

by any smart-city application. Additionally, considering that a smart city will be based on the extensive use of radio communications, i.e., IoT, I consider it necessary to double the physical layer in order to respond better to IPv6 requirements and the effects of radio wave propagation in the urban environment.
Aspects to be considered in the integrated management of smart cities may include:

- planning:
  - reference architectures for smart cities
  - urban platforms accessible to anyone
  - adapted standards
- - aspects related to sustainability:
  - objectives of sustainable development
  - free standards (open standards)
  - free interfaces (open interfaces)
  - free sources (open sources)
  - free data (open data)
- - aspects related to resilience
  - reliable ICT infrastructure with a high level of availability; data terminals (e.g., human operators, sensors of various applications, everything that can be considered a source or receiver of information) robust, reliable and with low energy consumption.
- - technical aspects:
  - innovative technologies;
  - aspects related to quality assurance;
  - phased development;
  - testing and certification.
- - safety and security:
  - environmentally friendly equipment;
  - cyber security;
- - legislation:
  - new legal aspects;
  - e-governance.
- - social:
  - increasing the quality of life;
  - accessibility to services;
  - fair living conditions;
  - quality education.

Another proposal is to use a crowdsourcing solution for these functional components of a smart city, as an additional source of information, next to the sensors located in the city, with the potential to allow competent authorities and city officials to collect a huge amount of useful data subsequently in key areas of development: infrastructure design, improvement decisions, traffic information and multimodal urban travel, adaptive route guidance, safe operation (traffic incident monitoring, power outages, utility distribution network interruptions, etc.). All these will have the effect of increasing the efficiency of the administration processes, of restoring after an interruption and forming a database, that will allow much more useful statistical analyzes in the planned urban development.

Based on this positive experience in the field of intelligent transport systems, other similar applications could be developed for other functional components of the smart cities from the future. Through these integrated crowdsourcing methods, a multitude of services and applications would be made more efficient much faster, to the benefit of all users. Thus, they could be monitored through crowdsourcing applications: the management of environmental conditions in living spaces and offices, smart indoor lighting, monitoring the level of emissions combined with traffic management, monitoring consumption and losses in utility distribution networks and many others.

For applications of a social nature, maintaining a certain level of anonymity, the quality of many services that today leave something to be desired, such as medical or care for the elderly, disabled, etc., could be improved - if there were social networks (other than Facebook, Instagram, Tweeter, Tik-Tok, etc.) adapted to the respective category of services.

The requirements of information and communication technologies for cities and intelligent transport systems were also analyzed in the doctoral thesis. The demand for mobile communications has increased a lot, constantly recently - especially in the context of the SARS-COV2 pandemic. Emphasis is placed on mobile data transmission via GSM networks, but also on expanding coverage in rural areas. The main data communication technologies analyzed are: cellular networks, LoRaWAN, LPWAN, Zigbee, WiMAX, Bluetooth, Wi-Fi and DSRC. Elements analyzed: bandwidth used, access system, technologies, access times and transmission distance, advantages and disadvantages, these being the criteria that determine applicability in the field of smart cities and transport. As an experimental part, speed tests were carried out in several areas of Bucharest, using several mobile terminals and having activated the mobile data service offered by several telephone operators in the country (Orange, Vodafone, Digi), and the results demonstrated significantly higher internet browsing speeds with 5G compared to previous generations.

An exponential increase in the complexity of the management of the multitude of functional components involved in the development of a smart city is estimated, the effects of which can also be observed in the difficulties of manual operation of maintenance and restoration activities of communication networks. The solution proposed in the thesis for this challenge is the use of intelligent agents (based on specific AI algorithms), specialized, for monitoring the different areas of activity involved in a smart city. The solution must have the possibility of scaling and global control by means of a Super-agent Supervisor that makes logical connections, based on causality and effects analysis, between the information presented by the regional agents.

The expansion of virtualization and cloud computing has led to the appearance of a huge number of elements that must be managed. Today's IT systems are geographically redundant and run on different operating systems, which complicates their management. The monitoring of IT systems must be adapted to the new volume requirements of the current stage and conditions, since the good working condition of these applications has become critical to be able to provide customers with support and assistance 24/7.

In the framework of the thesis, the fundamentals of monitoring were analyzed in depth, monitoring at the infrastructure level, key performance indicators were proposed to be tracked for each functional area of interest of the city, monitoring mechanisms with and without an agent, evaluation criteria and choosing the best monitoring tools.

A case study of five such tools was also carried out from several points of view and a comparison was made between them. Two important measures can be noted following the studies carried out: it is important to achieve the most efficient management of physical resources (physical level, data link level, network level), simultaneously with ensuring that the agreed QoS threshold is reached, regardless of the level of virtualization applied over the physical infrastructure. The monitoring programs used should be applicable to different resources and be able to extract performance parameters, the monitoring impact on the resources as small as possible, and the monitoring system should be easy to scale and configure, ideally even dynamically configurable.

Another concept intensively analyzed in the thesis is the APM – Application Performance Management, a methodology which is superior to classical monitoring tools. This represents the practice of tracking key performance indicators of applications using complex AI algorithms, combined with telemetry data and two monitoring techniques called data logging (tracking the activity of an individual application - through activity logs) and distributed tracing. An example of a program that meets the criteria of the APM discipline is Dynatrace. It is one of the best performing today, it provides advanced all-in-one observability for operations, infrastructure, applications, AI assistance allows teams to automate operations, and last but not least, it provides accurate answers to complex problems in real time. The most useful features of APM solutions are automatically discovering the topology of the network or services and streamlining the administrator's investigation to get to the root of the problem as quickly as possible.

Lagging applications is the problem faced by the vast majority of application administrators, developers and IT managers. Statistical studies have shown that a delay of just one second in the load time of an application produces very negative effects from a business point of view, such as a 7% reduction in conversions of visitors to customers, a decrease of up to 16% in customer satisfaction and a 73% of organizations have productivity losses due to this fact.

As part of the thesis, a case study was carried out as an experimental part, more precisely an event of high response times recorded during the operation of a generic My-Account mobile application, lasting 20 minutes. Operation analysis was performed with Dynatrace, which, at time T0, detected that the service time for some user actions in the application increased by 180% from the baseline (from 1.3s to 3.64s), and for other shares even 509% from the base value (from 1.48s to 8.99s). Dynatrace applied distributed tracing techniques to trace customer-initiated transactions (from the MyAccount application) along their entire route through all components of the application architecture, and were able to discover that they were no longer receiving a response from the database within the expected time. Dynatrace was also able to spot concurrent performance issues on the database, and correlate the discovered issues with the behavior of the database, directing application administrators down this investigative path to the root cause of the problem.

It could be concluded from the case study that APM solutions (Dynatrace) prove their effectiveness in pointing the application administrator in the right direction to find the source of a problem, that the increase in the number of requests can be caused by both operational actions with a predicted impact, and dysfunctional situations, and that actions directed towards predictive maintenance are very important.

After conducting this experiment, new metrics and their meaning were proposed to achieve the mathematical modeling of the monitoring process. The tracing process is given by a relationship that collects information in the form: The route (trace) belongs to labeled time intervals, composed of Span and Tag, at different moments of time and on different paths, where Span signifies information regarding relationships, links of parent - child type, collected with the aim of identifying the specific path that a certain transaction takes through the services or components accessed by the application, and Tag - identifies a specific moment of the traced path or a component.

Also, it was introduced the notion of an application's service level, which was presented as the ratio of response time to the number of requests per minute, meaning "how efficiently the application resolves requests".

Another proposal discussed in the thesis is the notion of temporal degradation for a service, which can be quantified by applying Amdahl's law on new bases: from the total running time, any deterioration has a duration of manifestation of the effect; we can then determine the temporal degradation for service x, defined as the time ratio between the average hourly execution time of the service, and the new extended execution time, due to the occurrence of a malfunction in the operational flow (Amdahl).

Next, in the framework of the thesis, other proposals for solutions to the problem of the difficulty of manual operation of maintenance and restoration activities are given:

- the use of specialized AI agents for monitoring different areas of activity and by separating the tasks on the components of the architecture (OSI layering).
- global scaling and control via a Supervisor Super-agent.
- segregation of duties to regional agents.
- hierarchical architecture, where at the basic level, the agents responsible for monitoring each network are interrogated by a regional or functional agent, being warned only when certain service levels are exceeded
- to create such an architecture, it will be necessary to rethink each local agent to collect only information relative to the applications involved in smart city processes.

A chapter was devoted to the study of artificial intelligence-assisted management of communication networks for smart cities. In order for it to be carried out as effectively as possible, it is advisable to facilitate collaboration between the four relevant categories of the Quadruple Helix model of innovation: the private environment, the academic environment, public authorities, NGOs, ideally with the added value also brought by the component of crowdsourcing, to supplement information collected automatically by applications and sensors, with data and concepts from citizens. The necessary steps to be able to set up a city management solution assisted by artificial intelligence have been determined:

- Establishing the functional areas that the community considers priority and then integrating them into sustainable development plans.
- Establishing intelligence gathering channels: automated channels, based on IoT sensors and intelligent network monitoring agents, and social media channels, with AI-based algorithms for keyword recognition for early detection of anomalies in smart city management.
- Establishing the structure and way of organizing data in Big Data.
- Defining monitoring agents and their areas of operation.
- Increasing the resilience of the AI-assisted management system, through the use of self-learning (recurrent neural networks) – the system becomes capable of learning from its own experience.

A case study was carried out for some of the previously defined functional areas (Energy, Transport, Economy - prediction of digital commercial markets, Economy - supply chains, Economy - use of human and material resources, etc.), for which there were proposed various key indicators that can be monitored. They were classified as follows:

- Key performance indicators for automatically collected data.
- Key performance indicators for data collected through operators.
- Key performance indicators resulting from a calculation process.
- Key performance indicators for additional data – crowdsourcing (support early alerts).

Using these indicators, a methodology was proposed to make anti-crisis measures more efficient:

- The first step is the definition of the problem, carried out by highlighting some functional cycles, considered normal, of the tracked services, based on key KPI indicators, and the detection of situations that do not fit into these scenarios (the onset of the crisis).
- Identifying the type of crisis management that must be adopted.
- Defining crisis measures according to the type of management chosen.
- Evaluation of the results of the application of specific methods for exiting the crisis, based on KPI.
- Evaluation of optimal restoration conditions, best practices, solutions for the future.

Applying the Mini-Max criterion for assistance in crisis situations (regret minimization) is one of the proposed anti-crisis measures. The Min-Max control criterion for determining the optimal crisis management process is the minimization of the maximum loss. To identify the optimal variant, the maximum values of the regrets will be determined, and from these the minimum value on each variant will be determined.

Another case study carried out in the chapter dedicated to the implementation of an integrated and assisted management methodology of smart cities is for the management of uncertainty situations. A smart city administration was considered to have a capital of $100,000. which he wants to capitalize on through investment. The users of the assisted management platform, who may be people from the public administration of the city, request an opportunity study analysis in the AI-based assistance platform for the operational management of the smart city, by which it can be decided which is the optimal option to investment.

Four possible stages of the city's economy were considered:

- Recession/economic crisis/pandemic.
- Inflation.
- Stagnation.
- Economic growth.

Based on the investigations undertaken by the AI agents, a matrix of profits was created, as a central result of the algorithms applied and the performance of data mining. The rest of the analysis steps will indicate the optimal option, indicating and guaranteeing the solution recommended to the user. The investment variants entered into the system by the administrators are the following:

- V1 investment in smart building.
- V2 energy and fuel management investment.
- V3 investment in environmental management.
- V4 investment in the field of transport services.

Five criteria for determining an optimum, in the theory of uncertainty management, were taken into account and presented in detail within the thesis, namely:

- Pessimistic rule.
- Optimistic rule.
- Optimality rule (Hurwicz).
- Proportionality rule (Bayes – Laplace), and
- The rule of minimizing regrets.

Performing the calculations automatically based on each criterion, the following has been found:

- V1 and V3 are not accepted by any criteria, so they will not be considered.
- V4 is preferred by only one criterion.
- V2 is approved by four criteria.

In this example the majority rule can be successfully applied and the platform will offer V2 as the optimal investment option.

Numerous studies and researches are conducted worldwide to improve preventive maintenance solutions to keep up with the rapid development of technologies and services. Not only natural factors can cause network failures, human intervention can also be a cause of failures, instability or malfunction. Preventive maintenance has always been a priority for critical applications and in industry. The penultimate chapter of the thesis focuses on the proposal of an integrated preventive maintenance platform dedicated to complex data communication networks with smart city services. As a continuation of a previous research, the use of intelligent agents in the early detection and detection of deviations from normal operation and service level degradation is associated in this paper with a future state prediction matrix intended to provide the operator with alerts and suggestions for mitigating the effects negatives of malfunctions and malfunctions.

To achieve this goal of implementing the AI-assisted integrated management platform, a specific algorithm for monitoring service levels was developed, as well as an integrated preventive maintenance management assistance tool based on the prediction of future network states.

A case study for smart city applications was investigated to verify the scalability and flexibility of the approach. The purpose of this proposal is to improve the efficiency and response time of preventive monitoring, helping to quickly recover the required service levels and increase the resilience of complex systems.

The need for automated maintenance processes, supported by intelligent agents capable of early detection of faults and any other faulty operations, is evident from the above. At the same time, even manual upgrade, deployment of new software versions, operational support, troubleshooting, etc., could also prove to be a source of malfunctioning of functional components in complex networks. In fact, according to personal observations, on one of the mobile communication networks in Romania, intensive modernization and improvements of functional components (hardware or software) caused more than 55% of events leading to low service levels. This might be somewhat justified given the vast complexity of the network and the implications that a server, or application, might have on the overall process, implications that human staff might not be able to imagine in the first place. Moreover, there are some causes that cannot be predicted, such as natural disasters (floods, earthquakes, fires, etc.), or field works, carried out by third parties, that could interfere with the physical wiring, but these seem to be much more rarer than the effects of human intervention. It is necessary to maintain a balance between the number of maintenance interventions applied and the costs of their adverse effects.

Appropriate maintenance service can be determined by two different approaches:

- Preventive maintenance – through scheduled procedures, conditional procedures or maintenance focused on increasing reliability.
- Corrective maintenance – is carried out after the fault has already appeared. It could also lead to measures such as changing the network structure, upgrading software components, etc.

Mathematical modeling of maintenance should consider an objective function, seeking an optimum among the following criteria: minimization of recovery time, minimization of maintenance costs, minimization of risk. We believe that a model using risk management is important in AI-assisted preventive maintenance, being more effective in suggesting to human operators the appropriate actions to be taken and their predicted risks in terms of operational service levels, for different hardware and software components. Risk quantification enables the determination of an optimal level of risk that provides the most effective maintenance strategy for complex systems and networks.

The methodology in this chapter proposes the automation of multiple integrated processes, namely: i) introducing functional monitoring agents based on risk assessment, and ii) monitoring customer satisfaction. To determine an optimal preventive maintenance, it is necessary to analyze several possible states and scenarios of operation, based on state transition matrices. A multi-level approach is easier to put into practice, especially when complex networks and services are involved. In this way, a dedicated monitoring application and model should be developed for the data communication network. Then, a higher-level application for monitoring complex services (including the monitored network) is to be set at a higher implementation level. This top-level application will also be responsible for monitoring customer satisfaction.

The proposed approach to achieve an automated process of preventive maintenance, assisting human operators in the activities of rapid recovery of the data communication network, or preventing the occurrence of a failure, thanks to early warning messages, was described.

This model is based on the analysis of a complex data communication network and a set of relevant monitoring agents of the smart city, from the point of view of the operating states, the main causes of the decrease in the level of some services, as well as the analysis of the causes of the most frequent hardware and/or application errors. A transition matrix is then constructed, considering different failure rates and corresponding risk factors, with associated causes. Risk is defined as the product of the probability that a failure will occur and the expected cost of the failure in the system. The risk is defined at the level of the data network under consideration. The evaluated data network is a complex one with different services and applications and is used as a core data communication network in a smart-city environment, where different services also rely on smaller communication networks such as ZigBee, Bluetooth or LoRa.

For intelligent monitoring of the data network core, the following intelligent agents have been used to monitor smart city services:

1. Traffic service levels monitoring service.

2. Monitoring the levels of energy distribution services.

3. Environmental monitoring service.

4. Crowdsourcing monitoring service.

5. Public lighting monitoring service.

6. Waste disposal monitoring service.

Each individual agent is set to monitor a particular service for its functionality, iteratively and/or by event triggered. Each record is indexed with the start and end timestamps of the event to determine the duration of service unavailability. The evaluation took place over a period of one year, during which time all six services were monitored for availability, i.e. the ratio of the number of successful service requests to the overall requests (successful plus unsuccessful service requests).

Some of the most common failures observed were caused by human interventions, including corrective maintenance, curative maintenance, software upgrade, preventive maintenance, peer-to-peer migration, hardware replacement, hardware upgrade, standardization. Considering the impact of these malfunctions, the following are the main effects, on a scale from most severe to least harmful impact: complete failure, loss of traffic, inconsistency/loss of data, latency, loss of administration, loss of oversight, mini failure (complete failure for max. 10 minutes), slow response.

The proposed approach is based on the analysis of Markov chain processes, for the states in which the (super-)network (i.e., the network of networks) could evolve, based on the events tracked over a given period. The established quantified states in which the (super-)network could evolve are the following:

- 100% functional (no failures),
- level 1 degraded (minor service degradations, acceptable – for example, delay in service delivery),
- level 2 degraded (some non-essential services are missing),
- level 3 degraded (some essential services are missing),
- completely degraded (out of service).

The approach was developed in two directions:

i) Reliability analysis.

ii) Customer satisfaction analysis.

In practice, the reliability analysis algorithm works based on the following processes:

• Process 1: extracting information on the availability of services during the determined period, observing possible patterns and creating a table with the availability of agents, which also includes the average probabilities of interruption.

• Process 2: detecting the transition from the current state to another state and creating a database table of these transitions.

• Process 3: calculation of the state transition matrix based on Markov chains.

• Process 4: Execution of the subroutine for defining the risk levels according to the transition probabilities between the states:

Case P (Current state => Possible state x) between {interval 1}, Risk level = "Very Low"

(Current state => Possible state x) between {interval 2}, Risk level = “Low”

(Current state => Possible state x) between {interval 3}, Risk level = “Medium”

(Current state => Possible state x) between {interval 4}, Risk level = “High”

(Current state => Possible state x) between {interval 5}, Risk level = “Very High”

For the present reliability analysis case study, to obtain information on the transition probabilities between these states (transition matrix), an analysis period of one year with a sampling interval of one minute was evaluated. The data was collected from a large network and service operator. For each trial, the current state (of the six possible) was recorded along with the timestamps. The developed algorithm extracted information on the types of transitions (from the previous state to the new one) and with the results the transition matrix was built for the analyzed period.

SN_x represents each possible state, and 4 such possible states were considered. SN_0 represents the full availability state when all services are operating within parameters. SN_1 can represent that a local network has a longer response time, SN_2 – the host domain for several services in the main network is down, SN_3 – the physical hardware in the data center is malfunctioning or several IP addresses are unreachable, or the routing rules are not working properly and SN_4 – physical layer damage of the OSI stack has occurred or there is a huge increase in all unanswered client requests. Based on the data collected from the case study, the following results were obtained for service availability.

The numerical data from the transition matrix were obtained by monitoring over a period of one year the most important services in a communication network and recording all types of incidents that led to their degradation. The degree of service degradation (representing the low value of availability) was analyzed, as well as the number of incidents and their duration. Each service transition from a 100% availability operating state to any other state of degradation was considered for each individual type, as well as transitions from intermediate states of high degradation to those where services are nearly recovered. In all this analysis, the duration of each incident and its impact is very important.

Incidents/failures are most often detected by applying Application Performance Management (APM) methodologies with agent-based and AI monitoring tools such as Dynatrace. Without these tools, technical teams often find it difficult to find the root cause of an application performance issue.

However, sometimes some incidents are detected reactively by being informed by third parties about the existence of a problem or by noticing an increase in the number of complaints. Operations teams tasked with maintaining high application availability, 24/7, use a host of monitoring and alerting tools for information and rapid intervention in the event of an incident. For each incident, the time of onset, its severity, the impact on services and the time of recovery are recorded. After the complete recovery is carried out, most of the time through reverse engineering (reverse engineering) or the analysis of the last interventions performed on the system, the cause of the problem is also checked and noted.

The values in the matrix were collected based on the historical query of the database and represent the transition probabilities between a certain state (of degradation) to another state, representing the number of events recorded during the one-year period of analysis. Based on the current state and the state transition matrix, it now becomes possible to estimate the future state of the network after n sampling steps in the future using the Markov chain approach: $S_n = p^n S_0$, where S_n is the probability of the predicted state at the n th sampling moment, p^n the transition matrix raised to the power n and S_0 the probability of the current state. The ultimate goal is to create a risk assessment mechanism to improve the preventive maintenance process.

Using the Apdex index (APDX), for a period of one year, customer satisfaction with the various services was also evaluated. The APDX index is defined by the ratio between the sum of satisfactory and tolerated requests compared to the total number of requests made during the analyzed period (one year, monthly average).

- Satisfied - satisfied customer who experienced a high responsiveness of the application. (Depending on the application, less than 1s, usually tens of milliseconds).

- Tolerant - a client who has experienced slow, noticeable response from the application. (Depending on the application, less than 5s, usually in the range of 1 – 3s.)

- Dissatisfied (frustrated) – a customer who has experienced unacceptable performance of the application, which leads to abandoning its use (usually more than 5 seconds).

However, it is important to note that different categories of customers may have different expectations for services or application performance. Customers will be willing to wait if the service brings a very high added value, while in other areas, if the customer does not enjoy the process, maintaining a high APDX score could prove crucial. For the same analysis period, the APDX index was calculated for all six services mentioned above.

The goal of this approach was to design an automated solution for collecting data on the health of multiple networks and services (based on AI agents) to help application managers operators make decisions based on the future prediction of possible risks. The construction of an AI-based risk assessment matrix, the global information table containing the risk assessments, with or without control measures, is presented. Additional information may include responsible departments and recommended actions. In this approach, those that might still occur after the first set of maintenance/correction operations have been performed are also considered residual risks.

Based on the results obtained above, an AI-based risk assessment matrix was designed through the following processes:

- For each of the current states SN of services and networks, a table is built with possible transitions to the next states S(N+1) and the risks associated with them.
- Calculation of residual risk levels (the risk of going into a non-functional state, partially or totally, following restoration interventions already applied).

- Display of residual risks.
- Display of current operating status. If the current status is not 100% operational, then display actions, recommendations, alarms, departments involved. Display the most likely next state, according to the forecast.
- Display the gradually decreasing precalculated risk levels for transitions in all other possible states.

Considering previous experience in maintenance work, the algorithm has been enhanced with an additional risk analysis feature, namely the Residual Risk with Control (RRC) matrix. This feature should improve the view of administrators with more actions to avoid falling into a new network and/or service failure situation, when inappropriate actions during recovery could trigger cascading failures or impact on others services that were previously in good condition. To achieve less defective results in recovery actions, records of failures caused by incorrect or insufficiently documented maintenance operations could be used to build a probability matrix. Based on this database, a model for the evolving states of the system could be obtained by a process similar to that previously described.

For the case study in the analysis, the AI-based risk assessment matrix was supplemented with the control risk assessment section. This matrix can also be considered a useful tool in preventive maintenance, serving as a tutorial for:

• building new regulations for assessing the risks to which subsystems or services could be affected when periodic maintenance interventions are carried out;

• defining new operating procedures,

• creation of standardization, etc.

The following risk ratios were taken into account:

Very low – risk rate $R_r \leq 20\%$.

Low – risk rate $21\% \leq R_r \leq 40\%$.

Medium – risk rate 41%≤R_r≤60%

High – risk rate $61\% \leq R_r \leq 80\%$.

Very high – risk rate $81\% \leq R_r \leq 100\%$

Each change in the system state is automatically detected (by the sudden change in the values of the availability indices and APDX) and after such a change, a new line with the current state is recorded in the array (current state ID). For this new state, the possible future states are calculated, the probability of transition into them, the impact that the transition would have, and based on these last 2 criteria, the estimated risk is displayed, if no corrective measures are taken. Retrieving information from adjacent monitoring tools such as Dynatrace can also help detect possible root causes that led to the state change. Based on the history related to the impact of the application of the basic corrective measures in the past, the possible future states with control and the risk of their occurrence are calculated and displayed.

In both cases, the risk assessment tool provides the user with an overview of the evolution of the system/network and informs them which departments are responsible for corrective measures. The AI-DRAM platform shows an overview of how many low, medium or very high risks the maintenance operator might have, to be able to deal with different situations and choose the most suitable measures, depending on when the maintenance procedures are executed. This tool immediately provides the entire table of possible implications that the maintenance operation could have.

As the complexity of automation components, connected IoT devices and communication networks increases day by day, maintenance of heterogeneous systems becomes more and more difficult. Therefore, the support that an automated maintenance process could bring is considered beneficial in increasing the productivity and resilience of IoT-based smart city services. In this chapter, a solution for risk assessment and estimation of future states of the complex environment of a smart city has been developed. When intelligent monitoring agents for hardware, software components and user satisfaction are used, the harmonization of recorded failure and malfunction events should also be subject to automated processing. In order to do this in an efficient manner, a risk assessment matrix was developed in the present research, based on a one-year analysis of a case study comprising six smart city services and related communication networks data. The purpose of this review was to create records of service availability and APDEX.

After this analysis was completed, a second quantitative assessment of the causes of the incidents and how these incidents affected the functionality of the system was carried out. Any incident that occurred caused a drop in performance indicators. However, of particular interest was the analysis of the causes that produced incidents. It was emphasized that human interventions (maintenance operations) that caused incidents were considered in this study.

The next phase was to note the number of incidents and calculate their probabilities. Based on the obtained probabilities, a state transition matrix was developed. Using a Markov chain approach, possible future states of the system could then be estimated. For each of the failure states, an impact and a scaling of the respective occurrence probabilities were associated. AI-DRAM was developed based on a dedicated algorithm. In this algorithm, any time the current state changes, a new record is noted and the new, estimated probabilities of the system evolving into any possible state, along with the associated impacts, are calculated. The main KPI of this process is the availability indicator; however, APDEX is an improvement to correlate service quality with customer satisfaction.

The optimal combination of hardware sensors and intelligent agents can achieve the highest degree of reliability in the complex preventive maintenance process. Preventive maintenance is a proactive approach to keeping hardware infrastructure and software applications in optimal condition by using historical data analysis and artificial intelligence (AI) to anticipate and prevent failures, reduce downtime and optimize performance. In this research, an attempt was made to optimize the interaction between automated and human maintenance operations. The increase in the complexity of systems and services, which also involves the multiplication of operations, and at the same time the difficulties of their management, must be compensated by the introduction of automatic management support elements, such as monitoring agents and FMS decision-making support services. The main contributions of this chapter can be summarized as:

• Analysis and synthesis of up-to-date information on automated or partially automated systems and solutions to support pro-active and post-event maintenance services.

• Development of new solutions for efficient use of data taken from hardware and software monitoring systems of telecommunications networks, integrated with data from application performance and customer satisfaction monitoring agencies.

• Carrying out a case study with data taken over a period of one year from a series of applications for monitoring the specific services of communications of a smart city, representing the availability and satisfaction of customers.

• Analysis and recording of all events and incidents during the monitoring period, with ranking according to severity and impact criteria.

• Defining a set of states of services and systems and creating a matrix of states and transition probabilities from one state to another.

• Using Markov processes of order 1 to describe future states, based on the transition matrix.

• Defining an integrated application for preventive maintenance and risk and impact analysis, including residual impact.

A smart city represents an opportunity for the large-scale inclusion of citizens who can benefit from the advantages of new technological and informational solutions, with the aim of simplifying their existence, creating comfort, a healthy climatic environment and a less expensive life in many aspects. That's why I proposed that all studies, research, experiments carried out, algorithms implemented and innovative solutions discovered be integrated into a business idea.

The proposal for the development of a business plan with applicability in the field of digitalization of a city promotes the relationship between citizens and the administration, providing information and means to encourage the participation of citizens more actively in the life of the community. The main attributes considered by the business proposal are directed towards smart mobility, smart infrastructure, smart technologies, smart energy, more informed and therefore smart citizens.

The "City Master Companion" integrated solution, proposed and detailed in the last chapter of the thesis, addresses local communities, being focused on digitizing and simplifying the way of interaction between public authorities, on the one hand, and urban infrastructure, respectively citizens, on the other part.

It is also supported to open the widest possible public access to information needed in everyday life, by designing and interconnecting intelligent systems for the development of services in favor of the city's citizens.

General business information

• Business scope: software design, systems integration, development of hardware/software solutions for functional components of smart cities.

• Investment name: development of functional components for AI-assisted management of the urban environment

• Company name: S.C. Intelligent City Development (ICD) SRL. Headquarters: Bucharest, Splaiul Independentei 313, sector 6.

City Master Companion Platform Solutions Portfolio (CMC22)

• Integrated crowdsourcing solutions: CMC22 smart portal for citizens

• Solutions for collecting, managing, analyzing and forecasting based on data from the field: automated call center solutions

• Info kiosk solutions in public transport stations and other places frequented by the public

• Solutions for intelligent management of sanitation services

• Solutions for managing electricity consumption and public lighting

• Traffic monitoring solutions

• Information solutions regarding the level of pollution

• AI-based support of complex smart city facilities management process

• Automated assistance for crisis situations

Business development directions:

• Stage 1: consulting for public administration: establishing the needs of citizens of the administration and other users.

• Stage 2: documentation, data collection from the field. At this stage, the company will hire personnel with medium and higher-level qualifications (young graduates of specialized faculties) in order to collect some information from the field.

• Stage 3: designing the integration solution of smart city components. In this stage, based on the information collected in the previous stages, the design of the functional components integrated into the smart city management solution will be carried out, through consultation with local administrations.

• Stage 4: consulting for the purchase of services. Elaboration of the specifications, assistance in tendering, bidding and purchase of products and services.

• Stage 5: assistance during the integration period of hardware/software products. The trading company will provide the integration of its own software products, assistance for the installation of sensors in the field, development of web pages and mobile applications.

• Stage 6: training of administrative staff for CMC22 operation.

• Stage 7: technical assistance during the 2-year warranty period.

The vision of the newly established firm focuses exclusively on the technical component of architecture design and the development of software components and AI agents for the assisted administration of the smart city (stages 1, 3, 6). If the beneficiary wants to purchase services from S.C. Intelligent City Development SRL for stages 2, 4, 5, 7, additional documents will be concluded after initialing a framework service contract.

The idea of this business was born from the analysis of the current trends of the software market and the integration of services for the development of smart cities, an emerging market at the moment and of great interest to many administrations. In a world in constant transformation and, at the same time, in a permanent interconnection, a city's ability to adapt to new trends manifested at the international level plays an essential role in its further development. Today approximately 360 million Europeans (approximately 72% of the total EU population) live in cities and their suburbs, and the trend is increasing. According to United Nations estimates, the percentage of the urban population is increasing, more precisely, it is expected that at the level of the 2050s it will exceed 80% (approximately 6.3 billion people out of 9.3 billion).

Increasing the comfort of urban life, providing digitized services and electronic payment methods will allow the development of smart city components in the near future, increasing the interest and support of citizens towards a safer, more convenient and environmentally friendly future.

The global trend of smart city transformation has created a community of global markets, regions, countries, metropolises, alliances, associations, innovation groups that collaborate in this endeavor and have adopted strategies, programs, initiatives, action plans and declarations in this regard for which more and more funds are allocated worldwide. Thus, a new business market is being developed, with numerous opportunities and jobs for many social categories, while promoting excellence in areas such as IT, applied electronics, social services and others. Any approach to a smart city development process must begin with intelligent, assisted management; this business was also conceived in this sense, with the aim of promoting excellence in the integrated and assisted management of services in a smart city. The executive in the local administration, the town hall through its specialized apparatus will be the first to ensure the development of the intelligent public services community, explaining to citizens the importance of an intelligent development strategy based on technology. Moreover, the Europe 2020 strategy promotes smart cities throughout the continent by investing in ICT infrastructures, for the development of human capital, and in solutions that take advantage of the advantages related to new technologies and digitalization to achieve the following objectives: improving sustainability and the quality of life and work citizens and businesses, optimizing the efficiency and accessibility of services, reducing poverty, the unemployment rate, social exclusion, pollution and environmental degradation.

In this context, as well as in that of conducting doctoral studies, it was considered that this business will bring great benefits to all people living in big cities and beyond. The software applications that the company will develop have as their main role the safety and daily comfort of people.

As a result of these elements, an idea was developed and applied to respond to important social needs, considering the fact that everyday life requires safe, efficient services with wide recognition by the urban community. At the same time, safety and comfort are other important aspects of our lives. This business was born with the intention of addressing and solving a social need in a positive and beneficial way.

Thus, as stated, the innovative character of this business is ensured by the original research that was the basis for the development of the first software application (Online gas sensor monitoring platform, based on LoRaWAN technology), as well as the idea of developing integrated services for monitoring based on artificial intelligence agents specialized in the automatic control of telematic systems to ensure services in smart cities.

By developing the applications and services that the newly established company aims to provide, it is hoped that in the coming period a sustainable urban environment will be created, able to ensure:

• A better and smoother transition from traditional cities to smart cities, by introducing the digital factor in several sectors of the city's activity, a factor that is easier to administer through the proposed solution, City Master Companion;

• An economic growth and a territorial organization of balanced activities, with a polycentric urban structure; The support provided through AI-assisted services will ensure secure and fluent growth, as well as development based on scalable applications;

• The creation of strong metropolitan regions, which can offer better accessibility to services of public interest to the citizens of the smart city;

• Ensuring a high degree of environmental protection and quality in and around cities.

The solutions to be analyzed in the near future and to be recommended to the beneficiaries, for increasing the efficiency of the smart city management include the following directions of approach:

• New strategies for expanding social services.

• Digital transformation of businesses.

• Business optimization and electronic reporting.

• Regional exchange of information and best practices in the field of smart cities.

Thus, the developed product proposes a monitoring and support platform for real-time predictive decisions, which addresses both the control of operations and the information needs of the city's citizens. The platform will be able to provide the authorities with forecasts on the evolution of various monitored services within the urban, transport, environmental, electricity, etc. sectors. , based on information captured by AI super-agents, taking into account the unpredictable events that may occur. It will then communicate this information to platform users and consider their response.

Through this initiative, collateral research actions can be further developed and started in urban areas where there is a demand for digitalization of certain facilities or services.

Contributions within this chapter:

• Creation of the business framework for the development of a service intended for the assisted administration of smart-city services;

• Making a business plan for automated smart city management support services.

This doctoral thesis focuses on the field of services in the sphere of smart cities and aims to identify feasible solutions for their digitization, based on new information and communication technologies, and also on their integrated management, which will contribute to increasing the quality of life of citizens. The research carried out was aimed at identifying and developing innovative solutions based on the theoretical concepts described in the specialized literature, so that new feasible methods, techniques and algorithms can be obtained for improving the response time of online applications in the sphere of smart cities, offering a maximum availabilities, increasing customer satisfaction and last but not least, helping operational administrative staff to identify and resolve incidents as quickly as possible.

Considering all these aspects, the main conclusions that emerge from the experimental research carried out in this doctoral thesis are the following:

• Romania benefits from a modern communications infrastructure, with good to very good Internet access speeds, but the level of digitization and knowledge of data devices is still developing, especially in rural areas.

• Comparative analysis of different communication technologies such as cellular networks, LoRaWAN, LPWAN, ZigBee, WiMAX, Bluetooth, Wi-Fi and DSRC revealed their advantages and disadvantages in the context of smart city and transport applications.

• For the development of smart homes, important requirements have been identified, such as the level of complexity of application development, adaptability, time constraints, synchronism, mobility, technical requirements, expandability, security and resource management.

• Wireless sensor networks have demonstrated their utility in areas such as home automation, transportation, health, territorial surveillance, and environmental monitoring.

• For the complex management of a smart city, it has been proposed to use specialized AI agents and a Supervisor Super-agent to monitor and manage various components and activities.

• Maintenance and resilience of communication networks are becoming increasingly important in the context of increasing demand for data services and communications. Using AI tools and optimization-based approaches can help improve management and reduce recovery time in the event of failures.

• Case studies have shown that monitoring tools are relatively effective in detecting problems, but do not always provide quick and useful information to identify the root cause of failures.

• Maintenance and upgrade activities can cause service level drops in communication networks, and cross-network application-oriented supervision with the help of AI agents is considered necessary for the further development of data communication systems in smart cities.

• For effective network management in smart cities, it is recommended to develop and implement proposed solutions that involve the use of monitoring agents and artificial intelligence to ensure proper monitoring and optimal management of communication networks.

• The ideal combination between hardware sensors and intelligent agents can achieve the highest reliability in the complex preventive maintenance process.

• Preventive maintenance is a proactive approach to maintaining hardware infrastructure and software applications in optimal condition. This involves using historical data analysis and artificial intelligence to anticipate and prevent failures, reducing downtime and optimizing performance. In this research, an attempt was made to optimize the interaction between automated and human maintenance operations.

• The increasing complexity of systems and services, involving the multiplication of operations and management difficulties, requires the introduction of automatic management support elements, such as monitoring agents and FMS decision support services.

• The better a company is in an economic-financial situation, the more it can take greater risks in the hope of obtaining superior results. However, it is necessary to have resources to compensate in case of failure.

• The use of decision optimization techniques in conditions of risk and uncertainty gives managers the opportunity to take risks consciously, selecting them according to the effects and consequences that these risks could have if they materialize.

Contributions:

The original contributions resulting from these activities of study, analysis, research, experimentation, testing and implementation of solutions, carried out throughout the period of the doctoral internship, are presented in the following:

1. Synthesizing a rich package of information from a multitude of specialized works.

2. Proposing a modified OSI model, having a better applicability in the context of very heterogeneous support technologies used for data transmission within the communication network of the smart city.

3. The idea of using, in an infrastructure of the future smart city, not only the information automatically captured from sensors installed in the network, but also crowdsourcing services, i.e., applications available on mobile terminals where the information and possible feedback be entered by the users themselves.

4. Two solutions were proposed for effective coordination and monitoring of networks within smart cities. The first scenario proposes a structure based on monitoring agents at the level of communication networks, with a focus on monitoring smart city applications and presenting performance indicators for each application. The collection of data at the regional level through the regional monitoring agents and their processing at the local level, with the presentation of the results at the level of the same regional agents. The second scenario proposes an overlay structure dedicated to the control of the cross-network service level of smart city applications, interfacing with the FMS systems of each communication network.

5. The study was carried out on the importance of monitoring communication networks adapted for specific applications of smart cities, different ways to apply monitoring mechanisms were analyzed and software programs intended for this purpose were compared.

6. A case study was carried out where it was found that monitoring tools are relatively effective in detecting problems, but their single use is often insufficient. A cross-network specific application-oriented supervision based on artificial intelligence agents was considered necessary in the further development of data communication systems in smart cities.

7. A solution was proposed to coordinate several such programs in order to finally have the most efficient, autonomous and exhaustive management of network maintenance in the scenario of smart cities.

8. Analysis of the efficiency of APM type solutions.

9. Proposing a mathematical model of the monitoring processes, based on Amdahl's law with rethinking on new bases.

10. Carrying out a case study for a communications network with over 10 million subscribers, equipped with Dynatrace, to exemplify the effectiveness of finding the root cause of a malfunction in different scenarios, where the high share of malfunctions created by operational activities, including network development and maintenance.

11. The proposal of two scenarios for the development of FMS-type services for communication networks dedicated to smart cities.

12. Synthetic analysis, classification and organized presentation of the main functional components of smart cities, through the lens of their integrated management.

13. Case studies of examples of applications useful for integration into a centralized digital management solution of smart cities.

14. Analysis and definition of the main key indicators and metrics required for the development stages of the smart city.

15. Proposing a model and architecture for the development of an AI agent for the management of a smart city.

16. Proposing a methodology for urban crisis assistance based on Min-Max algorithm with Alpha-Beta pruning.

17. Opportunity study for the management of uncertainty situations.

18. Example of automatic calculation based on multiple criteria, in various economic stages, to warn of the emergence of crisis conditions.

19. Analysis and synthesis of up-to-date information on automated or partially automated systems and solutions to support pro-active and post-event maintenance services.

20. Development of new solutions for efficient use of data taken from hardware and software monitoring systems of telecommunications networks, integrated with data from application performance and customer satisfaction monitoring agencies.

21. Carrying out a case study with data taken over a period of one year from a series of applications for monitoring the specific services of communications of a smart city, representing the availability and satisfaction of customers.

22. Analysis and recording of all events and incidents during the monitoring period, with ranking according to severity and impact criteria.

23. Defining a set of states of services and systems and creating a matrix of states and transition probabilities from one state to another.

24. The use of Markov processes of order 1 for the description of future states, based on the transition matrix.

25. Defining an integrated application for preventive maintenance and risk and impact analysis, including residual impact.

26. Creation of the business framework for the development of a service intended for the assisted administration of smart-city services.

27. Presentation of the economic-financial opportunity of developing a software application for the integrated management of services.

28. Making a business plan for smart city management automated support services.

Taking into account all the research carried out so far to find the best practices and solutions to improve the process of transforming cities from traditional to cities with a smart component, and at the same time implementing the most efficient and integrated management methodologies of the component services of a smart city ecosystem, future research will consider several aspects:

• Carrying out a more in-depth preliminary study to determine the shortcomings in the development of web applications that can lead to various behaviors that introduce dysfunctions into the system, this also includes a proactive approach to writing code that can be more easily supervised.

• Creation of an elaborate database, dedicated to the management of smart city components so that it is possible to improve the solutions developed in the doctoral thesis. Using this data for complex analysis and significant improvement of non-intrusive predictive maintenance procedures.

• The development of other solutions for the monitoring of services will be attempted, solutions that could have in mind the identification of the possibility of replacing, to a large extent, human activity on the systems, be it preventive.

• Future research will also consider the development of exhaustive clean-up mechanisms on the systems, when components are replaced or elements are introduced and changed in the architecture of the smart ecosystem. This is imperative because in practice there are many cases when certain teams are not aware of the changes that are made on the system and do not propagate these changes in the systems they manage, thus there are residual risks of incidents occurring.