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Exploring the Usability of Process Mining in Smart City

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Abstract: The aim of this paper is to explore the usability of Process Mining approaches in Smart City applications. Our research was triggered by the following three research questions, concerning the initial investigation of: i) the most researched Smart City problems using the methods of Process Mining; ii) the most utilized Process Mining methods in Smart City applications; iii) the most popular Smart City topics that were not approached yet from the perspective of Process Mining. This analysis will result in a set of challenges and opportunities of utilizing the most innovative Process Mining methods for solving emergent Smart City problems.

Keywords: Optimization and Decision Making in Smart City Control; System Theory in Smart City Control; Cyber-Physical Systems.

1. INTRODUCTION

Smart City (SC in what follows) is both a social and economic reality, as well as a modern technological concept that recently emerged as resultant of both high urbanization phenomena, as well as of rapid technological developments spanning a multitude of industries, including transportation, energy, construction and ICT.

One of the first definitions of SC was proposed one decade ago by Deakin and Al Waer [2011] clearly emphasizing the role of ICT for the development of the modern city concept. Since then, the concept of SC and its understanding in various areas of science and technology has evolved a lot, leading to a multitude of definitions, recently synthesized by Sánchez-Corcuera et al. [2019] using the following classification: technology-based, domain-based, integration-based, architecture-based and data-based.

Modern organizations are designed to deliver valuable services to their customers. Each service delivery assumes the execution of a business process inside the organization. While the service is delivered, the underlying business process is enacted and event data is recorded during process execution and stored inside the organization process-aware information system as event logs. Process Mining (PM in what follows) assumes the analysis of such event logs for extracting knowledge useful for improving the organization business processes. Traditionally, PM is part of the broader field of Business Process Management (BPM in what follows) (see Dumas et al. [2018]).

According to van der Aalst [2016], there are three classes of offline analytics applications of PM: process discovery, conformance checking and process enhancement. Process discovery assumes the construction of a process model that can explain the data recorded in event logs. Compliance checking assumes that the process model is *a priori* available and it checks if the event logs are consistent with the process model. Process enhancement achieves some improvement (e.g. repair or extension) of an existing process model, using the data recorded by event logs. Moreover, according to Folino and Pontieri [2021], PM can be also used for online process operations by supporting detection, prediction and recommendation on running process cases.

SC can be seen as a complex and heterogeneous network of organizations that delivers services to its citizens and institutions. Such domain-based services are backed by appropriate business processes that must efficiently deploy available infrastructure elements and resources for satisfying the needs of their customers. According to Hoffman [2016] and Javidroozi et al. [2019], BPM plays a very important role in the implementation of SC as a complex integrated enterprise.

This view of SC clearly creates the opportunity of the application of all types of offline and online PM for enhancing SC operations.

According to Bouroche and Dusparic [2020], SC operation can be described under the umbrella of "urban computing" as a sense-analyze-actuate loop. This operation is supported by an appropriate ICT infrastructure involving multiple heterogeneous sensing, computing and actuation elements that are interconnected by suitable network and Internet of Things (IoT in what follows) technologies. According to Şimşek [2022a], one of the four trends that have the potential to fuel the future of PM is the integration of PM with IoT networks of sensors and devices. This can bring in huge amounts of real-time data gathered by the ICT infrastructure of SC to be processed by PM tools.

Moreover, SC use cases represent complex application scenarios involving multiple stakeholders. They are character-

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ized by a high variability of the processes under analysis and they are affected by various data quality issues like completeness, trustworthiness and uncertainty. Following the analysis of Folino and Pontieri [2021], SC use cases can be addressed by AI-empowered PM approaches that aim to increase the amount of AI methods supplied to PM tools. Such AI methods include use of background knowledge and performance of multiple AI tasks (e.g. Multi-Task Learning).

This initial analysis clearly shows the high relevance of PM to SC applications, thus triggering and motivating our research following questions:

(1) RQ1: What are the most researched SC problems using PM?
(2) RQ2: What are the most researched PM methods applied to SC?
(3) RQ3: Are there any popular SC topics that were not approached using PM yet?

We aim to address these research questions in the subsequent sections of our paper.

2. BACKGROUND

There are many definitions of SC. Moreover, according to James et al. [2020], it seems that this concept is not entirely new, being also related with other older "metaphors" like "Knowledge City", "Creative City" and more recently with "Sustainable City". Typical for most of SC definitions is to set the emphasis on the various dimensions of the concept, including humans and institutions, technology (ICT, energy management), infrastructure (buildings, roads), system integration (SC computational architecture, components, interfaces and data management), domains (education, healthcare, well-being, shopping, governance, tourism, entertainment, law, emergencies), and environment (emissions, pollution, waste management) (see James et al. [2020] and Sánchez-Corcuera et al. [2019] for details).

Contemplating this large list of heterogeneous dimensions clearly shows the difficulty of proposing a unique and integrative definition of the complex and dynamic concept of SC. One possibility is to use dimension abstraction and to group accordingly these heterogeneous elements into three abstract classes comprising: i) living dimension; ii) infrastructure dimension; and iii) resource dimension.

The living dimension covers all the elements concerning life and well-being, thus addressing goals and benefits of humans (citizens), society, institutions and environment. The infrastructure dimension covers all the technological artefacts (ICT and non-ICT) that enable the SC to achieve its goals, including for example movement of citizens, communication between citizens, institutions and government, as well as deployment of various services for citizens (for example hospitals for healthcare, schools for education and facilities for entertainment). Last but not least, the resource dimension comprises measurable quantities usually associated with infrastructure elements, that fuel SC service deployments including for example energy, water, air and various service capacities (e.g. road infrastructure capacity, transportation fleet capacity, hospitalization capacity, road space a.o.). According to this view, the aim of SC is to support goals and benefits for the living dimension, using available infrastructure dimension, by minimizing or rationalizing use of resource dimension. We can observe the similarity of the SC aim with the aim of a complex integrated enterprise to efficiently satisfy the needs of its customers.

Data Mining (DM in what follows) is a hot topic that attracted a lot of applied research in various areas, including of course SC. Modern DM is fueled by Big Data and Machine Learning (ML in what follows) advances. In particular, huge amounts of data are generated by IoT systems, thus raising enormous opportunities and challenges for DM.

DM is different from and it should not be confused with PM. Although they have the apparently similar goal of knowledge discovery, their focus is very different. DM applications include prediction, pattern discovery and control. Prediction involves predicting future behavior based on historical data analysis. Typical prediction methods are classification and regression. Discovery involves learning hidden patterns from unstructured data. A typical approach for pattern discovery is clustering. Finally, control assumes decision making for optimizing behavior based on continuous interaction and feedback. A typical approach is reinforcement learning.

On the other hand PM is focused on unraveling process knowledge by analyzing event longs of process aware information systems. An event long can be conceptualized as a relational table that must contain at least a process case identifier, an activity name and a time stamp. A process case or instance is thus captured by the set of all records that have the same process case identifier. A data set in DM can be also represented by a relational table. However, in this case, each record represents a data point or instance. Moreover, research on DM and PM has resulted in numerous and very different algorithms for each of these areas (see van der Aalst [2016]).

According to the very recent bibliographic research of Kousis and Tjortjis [2021], the application of DM and Big Data in SC has a huge popularity. This situation is very different with respect to PM (more details are discussed in the forthcoming sections of this paper). On the other hand, there are many applications of PM in process monitoring using IoT systems, especially in the areas of Smart Manufacturing and Industry 4.0 (see Osman and Ghiran [2019]) and human behavior modeling (see Lull et al. [2021]). These researches are clearly relevant for the application of PM in SC, as one of the key enabling technologies of SC is IoT. They thus provide both a good motivation for our research endeavor and a source of possible solutions for emerging SC applications.

3. RESULTS

As we were interested in investigating usability of PM in SC, our research methodology was based on searching relevant scientific databases for works involving the following two elements: "smart city" and "process mining". However, this initial attempt revealed an insufficient number of research publications on the searched topics, rendering our bibliographic research incomplete. On the other hand, searching only for "process mining" produced a very large number of resources, thus making our search not well focused.

These initial findings triggered us to upgrade our research strategy by both expanding and refining our search. Therefore we decided: i) to also include into our bibliographic research few references of industrial "gray literature" (see Paez [2017] for a recent definition of "gray literature" concept), and ii) to refine our search based on specific topics of SC. For item ii), in order to define a relevant list of such topics, we considered the 20 themes defined by the ISO standard ISO 37120:2018 [2018] for sustainable cities and communities.

According to ISO 37120:2018 [2018], there were defined 20 themes of interest in SC, each theme comprising several core and supporting indicators. We used them to initially guide the search of relevant works fitting a specific domain associated to SC. Thus, our exploration of the research literature can be described as heuristic, being primarily guided by these themes, with the goal of creating a picture of the coverage of each particular theme with references to recent applications.

We discovered three types of papers addressing PM application on topics related to SC: i) general overview papers, covering a multitude of applications of PM, ii) domain-specific overview papers, covering the application of PM in a certain domain and iii) application-specific papers, referring to a specific application of PM.

Our results are summarized in Table 1 that at least partly answers to RQ1. Each row of the table corresponds to a specific theme extracted from ISO 37120:2018 [2018]. The name of each theme is included in the first column of the table. The second column contains a more refined description of that particular domain, eventually indicating a subdomain and possibly the name of a related domain. The third column contains the reference(s) pertaining to that specific theme and subdomain.

One of the main difficulties in extracting and synthesizing this information is the fact that different research papers on PM application (including research overview papers) use different wordings for describing domains that can be categorized within or at least related to a particular theme. For example, dos Santos Garcia et al. [2019] provides a comprehensive survey of research on PM application in various domains: healthcare, ICT, manufacturing, education, financial, logistics, public, security, call center, ux/usability, robotics/smart, entertainment, utility, garment, advisory, retail, pharmacy / biology, hotel, agriculture. We assigned them to ISO themes as follows: health (healthcare, pharmacy / biology), education, financial, recreation (entertainment, hotel), governance (advisory, public, call center), economy (retail, manufacturing, garment, logistics), energy (utility), safety (security), urban/local agriculture and food security (agriculture).

Probably the most complete collection of PM applications is provided by Cotroneo et al. [2021]. It contains a set of use cases gathered from companies all over the world, spanning a multitude of industries. For each case, the collection includes the name of the specific process, as well as a brief description of the application. However, in our opinion, although very useful, this resource suffers from two main problems that hindered its direct use in our research:

i) The division of the cases into industries and sectors is messy for two reasons. The document presents the lists of industries and sectors, but then, in the classification their use is inconsistent. Firstly, some elements appear both as industries and sectors, and secondly, in the presentation of the use cases we could find other industries and sectors, not present in the initial lists.
ii) References (papers, links) to the sources of information for those use cases are completely missing.

Analyzing the results of Table 1 we can conclude the almost all the themes of SC were approached using PM methods (excepting "Water" management). However, we can also notice that some themes are far more popular than other themes. While it could be difficult to sort this themes according to their perceived popularity, we can still make some interesting conclusions.

Clearly the most popular themes are "Health" and "Education". We could find good state-of-the-art and survey papers on this subject (see Dallagassa et al. [2022] and De Roock and Martin [2022] for "Health" and Bogarín et al. [2018] for "Education"). There are also many scientific references to these subjects (not included here because of lack of space). At the other extreme we find significantly less researched themes of "Solid and water waste management", "Environment and climate", "Sport and culture", "Population and social conditions", "Urban/local agriculture and food security", and "Urban planning". Slightly more attention was received by "Safety" and "Energy" sectors. Moreover, increasingly popular are the themes of "Finance", "Government", "Transportation" and of course "Economy". Note that this analysis provides answers to RQ1 and RQ3. Note also that these results are consistent with the findings of other researchers (although not focused on SC, see dos Santos Garcia et al. [2019]).

Moreover, for some themes we perceived a sort of gap between the industrial understanding and state-of-practice on one hand and the related academic literature on the application of PM to SC, on the other hand. Examples are those themes & subdomains for which Table 1 presents gray references coming from practice, companies and industry experts.

Clearly, the precise answer to RQ2 would require a more in-depth examination of all the relevant works to see exactly what were the most PM approaches utilized for SC and how are they spread onto the SC relevant themes. Nevertheless, our initial research still allows us to do a qualitative assessment of this subject, thus offering a partial answer to RQ2.

Basing our discussion mostly on the findings reported by survey articles (dos Santos Garcia et al. [2019], Bogarín et al. [2018], Dallagassa et al. [2022]), we can conclude that the classic methods of PM, namely process discovery, compliance checking and process enhancement were utilized for the most researched themes of SC: "Health" and "Education". Moreover, other popular SC themes were also approached using the classic PM methods.

Table 1. SC themes with literature references

Theme	Related domain / Subdomain	References
Economy	Unemployment benefits Recruitment Business Management Multiple subdomains (Retail, Manufacturing, Garment, Logistics)	de Leoni et al. [2016] Şimşek [2022b] Zerbino et al. [2021] dos Santos Garcia et al. [2019]
Education	Multiple subdomains (Personalized learning, Learning behavior, Learning path recommendation) Students' behavior analysis	dos Santos Garcia et al. [2019], Bogarín et al. [2018] Juhaňák et al. [2019]
Energy	Utility (multiple subdomains) Electricity and gas provisioning General overview	dos Santos Garcia et al. [2019] Perceptive Software [2020a] Fischer [2022]
Environment and Climate Change	Emissions reduction	Ueda [2021]
Finance	Multiple subdomains (Banking, Insurances, Risk) Financial statements audit	dos Santos Garcia et al. [2019] Werner et al. [2021]
Government	Multiple subdomains (Advisory, Public, Call Center) City governance	dos Santos Garcia et al. [2019] Perceptive Software [2020b]
Health	Multiple subdomains (Discovery of clinical protocols, Compliance to clinical guidelines) Personalized health	Dallagassa et al. [2022], dos Santos Garcia et al. [2019] Sztyler et al. [2016]
Housing	Smart home environments, Daily routines	Carolis et al. [2015], Leotta et al. [2015]
Population and social conditions	Social workflows	Rojo et al. [2022]
Recreation	Entertainment (music) Shopping Tourism	Rozinat [2018] Hwang and Jang [2017], Dogan et al. [2020] Lux and Rinderle-Ma [2017]
Safety	Security (multiple subdomains) Emergency response to chemical spills	dos Santos Garcia et al. [2019] Zhao et al. [2019]
Solid waste	Waste reduction Product lifecycle assessment	Rozinat [2011] Ortmeier et al. [2021]
Sport and culture	Football	Niks [2019], Kröckel and Bodendorf [2020]
Telecommunications	ICT, UX/Usability General overview	dos Santos Garcia et al. [2019] Gregusova [2019]
Transportation	Mobility process mining Taxi service Airline service Fleet tracking Train reroutings	Rath [2020] Rowlson [2020] Böhm et al. [2021] Ribeiro et al. [2020] Janssenswillen et al. [2018]
Urban/local agriculture and food security	Crop rotations	Dupuis et al. [2022]
Urban planning	Reindustrialization	Gontar [2017]
Wastewater	Wastewater treatment	Zhang et al. [2022]
Water	n/a	n/a

According to our initial analysis of selected works in the field, we claim the SC and its associated themes pose new challenges and opportunities for the PM methods. While most of the SC themes were addressed by PM, more work is needed to align the results to the real goals and requirements of SC.

4. CONCLUSIONS AND FUTURE WORKS

In this paper we presented our initial results of exploring the usability of Process Mining to Smart City based on the investigation of the scientific and gray literature in the field. Clearly, our research is limited in scope, as it was carried out heuristically by following a list of themes of an ISO standard associated to "Sustainable City", a concept that we deemed close enough to "Smart City". Moreover, the results presented are based on analysing works in the field addressing each of these themes, that most often where not carried out in the context of an SC project or application. Nevertheless, as the selected themes are clearly relevant for SC, this initial work allowed us to draw a set of interesting conclusions.

Firstly, we noticed the relatively few number of scientific papers directly referring to the use of Process Mining in Smart City. This can be contrasted to the very large number of works addressing the closely related field of Data Mining in Smart City. This clearly highlights the significantly higher popularity of Data Mining than of Process Mining in the context of Smart City. On the other hand, this could trigger new opportunities of research in the field of Process Mining applied to Smart City.

Secondly, by taking a closer look at the possible themes related to Smart City, we could depict an initial picture of approaching such topics using Process Mining. We noticed that there is evidence in the literature that all the themes are addressed (excepting water management). Moreover we were able to identify the most and less researched Smart City topics by Process Mining approaches.

Thirdly, we noticed that a multitude of Process Mining approaches were used to tackle Smart City problems, including the classic themes of process discovery, compliance checking and process enhancement. More research is however needed to see how were such approaches used for the various Smart City themes.

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