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Big Data and Data Analytics in Managing the COVID-19 Pandemic

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Full research paper

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Abstract

Big data and data analytics (BDA) have the potential to transform the public sector by providing a coordinated response to the COVID-19 pandemic and protecting the wellbeing of the people. Despite BDA's promising potential, agencies need to be aware that achieving a significant impact through BDA is not always guaranteed. Although it is essential to understand how organisations can harness the power of BDA that is used in policy-decision making, treatment and controlling of the pandemic, there is no widely accepted model that links BDA capabilities for enhanced management of public health emergencies. The focus of the paper is to address this gap. The research focuses on analysing how the public sector utilised BDA and acquired critical capabilities to manage the COVID-19 pandemic. The contribution of this study is to provide a framework for successful BDA application and extend the existing data readiness theory.

Keywords Big data, data analytics, COVID-19

1 Introduction

Big data and data analytics (BDA) have the potential to transform the public sector by improving its ability to address a variety of complex challenges and disruptions, including coordinated response and management of the COVID-19 pandemic. The spread of COVID-19 has had devastating economic, social and healthcare impacts worldwide, revealing many challenges around the appropriate responses to current and future pandemics (Blecher et al. 2020). Trillions of dollars globally have been invested to manage the COVID-19 pandemic, and protect economies and well-being across countries (Rai 2020).

During the COVID-19 pandemic, the governments' non-decisions became as important as decisions (e.g., policy delays or non-actions, information-reporting delays) (Weible et al. 2020). Since governments rely on evidence-based policymaking to reassure the public that decisions regarding COVID-19 management are based on informed judgements for the public good (Weible et al. 2020), timely, accurate, and sufficient data insights became more critical.

Addressing core areas of outbreaks' management includes early case identification, quarantining and preventing exposure to the community (Bansal et al. 2020) as well as diagnosis and treatment of the pandemic (Dananjayan & Raj 2020). In the search for an efficient and effective solution, BDA presents as a valuable tool for managing COVID-19 (Dananjayan & Raj 2020) and is considered an inevitable technological development in the field of infectious diseases (Garattini et al. 2019).

In comparison to traditional epidemiological predictive models, BDA provides adaptive learning, trend-based recalibration and the flexibility to estimate the impact of the intervention and improve it with new COVID-19 data (Bansal et al. 2020, p. 156). The difference from traditional data lies in the fact that 'big data' deals with massive, complex, real-time streaming data that requires sophisticated management, analytical and processing techniques to extract data insights (Gupta & George 2016).

Although large amounts of data are currently available, connecting big data to insights and successful outcomes remains elusive as it involves a complex process of alignment of business, technology, and agency practices (Bean 2020). Transforming a government agency through the use of new technology such as BDA can be a complex and costly exercise that first requires the development of core competencies within the organisation (Rogge et al. 2017).

The goal of this study is to develop a preliminary model for successful BDA application in the public sector, in particular developing BDA capabilities for enhanced management of the COVID-19 pandemic. Therefore, the focus of the study is to address the following research question:

RQ: *What BDA capabilities can help the public sector with enhanced management of the COVID-19 pandemic?*

While several studies have investigated the role of BDA and areas of its application in managing COVID-19 (Awotunde et al. 2021, Awotunde et al. 2021, Bragazzi et al. 2020) as well as the importance of real time evidence-informed policy during the pandemic (Cairney 2021), there is little research on examining the relationship between BDA capabilities and enhanced management of COVID-19, including agency's readiness for managing it successfully.

When agencies are equipped with the right mixture of capabilities (technological, data, human, culture and leadership), they are more prepared in identifying infectious diseases, preventing and managing outbreaks and, in turn, saving lives. As the number of cases can change rapidly, agility and proactive response are required for appropriate interventions based on timely, accurate, and sufficient data insights into the pandemic. The past studies focused on examining how BDA capabilities drive business outcomes (Torres et al. 2018, Wamba et al. 2017, Akter et al. 2016, Côrte-Real et al. 2016, Wang and Hajli 2016) rather than managing the COVID-19 pandemic.

This study extends the usage of the existing data readiness theory (Klievink et al. 2017) and promotes momentum for other researchers to explore the topic further. The research could also benefit the public sector and Australian citizens because it explores BDA capabilities from a government perspective and presents a causal link between theory and practice. This study also investigates and explains how organisations can ensure that they have the appropriate BDA capabilities.

2 Background

2.1 Big Data and Data Analytics (BDA)

BDA enables organisations to improve their ability to analyse different types of data (structured, semi-structured and unstructured) to reveal important correlation patterns (Wang & Hajli 2017), create actionable ideas (Wamba et al. 2017), obtain newer and deeper insights (Dutta & Bose 2015) and enhance understanding of fast changing environments. It is increasingly becoming part of the foundation for decision-making (McNeely & Hahn, 2014) and supports the creative application of large data sets, including those from the Internet and external devices (Bright & Margetts 2016).

Big Data includes data-related dimensions known as 5V: volume, variety, velocity, veracity and value (Wamba et al. 2017). Analysis of big data is performed via big data analytics tools that collect, manage and process big data at the right speed and within the right timeframe while providing the right-time analysis (Halper & Krihan 2013) and valuable insights.

In the area of COVID-19 management, leveraging BDA can allow the effective implementation of disease prevention and detection measures (Yen 2020). It can be used to improve the quality and accuracy of decisions, process a large number of health records in seconds (Wang & Hajli 2017), monitor disease outbreaks, stratify patients, understand risk exposure and predict outcomes and patterns with the aim of informing public health interventions (Garattini et al. 2019).

2.2 BDA Capabilities

BDA capabilities in the context of healthcare include the ability to acquire, store, process and analyse large volumes of health data in various formats to deliver meaningful information and data insights promptly (Wang & Hajli 2017). To ensure that public health is proactive in fighting against the COVID-19 pandemic, the required capabilities include data modernisation from tracing to predicting, changing decision-making processes and culture, integrating data science and experts' knowledge, and effective decision-making (Rai 2020).

Based on the existing research, BDA capability includes the following elements: data (Wang & Hajli 2017), leadership, talents, technical capability (Akter 2016) and a data-driven culture (Gupta & George 2016). Details of BDA capability are provided in Table 1.

BDA Capabilities	Sub-categories
Data	Data quality (Shin 2013); data openness (Lyytinen & Grover 2017); data understanding; data management; data privacy and security (Sejahtera 2018).
People and talents	Consistency in analytics talent (Lyytinen & Grover 2017); right people with the right skills (Rizzon et al. 2018; Wamba et al. 2015); availability of champions (Dutta & Bose 2015; Sejahtera et al. 2018); business partnership with technical team/strong partnering relationship (Mishra et al 2018; Shan et al 2019).
Leadership/ management	Strategic leadership (Rizzon et al. 2018), including business strategy to drive value and the company's general attitude towards data analytics (Rizzon et al. 2018); executive sponsorship (LaValle et al. 2011); sufficient investment and adequate time (Gupta & George 2016); availability of data management framework (policies, practices and procedures) and data business processes (Braganza et al. 2016).
Culture	Collaboration (Sejahtera et al. 2018); organisational learning (Mikalef et al. 2020; Gupta & George 2016); defined mechanisms for people to make data-driven decisions (Marchand & Peppard 2013).
Technology	Appropriate infrastructure (Rizzon et al. 2018) and strong analytical tools (Lyytinen & Grover 2017) that ensure system integrations (Sejahtera et al. 2018), connectivity and modularity (Akter et al. 2016), IT deployment capabilities (Mishra et al 2018).

Table 1. BDA Capability Categories

2.3 Managing the COVID-19 Pandemic

The core areas of application where BDA can assist fighting with the pandemics include monitoring and forecasting of COVID-19, outbreak virus spread, disease treatment, vaccines/drugs discovery (Awotunde et al. 2021). BDA can improve understanding of the disease, estimate the impact of an intervention (Bansal et al. 2020) and monitor COVID-19 outbreaks and risk exposure (Dananjayan & Raj 2020; Garattini et al. 2019). BDA has the potential to enhance the quality and accuracy of decisions by revealing valuable insights from a large number of health records (Wang & Hajli 2017) and could represent a crucial component for the modelling of transmission and implementation of infection control measures (Garattini et al. 2019).

Furthermore, BDA can assist in gaining unprecedented insights in relation to early detection, discovery, diagnosis and treatment of the pandemic (Dananjayan & Raj 2020). It can also be used to streamline data sharing, accumulation, processing and advice provisioning (Garattini et al. 2019, p. 72). Since BDA can handle both complex structured and unstructured data, it allows researchers to access all relevant data to analyse the behaviour of COVID-19's spread, identify biomarkers and develop therapies to fight the pandemic (Seghier 2020, p. 512).

There are three steps in managing the crisis, such as disease prevention, disease detection, and disease treatment and uncertainty (Yen 2020). The details of each step and how BDA can assist with the pandemic are provided in Table 2.

Steps	Details	BDA Application
Disease prevention	Measures can involve border control, regulations on social gathering, quarantine policy, mask-wearing policy (Yen 2020).	BDA can assist with disease prevention by identifying risk early and alerting decision-makers. It often requires mobilising and integrating different government databases (e.g., national health database, customs and immigration database) (Bansal et al. 2020). Having access to the same information and working towards the same goal avoids duplication of effort and suboptimal solutions (McKinsey & Company 2013).
Disease detection	Measures include screening, quarantine policy, testing policy and contact tracing (Yen 2020). Each of the measures plays an important role in fighting the pandemic. Contact tracing is vital for early diagnosis and ensuring infected people are cared for (Agbehadji et al., 2020). This includes identifying potentially infected individuals before severe symptoms emerge to prevent onward transmission and reduce the spread of COVID-19, which is essential during the early stages of an outbreak when treatments are limited (Yen 2020, pp. 2–3).	BDA can be applied in forecasting the likelihood of COVID-19 outbreaks from newly detected case(s) (Seghier 2020), performing comprehensive contact tracing (Agbehadji et al. 2020), monitoring disease outbreak (Garattini et al. 2019), its course and evolution (Bragazzi et al. 2020), providing real-time classifying and monitoring capability (Yen 2020).
Disease treatment and uncertainty	Disease uncertainty focuses on understanding the origin, transmission and disease features; while disease treatment centres on healthcare facility surge capacity, and vaccine research and development (Yen 2020).	BDA application includes developing comprehensive treatment with high reliability (Awotunde et al. 2021), processing unstructured complex data to predict and diagnose diseases more efficiently, faster and with high accuracy (Seghier 2020), as well as stratifying patients to determine treatment, risk exposure and treatment outcome(s) (Garattini et al 2017).

Table 2. Application of BDA using the Crisis Management Framework

3 Theories Informing the Research

The study was informed by the big data readiness framework and the capability building view. These theories can potentially complement each other, especially when an agency's readiness level for big data is low and there is uncertainty about how BDA can be implemented promptly.

Big Data Readiness Framework:

The big data readiness framework evaluates public organisations' big data readiness according to three main components: organisational alignment, organisational maturity, and organisational capabilities (Klievink et al. 2017). To increase big data readiness, an organisation can progress to higher stages of organisational maturity – although this process does not necessarily need to be sequential – by acquiring the required capabilities needed for that stage (Klievink et al. 2017, p. 273). The required level of BDA readiness can be achieved by developing competencies in data, technology, analytical expertise, management support, and strategy (Chen & Nath 2018).

Capability Building View:

Capability building is the ability of an agency to build unique competencies that can leverage its resources (Karimi et al. 2007; Wang & Hajli 2017). In particular, organisations need to build capabilities by selecting and deploying resources and assembling these resources into synergetic combinations for transforming inputs into valuable outputs (Wang & Hajli, 2017). Such a pathway between big data analytics capabilities and benefits is crucial for healthcare transformation and is one of the most discussed topics in the areas of computer science, information systems (IS), and healthcare informatics (Wang & Hajli 2017, p. 288).

Organisations can be restricted in responding to the COVID-19 pandemic by the number of factors, including manual processes, legacy systems, lack of integration, and limited access to the required data. Thusly, the benefits from BDA implementation can be released by acquiring the required BDA capabilities. To increase chances for enhanced COVID-19 management, development of BDA capabilities can be guided by the capability building view and informed by the big data readiness framework (see Figure 1).

Figure 1: Enhancing BDA Readiness to More Effectively Manage COVID-19

4 Pilot Study (Phase 1)

4.1 Research Method and Process

The pilot study phase focuses on the second wave of COVID-19 in Victoria, Australia (VIC) from June to October in 2020, to examine how the public sector utilised BDA and acquired the required capabilities for its successful use. In order to navigate through the emergency response to COVID-19 and the associated health and economic impacts, the Australian government's decisions were informed by the data to perform minute-to-minute decision-making (Morton, Feb 2021). As responses to COVID-19 differed across Australian states, Victoria was selected for a case study because (at the time) it had the highest number of COVID-19 cases in Australia, with a variety of state policies implemented, and several BDA technology and capabilities acquired to manage the pandemic. The qualitative analysis and a case study approach were applied to gain insights into how government organisations used BDA for managing the pandemic, and in what way it can assist the public sector.

- **Aim:** Examine and understand how the Victorian public sector utilised BDA and acquired the required capabilities for successful use during the second wave of COVID-19 in 2020.

- **Data Collection:** The main source of data collection has been documents and observations. The documents include parliamentary hearing transcripts related to the Victorian Government's COVID-19 contact tracing system; government publications and published interviews by the government representatives; the relevant report from the Legislative Council Legal and Social Issues Committee (the Parliamentary Committee); press releases; the federal and state government websites; open tender requests; and the author's own notes taken when living in Victoria during the pandemic.

  Three groups of search themes were used: i) COVID- 19, the second wave, Victoria; ii) keywords (big data, data analytics, AI, predictive modelling); and iii) the subproject and the system titles (e.g., COVID-19 management, contact tracing, COVID -19 testing, Salesforce CRM, IBM i2, PHESS, Digital Test Tracker).
- **Data Analysis Method:** Content analysis has been applied to examine the data, elicit meaning, gain understanding, develop empirical knowledge and search for underlying themes.
- **Expected Outcomes:** Gain insights into how government organisations used BDA for form questions for Qualitative Analysis

To minimise existing bias as a result of living through the COVID-19 pandemic in Victoria, the researcher reflected on the experience and pre-existing understanding of the situation. This included working with underlying assumptions, remaining impartial and exposing themselves to alternative reframing of the current thinking (Coghlan et al., 2019).

4.2. Analysis and Results

The Australian state of Victoria (VIC) was analysed as a part of pilot study to understand how the public sector utilised BDA and acquired critical capabilities, with the limited BDA maturity level and high time pressure to contain the COVID-19 pandemic. During the second wave, the Department of Health and Human Services Victoria (DHHS) was able to enhance the maturity of its BDA readiness. This includes moving away from manual time-consuming data collection to automatic processes for gaining valuable insides into COVID- 19 transition, outcomes prediction, and enabling all key stakeholders to have access to the same information in real-time. Although organisational readiness for BDA is considered an evolutionary process by some researchers (e.g., Chen & Nath, 2018), the DHHS case reveals that an agency can enhance its big data readiness within a short timeframe. These findings show an importance of agency's progression towards next level of their BDA maturity to be able successfully use BDA tools in management of the COVID-19 pandemic.

At the beginning of the second COVID-19 wave, the Victorian Government faced several challenges that were similar to other countries with a limited BDA maturity level. There was no single view or real-time access to the COVID-19 data, manual data entry, both digital as well as 'pen and paper' methods for collecting data, and limited access to the data for external parties. All of these resulted in lengthy delays to obtaining valuable insights from the data.

As a part of the maturing contact-tracing system, manual data collection was replaced by an end-to-end contact-tracing solution, provided by Salesforce's CRM technology. This was followed by implementation of the Digital Test Tracker to enable automated processing of COVID-19 test results from swab to result notification. In addition to this, a single source of truth was established where all key existing platforms were consolidated and aligned onto one platform. Synchronisation of all internal and external teams improved management and monitoring of the pandemic.

The leadership approach was adjusted to cater for a more data-driven culture where data and data insights were shared both internally and externally. The main emphasis was on using data for policy decision making, management of managing COVID-19 and the easing of restrictions.

Data quality, integration and richness were enhanced to allow further analysis on how the virus was spreading in Victoria, including where weak points and risky workplaces existed. Using unstructured data from contact-tracing interviews allowed a better understanding of where instances of virus transmission took place and who the potential close contacts were.

At the beginning, there has been some limitation of the data quality due to manual data entry, which were later fixed with the standardised VIC application for mobile check-in. DHHS engaged both private sector (e.g., Salesforce, IBM), federal agencies and subject matter experts to assist with the state recovery and close of some of the people and talent gaps.

During the second wave, the DHHS decided to enhance the health-tracing tool with the implementation of IBM i2. The project formally commenced on 2 September 2020; however, the work on the i2 platform deployment was stopped on 14 October 2020. The IBM i2 platform did not have the capability for predictive analysis or to produce the automated alerts that the DHHS needed. There was limitation around availability of required data for predictions.

To summarise, the DHHS rapidly matured its organisational alignment and organisational maturity from Level 2 to Level 4 (Big Data Readiness Framework, Klievink et al. 2017). This includes progression of the data collection to real time or near real time for continuous COVID-19 monitoring; extensively sharing information with different organisations through inter-organisational system integration; and regular publication of data insights.

5. Qualitative Analysis (Phase 2)

5.1 Research Method and Process

Qualitative analysis was chosen as it provides an opportunity for exploratory, in-depth analysis of the research topic to develop a richer understanding of how, why and in what circumstances BDA capabilities can assist with Covid-19 management. Six semi-structured interviews have been conducted with subject matter experts, who are familiar with the use of data, data analytics and/or big data for managing COVID-19. Participants of different roles were interviewed, including a Senior Data Analyst, a Manager, a Head of Analytics, a Chief Executive Officer, an Assistant Director, and Directors in areas of Policy, Government Services, and Data Analytics from Australia and New Zealand.

Creswell and Creswell's (2018) approach was followed where interviews focused on learning what the participant understands about the role of BDA and its application in managing the COVID-19 pandemics. The interview protocol included an introduction, semi-structured open-ended questions, recording of answers, and their transcription.

As qualitative analysis relies on research interpretation of data which can affect the validity of the results (Macnamara, 2005), multiple approaches have been applied to ensure the validity of findings, such as self- reflection to clarify existing biases, checking the accuracy of findings and themes, triangulation, and peer debriefing.

- **Aim:** Build an understanding as to how BDA can be used to help the public sector for enhanced management of the COVID-19 pandemic, including effect of organisational BDA capabilities in successful application of BDA.
- **Participants:** Subject matter experts who are familiar with the use of data, data analytics and/or big data for managing COVID-19 from several public sector agencies with different level of organisational BDA readiness.
- **Data Collection Method:** Semi-structured and unstructured interviews have been conducted.
- **Data Analysis Method:** The interview transcripts were coded by following the Strauss and Corbin (1998) coding paradigm, which includes open coding, axial coding, and selective coding. NVivo was used for coding to retain the language of the participants and original data sources. The most prominent and strong connections were investigated.
- **Expected Outcomes:** Identify key elements of BDA capabilities and analyse its effect on enhanced management of the COVID-19 pandemic.

5.2. Analysis and Results

During conducted interviews, it was investigated how BDA can be applied for COVID-19 management, such as decision-making, enhanced contact tracing, COVID-19 treatment, monitoring, and prediction. Key BDA capabilities for the successful application of BDA was revealed (see Figure 2). Some of these capabilities are aligned with the existing literature, including data availability and quality, strategic leadership, system integrations, sufficient investment, availability of staff with the right analytical skills, collaboration, and data-driven culture (Table 1 in Section 2.2); while other elements were discovered during the interviews.

For example, data timeliness, richness, and completeness are critical to be able to use data for COVID-19 management. When data is delayed, there is not sufficient time for preventative measures as the event could already happen *("sometimes the data was so delayed people already knew they had COVID by the time we called them",* Participant 2). It can also affect daily reporting on COVID-19 cases where

adjustments need to be made to ensure the accuracy of the published results across states. In addition, it is necessary to bring different types of data and key information together to be able to see a complete picture and cross-check results (*"I really believe in an integrated data model, not separating out: here's for vaccines, here's for lab results, here's for [Covid-19] cases, it has to be integrated…I also don't believe in one source of truth for data. I believe in data layers because you find that one source fails you, but you've got another one*", Participant 4).

During an emergency event, automation of core processes and having one platform could bring efficiency and effectiveness. Having a large amount of data to be entered and uploaded manually requires an extensive number of staff members, increases the chances of human error and processing time which can lead to delays. To be able to get accurate data insights in real-time or near to the real-time, automated feed of data, auto-population of information, and minimising a number of manual steps are essential. Having one platform that can be used by multiple organisations and different stakeholders that are responsible for the COVID-19 management can increase its timeliness (*"If you keep doing point to point integration, you'll just get far too many integration points. If you have all of the data coming down into our one place and there is enough real time"*, Participant 4).

When working with COVID-19 data, both data literacy and health literacy are central. If a data scientist does not understand the context of a problem, their capabilities can be limited in interrogating data for different data insights, understanding what it means, how it fits together and can be applied to addressing the problem. When there is cross-disciplinary knowledge in medicine and data analytics, it increases the chances of generating valuable insights for enhanced COVID-19 management. One way to address it is to have specialists with existing knowledge in both areas. Another way to close knowledge gaps is to have a good working relationship between a data analytics team and subject matter experts in building context and data understanding.

Last but not least, clear vision of what questions/target area need to be addressed by data insights, evaluation impact(s) of the pandemic, and adjustment are essential. ("*The biggest issue for us, I think outside of just the analytics and communication and tracing tools that we needed…, was understanding and articulating exactly what insights we needed to make decisions. So, it's actually that bit before you do the analytics that was more important…what do we need to know that we don't know now that we're gonna have to address",* Participant 6).

Other factors for enhanced management of COVID-19 with BDA include the willingness of citizens, private and public sector organisations to share information, and timely legislative changes to enforce guidelines for COVID-19 management and support states. *("We changed a legislation in order to allow Commonwealth employees to work for local governments …that would be required until this crisis"*, Participant 2)

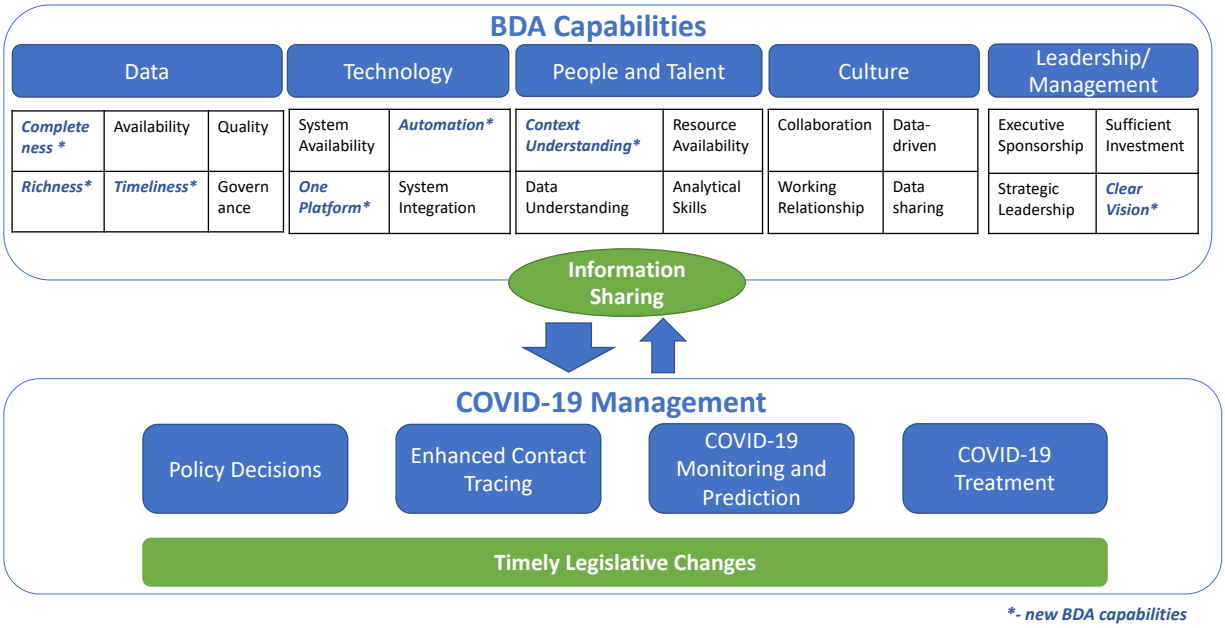

Figure 2: BDA Capabilities' Framework for Enhanced Management of the COVID-19 Pandemic

6 Conclusion

BDA application in the public sector can assist with the early detection of cases and the implementation of successful measures against COVID-19. The research has the potential to contribute both theoretically and practically. Currently, no widely accepted model exists to demonstrate the effect of BDA on governments in terms of linking organisational readiness and BDA capabilities for enhanced management of public health emergencies. The past studies examine how BDA capabilities affect the delivery of particular business benefits (Torres et al. 2018, Wamba et al. 2017, Akter et al. 2016, Côrte-Real et al. 2016, Wang and Hajli 2016) rather than the management of an emergency event. This study investigates BDA capabilities in order to increase chances of BDA success in managing COVID-19.

BDA capability development can be one of the key enablers for enhancing organisational BDA readiness to contain the pandemic. The progression to higher stages of maturity is dependent on acquiring the required capabilities needed for that stage (Klievink et al. 2017). The study provides lessons learnt and challenges related to the BDA capabilities in the areas of technology, data, people, leadership, and culture for COVID-19 management. In addition, new sub-elements of BDA capabilities were studied (see Figure 2). The research extends the use of the existing big data readiness framework and the capability building view for other researchers to explore the topic further.

BDA could enhance the efficiency of COVID-19 management, including modelling of the transmission, (Garattini et al. 2019), improving the understanding of the disease (Bansal et al., 2020), monitoring of COVID-19 outbreaks, risk exposure, implementation of infection control measures and policies (Dananjayan & Raj 2020; Garattini et al. 2019). The research can benefit the public sector since it explored capabilities for BDA from the government's perspective. The study has the potential for practical impacts on society when data-driven decisions are used to develop effective measures, legislative changes, government policies and services to manage pandemics. Based on research findings an agency needs to have sufficient BDA capabilities to harness the power of BDA. It also provides practical recommendations on where to start when using BDA for COVID-19 management.

The study was constrained by several limitations. It is possible that the results would vary in a different research environment (Street & Meister 2004), including managing pandemics other than COVID-19 and other public health emergencies. Future research will further explore whether the identified BDA capabilities apply to other contexts and have a similar effect.

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