A Systems Approach to Effective AIOps Implementation

by

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Abstract

Artificial Intelligence in IT Operations, or AIOps, has gained considerable attention and expectations over the past few years [1]. However, implementing AIOps in organizations is challenging. This research aims to guide effective enterprise-level AIOps implementation by building a general framework using systems thinking methodologies. The framework proposed builds a structure on the rubric of socio aspect, technical aspect, socio-technical intersection, system dynamics, and environmental factors of AIOps implementation. Each aspect has its corresponding methodology from systems thinking theory.

This research is beneficial and critical to organizations wanting to implement or in the process of implementing AIOps. First, this research helps to outline the whole problem space, including both socio and technical aspects. Second, it proposes a comprehensive framework that can be used as a reference for guiding AIOps implementation in real-world scenarios. Based on the actual situation of each organization, companies can build their own AIOps reference models using this framework. The framework bridges gaps between various teams, enabling effective cross-disciplinary collaboration. The framework also provides a big picture and a way to think holistically to all AIOps-related stakeholders and keep their expectations aligned. Moreover, with the systems thinking methodologies embedded in the framework, organizations can guide effective planning, communication, and risk management throughout the AIOps implementation process.

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Chapter 1

Introduction

This chapter provides background information and objectives for the research, motivation behind it, research approach, and a brief outline of the entire thesis.

1.1 Background

Nowadays, everything is moving online, and internet service is getting more and more prevalent. People are less patient than ever in history. They constantly desire for higher availability of internet services. Even a tiny glitch would be magnified as people's tolerance level of latency become lower and lower. Switching to the IT operations perspective, that means higher reliability, longer uptime, more sophisticated high-available architecture, and of course, more effort from IT operation teams making design, routine work, troubleshooting, and process improvement.

Unlike development for application and other 'innovative' work creating a new product from 0 to 1, IT operation is a long-term continuous effort to maintain and improve the technical operation and infrastructure of a product or entire organization's IT system. With the increasing scale and complexity of modern software and internet services, traditional IT operation becomes more and more stretched as it requires intensive labor and time for manual work.

AIOps is here to help. Coined by Garter in 2016 [8], the term AIOps stands for

Artificial Intelligence for IT Operations. As more and more data become available, AIOps aims to utilize big data and machine learning algorithms to help reduce heavy manual work, thus increase operation efficiency. It is crucial not only from a financial perspective but also, more importantly, from socio-technical and sustainability point of view.

Implementing AIOps, however, has substantial challenges. Being a complex system, AIOps faces challenges from technical perspective and organizational behaviors. Some common ones include lack of usable data, difficulty building and training models, cross-function collaboration, mindset and work style shift, over- or under-inflated management expectation, and lack of shared vision and understanding of the system. A detailed literature review is discussed in Chapter 2.

1.2 Research Objectives

This research has three main objectives:

- To understand the evolvement and the current state of AIOps, and the opportunities and challenges during the implementation in organizations.
- To apply systems thinking methodologies to analyze the architecture of AIOps implementation problems.
- To construct a practical framework to guide effective AIOps implementation.

1.3 Motivation of Research

The idea of AIOps has been out for years, but its implementation still faces several challenges. The general motivation of the research is to make AIOps implementation process effective so that organizations can benefit from the technology, including saving operation cost, increasing operation efficiency, and improving the overall satisfaction level of the operation team employees.

The intention for focusing on operation is that operation work is rarely conceived as impactful as development work. Nevertheless, it is often toilsome and underrated. It is the cost center in an organization [9]. Based on the author's experience and observation, if a service runs smoothly, it should be; if something goes wrong, it is the operation team's fault. Worse, even when operation engineers spend days and nights fixing a bug that would cause fatal damages if not done so, little credit is given. If AIOps could be implemented successfully, it would be beneficial to the organization as the operation efficiency increases, and it would make the operation team's life easier and more impactful as well.

This thesis aims to provide guidance and reference to AIOps implementation for personnel from all levels and disciplines. Instead of only focusing on technical details, it adopts a holistic approach using systems thinking methodologies to guide effective enterprise-level AIOps adoption and implementation.

1.4 Research Approach

As AIOps is a relatively new concept, its definition, together with the motivation behind it is examined first by reviewing the literature. Then, more information regarding the current market status and market trends is examined, followed by opportunities and challenges to provide a broad understanding of AIOps. Next, detailed research aims and scope are defined based on the understanding gathered from the literature review. The bulk of the research focuses on using various systems thinking methodologies to analyze the system architecture of the AIOps implementation problem. From the analysis, a general framework orchestrating the methods in a structured way is proposed.

1.5 Thesis Outline

This thesis consists of six chapters as follows:

- Chapter 1: Introduction - Outlines research background, objectives, motivation, and approach.

- Chapter 2: Literature Review - Provides an overview of the definition around AIOps concepts, motivation of using the technology, its market status and trends, and overall opportunities and challenges.
- Chapter 3: Research Approach - Defines detailed research aims and scope of the research. Introduces main systems thinking methodologies used in the research.
- Chapter 4: System Architecture of AIOps - Applies systems thinking methodologies and analyzes the system architecture of the AIOps implementation problem.
- Chapter 5: Framework - Proposes a practical framework and explains how it can be applied.
- Chapter 6: Discussion - Summarizes research process and outcomes, and discusses limitations and next steps.

Chapter 2

Literature Review

This chapter gives an overview of various terminologies around AIOps and other related topics, including the motivation behind AIOps adoption, its evolution, and potential trends, followed by opportunities and challenges.

2.1 What is AIOps

AIOps stands for Artificial Intelligence for IT Operations. It is a term coined by Gartner back in 2016 to address the extended application of big data and machine learning in IT operation analytics (ITOA) [8], though at that time, it was referred to as "Algorithmic IT operations." Before diving into more details of AIOps, it is helpful to first review the definition of "AI" and "Ops" separately to better understand the context.

2.1.1 Artificial Intelligence

AI, or Artificial Intelligence, is an umbrella term for a collection of definitions. At a very high level and in an extremely abstract way, artificial intelligence refers to "intelligence" demonstrated by machines that mimic "cognitive" functions that humans associate with the human mind, such as "learning" and "problem-solving" [10].

Classifications of AI

There are two common classifications for AI, and each has several sub-classifications [11]. The first classification is based on the similarity between AI-enabled machines and human beings. The higher level a machine is in this classification, the more "human-like" it is in terms of intelligence. Four types are: reactive machine, limited memory, theory of mind, and self-awareness. A reactive machine is the most basic type of AI system, and it behaves the same way every time it encounters the same situation. A reactive machine does not have past data stored for future usage. However, a limited memory type of machine can look into the past, learn from historical data, and make certain decisions. Nearly all existing applications that we know of, from chatbots and virtual assistants to self-driving vehicles, come under this category of AI. In the context of AIOps, limited memory AI is the type of artificial intelligence to be concerned about. A theory of mind type of AI utilizes past data and discern the need and mental status of the object [12]. Furthermore, self-awareness, as the name suggests, refers to AI that develops its own awareness similar to a real human being. Compared to the previous two types of AI, theory of mind and self-awareness are still in the conceptual or very early stages therefore not applicable in the current stage of AIOps.

The second classification adopts a technology development perspective. It categorizes AI into three levels: Artificial Narrow Intelligence (ANI); Artificial General Intelligence (AGI); and Artificial Superintelligence (ASI) [13]. ANI can only perform a specific task autonomously using human-like capabilities. It corresponds to reactive machine and limited memory machine as mentioned in the first classification. Even the AI system that can beat the world chess champion belongs to this category. AIOps also falls in the ANI classification. On the other hand, AGI reaches the level of human intelligence, and ASI even surpasses the most intelligent human brain in any practical field [13].

2.1.2 IT Operation

Both "IT" and "Operation" are commonly used terms that change meaning with context. IT operation, similarly, despite having a generalized definition, has slightly different meanings and use cases across industries and organizations. Here are the definitions given by some of the sources:

Gartner: The people and management processes associated with IT service management to deliver the right set of services at the right quality and at competitive costs for customers [14].

Sumo Logic: The set of processes and services that an IT department administer within a larger organization or business [15].

Optanix: A term that encompasses all the activities involved in the setup, design, configuration, deployment, and maintenance of the infrastructure that supports business services [16].

Instead of providing a single definition of IT Operation, it is vital to understand various related terms to have a more comprehensive view of IT Operation in the context of AIOps.

I&O

Infrastructure and Operation, or I&O, refers to two areas of information technology that work hand in hand, and is a common function inside an organization responsible for the administration and management of technology, information, and data [17]. Each of the two aspects has its focus. Activities in IT Operation are based on the infrastructure, which refers to technologies that consist of the physical and virtual systems that provide essential services business relies on, such as networking, processing, and storage capabilities [16].

SDLC

Software Development Life Cycle (SDLC) refers to a series of stages or phases when a software or an application goes from ideation to decommission [18]. It typically involves the following phases: requirement analysis and planning; system design, development and implementation; integration and testing; deployment, operation and maintenance; and optionally disposal and decommission. Some common models adopted by industries include waterfall, spiral, and agile [18].

ITSM

According to FitSM [1], Information Technology Service Management (ITSM) is "the activities performed by an IT service provider to plan, deliver, operate and control information technology (IT) services offered to customers."

While the focus for SDLC is the actual application or software that creates business and market value for an organization, the scope of ITSM is often much more significant. Their customers inside an organization would include both the software development team and almost all other departments who require IT as a service (e.g., laptops used by finance team).

ITIL

ITIL (formerly known as Information Technology Infrastructure Library) is a framework and set of best practices in ITSM [20]. It has five pillars consisting the full IT service life-cycle, namely service strategy, service design, service transition, service operation, and continual service improvement. Within service operation, there are four key function modules: IT operation management (ITOM), technical management, application management, and service desk. ITIL is an evolving framework to keep up with the emergence of new technologies and methodologies [20].

SRE

SRE or Site Reliability Engineering is a term created by Google in 2004 [4]. As more and more servers and services need to be maintained at that time, managing all

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[1] FitSM is a free and lightweight standards family aimed at enabling effective IT service management in the broadest range of organizations. [19]

of them manually became nearly impossible for System Administrators. Using code to tackle the problem was an obvious choice. SRE is often referred to as software engineering approach to IT operations. Benjamin Treynor Sloss, the founder of SRE at Google, describes it as a way of thinking and approaching production [4].

DevOps

Another term not to be left out is DevOps. It originates from the inherent conflict of interest between software development (Dev) and IT operation (Ops) team, and has the intention to combine the two functionalities to improve efficiency. It is a set of practices to promote collaboration between developers and operation teams to enable fast and continuous integration (CI) and continuous delivery (CD), allowing more frequent feedback for continuous improvement. CI/CD is one of the keys to the successful implementation of DevOps. SRE can be one efficient way to implement DevOps [21].

NoOps

NoOps is a term coined by Forrester to go one step further from DevOps [22]. Instead of close collaboration between Dev and Ops, NoOps aims to have application developers get desired resources when they need them without talking to the operation team using solutions such as PaaS (Platform-as-a-Service [23]). It does not mean eliminating operation teams. It is a state where developers can be more efficiently and independently deploy and release code and services.

2.1.3 AIOps

From the above definitions of various AI- and Ops- related terms, AIOps would inevitably be another over-generalized term that could mean different things under different circumstances. However, the fundamental function is clear, that is to utilize large amount of data and Artificial Intelligence (more specifically, ANI) techniques to make IT operations more effectively and efficiently, thus resulting in higher service or product quality, higher customer and employee satisfaction, higher engineering productivity, and lower operation cost.

Use Cases

Some typical use cases of AIOps include anomaly detection, root cause analysis, and event correlation. Figure 2-1 shows AIOps use cases over the life cycle of software applications.

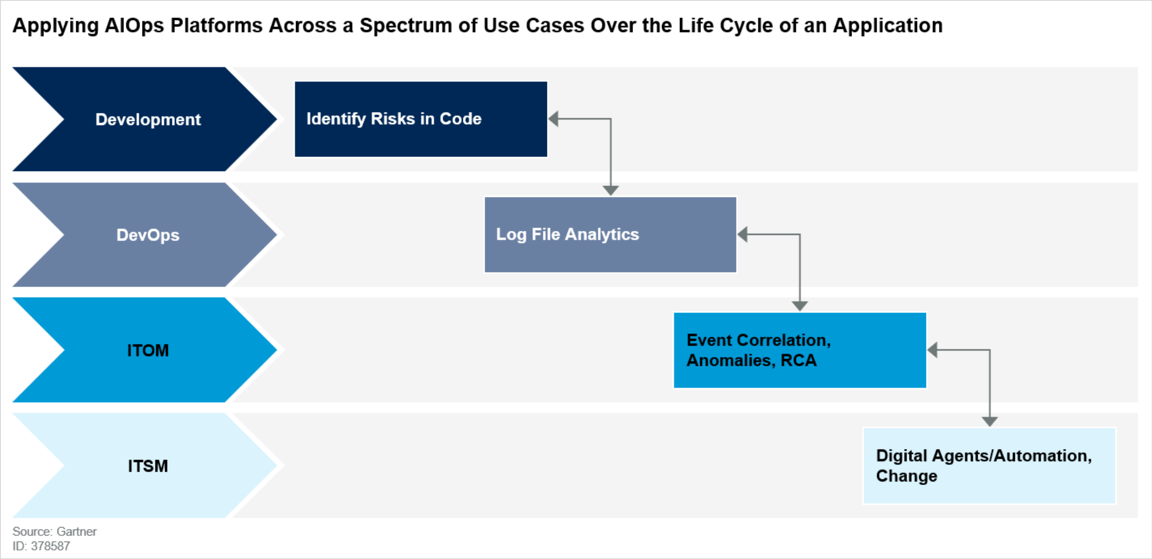

Figure 2-1: AIOps Use Cases Over the Life Cycle of an Application [2]

Capabilities and Stages

There are three main capabilities and phases in AIOps based on the logical flow of data: data ingestion and handling; machine learning analysis; and data remediation [2].

Data ingestion and handling phase may involve various automation and AIOps opportunities. It refers to statistical analysis using basic visualization like formulate error frequency chart from server logs. When used appropriately and in conjunction with other AIOps capabilities, it can serve the desired objective to some extent. However, this process does not involve any advanced techniques such as machine learning for prediction and remediation purposes. It is known as "descriptive IT", which means describing existing data in some alternative forms.

ML analytics is one level above descriptive IT. It uses numerous amounts of data available and applies advanced machine learning algorithms to achieved capabilities such as anomaly detection and diagnostics. Typically, the machine learning model itself can be updated and optimized as new data become available.

Remediation leverages AIOps capability to achieve reactive detection and proactive operation such as prediction to avoid incidents from happening.

Types of Data

As data is key to AIOps, more details regarding types of data and data processing models are reviewed.

There are various ways to categorize data, and there is no standard way. One possible way is to classify data according to their sources [24]. Machine Data includes system self-reported data of its activities such as CPU and memory usage and event logs. Wire Data refers to data transacts on wires in the network. It contains communication data such as those between client and server applications. Agent Data includes behavior by software agents on the host. Synthetic Data or Probe Data is generated from service checks and synthetic transactions. Some examples include ICMP ping [25] and HTTP GET [26].

Another way is to classify data based on their property. Metrics Data are measurement of particular property over intervals of time. They are often used to construct dashboards for monitoring. Logging Data are timestamped records of events happened over time. Tracing Data are collected on a trace, which is a representation of several causally linked events. It is a representation of series of logs and also outlines the structure of a request. Metrics, logs, and traces together are also called the "Golden Triangle of Observability" or the "Three Pillars of Observability" [27].

Types of Data Processing Model

There are two main types of data processing models: batch processing and stream processing. Batch processing processes data collected over time in blocks. Because collecting a batch of data takes time, batch processing is usually meant for large quantities of data and is not time-sensitive [28]. Stream processing process data piece-by-piece as they arrive continuously in real-time. It is faster than batch processing and is meant for processing results needed immediately, such as fraud detection [28]. However, stream processing is more challenging than batch processing as the rate of data coming in varies and data amount is unbounded [29].

One common issue regarding the two data processing models is that using them simultaneously might lead to two pipelines extracting different features [29]. Some companies have innovated new infrastructure to unify the two processing pipelines [30].

2.2 Why AIOps

After knowing what AIOps is, one must also understand the significance behind it; that is why companies should care about AIOps. If doing everything manually worked well ten years ago, why should companies bother to adapt to AIOps now or in the future?

The answer lies in the fact that more and more data become available to all kinds of services and industries with digitalization and the development of the Internet. According to Statista, the total volume of data worldwide has grown from 2 zettabytes[2] to 59 zettabytes in 2020 and will continue to grow exponentially in the following years (see Figure 2-2) [3]. In addition, per GB data storage cost continues to fall [31], and the prevalence of cloud computing makes storage and computing even more accessible and affordable. Not only the volume but also the velocity at which the data is generated is increasing rapidly. Organizations are experiencing an influx of data nowadays.

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[2] $1 Zettabyte = 1000^7 Bytes$

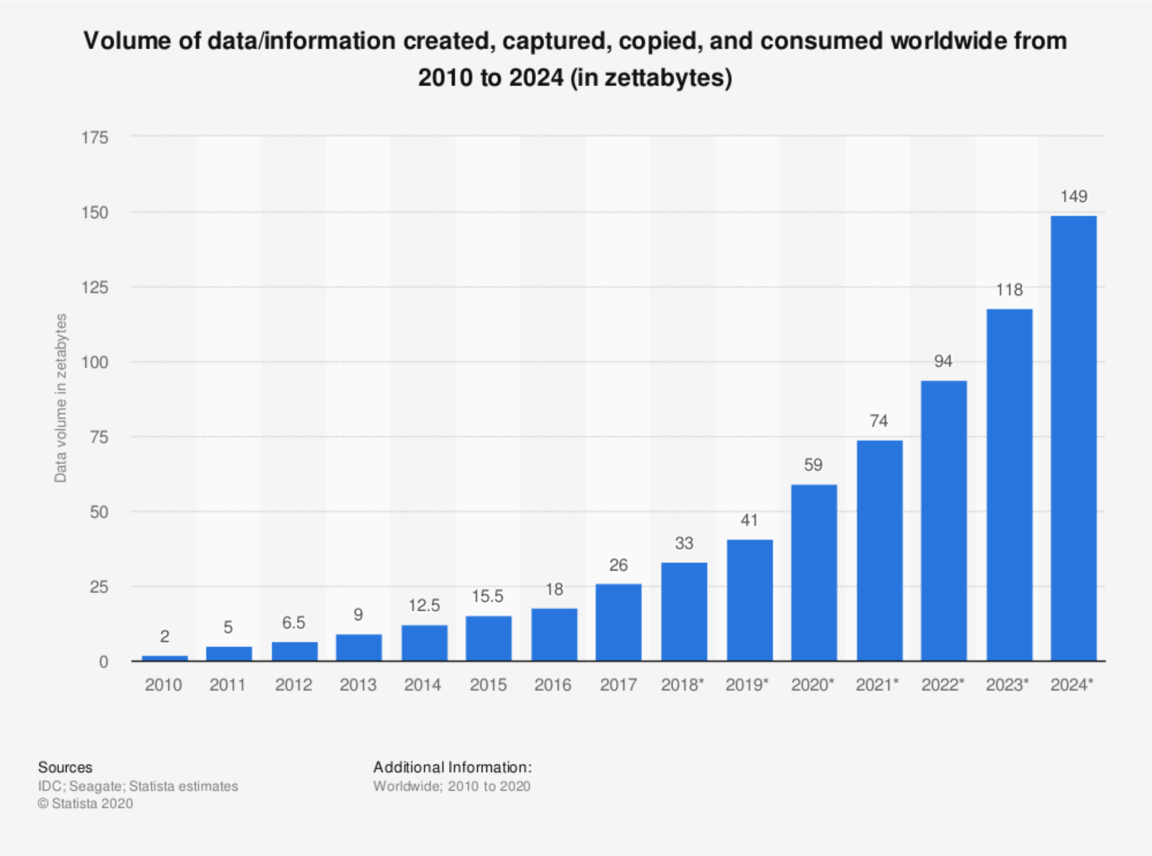


Figure 2-2: Amount of Information Globally 2010-2024 [3]

Figure 2-3 is featured on the homepage of Google Site Reliability Engineering under "The Museum of Borgmon Abstract Art" [4]. This "museum" shows several pictures of Google's monitoring visualization. Some of them are so complicated and even become abstract art from the perspective of a layman. It reflects that some traditional monitoring tools are longer insightful when situations become more and more complicated. That is where AIOps can help ease the burden of operation engineers by revealing more easy-to-understand insights.

In addition, IT operation is a vital part of improving engineering productivity but traditionally labor-intensive. With the help of AIOps, organizations can make better decisions more efficiently with less human intervention, thus striving more competency with less cost.

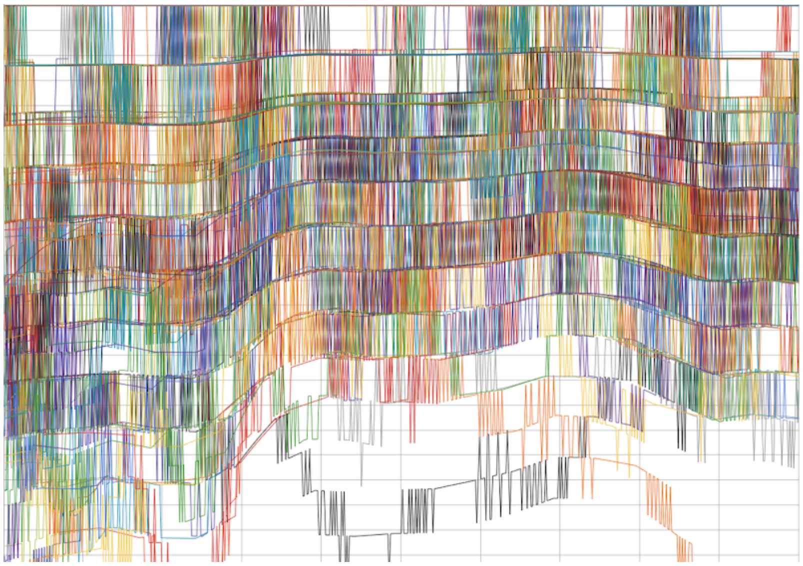


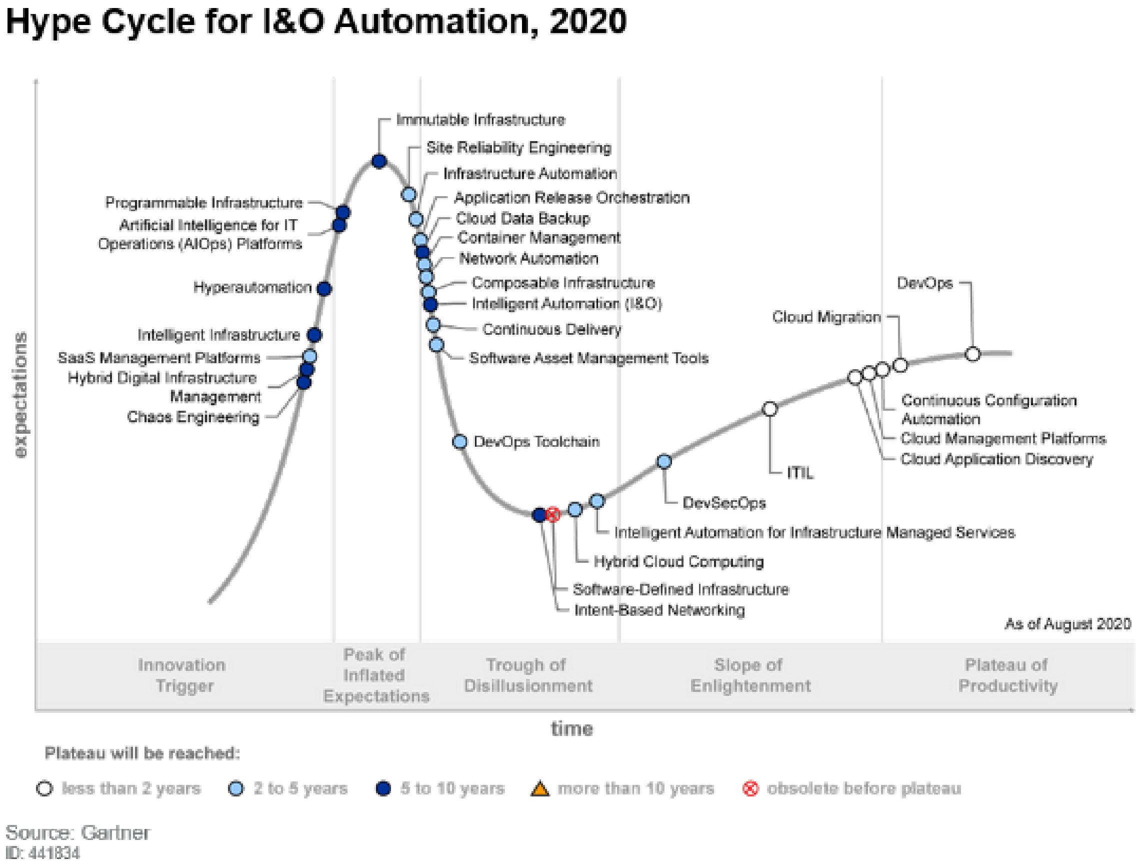
Figure 2-3: Google SRE "Tapestry" [4]

2.3 Evolution of AIOps

Back in 2011, Gartner has brought up the concept of "Pattern-Based Strategy Thinking to IT Operations" in which they claimed "IT Operations Analytics" or ITOA technology would grow and play a vital role [32]. In 2016, Gartner first used the term "Algorithmic IT operations (AIOps)" platforms technologies to generalize and replace IT operations analytics, with more focus on big data and machine learning technologies [8]. Finally, in 2017, with the prevalence of Artificial Intelligence, Gartner eventually redefined AIOps to be "Artificial Intelligence for IT Operations" in the report "Market Guide for AIOps Platforms" [33]. The report is now in its third revision, which was published in 2019 [2]. This report is used as a significant reference in this section to examine the current market status and future trends of AIOps.

2.3.1 Recent Market Status

In Figure 2-4, a "Hype Cycle" is shown for I&O Automation-related technologies as of August 2020 [1]. AIOps has just entered the phase of "Peak", where the expectation for it starts to inflate to a maximum level. According to Gartner in the report, AIOps was categorized as "Emerging" maturity level, with a benefit rating of "Transformational" and market penetration of 5% to 20%. It indicates that AIOps has gained recognition and expectation in the past few years because of its potential high return in terms of assisting I&O teams.



Source: Gartner
ID: 441834

Figure 2-4: Hype Cycle for I&O Automation [1]

With increasing market demand, various solution providers start to emerge with different focuses in the market. Gartner categorizes the overall market into three dimensions: Domain-agnostic AIOps, Domain-centric AIOps, and Do-it-yourself (DIY) [2].

Domain-agnostic AIOps refers to general-purpose AIOps. Such providers typically focus on downstream data analytics using data from various downstream sources such as monitoring tools to achieve functionalities such as cross-domain correlation.

Domain-centric AIOps refers to more use-case-specific AIOps. As the name suggests, a domain-centric AIOps platform providers more domain-specific coverage such as network, IT service management, DevOps, Application Performance Management (APM).

Do-it-yourself (DIY) refers to enterprises building their own in-house AIOps platform using open-source projects and other solution providers.

Note that there is no clear cut among the three dimensions. A single product can offer more than one category and some DIY AIOps platforms. A DIY AIOps platform can contain solutions from domain-agnostic and domain-centric AIOps providers. However, knowing the different dimensions and approaches is helpful for organizations to make plans and strategies that suit their needs and infrastructure context the most.

2.3.2 Market Trends

From the hype cycle, it is clear that AIOps technologies still have 5 to 10 years to go before reaching the plateau of productivity (i.e., mainstream adoption [34]). However, before the plateau is reached, there is typically a trough formed by a downhill followed by a slope leading to the plateau. The trough is usually a result of the previously high expectation, and the gap between the existing technology and the desired outcome. For AIOps, the time has not come, but those scenarios have to be considered when deploying and planning investment in relevant technologies.

On the other hand, in their latest "Market Guide for AIOps Platforms" report [2], Gartner predicts that 40 percent of DevOps team will have AIOps platform integration in their monitoring systems by 2023. It suggests that a significant amount of potential market will at least start to take actions in adopting AIOps or preparing for it if they have not already done so.

To sum up, there will be development in various AIOps platforms and technologies, and a wide adoption of the technologies in various forms going forward. At the same time, as the expectation of the technology start to peak and more attention shifts towards implementation, enterprises will need to make the right decision that suits their specific operation and business needs and develop strategic plans to guide and govern relevant works.

2.4 Opportunities and Challenges

Opportunities and challenges are both essential aspects to be taken into account while making decisions regarding AIOps from both technical and business perspectives.

2.4.1 Opportunities

Demand for Higher Efficiency and Productivity for IT Operation

IT operation has always been a pain for I&O or SRE teams. It is especially true for incident response during on-call when the on-call engineer needs to resolve production issues during both working and non-working hours. Being on-call can be highly stressful because of the importance and user impact of the affected service and the Service Level Agreement (SLA) to be met [35]. If correctly implemented, AIOps can offer the engineers a tool to identify issues faster and more accurately, thus improve their productivity and reduce their stress.

Growing Data Volume, Variety, and Velocity (3Vs)

As mentioned in 2.2, the 3Vs have been growing rapidly: data volume, data variety, and the velocity at which data is being generated. All 3Vs are likely to continue to grow as the world became highly digitized. To deal with the massive amount of data and make as much sense as possible, AIOps has a vital role in IT operations. One important point to note here is that the 3Vs of data is not only an opportunity for AIOps but also a challenge at the same time. More details regarding the challenge aspect are discussed in Subsection 2.4.2.

Data-driven Mindset

Another critical opportunity comes with the change of mindset of enterprises, especially the management [36]. Traditionally, when there was not enough historical data, people usually made decisions based on experience, intuition, or authority. These decisions would have been less rigorous than a data-driven approach. Now that more and more enterprises realize the power of data, they adopt more data-driven decision-making. That mindset is likely to develop a data-driven practice and culture across the organization.

2.4.2 Challenges

Misunderstanding and Over-inflated Expectation

When it comes to Artificial Intelligence, misunderstanding and over-expectation commonly happen because of the broad scope of AI, as mentioned in section 2.1.1. The expectations for various AI-related technologies are still climbing up the hill of the hype cycle, and there seems to be an AI-can-do-everything mindset. According to Gartner [37], as of 2020, 70% of the current AI technologies are at the "uphill" where their expectations are accumulating. Only seven technologies have exited inflation. As shown in the hype cycle in Figure 2-4, AIOps has just entered the zone of the peak of inflated expectation. The gap between the unrealistic expectation and the actually available technology and the capability to implement those technologies remains one of the main challenges for AIOps.

Infrastructure-related Challenges

AIOps is unsurprisingly a "good-to-have" feature for many organizations, so it is usually not the thing to be considered when setting up a brand-new system. When organizations begin to think about AIOps, the existing system and infrastructure have already been run for some time and any major change to it becomes difficult. Those legacy systems might have either integrability issues where there are no adequate interfaces to add in AIOps related features or stability issues where adding additional features might break the existing functionalities. As a result, unless sufficient flexibility is built in when systems were first build, integrating AIOps to legacy infrastructure will be a challenge [38].

Data-related Challenges

Another major challenge is the data challenge, which is a collection of challenges ranging from data quality, data aggregation to the 3Vs of data and many others.

- Data Quality Challenges: According to [39], upstream data quality and quantity as of 2019 do not satisfy the demand of AIOps solutions. The key here is the quantity of high-quality data that is useful to build AIOps solutions. The research mentions that enterprises also need to change their way of instrumenting and collecting of monitoring data from simple "logging-for-debugging" to more sophisticated methods suitable for AIOps platforms.

- Data Manipulation Challenges: As also mentioned in the opportunities section, the 3Vs (Volume, Variety, Velocity of growth) of data can also be a challenge imposed to the data aggregation phase. First, increasing data volume requires more data storage and more efficient data partition and indexing techniques. Second, increasing data variety makes data aggregation difficult since the AIOps platform or dedicated data manipulation layer of the system needs to collect data from various sources, and integrate them together so that the data can produce meaningful information. Third, the growing velocity at which data is generated raises a higher requirement for throughput of AIOps platforms. Last but not least, all the growth and changes mentioned are constantly evolving as well. Therefore, it also imposes challenges to the adaptability of AIOps platforms.

Algorithm-related Challenges

This challenge mainly happens during the data analysis phase, where big data and machine learning algorithms. According to [39], it is not easy to build machine learning (ML) models for AIOps. The research mentions that AIOps ML model building has several difficulties, including no evident ground truth labels or intensive manual efforts to create high-quality ones, highly complex interdependencies and connections among different components in a system, arduous feature engineering efforts, continuous learning and model updates, and the risk of misbehaving. It also mentions that it is complicated for the models to define "normal" since the services are continuously evolving.

Lack of Data Science Skills within I&O

Data science skills shortage has continued to be an issue in recent years as demand keeps raising [40]. With the skillset shortage, inadequate and even less headcount would be given to I&O teams as it is further down in the value chain compared with business intelligence which can generate revenue more directly when appropriately applied.

Lack of Trust

As opposed to the first challenge of over-inflated expectation, there is also a potential challenge of under-estimation, leading to lack of trust of AI solutions. Some people do not trust algorithms and models to make crucial decisions instead of human-being [41]. One reason might be that majority of AI applications are still at their early phase, so there is just not enough exposure of successful cases. Another possible reason is difficulty in mindset shift. Human beings have a strong desire for control [42]. As a result, giving away the control to machines and algorithms is not a natural thing to do, and some people might even be afraid they could be replaced by AI [43].

2.5 Chapter Summary

In this chapter, in-depth details regarding AIOps-related concepts are examined. The scope of AIOps, its use cases, capabilities and stages, types of data injected, and data processing models are also reviewed. Next, the motivation and driving factors for adopting AIOps are understood. It is learned that AIOps is indeed an inevitable route to take. Following the rationale behind AIOps, its evolution including the past, present, and future is looked into to get a clear sense of its current market status and future trends. From there, various opportunities and challenges for AIOps implementation are evaluated to provide a grounding for further analyses in this research.

Chapter 3

Research Approach

In this chapter, the detailed research objectives are outlined. In addition, the scope of the thesis is defined by laying down the specific use cases, stages and capabilities, and dimensions of AIOps of interest. Lastly, systems thinking methodologies used in the research are introduced and explained.

3.1 System Problem Statement

Understood that AIOps is now at the peak of inflated expectation and might be facing the trough of disillusionment now or anytime in the coming years, this thesis aims to build a framework for effective AIOps implementation for organizations. The research does not emphasize industry emergence since it is merely one contextual factor to be taken into consideration by individual organization. While being part of the industry, each organization has various endogenous challenges while implementing AIOps. Moreover, although specific challenges and factors might be unique to each organization, there are commonalities that can be addressed using a general framework.

The thesis mostly uses systems thinking methodologies (discussed in detail in section 3.3) to approach the research problems and targeted system from a holistic perspective. The aim of the thesis is defined in the following System Problem Statement:

To guide effective enterprise-level AIOps adoption and implementation

By building a general yet comprehensive framework

Using systems thinking methodologies

The framework attempts to answer the question of HOW: How can an organization effectively and successfully implement AIOps, not only from technical viewpoint, but also from leveraging human aspects? The framework would design for weakness and threat while leveraging current AIOps technologies and development opportunities.

This research also assumes that the majority of necessary technologies are already available, and though there are various challenges as mentioned in Chapter 2, some sort of best practice of designing and building the AIOps systems are also present to get organizations started on the AIOps system implementation as long as the other conditions (e.g., management permission, budget, time) are satisfied.

It is also well recognized that different organizations are in different status quo and they all have different strategy and business goals. The analysis and framework consider the fact, and attempt to provide a generalized and unified approach to AIOps implementation.

3.1.1 System Success Measures

The expected system success is the effective implementation of AIOps, which may include but not limited to the following metrics:

- AIOps project return on investment (ROI) which equals the business value AIOps solution generates minus its cost
- Employee productivity
- Employee (primarily technical operation personnel) satisfaction level

Since every organization is different, it is up to each company to determine its specific success metrics and how they want to quantify them. They might also have different data and technology available, so their end goals might be scattered.

3.2 Scope

3.2.1 Use Cases

Section 2.1.3 outlines the main capabilities and functions of AIOps. If used properly, a wide range of use cases that can be realized and empowered by AIOps technologies. In the interest of this thesis, representative use cases such as event correlation, anomaly detection, and root cause analysis are used to illustrated relevant concepts and conduct analysis. Some other use cases, such as identifying risks in code and release management automation, are in the overall problem space of the research as well but are not illustrated in detailed analysis in Chapter 4.

3.2.2 Stages and Capabilities

As mentioned in 2.1.3, three levels of AIOps capabilities are defined: Descriptive IT; Machine Learning; and Remediation. This thesis focuses on Machine Learning analysis and remediation capabilities of AIOps. "Descriptive IT" is out of scope as it is relatively straightforward to implement.

3.2.3 Dimensions

Section 2.3.1 mentions three dimensions for the AIOps market: domain-agnostic AIOps, domain-centric AIOps, and do-it-yourself (DIY). As DIY can involve both domain-agnostic and domain-centric AIOps, and in-house developed AIOps solutions, it has the most complete coverage of various dimensions. So, for the sake of comprehensiveness of the analysis, DIY AIOps of mixed dimensions is used in the example in the analysis part of the thesis.

3.3 Systems Thinking Methodologies

This section introduces different systems thinking methodologies that are used to analyze AIOps system architectures in this research. The essence of systems thinking is to think of things as systems, and perform problem-solving with interdependencies and dynamics of complex systems in mind [44]. Four main methods discussed in detail in this section are: socio-technical systems approach; CONOPS; STAMP and STPA; and systems dynamics.

3.3.1 Socio-technical Systems Approach

Social-technical refers to the social and technical aspects of an organization [44]. Social can mean both people and society, and technical is a term used to mean structure and a wilder sense of technicalities [44]. Socio-technical systems approach is a method to approach complex organizational problems concerning both aspects and their joint optimization [45]. It means both aspects and their interaction need to be considered to achieve successful organizational performance. One principle of socio-technical systems is that if only one aspect is optimized, it is likely to increase the probability of unpredictable and unintended relationships, which could be harmful to the system's performance. A typical social-technical system structure is shown in Figure 3-1.

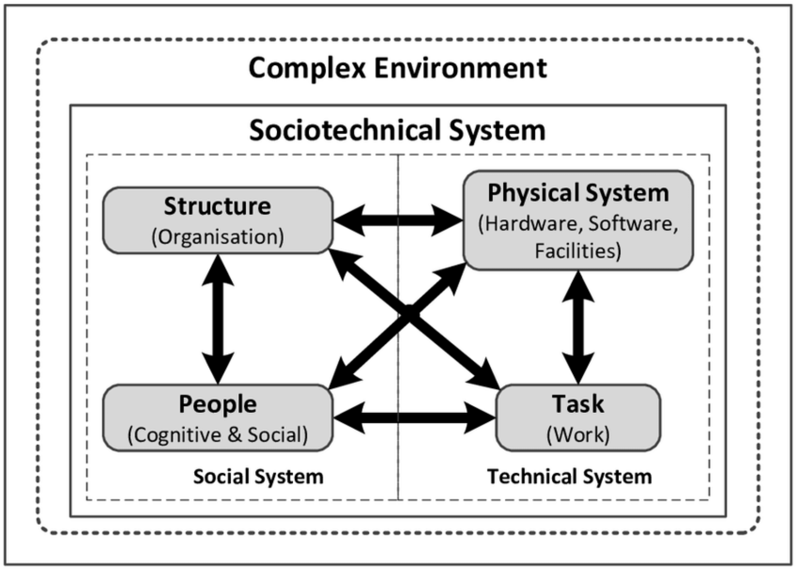


Figure 3-1: Sociotechnical System [5]

A socio-technical system is composed of a socio system and a technical system. A socio system contains structure (organizations) and people (stakeholders). Whereas a technical system contains physical system (hardware or software) and task (work to be done). Each element is a sub-system, and they interact with each other as show in Figure 3-1. Finally, the socio-technical system is part of the big environment that has various environmental factors that can impact the social-technical system.

Because each element in the social-technical system is a system on its own, systems thinking methodologies can be applied on them individually as well as the overall socio-technical system. In the following sections, several systems thinking methodologies are introduced focusing on different aspects of a socio-technical system. The selection criteria for each method are also explained.

3.3.2 Organization Structure & Stakeholder Analysis

An organization structure defines how activities are directed toward the organizational goals [46]. There are many types of organization structures, but the most common on is the divisional structure in America [47]. A divisional structure is usually in the form of a hierarchical tree with departments, teams, or individual roles as its nodes. Divisional organization structure is chosen to analyze structure part of the socio system because of its widely availability in organizations as almost all of the organizations already have it in place.

To analyze people element of the socio system, stakeholder analysis is selected to identify and understand the needs and expectations of people interested or have impacts on a project [48]. Since stakeholder analysis is already part of standard project management process, it is easy to implement and does not require additional resource to be carried out.

3.3.3 CONOPS

Standardized by The Institute of Electrical and Electronics Engineers (IEEE) [49], a concept of operations (CONOPS) is a document illustrating proposed system characteristics from a user's perspective. It is used to facilitate a common understanding and communicate system specifications and workflows to all stakeholders without being overly technical [50]. A good CONOPS should tell a story about the steps involved in putting a system in place and letting stakeholders know their roles in the process [51]. It is often the first step for developing system requirements. Note that CONOPS should be updated throughout the system's life cycle to sustain a common vision of the system for all stakeholders. While developing a CONOPS, one should keep in mind that it should contain a conceptual view and only top-level functional threads of the system. In addition, it should propose the system from user perspective using user's language in a simple and clean way.

CONOPS is not just a static document consisting detailed technical specification. Compared to other technical system specification tools such as requirement diagram [52], CONOPS also acts as a communication tool thus has closer relationships with socio system.

3.3.4 STAMP & STPA

To understand the interaction between socio and technical systems, and potential risks might arise from the overall system, another two systems thinking methodologies are reviewed: STAMP and STPA.

STPA stands for System-Theoretic Process Analysis, an analysis framework based on the Systems Approach to Safety Engineering (STAMP) accident-causality model [53]. STAMP model treats accidents as control problems to identify root causes such as unsafe interactions between components, faulty design, and flawed requirements [53]. A STAMP model includes (1) safety constraints, (2) hierarchical safety control structure, and (3) process models used to determine safety control actions [6]. A basic building block of a system control diagram (SCD) is shown in Figure 3-2. Controllers have control algorithm and process model in place. Controllers process model determines what control actions to take. After receiving the controlled action, the controlled process sends its feedback back to the controller.

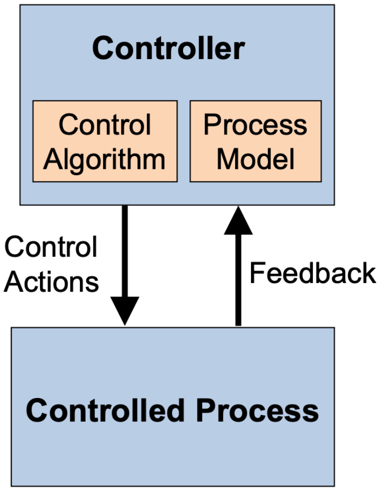


Figure 3-2: System Control Diagram - Basic Building Block [6]

There are two types of analysis tools under STAMP. Besides STPA, the other one is Causal Analysis using System Theory (CAST). CAST is usually done after accidents happen and aims to find out inadequate controls that lead to the accidents. On the other hand, STPA is usually performed before any accident to try to find out inadequate controls in design to prevent accidents from happening.

There are four main steps in STPA: (1) identify potential errors and failures; (2) draw out control diagrams; (3) identify unsafe control actions; and (4) identify causal scenarios. In the next chapter, a detailed STPA is carried out for AIOps implementation systems [53].

Besides STPA, there are other hazard analysis methods such as failure mode and effect analysis (FMEA) [54]. The reason for choosing STPA in this research is that STPA makes use of a functional/safety control diagram instead of a physical component diagram used by traditional methods [55]. STPA formulates the system safety/success as a control problem and identify inadequate controls rather than only focusing on component failures.

3.3.5 System Dynamics - Causal Loop Diagrams

System dynamics is another method to model, understand, and analyze complex system behavior. It emphasizes the nonlinear, self-adaptive, and policy-resistant nature of the system [56]. It is a useful systems thinking approach, especially when complicated system behavior and dynamics over a long period of time is of interest. In the case of AIOps, because the implementation process can take a long time, system dynamics is ideal to be adopted. Some important concepts in system dynamics include causal loop diagrams, feedback loops, stocks and flows, and time delays.

A causal loop diagram (CLD) is used to represent a complex problem or system. It consists of variables and causal links between dependent and independent variables. When causal links form circles, feedback loops are created. There are two types of feedback loops: reinforcing feedback loop, which drives exponential growth or decline of variable quantity/amount, and balancing feedback loops which move a system towards a goal or a stable state [56]. While a CLD is sufficient to perform qualitative analysis, more advanced concepts such as stock and flow and time delay are needed for more quantitative analysis. Stocks are accumulated quantity determining the state of a system, and they are changed through their flows [56]. Since quantitative analysis is not in the scope of this thesis, a CLD without stock and flow is used.

3.4 Chapter Summary

In this chapter, the overall system problem statement is proposed first to set the objective of the research. That is to guide effective enterprise-level AIOps adoption and implementation by building a general yet comprehensive framework using systems thinking methodologies. Next, the scope of the research is defined regarding aspects of AIOps use cases, stages and capabilities, and dimensions. Lastly, different systems thinking methodologies used in this research and the reason for choosing them are explained.

Chapter 4

System Architecture of AIOps

In this chapter, system research methods discussed in the previous chapter are used to understand the status and potential problems with AIOps. This chapter: (1) Defines the whole problem space of AIOps adoption and implementation; (2) Establishes common ground among various stakeholders who might be interested and involved in AIOps systems; and (3) Identifies weak links and gaps in the AIOps systems and implementation process. The system of interest here is more than just AIOps technical systems. It refers to general AIOps systems including organizations and other human aspects of the entire implementation process.

Following Bostrom and Heinen's model of socio-technical system [57], a general AIOps system has all components shown in Figure 3-1. Each component is analyzed in detail using a system research method mentioned in section 3.3. Here are the questions to be addressed via the analysis:

- **Structure**: What is a typical organizational structure of an entity that would be interested in implementing AIOps technologies?
- **People**: Who are the stakeholders of the system, and what are their roles and responsibilities?
- **Physical System**: What are the software and processes involved in implementation and operation of AIOps? What is the information flow in the system?

- **Task**: How are individual tasks controlled and operated? Who are the controllers for individual tasks? What are the potential inappropriate control actions that would potentially lead to issues and problems?
- **Dynamics**: How do the above-mentioned aspects interact with each other over time and what kind of dynamics are produced?
- **Complex Environment**: Where is the system boundary? What are other environmental elements interacting with the system?

4.1 Structure - Organization Chart

First, an organizational structure is analyzed for a typical enterprise that implements AIOps. Figure 4-1 shows the organization chart containing people/departments who might be concerned with AIOps implementation. It is a generic and simplified organization chart representing only teams playing a pivotal role in AIOps. Other functional teams, such as human resource and finance, while important, are not shown in this chart in the interest of specificity. They are addressed in the later part of the analysis.

As shown in the general organization chart, there are two central departments: Product/Business and Technology/Engineering. Under the Engineering organization, there are three sub-organizations: a Development team, an Infrastructure and Operation (I&O) team, and a dedicated Data team. The I&O team is the one mainly responsible for AIOps implementation. Under the I&O team, it is further divided into four sub-teams: Infrastructure, System Architect, Technical Operation, and Program Management. As highlighted in the graph, all I&O sub-teams except Infrastructure are core function teams to AIOps solution and platform building. Third-party vendors are not part of the organization, but are also included since mixed-dimension AIOps is assumed, and vendors would have a close relationship with AIOps implementation.

A brief introduction of each team is listed below. The teams are divided into five

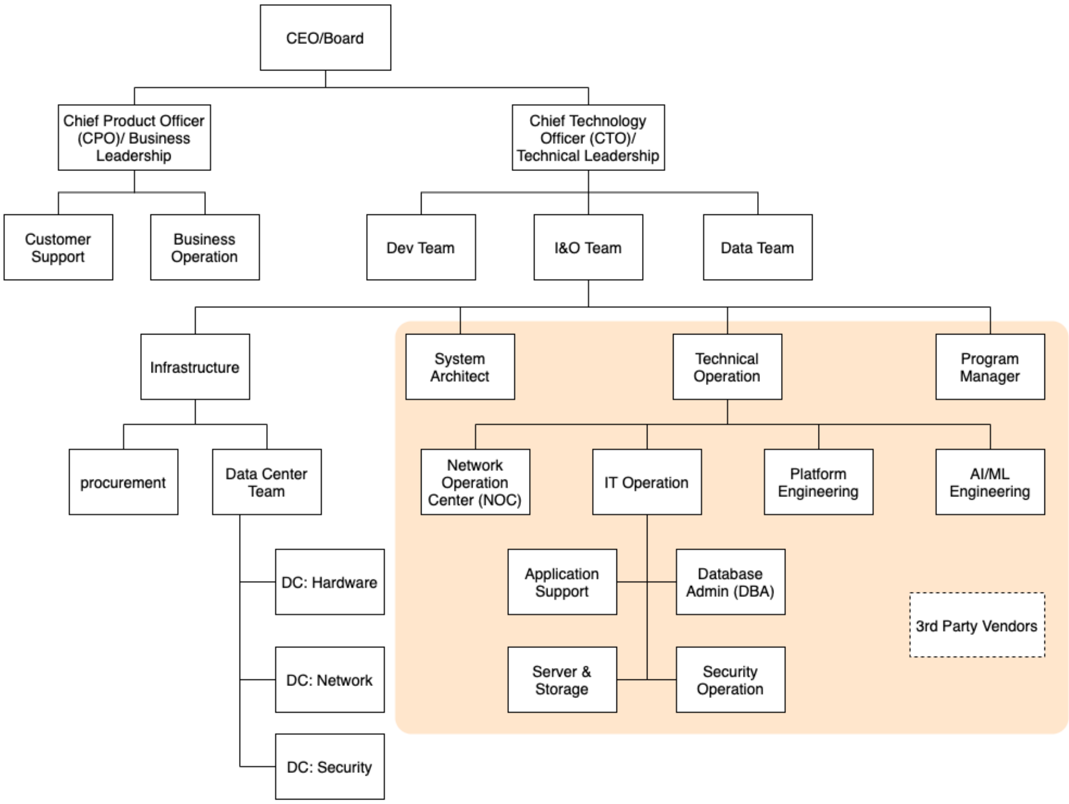


Figure 4-1: AIOps - Organization Chart

main categories.

Senior Management

- CEO (Chief Executive Officer)/Board: makes overall strategies for the company
- CTO (Chief Technology Officer): decides engineering directions

Product and Business Operation

- CPO (Chief Product Officer): is responsible for the success of the company product
- Customer Support: deals with customer issues and ensure customer satisfaction
- Business Operation: ensures a smooth and healthy process of daily operations such as marketing

Infrastructure Team

- Procurement: is responsible for all purchase-related activities, including evaluating suppliers, negotiating contracts, tracking delivery, etc.
- Data Center Team: deals with all data center operations such as power management and cooling

Core Teams around AIOps

- System Architect: is responsible for designing and evaluating the system architecture of the technical system
- Program Manager: coordinates collaboration and communication between different teams, and ensures successful delivery of projects
- Technical Operation:
    - NOC (Network Operation Center): monitors the health status of all system components and is responsible for incident escalation
    - IT Operation: deals with technical operation tasks such as service deployment, incident response, and service maintenance
    - Platform Engineering: is responsible for platform development, which serves as a common infrastructure for application developers or IT operation engineers
    - AI/ML Engineering: is responsible for AI and ML related algorithm development

Other Engineering Teams

- Dev Team: refers to application developers who are responsible for building application side logic
- Data Team: typically includes data engineering and data science teams where the former is responsible for data ingestion and handling pipeline, and the latter focuses on discovering business insights and helps with decision-making

4.2 People - Stakeholder Analysis

Based on who needs to provide input to make the project successful and benefit from the project success, there are broadly speaking two types of people: stakeholders and beneficiaries. These two groups might have an overlap called beneficial stakeholders that need to provide input to and can benefit from the project. Charitable beneficiaries is the group that is only beneficial but does not need to provide any input. Lastly, problem stakeholders is the group that needs to provide input to the project but is not likely to benefit from it. An illustration of the three groups is shown in Figure 4-2.

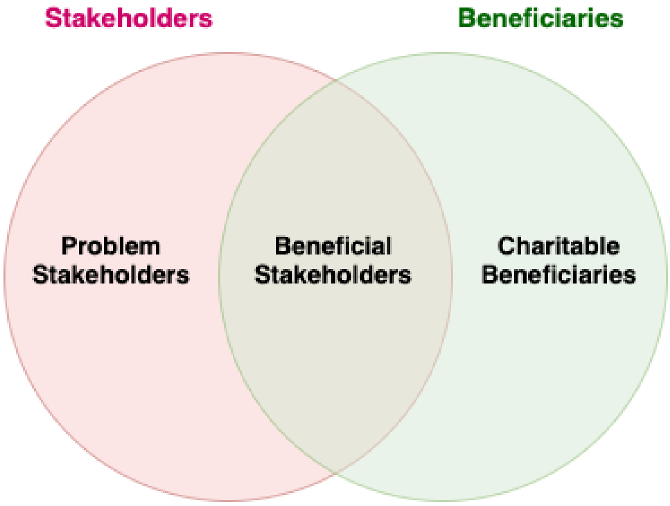


Figure 4-2: Stakeholder and Beneficiaries

Among the three groups, charitable beneficiaries require lowest attention since they have no stake in the project, yet could receive benefits. Beneficial and problem stakeholders are the ones to be managed closely, especially problem stakeholders, because implementing the project might be against their interest.

Figure 4-3 shows one possible categorization for stakeholders and beneficiaries for AIOps projects:

The entire product and business team, as well as external customers, are identified as charitable beneficiaries. It is because AIOps solutions can enable fast problem-solving and overall stable system and service performance. These

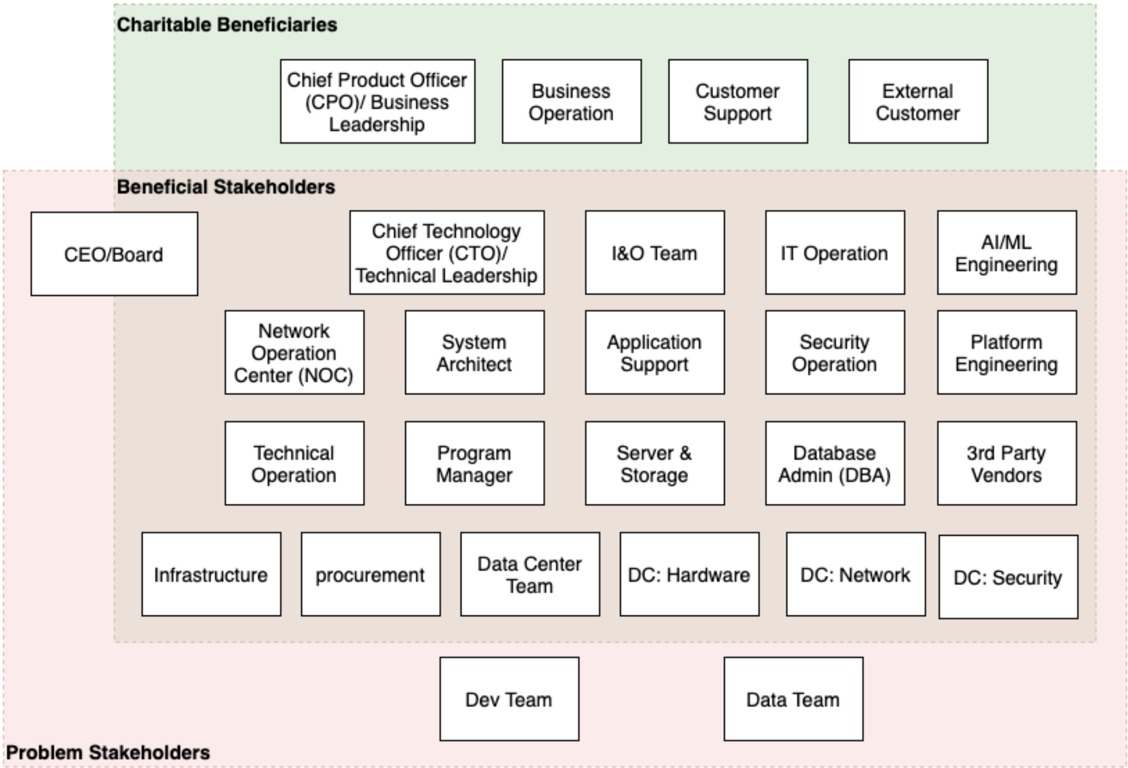


Figure 4-3: Stakeholder and Beneficiaries - AIOps Projects

improvements directly benefit the user and customer of the company and reduce the burden on the product and business side who needs to respond to customers in case issues happen.

Development and Data teams are likely to be two of the problem stakeholders. As mentioned in Chapter 2, there has typically been a conflict of interest between Dev and Ops team. The successful implementation of AIOps solutions does not provide any significant merit to the Development and Data teams as their scope of work is independent of AIOps platforms. Nevertheless, AIOps implementation is likely to have non-positive impact on them, such as change of process and input request.

One ambiguity here is the attitude of the CEO/board members. Depending on the amount of investment needed for AIOps implementation and the CEO's perception of the potential outcome, they could be either beneficial or problem stakeholders.

The rest of the teams can all be categorized as beneficial stakeholders. However, their interest and influence vary. Figure 4-4 shows the stakeholder mapping with the two dimensions.

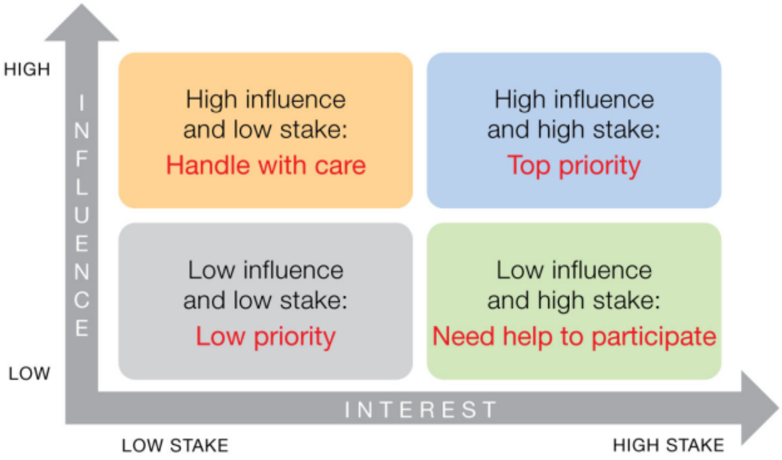


Figure 4-4: Stakeholder Mapping [7]

The mapping divides the entire stakeholder space into four quadrants: (1) High Influence High Stake (HIHS) - Top priority; (2) High Influence Low Stake (HILS) - Handle with care; (3) Low Influence High Stake (LIHS) - Need help to participate; and (4) Low Influence Low Stake (LILS) - Low priority. The mapping indicates a general guideline on how to interact with different types of stakeholders. The more a stakeholder is located towards the upper-right corner, the higher priority should be given because they have both high interest and strong influence on the project. Positions of different AIOps stakeholders in the quadrant are very much organization-dependent and context-specific. The categorization can be used as a reference when considering stakeholders in a specific context.

4.3 Physical System - CONOPS

After looking into the social system, the technical system is examined in detail. Figure 4-5 shows a Concept of Operation (CONOPS) view of an AIOps system operation process, indicating data and information flow in the system, corresponding processes and phases, and potential output from the system.

It starts with the data ingestion and handling pipeline. Raw data from various sources are first identified. It can be either batch data or stream data, depending

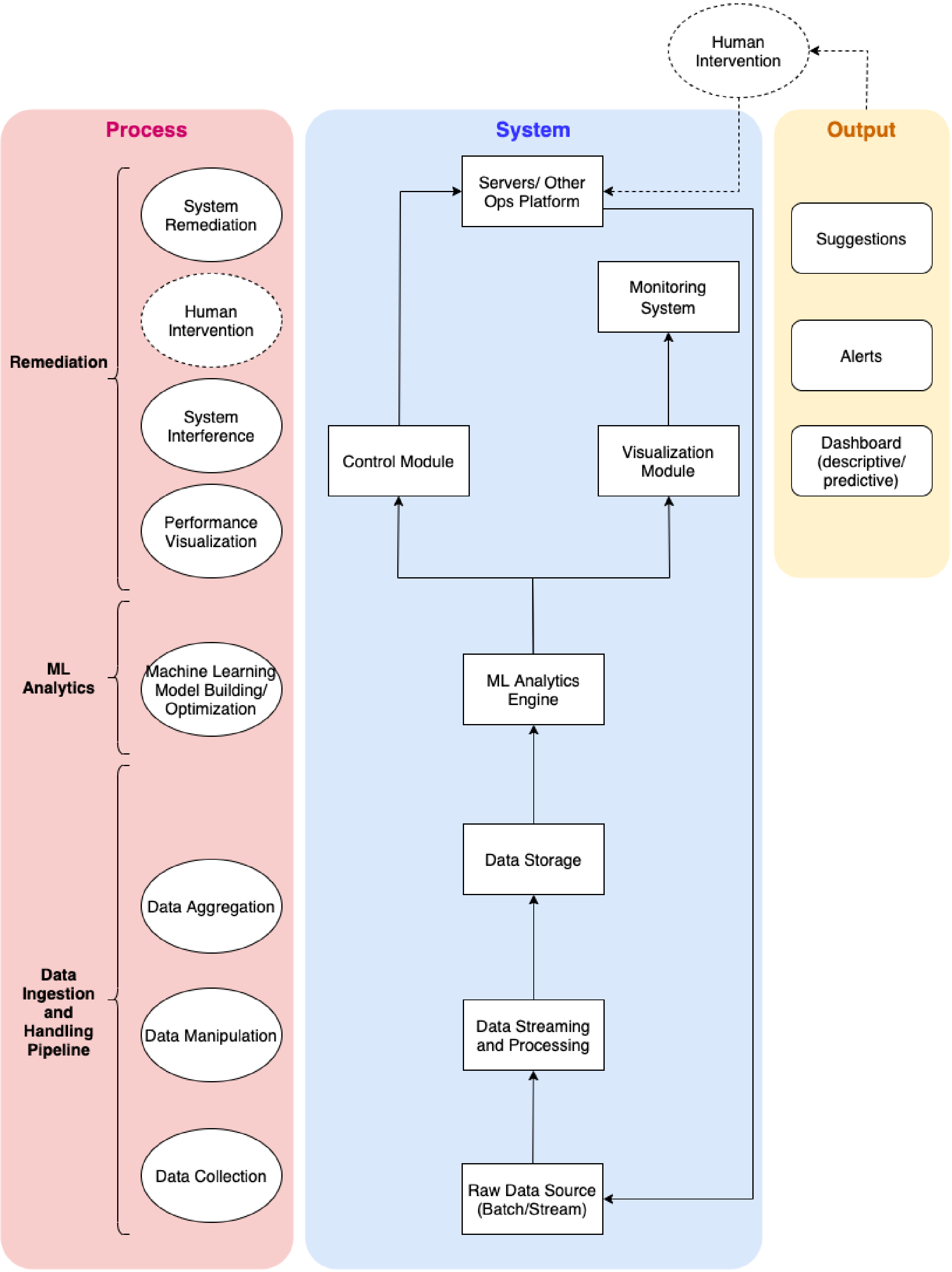


Figure 4-5: AIOps System CONOPS

on the nature and objective of the system. It is reasonable to assume it is a mix of both types, as historical data and real-time information are vital in constructing a meaningful model. Then the data are processed and streamed, during which data manipulation and aggregation occur as necessary. Following that, processed data are stored in the desired type of storage devices such a data warehouse and a data lake.

The second phase is machine learning analytics, where an ML analytics engine is present to build and optimize machine learning models. The ML algorithms inside the engine are obviously the key part of the entire system, which can be very complicated. For this thesis, since the more extensive general AIOps system is the one of interest, the ML analytics engine is treated as one entity interacting with other subsystems. Details inside the engine are not discussed.

After the analytics engine discovers meaningful results and insights, a visualization module helps to put everything desirably in graphs and charts, often in the form of dashboards. These results include descriptive information such as the current server performance predictive trends and forecast for the near future. Other than the dashboards, alerts are also a part of the monitoring system to help to highlight critical activities that need immediate attention. In addition, with more advanced ML technique and relevant data, the systems can also provide suggestions on what action to take to maintain the healthy condition of the system or prevent potential incident from happening. There are two routes from here onward. For critical system changes or those can only be performed by human (e.g., swapping hard disks for a server), human operators evaluate the situation based on the outputs and take action if necessary. For trivial and non-critical fix actions, the control module in an AIOps platform can interfere and take appropriate action on its own to implement a fix and resolve issues. Regardless of which approach is used, after the remediation, data reflecting the changes are then fed back into the data source, and the cycle just keeps running.

4.4 Task - System-Theoretic Process Analysis (STPA)

To interpret individual tasks, it makes sense to bring in the people involved in performing the tasks while interacting with the physical technical system. As introduced in section 3.3, System-Theoretic Process Analysis is used to find potential inadequate control in the overall AIOps socio-technical system while analyzing the tasks.

4.4.1 Errors and Failures

Although STPA and STAMP are mainly concerned with safety-related accidents and hazards, they can be used to explore general errors and failures in a system. Here is a list of potential failure scenarios:

- Inadequate management support (budget, headcount, time)
- Inadequate expertise from the I&O team
- Inadequate vendor support
- Inadequate usable data
- Inadequate technology
- Biased or wrong output produced
- Mis-operations by AIOps
- Difficult to justify success: measure benefit received, ROI

Note that this list is not meant to be exhaustive, but provides some possible scenarios. In real-world cases, organization might have different approaches to determine the list. One common approach is brainstorming [58]. Project members and stakeholders from cross-functional teams are assembled to discuss the list together. They should each identify the possible ways a failure could happen in their function and potentially at the interface with other functions.

4.4.2 Control Structure

Figure 4-6 shows a Safety Control Diagram (SCD) of the AIOps system, with the upper half concentrating on the social system and the bottom half indicating the technical system. The social system is on top because humans are the controller of the technical system, which is the controlled process. The same structure applies to all the entities in the SCD. The SCD is different from CONOPS not only because human entities are added, but also in the sense that it does not emphasize the data flow aspect. Instead, the focus is on control power and potential process model flaws present in the entire system.

4.4.3 Unsafe Control Actions

Based on the SCD constructed and potential failure scenarios identified, each "Controller-Controlled Process" pair is analyzed. A list of possible unsafe control actions (UCA) in the AIOps system is then generated. Here unsafe control actions refer to the general system or social behavioral problems that might lead to potential risks or even system failure.

Senior Management - Engineering: Senior management has unaligned strategies with AIOps implementation when AIOps implementation is at odds with company strategy or provides inadequate resource including a budget, human capital, and time when resources are limited and AIOps is not prioritized.

System Architecture - IT System & Infrastructure: System Architects provide architecture design that is not optimal for implementing AIOps.

Infrastructure - IT System & Infrastructure: Infrastructure team could not provide adequate infrastructure support when needed.

Program Management - Technical Operation: Program Management does not provide clear requirement, scope, timeline, or budget for AIOps projects.

Technical Operation - IT System & Infrastructure: Technical Operation does not provide proper system operation to IT systems and Infrastructure. For example, IT Operation engineers do not set up logging mechanisms correctly, leading

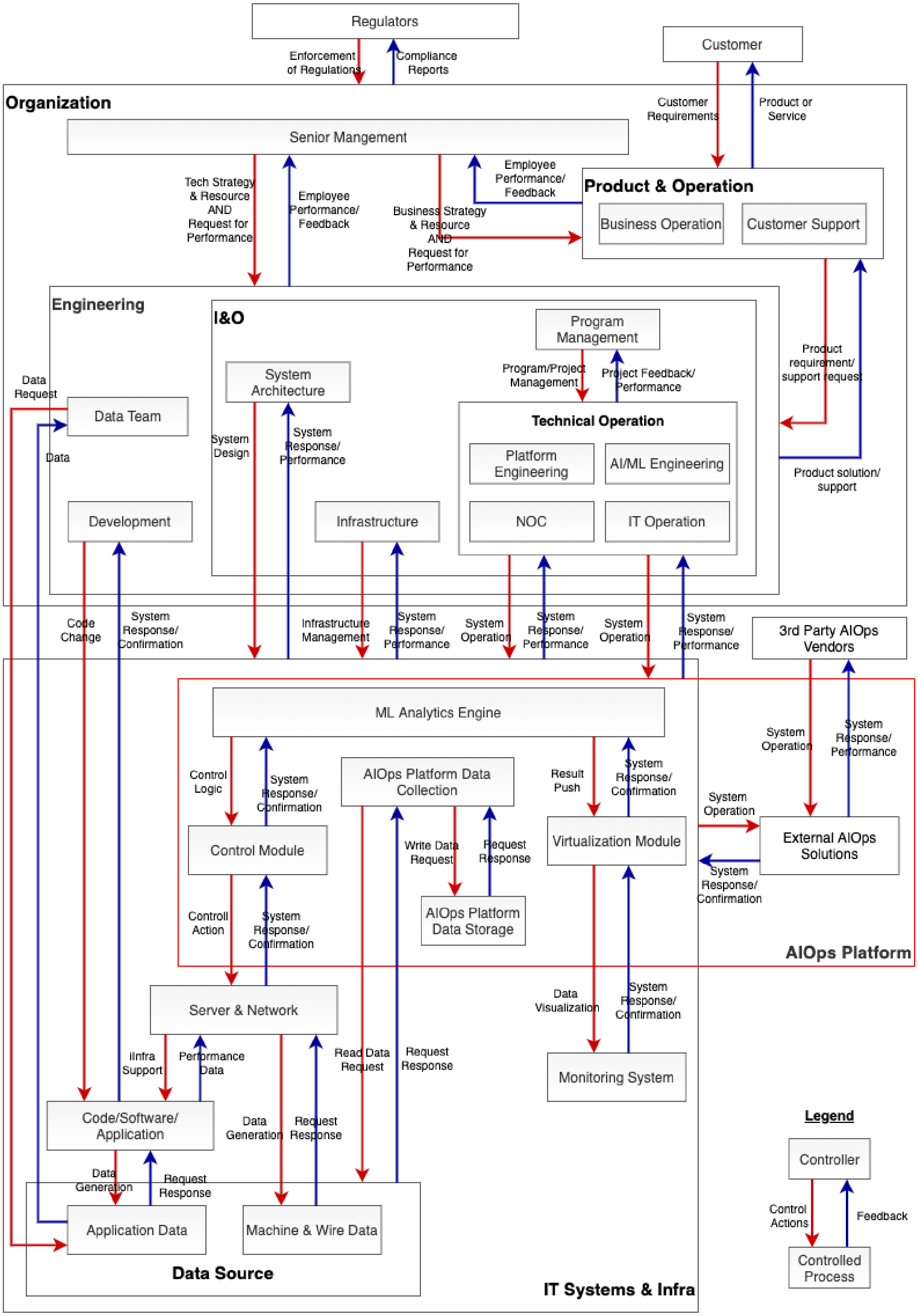


Figure 4-6: AIOps System Safety Control Diagram

to a lack of data.

Technical Operation - AIOps Platform: Technical Operation does not provide proper system operation to AIOps Platform.

Third-party AIOps Vendors - External AIOps Solutions: Third-party AIOps Vendors provide inadequate support for services (e.g., bug fixes, customization) of External AIOps Solutions.

IT System & Infrastructure - External AIOps Solutions: IT System & Infrastructure does not provide necessary system operation requests to External AIOps Solutions as a part of system integration. Although a majority of the time, it is caused by human controllers in the upper level, in some other cases, machine failures can lead to this inadequate control action.

ML Analytics Engine - Control Module: ML Analytics Engine provides faulty control logic to the control module because of faulty ML algorithm. An interesting point to consider here is that for machine learning algorithms, when the machine learns something wrong, is the machine's fault or the human controller who develops the algorithm?

Control Module - Server & Network: Control Module provides inadequate control action to the target server/network.

Server & Network - Code/Software/Application: Server & Network provides inadequate infrastructure support for higher layer Code/Software/ Application.

Development Team - Code/Software/Application - Application Data: Code/Software/ Application provides inadequate application data because of faulty configuration by Developers.

Data Team - Application Data: Data Team does not provide correct data pull requests to store Application Data in the data warehouse.

Server & Network - Machine & Wire Data: Server & Network does not generate necessary Machine & Wire Data.

AIOps Platform Data Collection - Data Source: AIOps Platform Data Collection subsystem does not provide valid data read requests from Data Source.

AIOps Platform Data Collection - AIOps Platform Data Storage: AIOps Platform Data Collection subsystem does not provide proper data write request to AIOps Platform Data Storage.

ML Analytics Engine - Visualization Module: ML Analytics Engine provides faulty/inadequate result data to Visualization Module.

Visualization Module - Monitoring System: Visualization Module provides inadequate data visualization support to the monitoring system, possibly due to incompatibility or limited functionality.

4.4.4 Causal Factors

In this final step, potential flawed process models, controllers, control paths, and feedback are examined to provide causal factors to the unsafe control actions identified in the previous subsection. These causal factors provide answers to the question of why those unsafe control actions or behavioral problems would occur.

Senior Management - Engineering

- Senior Management does not understand AIOps and the importance of it.
- Senior Management has an over-inflated expectation about AIOps.
- Senior Management understands the importance of AIOps but does not prioritize it compared to other strategies.
- AIOps is prioritized, but the overall resources are limited. It includes budget, human capital, and time constraints.
- There is little or no feedback from Engineering/Product & Operation teams mentioning pain points and concerns which AIOps can potentially solve.
- There is little or no feedback from Engineering/Product & Operation teams mentioning project resources are inadequate.

System Architecture - IT System & Infrastructure

- As the bulk of core IT System and Infrastructure is often designed and implemented before AIOps solution, there can be constraints and technical hurdles for System Architect to design an optimal AIOps-enabled IT System.

Infrastructure - IT System & Infrastructure

- Infrastructure team does not have control over the supply chain, quality of hardware and network, or physical location of the infrastructure.

Program Management - Technical Operation

- Program Manager does not receive clear requirements from the project sponsor (who is usually the CTO or Head of I&O team for AIOps projects).
- Program Manager does not have a correct and complete understanding of project requirements.
- Program Manager does not possess adequate program management skills to effectively manage project scope, timeline, and budget.
- There is no program management role in place.
- There is little or no or inaccurate feedback from Technical Operation regarding project progress and status.

Technical Operation - IT System & Infrastructure

- Technical Operation does not know a particular need exists to set up the system (i.e., knowledge gap).
- Technical Operation set up the system the wrong way (human error or inadequate skill set).
- There is no proper feedback mechanism set up to inform Technical Operation on what is lacking.

Technical Operation - AIOps Platform

- AI/ML Engineers do not provide effective ML algorithms to process the data.
- Platform Engineers and IT Operation Engineers do not correctly set up the integration among different components in the AIOps Platform.
- IT Operation and NOC Engineers do not have confidence in the advice given by AIOps.
- Collaboration among sub-teams in Technical Operation is inadequate.
- There is no proper feedback mechanism set up in AIOps Platform to inform performance and potential system problems.

Third-party AIOps Vendors - External AIOps Solutions

- Third-party AIOps Vendors do not receive enough feedback from the customer.
- Third-party AIOps Vendors do not have enough resources to provide requested support.
- There is a conflict of interest between customer requirement and overall product strategy.
- There are technical hurdles in implementing customer requests.

From the UCA and Causal Factor analysis, it can be shown that while human controllers can introduce various kinds of inadequate controls and flawed process models, those among the physical system components can be categorized into the following three types:

- **Faulty hardware**: Machine or system break down which is not caused by human operation
- **Faulty software logic/algorithm not generated by human controllers**: Inappropriate or missing control action generated by machine learning algorithms

- **Limited/Constraint functionality and compatibility**: Control logic is correctly implemented but could not occur because of controller/controlled process capability constraints. For example, Monitoring System might not present an animated visualization generated by the Visualization module due to incompatibility.

4.5 Dynamics - System Dynamics

To examine the interaction and dynamics among different elements within the socio-technical framework of AIOps, a causal loop diagram (CLD) is used. System Dynamics is used to understand the nonlinear behavior of complex systems over time.

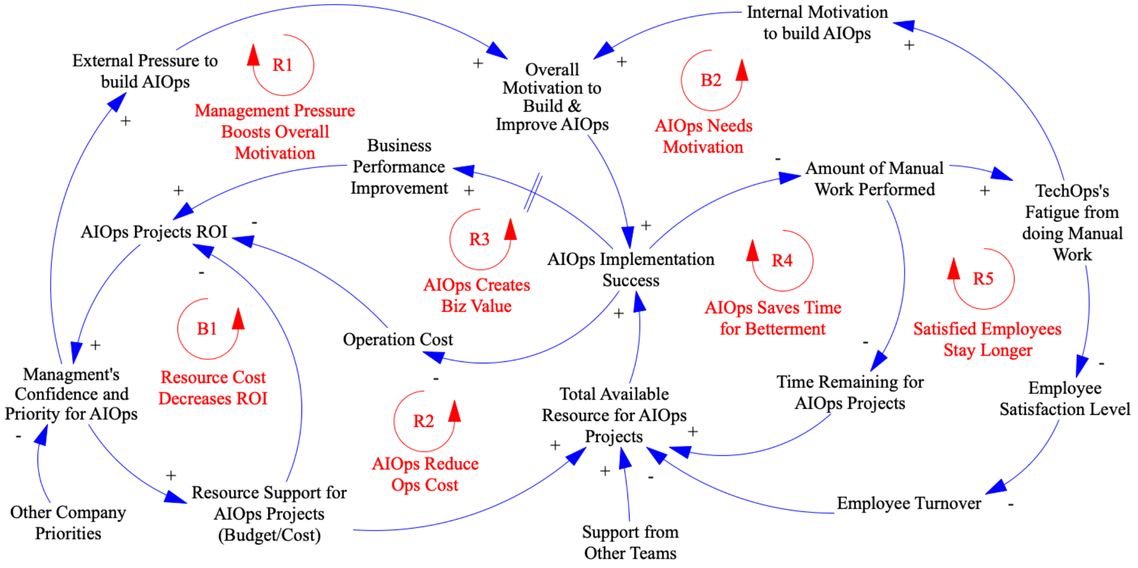


Figure 4-7: AIOps Causal Loop Diagram

4.5.1 Variable Definition & Relationship

There are several "key variables" in this CLD. They are the ones with more than one incoming causal link or more than one outgoing causal link. They interact with each other via some intermediate variables. Their definition and relationship are described as follows.

Management's Confidence and Priority for AIOps

In this model, there are two main factors affecting management's decisions towards AIOps: AIOps project return on investment (ROI) and other company priorities as compared with AIOps. The more ROI AIOps projects generate, the more confidence management have in AIOps. If other company priorities have more weight than AIOps, relatively less weight is put on AIOps projects.

The confidence and priority affect two downstream elements. When management's confidence and priority for AIOps increases, there are more resources and supports provided. At the same time, the pressure from management increases as well.

AIOps Projects ROI

Several factors determine AIOps project ROI. For the return part, the main one is the business value and performance improvements created by AIOps solutions. As mentioned in section 4.4.1, the business success of AIOps can be difficult to justify because sometimes it is not reflected directly through monetary values. Moreover, it takes time for the values to emerge (i.e., delay from AIOps implementation success to business performance improvement). For investment, both the early-stage resource support and long-term operation cost are taken into consideration.

Resource Support for AIOps Projects

As mentioned, resource support for AIOps projects comes from management and negatively affect AIOps ROI. In addition, the resource support from management becomes a part of the total available resource for AIOps projects, which is discussed next.

Total Available Resource for AIOps Projects

Except resources support from management explicitly for AIOps projects, other types of resources can also be counted towards the total available resource. First, there are support and collaboration from other teams. Second, time available for the project team to carry out the projects is also a critical part. Last, the employee turnover rate negatively affects the workforce available, thus the total available resource.

Overall Motivation to Build and Improve AIOps

There are mainly two sources of motivation: one is from management pressure; the other is from the team's internal self-motivation. The two sources add up together to become the overall motivation, but their respective weight can vary from organization to organization.

AIOps Implementation Success

AIOps implementation success is at the center of the model. It has two main direct determination variables, which are the total resource available and overall motivation. It then impacts three other variables. First, the more successful the implementation is, the less manual work there is because AIOps helps reduce the need for repetitive manual work. Second, successful AIOps implementation helps to reduce operation costs as it saves man-hours and, therefore labor costs. Last, as mentioned above, eventually, business performance improvement shall be seen if AIOps is implemented successfully.

Amount of Manual Work Performed

The amount of manual work, in turn, affects two factors. The less time one needs to spend on manual work, the more time there is for more AIOps-related work. In addition, because tedious toil is reduced, fatigue from doing those toils also decreases.

TechOps's Fatigue from Doing Manual Work

What happens after fatigue decreases? The first thing is that the team recognizes the importance of AIOps more and be more motivated to build and improve AIOps solutions. The other aspect is that the overall employee satisfaction level increases, and the team become more satisfied than they used to be.

4.5.2 Feedback Loops

As labeled on the CLD, there are two balancing feedback loops and five reinforcing feedback loops in the modeled system. The dynamics of each feedback loop are illustrated below. Either positive or negative dynamics are described, but both cases are possible in actual cases.

B1: Resource Cost Decreases ROI

This is a balancing loop concerning the cost of AIOps projects. When management's confidence and priority for AIOps increases, they are likely to invest more resources. All else equal, increasing cost reduces overall ROI. As a result, management's confidence and priority decrease.

B2: AIOps Needs Motivation

Another balancing loop in the system is about the project team's self-motivation. When the implementation of AIOps is not so successful, the amount of manual work performed is enormous. Then there is more fatigue leading to increasing self-motivation to build better and more successful AIOps solutions.

R1: Management Pressure Boosts Overall Motivation

High management confidence and priority lead to high external pressure to build AIOps solution. Resultant high overall motivation increases the chance of implementation success. It further yields improvement in business performance, which makes the ROI of AIOps project higher. As a result, management's confidence and priority for AIOps are even higher.

R2: AIOps Reduce Ops Cost

This loop is another route leading to reinforcement behavior for management. High management confidence and priority provide more resource support for AIOps projects. More resource support makes implementation more likely to succeed. The AIOps implementation success reduces the operation cost of work that needs to be done manually previously. As a result, the reduced cost increases AIOps project ROI, which boosts management's confidence more.

R3: AIOps Creates Business Value

R3 is similar to R2 except for the effect of AIOps implementation success. In this feedback loop, business performance improvement is going to emerge from successful implementation of AIOps. There is likely going to be a delay depending on the nature of the business and how AIOps is implemented. However, ultimately, the improvement should leverage the return and make the overall ROI and subsequent management confidence higher.

R4: AIOps Saves Time for Betterment

R4 is looking at the employee side of the story. When AIOps implementation becomes successful, the amount of manual work that needs to be performed should decrease. All else equal, the time remaining for AIOps-related tasks increases. That means more time resources for AIOps projects, and therefore, even more project success.

R5: Satisfied Employees Stay Longer

The other employee side reinforcing feedback loop is about employee satisfaction. When the AIOps projects are successful, less manual work is performed, and the fatigue from doing those manual work decreases. As a result, employee satisfaction level increases, and turnover rate decreases. That means the team can maintain and even attract talent, and therefore have more total available resources for AIOps projects. It then results in more considerable success.

4.5.3 Equilibrium

Because the main objective of the overall system, "AIOps Implementation Success", is at the center of the CLD and a part of most feedback loops in the system, the long-term stable state or the equilibrium state of it is the key performance of interest. Without quantifiable measures, it is still possible to reason through it and have some insights.

This model is dominated by reinforcing feedback loops. The key variable "AIOps Implementation Success" is part of all five reinforcing feedback loop and only one balancing feedback loop. There are two extreme cases where all reinforcing feedback loops drive the key variable positively or negatively. In the extreme positive case, if the confronting effect of the balancing loops is relatively small, almost everything is on the positive side: management's confidence and priority, overall support and motivation, and employee satisfaction level are all high. Then depending on the power of those two balancing loops, if any of them is powerful enough to dominate and turn the positivity around, the overall result could gradually shift towards the other side of the spectrum. Once the negative effects emerge and not able to be contained, the five reinforcing feedback loops pull the system towards the extreme negative side: management's confidence and priority, overall support and motivation, and employee satisfaction level are all low. And then, AIOps implementation fails.

Once the project goes into heavy negative status, it is very challenging and may even be unlikely for the result to be turned around. It is because there is only one balancing feedback loop trying to drive the result back to positive (i.e., the B2 self-motivation loop. For B1, spending less is likely to offset the negative return). Therefore, organizations should avoid going too deep into the negative state. In addition, the delay between the implementation and business performance improvement is another key factor to pay close attention to. Management should be well informed and educated regarding the delay and have a clear understanding.

It is critically important to be aware of different dynamics in the system and pay close attention to those negative trends in reinforcing feedback loops. It requires the organization to have a team or person with a high-level overview and big picture of the entire system and act as the liaison between different functional teams and break information silos. Typically, if present, a program or project manager is recommended to take this responsibility and make sure everyone is motivated and aware of the risks of a potential downturn.

4.6 Complex Environment - Ecosystem Factors

Finally, environmental factors outside of the system also need to be taken into consideration. While different organizations may have varying perspectives and priorities, the following items are often relevant:

- **Economy**: What is the overall economy? What is the overall financial status of the company?
- **Market**: How is the overall market in AIOps? Who are the major players?
- **Regulatory**: Are there any regulations regarding the usage of data and technologies?
- **Technology**: Are all necessary technologies available and accessible?
- **Workforce**: What does the workforce demographics look like at the moment and in the near future? Will there be enough candidates with the required knowledge and skillset?

These factors interact with components in the socio-technical system, creating positive or negative impacts to varying degrees. It is a good practice to research these factors and analyze the company's specific relevance while implementing AIOps solutions.

4.7 Chapter Summary

This chapter provides detailed analysis on the system architecture of AIOps implementation projects. Based on the socio-technical systems approach, four pillars namely structure, people, physical system and task, together with their dynamics, are illustrated in detail using selected systems thinking methodologies. The analyses propose potential practical guides for an organization's reference while implementing AIOps. It aims to provide a baseline and inspire the team with more innovative and effective approaches suitable for their organizations.

Chapter 5

Framework

Based on the analyses from the previous chapter, an AIOps Implementation framework is proposed and discussed in this chapter. Framework construction and guidelines to apply the framework are mentioned in detail.

5.1 The STDE Framework

The STDE (Social-Technical-Dynamics-Environment) framework's objective is to connect a set of actions or explain complex behavior that can guide people in different disciplines to build and implement AIOps solution. The framework aims to fill in gaps in knowledge and experience of AIOps implementation and combine existing ideas in a novel way to address potential risks and challenges in the process.

5.1.1 Construction

Analysis performed, as discussed in previous chapters, guides some best practices, unveils potential risks, and informs practical approaches to address those risks. It involves both technical and human aspects, so it is not biased towards either side, and can be performed and understood by the general audience involved in AIOps implementation. As a result, those analyses form the basic building blocks of the STDE framework.

As shown in Figure 5-1, there are four circles representing five pillars in the proposed AIOps implementation STDE framework: the "**Socio**" circle consisting organization structure and stakeholder analysis, the "**Technical**" circle consisting CONOPS, the intersection between "Socio" and "Technical" consisting STPA, the underlying "**Dynamics**" feedback loop circle representing the system dynamics, and the outer-most "**Environment**" layer representing the environmental factors.

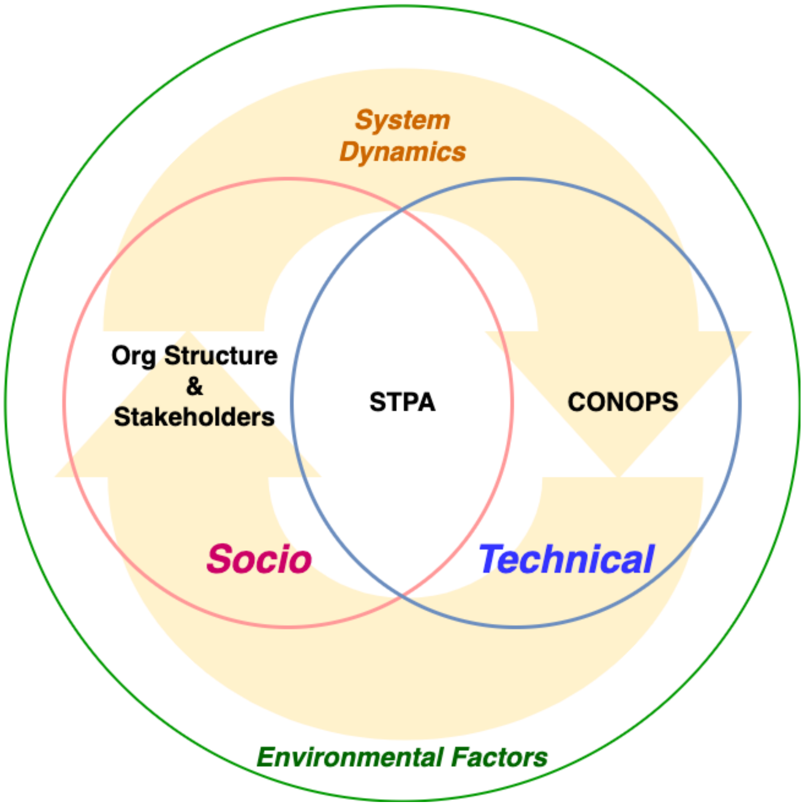


Figure 5-1: AIOps Implementation STDE Framework

5.1.2 Enabling Techniques

There are three areas to focus on when using the STDE framework: initiation, iterative mindset, and holistic thinking.

Initiation

Knowing where to start is critical. There is no one-size-fits-all answer regarding the initiation since each organization has its unique circumstances and working style.

However, in general, there are often two types of initiation on AIOps projects:

- **Top-down**: The initiative is pushed from management or upstream teams.
- **Bottom-up**: Certain pain points are present in the workflow, and the technical operation team takes the initiative to implement AIOps solutions.

When pushed from top-down, AIOps solution tends to be aligned with other company strategies. If not already assessed, environmental factors from the entire ecosystem should be considered first. After that, resource support shall be provided to the implementation team to figure out details regarding the socio and technical aspects. For example, who should be doing the work (organization structure and stakeholder), what should the system be like (CONOPS), how should the overall control and data flow so that the goal can be achieved (system control diagram), and how to assess and manage risks (STPA). So, from the viewpoint of the framework, it is going "inwards."

When initiated from bottom-up, the implementation team often has limited visibility to the upper-level strategy and roadmaps. They usually start with specific problems in the technical domain, and then design (CONOPS) and implement (STPA) specific solutions with available resources (organization structure and stakeholder) from socio circle. After they lay down the early work, then management is informed with more details. Together with the consideration of other company strategy and environmental factors, proper expectations are set. Opposite to the top-down pattern, it is going "outwards" in the framework.

Iterative Mindset

Despite the two initiation approaches, once the ball starts rolling, the inward/outward direction shall vanish and be replaced by an iterative mindset. System dynamics models could play a key role in setting up iterative mindset. During early implementation, enterprises shall set the right expectation while waiting for AIOps platform maturity to catch up. With the right expectation and appropriate number of resources, the technical operation team shall utilize their knowledge and expertise to design and implement AIOps solution. During the engineering and implementation process, teams/controllers shall get feedback from a respective downstream team or controlled process to continuously adjust their future control actions. With the different dynamics in place, the outcome is also different at different points in time.

The punchline here is: it is not a one-way street. Organizations should always think about the "loops": control loops in the system control diagram and feedback loops in the causal loop diagram. The ultimate goal is to continuously learn and improve the outcome until it meets the goal and becomes stable.

Holistic Thinking

Last but not least, it is essential to equip everyone involved in AIOps implementation process, from business leaders to technical operation engineers, with a holistic thinking mindset. As analyzed in Chapter 2 and 4, AIOps is still an innovative solution as compared with some existing methodologies. The problem space can be vast and complicated, from strategic planning, resource constraints, machine learning algorithms, data to system integration and collaboration among different teams. Breaking the silos and having everyone sharing a single vision, and understanding the big picture is critically important. A best practice to realize it is an artifact. As shown in Chapter 4, each component in the STDE framework has its graphical representation or tools to illustrate key concepts. Having all of these captured in detail, updated regularly, and shared with all stakeholders is a great way to enable holistic thinking.

Chapter 6

Conclusion

In this chapter, a summary of the research is presented, followed by limitations and potential next steps, and future extensions.

6.1 Summary

This research starts with an examination of AIOps concepts, market status and trends, and opportunities and challenges of the technology. By applying various systems thinking methodologies, different aspects of the system architecture of AIOps are analyzed. Based on the analysis, a framework is constructed that aims to guide effective AIOps implementation.

The STDE framework proposed consists of five main aspects based on elements in socio-technical system. These are: socio; technical; the intersection between socio and technical; system dynamics; and environmental factors. Each aspect has its systems thinking methodology, which can be referenced and applied by organizations in practice. For socio aspect, sample organizational structure and stakeholder analysis of AIOps implementation projects are introduced to provide a basic understanding of people element in the system. For the technical aspect, CONOPS of a typical AIOps platform is illustrated to outline the overall design and workflow. For the intersection between socio and technical, STPA methodology is adopted to analyze potential inadequate control in design to prevent risks of error and failure. System dynamics being a system behavior modeling tool wraps around the socio-technical aspects to simulate the interactions among variables in the system across time. Finally, the outer-most layer contains environmental factors outside of the system boundary but that impact the system performance.

Overall, this research considers both the socio and technical aspects of AIOps systems and integrates various systems thinking methodologies. As explicit examples of using each methodology are shown, applying this framework shall be straightforward. In addition, because of the comprehensiveness of the STDE framework, it has potential to enable effective cross-functional collaboration and bridge the gaps between different teams, especially technical personnel and management. The STDE framework also provides all AIOps-related stakeholders a shared vision and a way to think holistically. Moreover, organizations can also use the systems thinking methodologies embedded in the framework to direct effective planning, communication, and risk management throughout the AIOps implementation process.

6.2 Limitations

Due to time and expertise constraints, here are the areas and aspects not covered in detail in the research:

- Technical Details: This research work does not include detailed technical designs and specifications of AIOps platforms and solutions, such as a detailed design of data pipelines and type of machine learning algorithms, to be considered. Although not critical when discussing the organizational level strategy and planning of AIOps initiatives, technical details play a key role during actual implementation and are crucial to the success of AIOps. Furthermore, because a company has their unique context and challenges, it is not easy to recommend one design or set up a standard.

- Methodologies Considered: As described in section 3.3, a few key systems thinking methodologies are covered in this research. The methodologies chosen are based on the author's knowledge and best effort consolidating all appropriate tools and methodologies known. There may be other existing approaches that are suitable and might generate more insightful results.

- Validation of Framework: Since applying the framework developed to a real-world problem in an organization can be complicated, time-consuming, and involves privacy and legal considerations, framework validation is not part of the research. The framework proposed does not guarantee any outcome. Instead, it aims to find a way to bridge the gaps in current methodologies and provide a guide to improve effectiveness in AIOps implementation process.

6.3 Future Research Recommendations

Based on the limitations mentioned, several potential future extensions to the research are listed.

First, details regarding the technical design and implementation can be incorporated in future research. For example, recommended best-practice system designs for common AIOps use cases can be discussed. Difficulties in choosing the suitable machine learning model for AIOps is another topic worth looking into. More technical details can complement the STDE framework to provide a more comprehensive picture to various stakeholders.

Second, within the current framework, a more quantitative analysis could be performed when concrete data from real organizations become available. This step is specifically applicable to the system dynamics part of the STDE framework. The causal loop diagram in Chapter 4 does not contain any stock and flow structure. Therefore, it could only perform quantitative analysis. As projects are implemented, data regarding variable status become available and trackable. Adding stock and flow into the model and simulating the entire model can produce more insights regarding behavior trends and the potential stable state of the entire system.

Last, applying the STDE framework in real-world cases, gathering data and feedback, and continuously improving upon it are important and meaningful next steps to be considered. While this research can serve as a baseline and an initial attempt to solve the complex problems of AIOps implementation, validation and continuous improvement work are necessary to approve the usability and make sure the framework developed is widely acceptable and applicable.

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