Online Supplements to

A Theory of Strategic IT Unavailability

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Information Systems Research

Online Supplement A: Data and Methodology

Adopting positivist epistemological assumptions consistent with Eisenhardt (1989), our data-driven qualitative theory-building approach draws on Grounded Theory Methodology (GTM) (Glaser & Strauss, 1967; Glaser, 2007) with explicit choices to improve the emerging model's generalizability and accuracy. This study was motivated by the difficulty we encountered in explaining IT Unavailability (ITU) cases with diverse contingencies and strategic consequences.

Preliminary Literature Review: Following Urquhart & Fernandez (2013), we conducted a non-committal review of the literature to understand how practitioners and researchers conceptualize and operationalize IT unavailability (ITU) and its strategic impact. Our goals were twofold: (1) to define the scope of the study by identifying key inclusion and exclusion criteria, and (2) to develop theoretical sensitivity through awareness of the existing literature for future comparison. We deliberately kept this review non-committal, using the insights gained as a starting point rather than a prescribed framework. Ultimately, our data analysis led to a more comprehensive conceptualization of ITU and a new way to explain its strategic consequences. In line with Classic (Glaserian) GT practices, we minimized bias by deferring extensive engagement with established theories until our central categories had emerged from the data.

Data Collection:

Theoretical Sampling: We collected data on 28 ITU incidents (listed in Table A1) from online sources. We primarily relied on secondary data for several reasons. First, because organizations often consider ITU incidents sensitive and confidential, conducting primary data collection on them can be challenging. Second, using secondary data allowed us to capture incidents of varying severity and strategic impact in great detail. Moreover, drawing on rich descriptions from diverse sources for each incident allowed us to triangulate the information and more accurately represent the dynamics of each ITU incident. Thus, our data collection approach aimed to enhance both the completeness and the external validity of our emerging theory. *Theoretical sampling* is the process of determining where to collect data next, guided by the need to address emerging gaps in the theory. Our theoretical sampling unfolded in three distinct phases: homogeneous, extreme, and heterogeneous sampling.

Table A1. The ITU incidents analyzed (in sequence).

Case	Organization	IT resource	Duration	Date	Reputation Damage*	# of stories	Sources
1	Comair	Crew scheduling system	1 day	2004 Dec	CAT 5	9	CNN, Fox, USA Today, Westerman & Hunter (2007)
2	Virgin Blue Airlines	Check-in, reservation, boarding systems	21 hours	2010 Sep	CAT 5	14	Bloomberg, The Australian, The Register
3	American Airlines	Pilots' iPad App	12 days (sporadic)	2015 Apr	CAT 5	10	CNN, BBC, The Verge, Guardian
4	United Airlines	Router issue, airline's reservation system	90 minutes	2015 Jul	CAT 5	12	CNN, Washington Post, New York Times, USA Today
5	TransLink (Skytrain)	Communication circuit board	3 hours	Jul 17, 2014	CAT 5	14	Incidents' Audit report, Vancouver Sun, CBC, Globe&Mail, Translink website
6	TransLink (Skytrain)	Vehicle control centre (VCC) system	1 hour	Jul 21, 2014	CAT 5		
7	US Department of Health	Healthcare.gov (health care enrollment web site)	~2 months	2013 Oct	CAT 5	13	CNN, Fox, Washington Post, The Verge, Politico
8	British Columbia (BC) Government	Integrated case management (ICM) system	2 weeks	2014 May	CAT 5	12	CBC, Globe&Mail, Vancouver Sun, The Province, Huffington Post
9	UK Border Force	Self-service e-passport gates and staffed customs desks	1 day	2014 Apr	CAT 5	8	BBC, Guardian, News Week, Daily Mail, Huffington Post, Computer Weekly
10	US State Department	Passport database	3 days (plus 2 weeks at 50%)	2014 Aug	CAT 5	6	CNN, Fox, Washington Post
11	Royal Bank of Scotland (RBS)	Banking system	1 week	2012 Jun	CAT 5	6	BBC, Guardian, Financial Times, Bloomberg
12	Bank of America	Online banking	1 week	2011 Oct	CAT 5	7	CNN, ABC, Business Insider, Times
13	JPMorgan Chase	Database outage, online banking	3 days	2010 Sep	CAT 5	5	New York Times, Bloomberg

14	Development Bank of Singapore	Network outage, back-office services to ATMs	7 hours	2010 Jul	CAT 5	3	The Register, ZD Net, Information Week
15	Netflix	Amazon web service	close to 0 minutes	2014 Oct	CAT 0	3	Netflix, Gigacom, Tech Republic
16	Netflix	Online streaming	1 day	2012 Dec	CAT 5	6	CNN, CNET, Tech Crunch
17	University of X (UoX)	Learning management system (LMS)	1700 minutes	2013 Sep & Oct	CAT 1	3	Two interviews by the first author, local newspaper
18	BMW	Car-to-mobile app	1 week	2014 Jul	CAT 3	6	The Register, BMW website
19	BMW	Supply management system	3 months	2013 Jun-Sep	CAT 4	3	Bloomberg
20	Saudi Aramco	All computers hacked (but production lines)	5 months	2012 Aug	CAT 5	10	One interview by the first author, BBC, CNN, New York Times
21	BC Hydro	Customer communication website	2 days	2015 Aug	CAT 5	8	CBC, CTV, Global News, News 1130
22	Sutter Health	Electronic health record system	1 day	2013 Aug	CAT 5	4	Healthcare IT News, Spectrum IEEE, Biz Journal
23	Sony	Play Station online network hacked	25 days	2011 Apr	CAT 5	10	CNN, Wired, Bloomberg, PC World
24	Loblaw supermarket	Cash registers	10 hours	2016 May	CAT 5	5	CBC, Global News, CTV, Huffington Post
25	Amazon	Amazon e-commerce	20 minutes	2016 Mar	CAT 5	6	Reuters, Fox, CNBC
26	Target	Target website	1 day	2011 Sep	CAT 5	3	CNN, CBS, New York Times
27	UK's National Border Targeting Centre	A system checking passenger against watch lists of suspect individuals	~ 2 days	2015 Jun	CAT 4	4	Telegraph, i-hls.com
28	Delta	Ground operations software	3-4 hours	2016 Feb	CAT 5	3	CNBC, Reuters, Delta website

Note: * We leveraged the Google News search engine to find news articles covering ITU incidents. We use the popularity of the reporting website(s) (e.g., CNN, BBC) to evaluate client-base awareness of each incident. This popularity is measured using rankings provided by Amazon's Alexa service (i.e., alexa.com), which offers web traffic analytics. The maximum awareness of the reporting websites (e.g., global, multi-continental, national, provincial, or local) is compared to the client-base of the affected organization (e.g., global, multi-continental, national, provincial, or local) to arrive at a value from the following scale: CAT 1 (negligible), CAT 2 (marginal), CAT 3 (considerable), CAT 4 (significant), and CAT 5 (substantial) awareness. For example, UoX experienced CAT 1 reputation damage, i.e., a negligible client-base awareness: even though it has a global client-base (due to its large international student body), the ITU was covered only by a local newspaper.

Consistent with classic GT methodology, we began with *homogeneous sampling* by examining comparable ITU cases in the same industry (i.e., transportation). Focusing first on similar cases helped minimize errors, facilitated constant comparison, and made it easier to detect potential relationships among emerging categories. After collecting and subsequently analyzing data for Cases #1 through #6 (described next), we developed a basic substantive theory. At that point, we shifted to cases with characteristics different from those in the transportation industry.

We pursued *extreme sampling* to investigate particularly striking variations in outcomes. This aimed to increase the saliency of constructs and relationships in the initial substantive theory. This phase included organizations operating in highly competitive environments (e.g., large banks) as well as relatively unremarkable ITU incidents with fewer strategic consequences. This broader perspective revealed connections and gaps not apparent in the homogeneous sample.

After refining our categories and relationships using data from the extreme sampling, we proceeded to *heterogeneous sampling* to enhance the generalizability of the emergent theory. We included ITU incidents from a variety of industries. Adding these contrasting contexts enabled us to further confirm patterns and relationships, as well as discard categories that did not recur across multiple sectors.

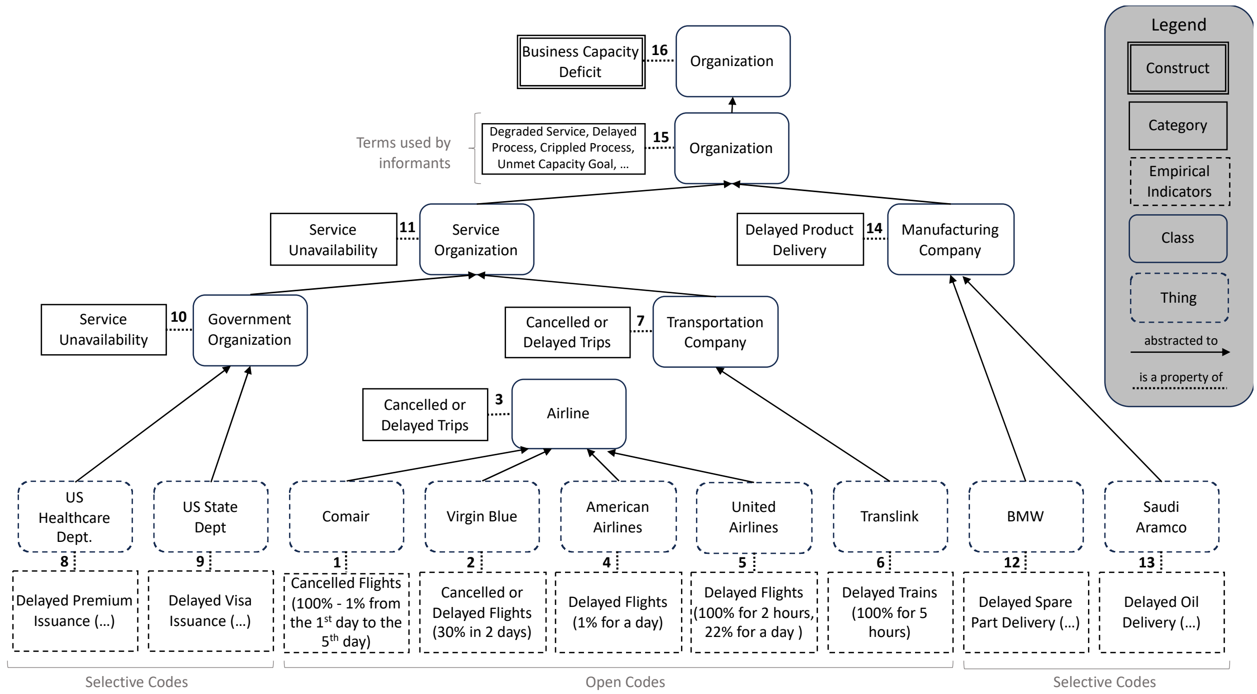
Data Analysis:

Open Coding: During *open coding*, we examined each source, usually a news story, press release, or organizational report, line by line, assigning labels wherever possible. A label includes an empirical indicator, such as an incident that happened to a thing, a property of a thing, an action taken by a thing, or an event related to a thing. Whenever possible, we used *in-vivo* codes (i.e., the exact words from the data); otherwise, we selected wording from similar data segments. We paid particular attention to specifying the relevant “thing” or “class-of-thing” and associated empirical indicators (e.g., Flight-Delay, Passenger-Delay) to avoid ambiguity.

Following Glaser (1978, 2007), we began by analyzing our first ITU incident (e.g., Comair). We openly coded two stories on this case, assigning one or more labels to each passage. To compile a complete, accurate list of all empirical indicators (e.g., incidents, actions, events) for each case, we employed *data triangulation* by collecting additional stories about the Comair ITU incident. When coding redundant sources on the same incident for reliability, we focused on new or contradictory information instead of recoding every line. This assertive choice helped produce a complete, accurate set of empirical indicators, thereby enhancing the reproducibility of categories generated during constant comparison. We repeated this process for Cases #1 through #6. By the end of the analysis of those six cases, we had 406 open codes.

Theoretical Memoing: In line with classic GT methodology, we engaged in *theoretical memoing* during the research process. In these memos, we documented relationships between empirical indicators (e.g., events, actions), between empirical indicators and categories, and among categories themselves. Those memos captured conceptual insights, emerging ideas, and categories. They became central to integrating categories during constant comparison, ensuring that the evolving theory is firmly grounded in our analytical process.

Constant Comparison & Theoretical Coding: At every step, we used *constant comparison* to revisit and compare newly identified incidents, categories, and relationships with previously coded material. We documented new insights in a *memo bank*, which included informal notes, *hierarchical diagrams* of categories, *lists of synonyms* for things and classes (in the form of a *thesaurus*), and *process models* illustrating causal or temporal sequences. Keeping these memos organized allowed us to detect emerging themes, explore potential rival explanations, and systematically resolve inconsistencies in the data.



Note: Numbers show the sequence of the process of the creation of substantive codes

Figure A1- A hierarchical diagram that visualizes the development of Business Capacity Deficit

To reduce mistakes and biases in generalizing empirical indicators to constructs, we used *hierarchical diagrams* (Miles et al., 2013). Figure A1 illustrates how the construct Business Capacity Deficit is derived from empirical indicators. By carefully generalizing specific *things* to appropriate *classes*, we ultimately arrive at a construct, consistent with the positivist ontology (Weber 2012), that represents a property of a *class of things*.

Because different sources may refer to the same thing (or class of things) with different names, the number of open codes can grow and hinder the formation of a precise and accurate model. To manage unique things and classes of things, we created a *thesaurus*. For instance, "passenger," "traveler," and "customer" all refer to the same class of things. Failing to recognize their equivalence would complicate generalization and increase errors. We recorded relevant terms in the thesaurus to track synonyms for both things and class-of-things. Whenever a potential new term (e.g., "guest") appeared, we compared it to existing thesaurus entries. If it was determined to be truly distinct, it was added as a new term in open coding. Otherwise, it was documented as a synonym, and the previously established term (e.g., passenger) was used during coding.

To reduce mistakes and biases in developing relationships, we employed process models and a cross-case analysis matrix. Process models are visual presentations of causal or temporal relationships among empirical indicators and can be created at any point during coding. An example of relationships from ITU to missing information capability to degraded business capability is shown in Figure A2.

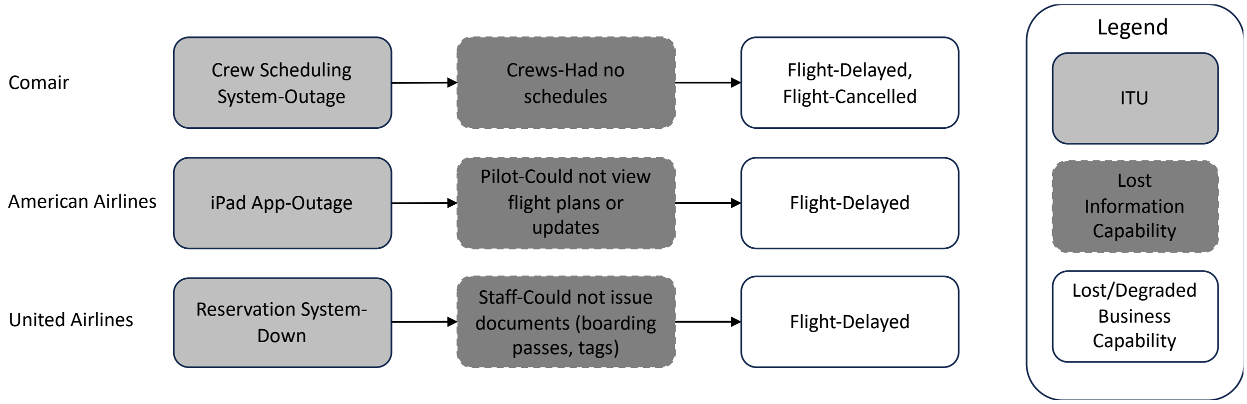


Figure A2- Process models that suggest the relationships between categories

Also, to help identify any missing constructs and empirical indicators, we used a cross-case analysis matrix.

Table A2- Partial cross-case analysis matrix

Case	IT Outage Duration	Duration to Resume Normal Operation	Impacted Clients	Media Coverage	…
Comair	1 Day	4 days	150,000	CNN	…
Virgin Blue	21 hours	2 days	50,000	Blomberg	…
United Airline	1.5 hours	2 days	400,000	CNN	…
…	…	…	…	…	…
…	…	…	…	…	…

Theoretical coding is the process of generalizing empirical indicators from open and selective codes to gradually develop relationships among constructs. Theoretical codes (TCs) emerge during constant comparison and are later consolidated through the process of memo sorting.

In keeping with classic GT, we considered all possible TCs. However, we specifically drew on the 6C family (i.e., causes, contexts, contingencies, consequences, covariances, and conditions) to build our theory. The other TCs were used to assess the emerging theory's explanatory power and completeness. Along with the process models of cases, we focused on causal and temporal terms in substantive coding. Conjunctions (e.g., "after," "before," "when," "since," and "because") or causal-indicative verbs or phrases (e.g., "forced," "prevented from," "consequences like," "this resulted in," "increased," "disrupted," and "postponed") provided valuable clues for identifying accurate TCs.

It is important to note that simply having empirical indicators in a sentence is neither necessary nor sufficient for a theoretical code to be included in the emerging theory. For example, consider the following passage: "All the rescheduling necessitated by the bad weather forced the system to crash. As a result, Comair had to cancel all 1,100 of its flights on Christmas Day." This appears to suggest TCs: "Weather-Bad → Comair-ReschedulingAmount → System-Crashed → Flights-Canceled". However, these TCs should not be taken as definitive relationships between constructs because additional empirical indicators may be missing. Through continued coding, we discovered additional empirical indicators, which led to a more accurate sequence as follows: "Weather-Bad → JetTires-Frozen → Flights-Canceled → Comair-ReschedulingAmount → System-Crash → Schedule-NotAvailable → Airline-CannotAssembleCrewsOnFlight → Flights-Canceled". Thus, continuously reviewing potential TCs during constant comparison and memo sorting is vital. Examples of different types of coding from stories are provided in Table A3.

Table A3. Example of data coding

Quotes from data	Open coding (Empirical indicators)	Selective coding (Constructs)	Theoretical coding (Relationships)
"A severe winter storm hit the Ohio Valley. The snow came with sleet and freezing rain." (CIO.com) Comair "ran	• Airline-deicer fluid level *[thing-its property]* • Airline-deicing planes *[thing-action]*	Moving a plane is a complementary capacity. Not being able to move planes at the	The initial relationship, "Freezing weather → plane-froze to ground → canceled flights", was later

critically low on deicer fluid." (Foxnews.com) "De-icing the jets took much longer than expected and some jets' tires froze to the ground." (CIO.com)	• Plane-froze to ground *[thing-event]* • Freezing weather *[a thing]*	level demanded resulted in complementary capacity deficit.	refined into "natural disaster → complementary capacity deficit → business capacity deficit"
Therefore, "Comair canceled most of its Thursday flights" (Foxnews.com) "From Dec. 22 through the 24th, Comair had to cancel or delay 91 percent of its flights." (CIO.com)	• Airline-canceled flights • Airline-percentage of canceled/delayed Flight *[thing-its property]* • Airline-duration of canceled/delayed flights *[thing-its property]*	Offering a flight is a business capability. Not being able to offer flights at the level demanded results in business capacity deficit.	
Comair tried to place passengers on Delta flights and others (CNN.com), but most "airlines were fully booked for the holiday travel season, and there were few alternative flights" (Westerman & Hunter 2007).	• Other airlines-available seats *[thing-its property]* • Airline-place passengers on flights of other airlines *[thing-action]* • Airline-number of passengers *[thing-its property]* • Holiday travel season *[thing]*	Taking a flight is a demand for business capability. An increase in demand for flights means increase in demanded business capacity.	The initial relationship, "Holiday travel season (-)→ other airlines-available seats (-)→ demand for flights", was later refined into "special seasons (-)→ external surplus capacity (-) → demanded business capacity"

Memo Sorting & Explanatory Validation: Our final step involved *memo sorting* and *explanatory validation*. This was a systematic attempt to ensure that the consolidated theory adequately accounted for each event, sequence of reactions, and strategic outcome in all 28 ITU cases. In cases where the theory fell short, failing to clarify certain organizational reactions or timelines, we iteratively refined existing categories or introduced new ones. While we verified the emerging intermediate theory, which took the form of a linear causal chain, some details recorded in our memo bank remained insufficiently explained. Consequently, we conducted an additional literature search and identified system dynamics (SD) as a suitable lens to re-examine the data. This process resulted in a theory that clearly explained differing outcomes across multiple industries and contexts. The result is a grounded framework illustrating how IT unavailability events can escalate into significant strategic repercussions, as well as conditions under which these repercussions are amplified or minimized.

Overall, our qualitative theory-building approach, drawing on GTM, involved specific methodological choices aimed at producing a theory that is reliable, accurate, reproducible, and generalizable. Table A4 illustrates how these objectives were achieved.

Table A4. Characteristics of our research methodology

Characteristic	Summary of our Approach
Outcome	A theory with measurable constructs and associated relationships in which a construct either positively or negatively influences another construct
Reproducibility	- Using in-vivo codes, if possible, or descriptive code and avoiding analytical codes in open coding - Using codes which include thing or classes of things along with the knowledge point which is an action, an attribute or anything related to a thing or a class of thing. o For example, Passenger-DelayedArrival is in the form of thing-knowledge point. - Generalizing things into their suitable classes in constant comparison. o For example, Comair-DelayedFlights and United-DelayedFlights are generalized Airline-Delayed Flight (Class-Knowledge Point). When observing Translink-DelayedTrains, Airline-DelayedFlight and Translink-DelayedTrains are generalized to Transportation Company-DelayedTrips. - Knowledge points can be move up to higher-level of class of things from a lower class or thing. o For example, Knowledge point (CannotNavigatePlane) can move up from Pilot (Pilot-CannotNavigatePlane) to Airline (Airline-CannotNavigatePlanes). - Knowledge points can be generalized by combining related knowledge points. o For example, Airline-CannotNavigatePlanes and Translink-CannotControlAndMoveTrains can be aggregated to create a new category: TransportationCompany-CannotNavigateVehicle. - Avoiding generalization of identical knowledge point if things are different. o For example, Flight-DelayedArrival and Passenger-DelayedArrival as things are different although knowledge points are the same. - Creating a new category from empirical indicators which are related to the same set of categories. o For example, a new category called Information Capability is created as ITU is linked to Losing Carrying Capability through losing a particular capability after observing these empirical indicators: ITU → Losing Ability to Ascertain Route Safety → Losing Carrying Capability; ITU → Losing Ability to Check Passenger against No-Fly List → Losing Carrying Capability; ITU → Losing Ability to Issue Documents → Losing Carrying Capability; ITU → Losing Ability to Manage Schedule for Crew→ Losing Carrying Capability; ITU → Losing Ability to Access Navigation Plan → Losing Carrying Capability; ITU → Losing Ability to Communicate with Control Centre → Losing Carrying Capability; - Using thesaurus of things and class of things to keep the list of terms manageable. - Developing a cross-case comparison matrix to record knowledge points across cases. An entry of a new knowledge point recorded from a case would trigger reassessment of other cases. - Being cognizant to causal terms and distinguish them from temporal terms in theoretical coding. o For example, initially we have "Weather-Bad → Comair-ReschedulingAmount → System-Crashed → Flights-Canceled" as relationship between constructs. When we further do intra-story comparisons and consider causal and temporal terms used, we identified important intermediate events: "Weather-Bad → JetTires-Frozen → Flights-Canceled → Comair-ReschedulingAmount → System-Crash → Schedule-NotAvailable → Airline-CannotAssembleCrewsOnFlight → Flights-Canceled"
Generalizability	The theory explains various cases of ITU incidents with varying consequences
Accuracy	The theory is accurate since it fits the observations in all analyzed cases and explains events and reactions in various cases - Story triangulation enables us to accurately capture all events in the case - Extreme sampling increases saliency of constructs and relations - Constant comparison and saturation remove irrelevant concepts and hone in the relevant constructs - Identifying 6C family of Theoretical Code (TC) and use them to build the theory. Using other TC's to verify explanatory power and completeness of the emerging theory. o For example, an intermediate theory that we had was → Losing Information Capability → Losing Business Capability → Client Value Lost → Strategic Impact. We had some TC's which were not observed commonly. The intermediate theory could explain organization's use of legacy system as it reduced ITU or a software bug as it caused ITU. However, the intermediate theory could not explain how organization's action of queuing services or

	Christmas time affected the dynamics of ITU. This is one of the reasons why we explore literature a theoretical lens to explain observations which the intermediate theory could not explain.
Reliability	- Story triangulation enables capturing a complete list of empirical indicators - Keeping only concepts, events and relationships which are observed in multiple cases

Online Supplement B: Model Development

B1. Stock and Flow Diagram of a Resource or Capability

The way an organization provides a resource or capability demanded by clients, users, or customers can be represented using a stock and flow diagram depicted in Figure B1.

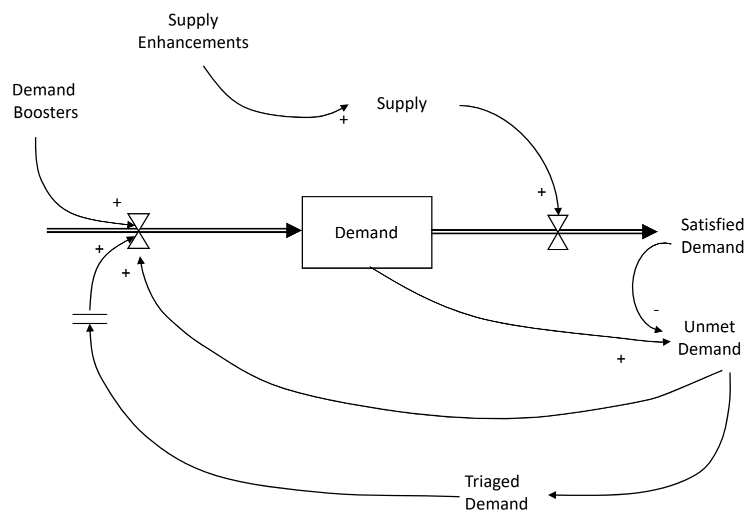


Figure B1. Stock and flow diagram of a resource or capability

B2. Developing a Complete Stock and Flow Diagram for ITU

This section explains the stock and flow diagram developed to understand the dynamics of IT unavailability (ITU) incidents and their impact on service delivery and strategic outcomes.

Before describing the variables in our stock and flow diagram, it is important to clarify the terminology we used. Let's use two contexts that many people can easily relate to:

- In a grocery store, checkout service is a business capability. Retrieving prices and updating inventory information is an information capability. A Point of Sale (POS) system that works in conjunction with a Product Information Management (PIM) system and an Inventory Management System (IMS) constitutes the IT resource. These systems provide IT capabilities in the form of read, write, and delete operations in their databases. Each capability has a specific capacity (i.e., level of performance). PIM systems can perform 1000 concurrent I/O operations (i.e., the IT capacity of PIM is 1000 concurrent I/O operations). Similarly, the information capability of price retrieval might have a capacity of 100 requests per minute. Consequently, the store can accommodate a capacity of 20 customer checkouts per minute, which is the business capacity for checkout capability.

- In the airline business, providing a flight service is a business capability. Depending on the size of the airline, a large airline can fly 100 planes simultaneously (100 flights at a given time are business capacity). Initializing the flight management system in the plane is an information capability, often done by the pilot who enters the flight plan, including route waypoints, altitudes, speeds, and other relevant information. Suppose 50 planes are being prepared to fly; the information capacity is 50 flight management system initializations. The flight information is provided via an Electronic Flight Bag (EFB), often a tablet. In recent years, many airlines, including American Airlines, Delta Airlines, United Airlines, and Southwest Airlines have developed their EFB apps, which pilots use on their devices. An EFB app is an IT resource with an IT capacity of 100 concurrent accesses.

ITU incidents occur when an IT resource becomes partially or completely unavailable, leading to disruptions in service delivery to customers. Figure 3 captures the flow from IT resources to information capability and then to business capability, ultimately affecting customer satisfaction and strategic outcomes.

IT capacity represents the level of the IT resource in question. Demanded IT Capacity is the level of the IT resource required to support information capacity. Satisfied IT Capacity is the need for the IT resource that is fulfilled. Unmet IT Capacity is the deficit that occurs when demanded IT capacity exceeds available IT capacity.

Information Capacity represents the level of the Information Capability in question. Demanded Information Capacity is the level of information capacity required to support business capabilities. Satisfied Information Capacity Demanded is the need for information capacity that is fulfilled. Unmet Information Capacity is the deficit that occurs when demanded information capacity exceeds available information capacity.

Business Capacity represents the level of Business Capabilities in question. Demanded Business Capacity is the level of business capacity required to meet clients' service demands. Satisfied Business Capacity is demand for the business capacity that is fulfilled. Unmet Business Capacity is the deficit that occurs when demanded business capacity exceeds available business capacity.

Available Service Capacity is the level of service in question. Clients represent the number of clients demanding services. Clients Served is the number of clients whose service demands are met. Clients Not Served is the number of clients whose demands are not met, leading to potential client loss or dissatisfaction.

In a stable situation depicted in Figure B2, the clients' demands for business capacity will be furnished. Demanded Business Capacity requires Information Capacity, and Demanded Information Capacity requires IT Capacity. Since the available IT capacity is sufficient in the normal operation of a business, all Demanded IT Capacity is satisfied. That would imply that there will be sufficient Information Capacity to meet all Demanded Information Capacity. Subsequently, this results in sufficient availability in Business Capacity to satisfy the Demanded Business Capacity, in turn, resulting in sufficient service capacity to meet the service demands of the clients. In the resource-capability chain from IT resource to business capability, if the available capacity at each stage meets or exceeds the demanded capacity, all demands are satisfied, resulting in no unmet capacity, no client dissatisfaction, or no reputation impact.

However, when the demanded capacity exceeds the available capacity at any stage, unmet capacity arises. The unmet capacity, if it is not fully diverted to an external entity or deprioritized, is added to the demanded capacity to be served in the next period.

In our data analysis, we recognized that there are three feedback loops that can be activated when there is unmet capacity.

Business Inertia is likely to be amplified when unmet business capacity results in a deficit in complementary business capacity, which, in turn, results in more unmet business capacity. Figure B3 highlights *business inertia* in gold.

Information Inertia is likely to be activated when unmet business capacity continues to be demanded in the subsequent period, leading to an increase in demanded information capacity. This increase can result in unmet information capacity if there is little or no slack in information capacity. Figure B3 highlights the *information inertia* in blue.

IT inertia is likely to be activated when unmet information capacity continues to be demanded in the subsequent period, leading to an increase in demanded IT capacity. This increased demanded IT capacity can result in unmet IT capacity if there is little or no slack in IT capacity. Figure B3 highlights the *IT inertia* in red.

The stock and flow diagram provides a comprehensive view of the interdependencies between IT resources, information capabilities, business capabilities, and client experience. In the next section, we will explain how we derived a more parsimonious model (i.e., the one presented in Figure 4 in the main text).

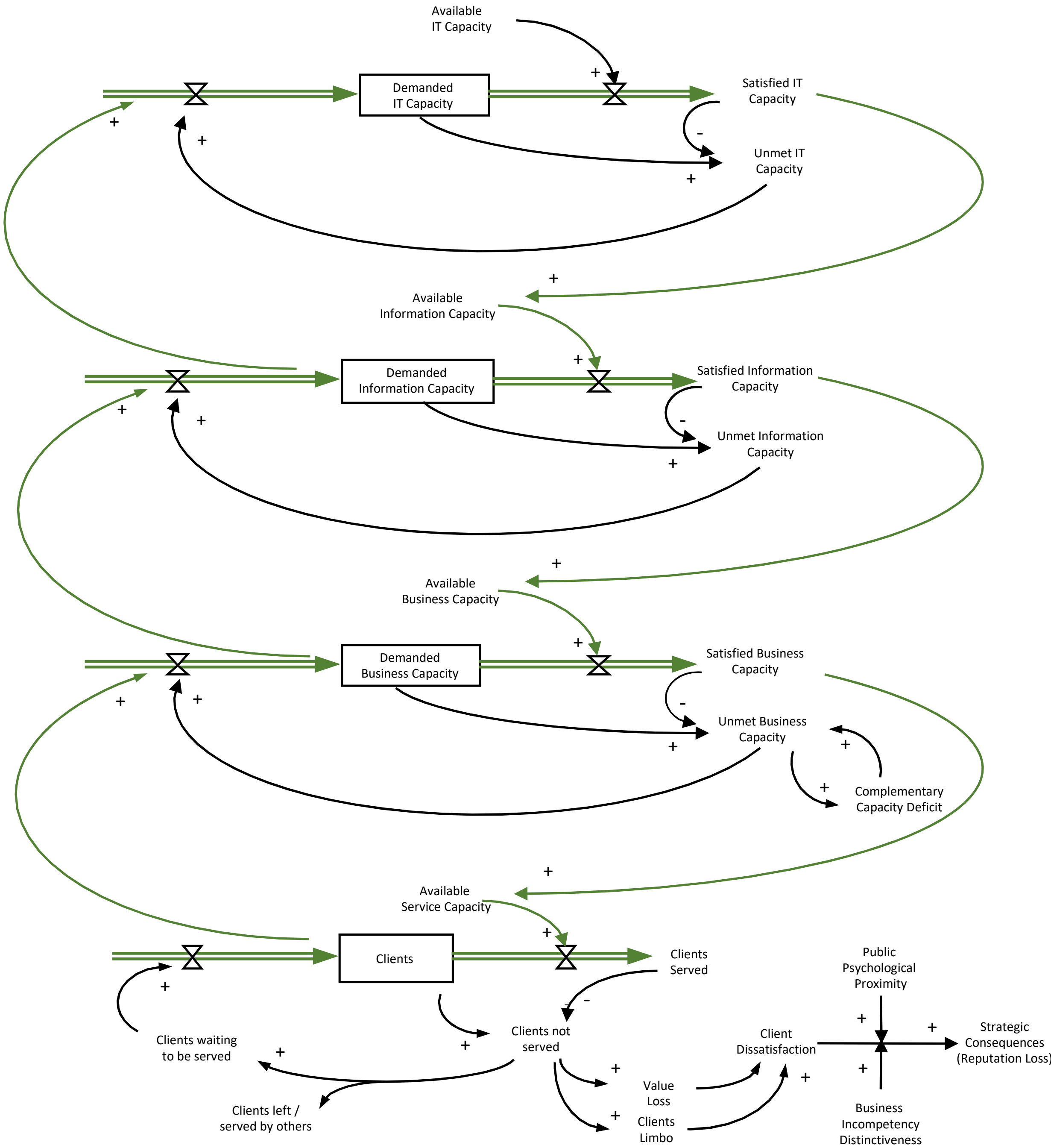


Figure B2. The normal flow (represented in green) when there is no unmet demand

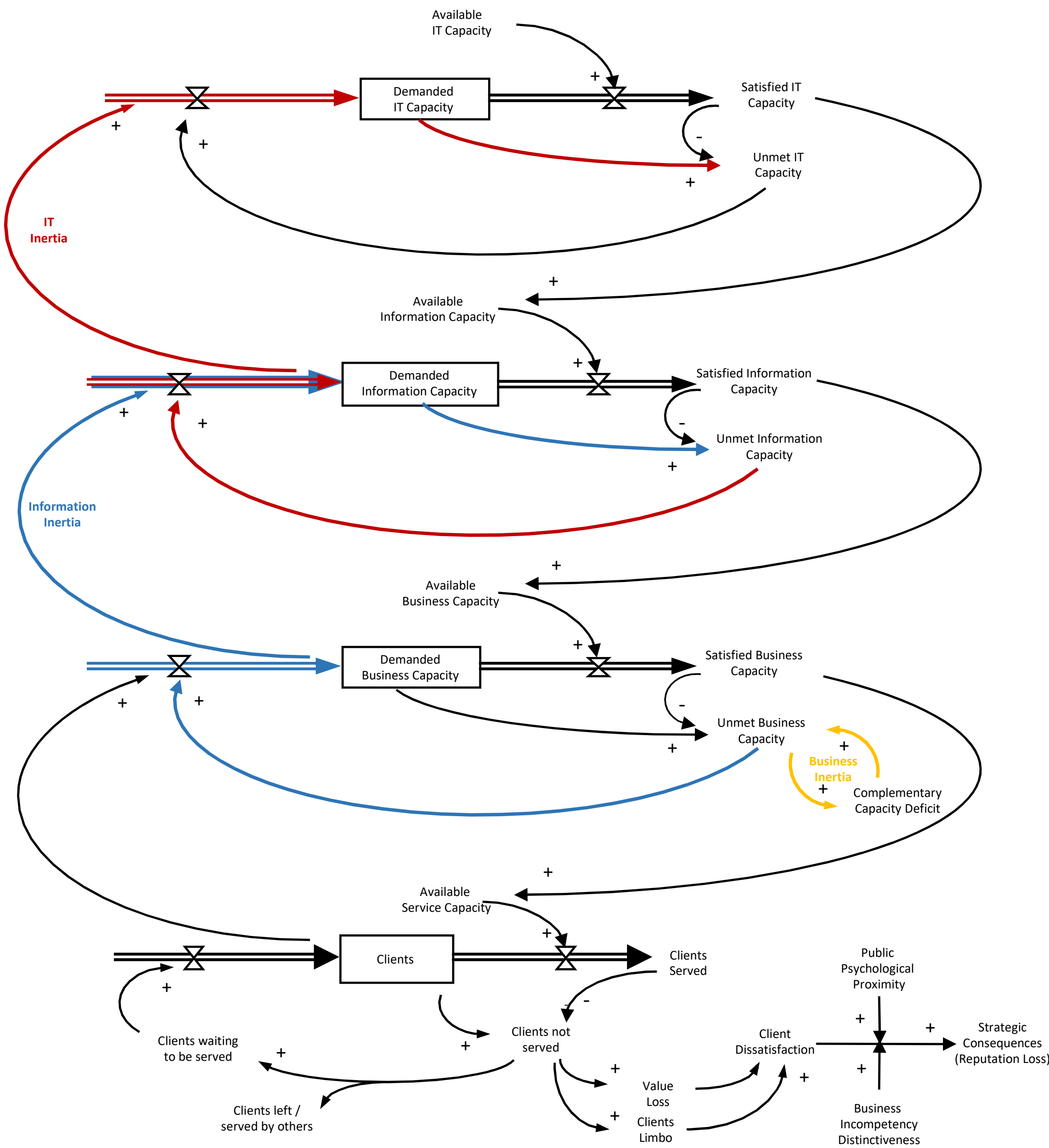


Figure B3. Business, Information, and IT Inertias (represented in orange, blue, and red, respectively)

B3. Converging to a Parsimonious Model

In our stock and flow diagram (Figure 3 in the main text), IT Capacity, Information Capacity, Business Capacity, and Clients are stock variables. In stock and flow diagrams, variables that are neither stocks nor flows are called auxiliary variables. These variables can influence, or be influenced by, stocks, flows, or other auxiliary variables. Available IT, Information, Business, and Service Capacities are auxiliary variables that determine the flow of the corresponding demand. Satisfied IT Capacity, Satisfied Information Capacity, Satisfied Business Capacity, and Clients Served are auxiliary variables that can be determined by the stock and flow variables at their corresponding levels. Similarly, Unmet IT Capacity, Unmet Information Capacity, Unmet Business Capacity and Clients not served are auxiliary variables that are determined by the demanded capacity and available capacity. The other variables in our stock and flow diagram are also auxiliary variables that interact with other components of the diagram.

While our stock and flow diagram effectively illustrates dynamic interactions among stocks, flows, and auxiliary variables, it is complex and not easily understood. To balance informativeness and parsimony, we iteratively created different levels of abstraction of our stock and flow diagram and finalized the one presented in Figure 3. We verified that the final model satisfactorily explains the dynamics observed in our data.

Several observations guided us in refining the final model with regard to each capacity variable in our stock and flow diagram (i.e., IT, Information, and Business).

1) Satisfied Capacity is the minimum of Available Capacity and Demanded Capacity. For example, Satisfied Information Capacity is the minimum of Available Information Capacity and Demanded Information Capacity. This means that if Demanded Information Capacity is greater than Available Information Capacity, Satisfied Information Capacity is equal to Available Information Capacity, which results in Unmet Information Capacity. However, if Demanded Information Capacity is less than or equal

to Available Information Capacity, Satisfied Information Capacity equals Demanded Information Capacity, leading to slack in Information Capacity.

2) Unmet capacity is the maximum of zero and Demanded Capacity minus Available Capacity. For example, if Demanded Business Capacity is greater than Available Business Capacity, there will be an unmet business capacity, which will be equal to Demanded Business Capacity minus Available Business Capacity; otherwise, there will be no unmet Business Capacity.

3) The satisfied capacity at a higher level in our stock and flow diagram influences the available capacity at the immediate next lower level. For example, Satisfied IT Capacity influences Available Information Capacity.

4) The demanded capacity at a lower level in our stock and flow diagram influences the demanded capacity at the immediate next higher level. For example, Demanded Business Capacity increases demand for information capacity (i.e., Demanded Information Capacity).

5) When Unmet capacity is sustained as ongoing demand at a lower level, it creates additional demand (i.e., an increase in demanded capacity) at the next higher level.

Given these observations, after various abstraction iterations, we concluded that the model presented in Figure 4 (in the main text) accurately captures the dynamics in the stock and flow diagram without violating these observations.

Online Supplement C: Inertial Loops

This online supplement presents a detailed discussion on inertial feedback loops in three ITU incidents from our dataset. In each case, we discuss the factors that positively or negatively reinforce these inertial loops.

C1. The BC Hydro ITU Incident

Table C1. Feedback loops in BC Hydro ITU case

BC Hydro During the 2015 windstorm in Vancouver, BC Hydro faced significant challenges due to the extensive damage caused by high winds. Over 710,000 customers lost power, making it the largest outage event in BC Hydro's history.	
Inertia / Reinforcement	Explanations / Quotations
Business Inertia	Complementary business capabilities are strained to support the recovery. “…over the course of three days, crews replaced approximately 200 power poles and 500 broken cross-arms on pole-tops, fixed 25 damaged transmission circuits, and replaced 10000 metres of wire and more than 1200 pieces of electrical equipment”
+	Not enough BC Hydro and contract crew as not enough heavy equipment
+	Delay due to safety for crew and heavy equipment “…saturated soil in certain areas has made it unsafe for crews to bring in heavy equipment for repairs.”
-	Call out all staff and getting help from other provinces “Additional crews were brought in to support restoration efforts from Prince George, Kamloops, …, and Vernon”
Information Inertia	The power restoration delay triggered the need for more outage reporting and status information
+	700,000 affected customers’ needs for outage reporting and recovery status information “…710,000 customers in the Lower Mainland and parts of Vancouver Island lost power”
+	Social media platforms were not effectively utilized in a timely manner “Hundreds of Facebook comments went unanswered … the response on Twitter was similarly disappointing”
IT Inertia	the failure of the website was followed by strained capacity to meet the surge in information requests “in the largest storm this decade, it was the website itself that went dark”
+	Many requests from customers who were not able to report and receive updates “…making it near impossible for anyone to find information about their power outage”
-	Some functionalities of the website were temporarily disabled to prioritize outage report and updates. “We did temporarily disable some of the functionalities of our website just so that we could ensure that our customers are going to continue to get the power outage information that they were looking for”

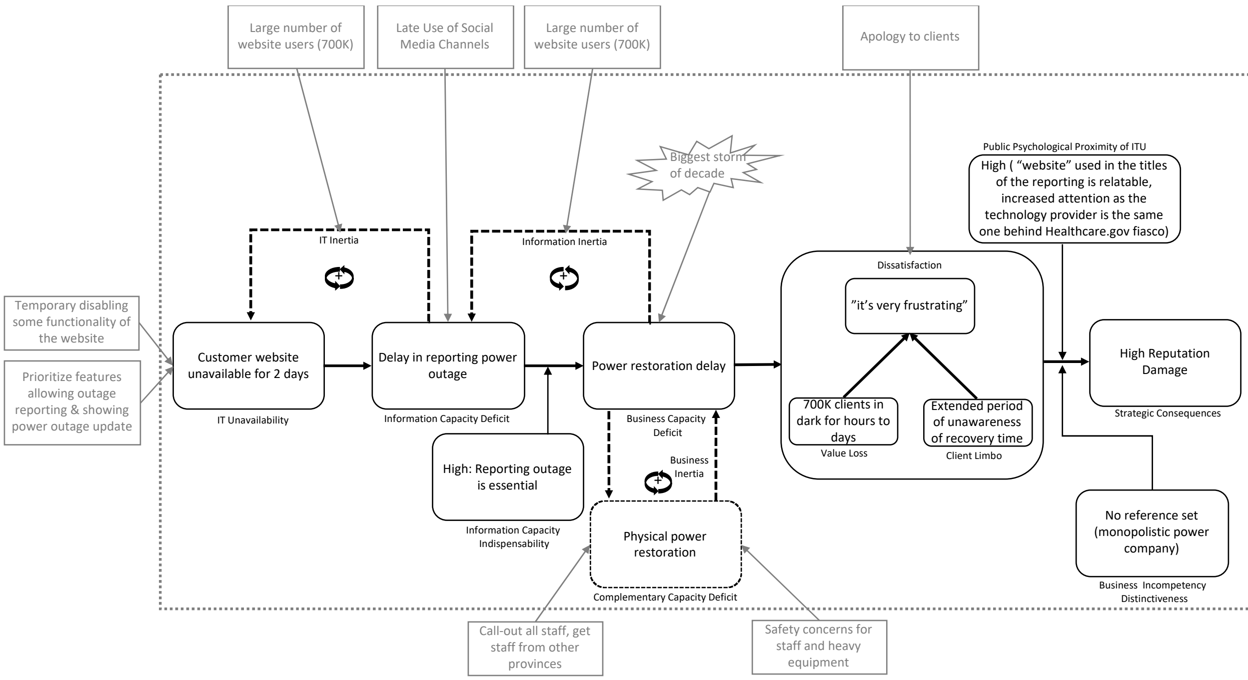


Figure C1. Illustration of BC Hydro Case

C2. The United Airlines ITU Incident

Table C2. Feedback loops in United Airlines Case

United Airlines On July 8, 2015, United Airlines experienced a network connectivity issue due to a router malfunction, leading to a temporary ground stop for all flights. The problem affected around 4,900 flights, causing widespread delays and disruptions. The ground stop lasted for about 90 minutes before operations began to return to normal, but delays continued throughout the day as the airline recovered from the incident.	
Inertia / Reinforcement	Explanations / Quotations
Business Inertia	4,900 delayed or canceled flights hamper ground crew's ability to provide Complementary business capabilities to get the plane ready to fly
+	Lost Gates "even flights that were able to land as planned would be delayed because there was no gate available to unload passengers"
+	crews ran out of hours that they can work due to aviation regulations "..the crews may have run out of hours."
+	Difficult to reassemble dispersed passengers
+	Call out new crew "…also have to deal with rearranging their crews, perhaps may run out of hours."
Information Inertia	Those passengers waiting need to check-in, require boarding passes, luggage tags.
+	Many travellers are affected in 4,900 flights
+	Backup failed "Because of the safeguards and the backups built into the reservation system, once that goes down, everything has to stop"

-	Reducing number of passengers waiting "United also waived change fees for affected customers. Additionally, customers scheduled to travel Wednesday were being permitted to change their plans without penalty."
IT Inertia	Not activated

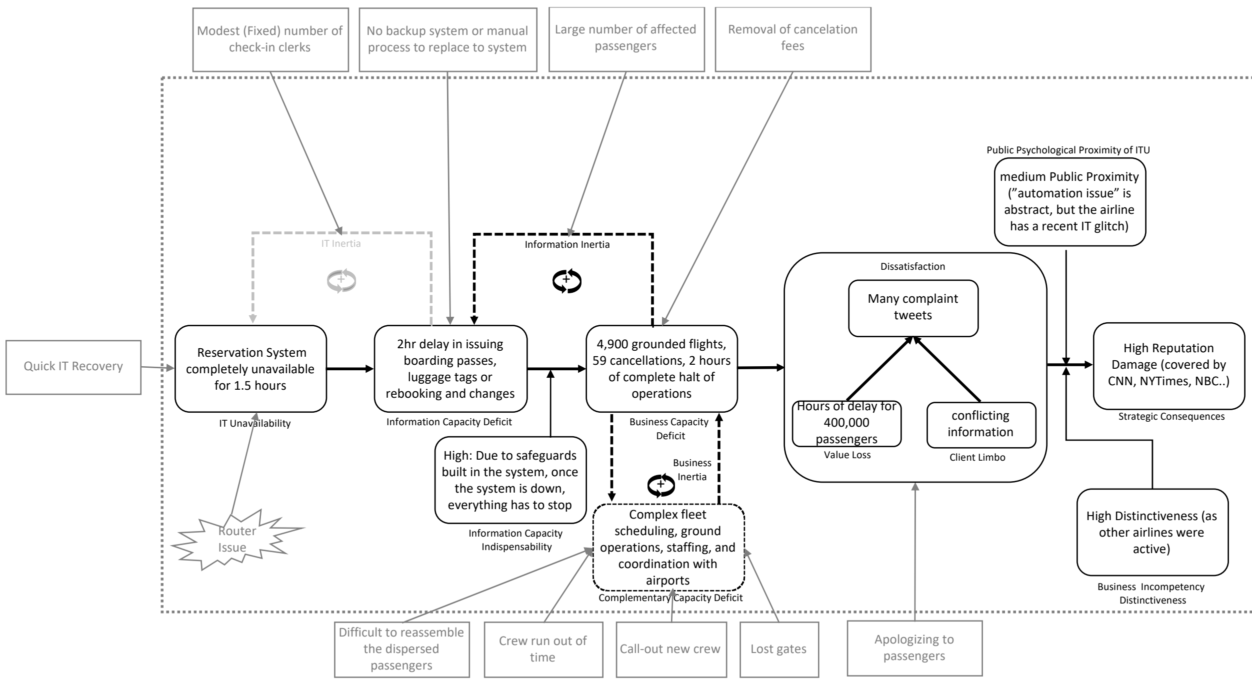


Figure C2. Illustration of United Airlines Case

C3. The Healthcare.gov ITU Incident

Table C3. Feedback loops in Healthcare.gov ITU case

Healthcare.gov The launch of HealthCare.gov in October 2013 was fraught with issues, leading to a significant failure as the site crashed almost immediately due to high traffic and various technical glitches. It took more than a month to stabilize the site completely. The enrolment deadline was extended multiple times.	
Inertia / Reinforcement	Explanations / Quotations
Business Inertia	Not activated as this is a completely digital business capability.
Information Inertia	Initial failures and repeated system glitches have made the individuals to attempt to request enrollment
+	Many required to enrol "The site got millions of visits and thousands of applications in the first 24 hours but only six people were able to enroll in plans"
-	Deadline extended "Heavily bug-ridden registration and enrolment process have now forced the government to postpone a February 15 deadline for purchasing coverage allowing an extra six weeks before fines are levied on those without insurance"
IT Inertia	The reinforcing causal link between poor IT capacity and its inability to meet sudden demand spikes exacerbated the situation

+	Invitation to visit “Obama compared the site to Amazon.com – an irresponsible comparison even if things were going well – and invited all comers to take a look. ('You don't have to take my word for it.')”
+	Just visitors “Healthcare.gov was inundated by many more people than anticipated which overwhelmed systems including ours.”
-	Capacity enhancement “Upgrades trouble-shooting and old pizza... Healthcare.gov can now handle 50000 concurrent users and 800000 consumer visits a day”
-	Queuing feature “If more than 50000 people attempt to use the site at any one time the site now has a queuing feature that will e-mail users with tips about when to return to the site at a less congested time and a link that will take them to the front of the line.”

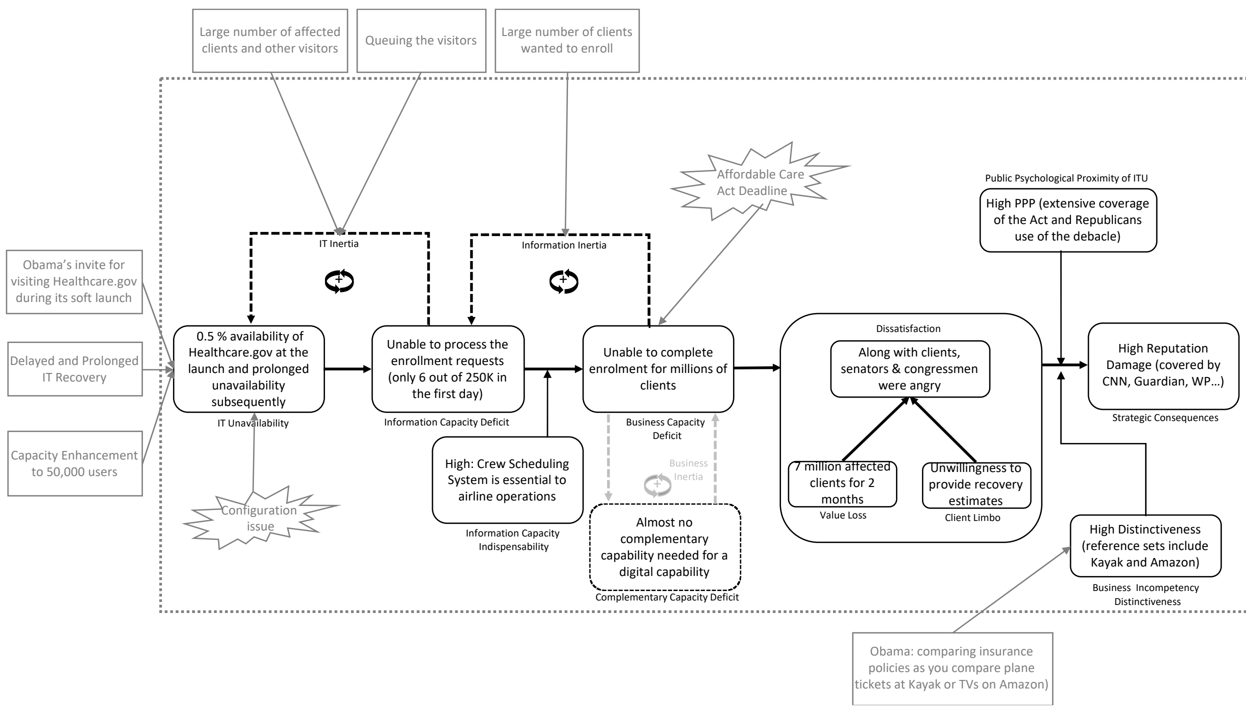


Figure C3. Illustration of Healthcare.gov Case

Online Supplement D: Illustration of the Theory

Since we use a GTM-based theory-building approach in which we constantly compare the evolving theory and data, the resulting theory should, by definition, fit the data. Section D1 presents an application of the theory using an ITU that occurred in December 2004 involving the airline Comair (i.e., case #1 in Table A1).

A natural question to ask is how the theory can be applied to an ITU incident that was not part of the original 28 used to develop it. To explore this, we applied our theory to an ITU incident that occurred on July 8, 2022, at Rogers Communications. Applying our model to a previously unseen ITU case demonstrates its applicability to other incidents beyond the original dataset. The illustration is provided in Section D2.

D1. The Comair ITU incident

Figure D1 illustrates how our theory can be applied to the Comair ITU incident.

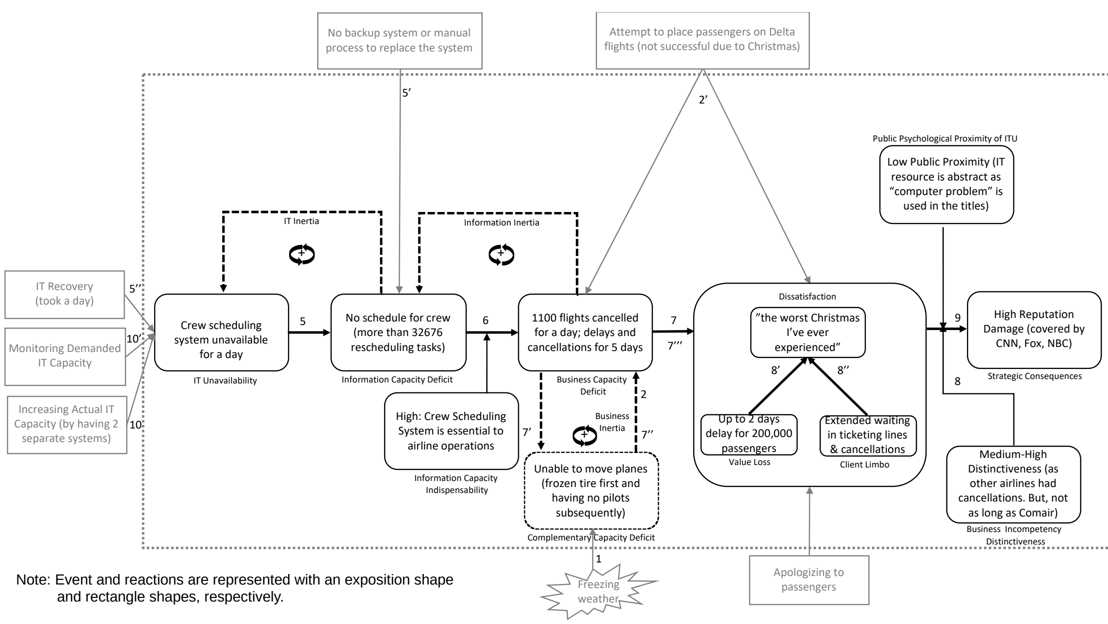


Figure D1. The illustrative narrative of the case of Comair using our developed theory

Below are actual quotes derived from the data to complement the illustration shown in Figure D1.

Table D1. The narration of the Comair case

Step	Case Details
1 2	"A severe winter storm hit the Ohio Valley. The snow came with sleet and freezing rain." (CIO, 2005) Comair "ran critically low on de-icer fluid." (Fox News, 2004) "De-icing the jets took much longer than expected and some jets' tires froze to the ground." (CIO.com, 2005) Therefore, "Comair canceled most of its Thursday flights" (Fox News, 2004) "From Dec. 22 through the 24th, Comair had to cancel or delay 91 percent of its flights." (CIO, 2005)
2'	Comair tried to place passengers on Delta flights and others (CNN, 2004), but most "airlines were fully booked for the holiday travel season, and there were few alternative flights" (Westerman & Hunter, 2007). [Therefore, Demanded Business Capacity could not be lowered]
3	"bad weather forced Comair to cancel or reschedule many flights" (Westerman & Hunter, 2007)
4	"As it turned out, the crew management application, unbeknownst to anyone at Comair, could process only a set number of changes—32,000 per month—before shutting down. And that's exactly what happened." (CIO, 2005) "At about 10 p.m. on Christmas Eve [Fri, Dec 24], when Comair entered one more flight change, exceeding the monthly capacity, the system abruptly stopped functioning." (Westerman & Hunter, 2007) [a slight increase in demand for crew scheduling system, but that was enough to shut down the system due to the hidden bug]
5 5'	"When the software went down, there was no backup system that could be pressed into immediate service, no outsourcer on call and ready to step in, no plan that could keep the company running manually while the system was fixed." (Westerman & Hunter, 2007) There was no other way to do the crew rescheduling. [Therefore, Demanded Information Capacity could not be lowered to reduce Information Capacity Deficit]
5''	"The tech team … relaunched the system late on December 25 [in 1 day]" (Westerman & Hunter, 2007)
6	"You can't operate an airline without a crew scheduling system" (Comair spokesperson Nick Miller). (Information Week, 2004) "Comair had to cancel all 1,100 of its flights on Christmas Day" (CIO, 2005)
7	"nearly two hundred thousand stranded Comair passengers helplessly roamed airport terminals throughout the United States" (all 119 cities that were served by Comair) (Westerman & Hunter, 2007)
7' 7''	"but by then Comair had problems assembling its widely dispersed crews and aircraft where they were needed. The airline didn't resume normal operations until December 29 [4 days later]." (Westerman & Hunter, 2007) "You can't just switch things on and get an airline running again…There's a lot of inertia and momentum lost when you shut down, and it's hard to get started again." (CIO, 2005) "Comair officials said about 75% of flights were running Tuesday [, Dec 28,] and it expected to resume its full schedule Wednesday" (USA Today, 2004). "It took Comair until [Wed,] Dec. 29 to return to operating a full daily flight schedule." (NBC, 2005) "Fewer than a dozen delayed or canceled Comair flights were listed on monitors at one point Tuesday, [Dec 30] at the Cincinnati/Northern Kentucky International Airport." (USA Today, 2004)
7'''	A family "spent five hours standing in a ticket line Thursday, only to find out their flight was canceled. Their flight was canceled again Friday, and they spent Christmas Eve at an airport hotel eating potato chips out of a vending machine because no restaurants were open" (Fox News, 2004).
8	Regarding other airlines, "half the airline's flights out of the Cincinnati airport on Friday also were canceled due to the bad weather" (Fox News, 2004). Also "thousands of U.S. Airways and Delta passengers, meantime, made it to their destinations but without their luggage. Airports from Miami to Philadelphia report piles of unclaimed bags." (CNN.com, 2004). However, Comair canceled flights for four more days and all over the country. [medium-high Business Incompetency Distinctiveness]
8' 8''	"It's the worst Christmas I've ever experienced…I know it's bad weather [Client Value Loss is understandable], but I just think it's disorganized [as we are in limbo], " Lobuono [, a passenger,] said gloomily" (Fox News, 2004)
9	"Throughout the Christmas holiday, camera crews from local and national television news outlets followed passengers through those terminals, broadcasting travellers' and Comair's distress to the American public" (Westerman & Hunter, 2007). CNN (2004), Fox News (2004), and NBC (2005) covered the news.
10	Comair resort to "dividing the legacy system into two modules—one for pilot schedule and another for flight attendant schedules—each with a 32,000 monthly limit of its own." (CIO, 2005) [increasing Actual IT Capacity]
10'	"Comair also began generating a daily report to monitor the volume of transactions going through the system." [monitoring Demanded IT Capacity]

D2. ITU Incident at Rogers Communications

To demonstrate how our theory can be applied to a case not included in the original 28 cases used to build the theory, we investigated a major ITU incident that occurred on July 8, 2022, at Rogers Communications, a Canadian telecommunications provider. The outage of Rogers' entire network lasted at least one day. Over 12 million Rogers internet, mobile, and landline phone customers were not able to use data or voice services. Rogers' wireless subsidiaries (Fido, Cityfone, and Chatr), as well as its radio and TV stations, were affected. Many Internet Service Providers, companies, and governmental organizations using Rogers' infrastructure could not provide services to their clients. Rogers' customers were not able to place 911 emergency calls. Customers of Interac, the largest debit card/ATM network and electronic fund transfer provider in Canada, were not able to serve Canadians for over 24 hours. One death that occurred during this period was attributed to the inability to call the emergency 911 number on the Rogers wireless network (da Silva & Augustin, 2022).

The incident occurred during a maintenance upgrade to Rogers' core network. It deleted the routing filter, which caused all possible routes to the Internet to pass through the routers in Rogers' core network. That resulted in the propagation of abnormally high volumes of routes throughout the core network and overloaded the routers. As more subscriber traffic failed to be delivered, it put more pressure on Rogers' core network. Quickly, demand for routers exceeded the actual capacity of routers, ultimately causing the collapse of Rogers' core network. Since the network was not able to route traffic, Rogers became incapable of serving its mobile, data, and landline customers, as well as providing data network infrastructure to its wholesale customers, public and private organizations. Given the reliance of Rogers' own information systems on its core network, the company was unable to diagnose the problem immediately and even struggled to mobilize the teams who would locate and fix the problem without access to the Rogers network. Once the teams were mobilized and physical access to network infrastructure was obtained, the malfunctioning equipment was disconnected, and the routing filter was restored. Then, the core network was carefully tested for proper routing and stability. Rogers started to prioritize the traffic based on criticality (i.e., access to emergency services, such as 911 calls) and gradually allowed the traffic to build up to its normal volume. It took a day for most Rogers services to recover, while intermittent performance issues persisted over three days (Woodhead, 2022).

Over 12 million Rogers subscribers and millions more using services from other companies relying on Rogers' infrastructure were affected. In their response to the regulatory body's information request, Rogers responded that "Rogers is simply not in a position to quantify the direct economic losses," though just the amount of credit Rogers planned to give its customers for five days of lost services amounted to $150 million (Woodhead, 2022b). This failure was a significant blow to Rogers' reputation. The company immediately ordered its retail stores to remove the signage saying "Canada's Most Reliable 5G Network" (Wikipedia, 2022). Those who suffered from the outage resorted to accessing the Internet at libraries, coffee shops and hotels. The daily volume of tweets mentioning Rogers increased more than tenfold, many of which came from angry, frustrated, and confused customers, and Rogers' customer service tweeted nine times more than their average daily volume during the incident. The spikes in the daily tweet volumes can be seen in Figure D2 and Figure D3.

We analyze this Rogers ITU incident in conjunction with our theory. The summary illustration in Figure D4 with the corresponding narrations in Table D2 shows that our theory explains the dynamics occurring during the Rogers unavailability incident. This provides a further illustration for our theory by using a new case that was not part of the original sample of cases used to generate the theory.

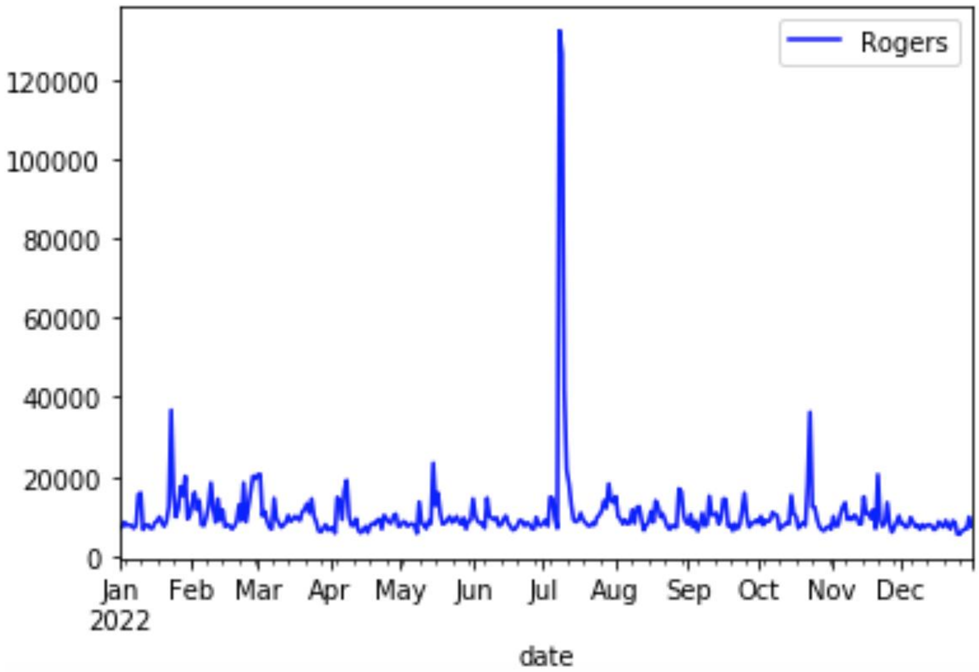


Figure D2. Daily tweet volume referring to Rogers in 2022

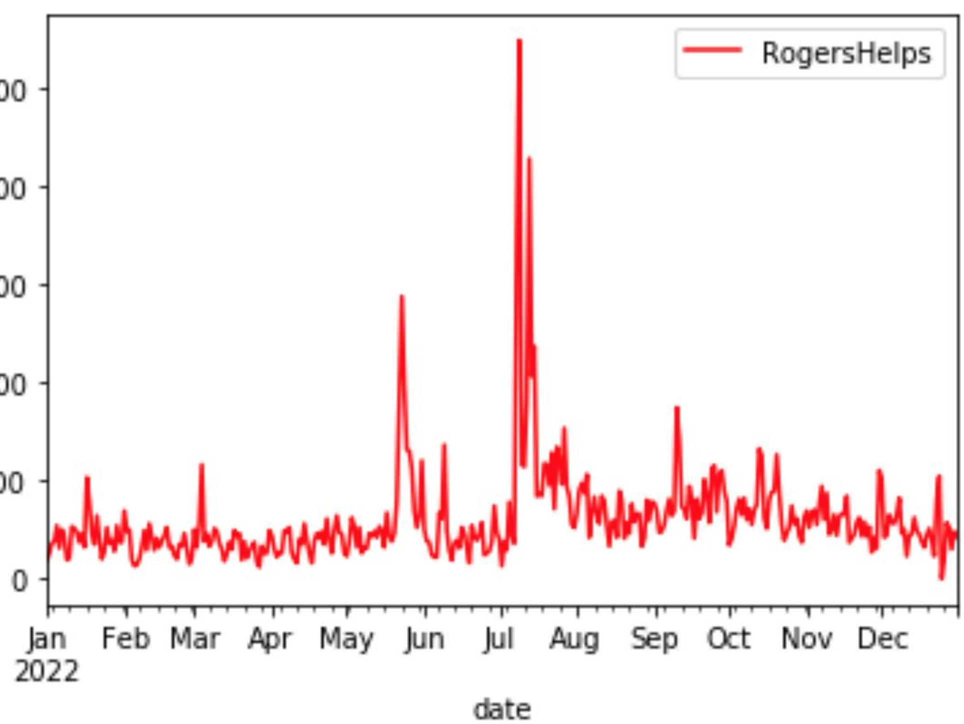
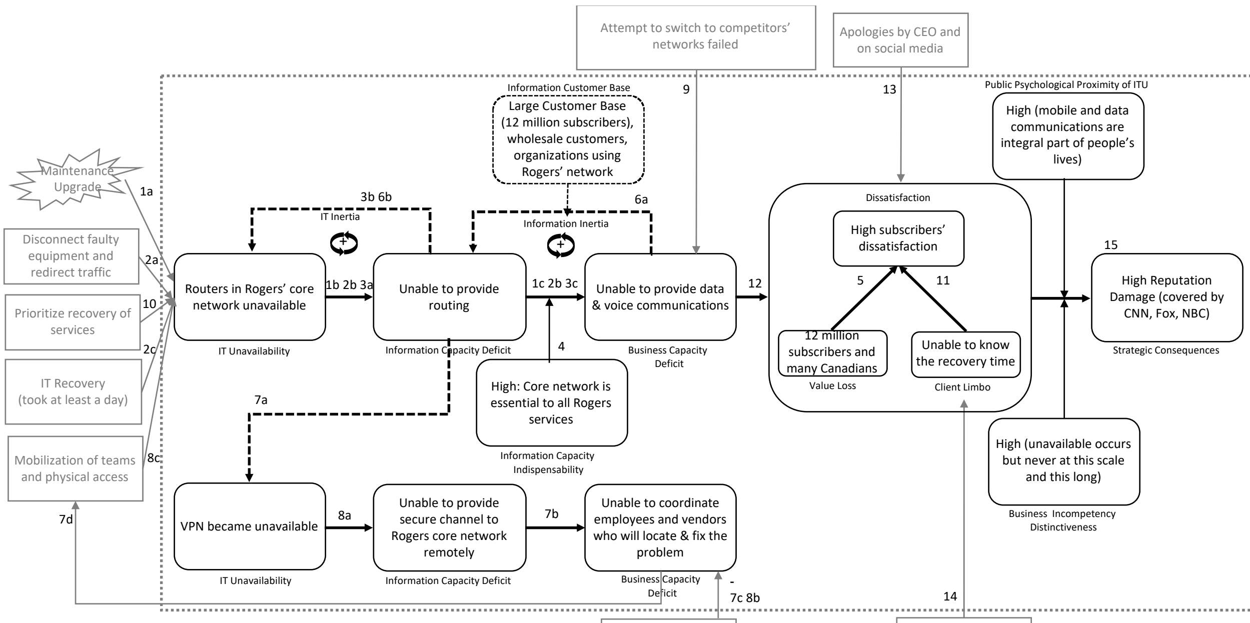


Figure D3. Daily tweet volume from @RogersHelps in 2022



Note: Event and reactions are represented with an exposition shape and rectangle shapes, respectively.

Figure D4. The illustration of the Rogers' incident using the grounded theory developed

Table D2. The narration of the Rogers' incident

Step	Case Details
1	"we've narrowed the cause to a network system failure following a maintenance update in our core network, which caused some of our routers to malfunction early Friday morning." (Staffieri, 2022) "We have identified the cause of the outage to a network system failure following an update in our core IP network during the early morning of Friday July 8th [1a]. This caused our IP routing network to malfunction [1b]." "On the morning of Friday July 8th, 2022, the implementation of this sixth phase started at 2:27AM EDT. …. At 4:43AM EDT, a specific coding was introduced in our Distribution Routers which triggered the failure of the Rogers IP core network starting at 4:45AM [1c]." (Woodhead, 2022)
2	"To mitigate this, we re-established management connectivity with the routing network, disconnected the routers that were the source of the outage, resolved the errors caused by the update and redirected traffic [2a], which allowed our network and services to progressively come back online later that day [2b]. While the network issue that caused the full-service outage had largely been resolved by the end of Friday, some minor instability issues persisted over the weekend [2c]." (Woodhead, 2022)
3	"The configuration change deleted a routing filter and allowed for all possible routes to the Internet to pass through the routers. As a result, the routers immediately began propagating abnormally high volumes of routes throughout the core network [3a]. Certain network routing equipment became flooded, exceeded their capacity levels and were then unable to route traffic, causing the common core network to stop processing traffic [3b]. As a result, the Rogers network lost connectivity to the Internet for all incoming and outgoing traffic for both the wireless and wireline networks for our consumer and business customers [3c]" (Woodhead, 2022)
4	"The common core is the brain of the network that receives, processes, transmits and connects all Internet, voice, data and TV traffic for our customers."(Woodhead, 2022)
5	"all of Rogers' services by all our brands (including Fido and Chatr) were impacted. Our wireless (voice, text and data), home phone telephony, Internet and TV services were down during the outage….. all our residential (cable and wireless) as well as our wholesale customers were impacted on July 8th… Rogers has several federal, provincial, territorial and municipal customers across the country which were impacted during the July 8th outage…Aside from Interac, Rogers provides wireless and wireline connectivity services to various customers who are classified as critical infrastructure (e.g. hospitals, gas and energy providers, etc.)…. Each of these customers' services were impacted by the outage. the outage of July 8th did impact 9-1-1 service across Rogers' service area, to both wireline and wireless services." (Woodhead, 2022)
6	"Rogers' teams began to systematically re-establish IP connectivity to elements of the broader network, while continuing to manage traffic volumes. This process had to be completed methodically and carefully to ensure stability of the network in order

	to avoid overloading the network, which would have caused another outage [6a]. … These intermittent issues did persist over the weekend, impacting some customers as outstanding issues were being rectified.... been working around the clock and have caught up on the backlog of issues [6b]" (Woodhead, 2022)
7	"..resulted in a nationwide loss of access to the company's phone and internet services, as well as internal access to systems such as the company's VPN to its core network nodes [7a], hampering the ability of the company's employees to mobilize a team and identify the issue [7b]. Some employees were able to connect through "emergency SIMs" on alternate networks [7c], …. Others traveled to centralized locations to establish network access [7d]." (Wikipedia, 2022)
8	"At the early stage of the outage, many Rogers' network employees were impacted and could not connect to our IT and network systems. This impeded initial triage and restoration efforts as teams needed to travel to centralized locations where management network access was established. To complicate matters further, the loss of access to our VPN system to our core network nodes affected our timely ability to begin identifying the trouble and, hence, delayed the restoral efforts [8a]…. Those equipped with emergency SIMs on alternate carriers that enabled our teams to switch carriers and assist in the initial coordination efforts [8b]. Further, we rapidly relocated our employees to two of our main offices in the GTA….The critical network employees were able to gain physical access to our network equipment. … were able to establish the necessary team to identify the cause of the outage and recover the network [8c]" (Woodhead, 2022)
9	"Rogers rapidly assessed and concluded that it was not possible to make the necessary network changes to enable our wireless customers to move to their wireless networks… no competitor's network would have been able to handle the extra and sudden volume of wireless customers (over 10.2M) and the related voice/data traffic surge" (Woodhead, 2022)
10	"Rogers prioritizes reinstating services with these important customers… The prioritization of service restoration was always dependent on which service was most relied upon by Canadians for emergency services….. We prioritized restoration efforts of emergency services, wireless services and key infrastructure (e.g., police, fire, hospitals, etc.)." (Woodhead, 2022)
11	"As of now, we don't have an ETA of when the problem will be fixed," says Rogers Senior Vice President Kye Prigg of the company's nationwide network outage. "I wouldn't like to say whether it's going to be fully online today or not." (CBC, 2022) "While people wait for access to Rogers to be restored, some have chosen to seek out working WiFi at local coffee shops, hotel lobbies, banks, libraries unaffected by the outage, and other publicly accessible spaces. Starbucks locations across the country have seen a rush of customers hoping to use their free WiFi, despite having issues in stores with some of their payment systems." (da Silva & Augustin, 2022). "It is important to note that until 10PM EDT on July 8th, Rogers did not have a precise time when services would be restored." (Woodhead, 2022)
12	"This outage caused real pain and significant frustration for everyone. Canadians were not able to reach their families. Businesses were unable to complete transactions. And critically, some emergency and essential calls could not be completed. We let people down" (Woodhead, 2022)
13	"..we sincerely apologize for the disruption this has caused our customers and we will be proactively crediting all customers." @RogersHelps, 4:01 am July 9, 2022. "We know how much our customers rely on our networks and I sincerely apologize." President and CEO of Rogers (Staffieri, 2022) "We're particularly troubled that some customers could not reach emergency services and we are addressing the issue as an urgent priority…. "As CEO, I take full responsibility for ensuring we at Rogers earn back your full trust…." (Staffieri, 2022)
14	"Rogers made dozens of customer communications during the outage and in the subsequent days, until July 13th. These messages were delivered via social media, media outlets, Rogers Sports & Media properties, website banners, virtual assistants, interactive voice responses ("IVR"), public service announcements and community forums." (Woodhead 2022)
15	"outage at one of Canada's biggest telecom operators shut banking, transport and government access for millions…Nearly every facet of life has been disrupted, with the outage affecting internet access, cell phone and landline phone connections." (Rajagopal & Shakil, 2022). "The network outage experienced by Rogers was simply not acceptable. We failed in our commitment to be Canada's most reliable network" (Woodhead, 2022) "Rogers is simply not in a position to quantify the direct economic losses. That said, as publicly announced, Rogers very carefully assessed the situation and decided to credit all our customers (residential, business and wholesale) the equivalent of five (5) days of service fees. The estimated value of this credit is around $150 million." (Woodhead, 2022b) On July 8, the same day as the outage, an internal email was sent requesting that retail locations remove signage stating that Rogers was "Canada's Most Reliable 5G Network." (Wikipedia, 2022) "A class action lawsuit was filed" (Wikipedia, 2022) "estimated the Canadian economy took a $142 million hit because of the outage, as some businesses nationwide weren't able to process debit or credit transactions." (Zadikian & Poshnjari, 2022)

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