Analysis of the Effects of Blackouts and Supply Networks on Performance, Resilience and Viability

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Abstract
A blackout, or the complete loss of power in a region (or a group of regions) for an extended period of time, can result from increased electrical demand, changes to the energy infrastructure, and disruptions in the energy supply. Production, shipping, and retail activities might all be severely impacted by this interruption. The degree to which supply chains (SC) are disrupted might vary depending on the size of the afflicted locations and the length of the blackout. Using anyLogistix digital SC twins, we conduct a simulation analysis in this work to determine the possible effects of blackouts on SCs with varying degrees of severity. One key finding from the simulation experiments is that various factors, including the duration of the blackout, the dynamics of power loss propagation across different regions, the simultaneous unavailability of supply and logistics, and the unpredictable behaviour of customers, may play a significant role in determining the impact of the blackout and influencing the choice of a suitable recovery strategy.

Keywords— Effects of Blackouts, Supply Networks, Performance, Resilience, Viability, Production, Shipping, Retail Activities, Supply Chains, Using Anylogistix Digital SC Twins.

INTRODUCTION

According to Ivanov (2018), supply chains (SCs) are multi-structural systems made up of structures related to information, finance, technology, processes, products, organisations, and energy. Like any complex system, SCs are not without danger and uncertainty. A substantial body of information about disruption hazards in SCs, such as earthquakes, fires, strikes, and pandemics, has been created by literature (Aldrighetti et al. 2021, Altay et al. 2018, Dubey et al. 2021b, Hosseini et al. 2019; Queiroz et al. 2020). Extensive research has been conducted on performance impact analysis, mitigation, and recovery strategies; most of this research has focused on the organisational SC structure. Examples of these strategies include back-up supply recovery and critical supplier identification (Baghersad et al., 2021, Bode et al., 2011, Chopra et al., 2021, Demirel et al., 2019, Dolgui et al., 2020a, Dubey et al., 2019, Ivanov 2021d, Lücker et al., 2021, A few studies concentrated on information structure disturbances like cyberattacks (Sawik 2020). Disruptions in the energy structures, however, continue to be an unmet research need. A blackout, which lasts for a longer period of time and involves the complete loss of electricity in a certain region, is the most severe type of power outage. Examples include a power outage that caused a significant portion of Texas' electrical supply to be lost in February 2021 (Bloomberg 2021) and the severe effects that China's Heilongjiang, Jilin, and Liaoning provinces experienced in 2021 for the survival of their societies and the durability of their social contracts (Disis 2021). According to Busby et al. (2021), economic losses in Texas alone might amount to $130 billion due to missed productivity and destruction. The blackout is one of the most likely and serious SC disruption hazards for the very near future because to increased electricity usage and changes to the energy infrastructure (Emenike and Falcone 2020). We surveyed SC managers informally in September 2021, and the results indicated that they were more afraid of a complete blackout than they were of pandemics or other serious emergencies. Later, in the spring of 2022, geopolitical tensions raised the possibility of global energy supply interruptions, which might disrupt material movements in supply chains. On the other hand, material shortages and supply delays brought on by the energy scarcity may spread downstream the SC and result in a decline in revenue, service quality, and productivity (Dolgui et al. 2018, Ghadge et al. 2021,The construction business frequently performs, produces, and uses resources less efficiently than other industries because of its unique characteristics (Costa et al., 2019). Short-term relationships, quickly changing surroundings, intrinsic complexity, schedule and expense overruns, and interruptions owing to unanticipated circumstances are all characteristics of construction projects (Koc and Gurgun, 2021). According to Dikmen et al. (2018), these traits make building projects risky. Construction projects are not an exception to the rule that all papers include some level of risk and uncertainty (Pham et al., 2022). According to Goh et al. (2013), risks are inevitable as building projects move forward. Extreme losses might result from disruptions in any stage of the SC (Niu et al., 2017). The profitability of whole business ecosystems may be impacted by the blackout in addition to the resilience of individual SCs. Viability is the capacity of the SC to withstand a severe crisis and, as noted in Ivanov and Dolgui (2020), Ivanov (2020b), and Ruel et al. (2021), secure the viability of critical ecosystems (such as food, mobility, and communication) that are responsible for providing society with goods and services. This point is also echoed by Nasir et al. (2021) and Wang and Yao (2021). A unique kind of SC disturbance that impacts ecosystem survival and SC performance is the blackout.

CASE-BASED ANALYSIS

We study the dynamic behaviour of a SC under rational consumer behaviour (i.e., when there are no panic purchases) with a homogeneous product of everyday necessity and somewhat consistent demand. The SC is made up of two regional distribution centres (RDCs), a plant, a downstream and upstream central distribution centre (CDC), and fifty clients (Fig. 1). Every seven days, 50 clients place orders totaling 8,988 units every order cycle. We allow for deter-ministic demand, which varies from 70 units to 1667 units depending on the consumer, in order to prevent randomness in the output analysis without sacrificing generality. The lead times are as follows: 4 hours for the factory and upstream CDC, 42 hours for the upstream and downstream CDCs, 2–10 hours for the downstream CDCs and RDCs, and 1–10 hours for the RDCs and consumers. Each region where the RDCs, CDCs, and factories are situated has its own power network, but because these networks are interconnected, a blackout in one zone might spread to another and produce a blackout there. There are three different lengths of blackouts: five days, ten days, and fifteen days. We see that our case study has a seven-day reorder frequency. This number is a standard business procedure. We take into account blackout propagation from the RDC's region upstream to CDCs and the plant with varying speeds and durations, as well as localised blackouts downstream at the RDCs and simultaneous blackouts at all SC echelons. Furthermore, we consider the irrational conduct of consumers in the event of a blackout, assuming that shortages will cause demand to spike by 200% during the blackout time.

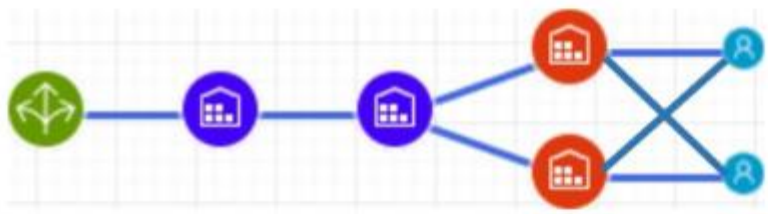

Figure 1- Supply chain design

METHODOLOGY

(i) Modelling the environment and control logic - Using the anyLogistix simulation and optimisation toolbox, our model which is a digital SC twin is built and solved. According to Ivanov (2019), Singh et al. (2021), Burgos & Ivanov (2021), and other authors, all of the locations (factory, warehouses), customers, demand, inventory, sourcing and shipment control rules, costs, revenues, and disruption events have been defined in the architecture of the SC in AnyLogistix. According to several studies (Macdonald et al., 2018, Ivanov 2020a, Li et al., 2020, Ivanov 2021b, Zhao et al., 2019), the simulation approach is a valuable tool for studying SC dynamics under disturbances. An OUT (order-up-to-level) policy, along with some safety stock, re-order point (s), and target inventory (S), forms the basis of inventory control (Disney et al., 2020; Boute et al., 2021)in Figure 2. The downstream sourcing from RDCs to customers is based on the Most Inventory (Dynamic Sources) rule, which states that the fulfilment of the
incoming order is scheduled at the RDC with the currently highest inventory level. Upstream sourcing is a linear system with fixed sources. It is acceptable to backorder (Schmitt et al., 2017).

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#	Facility	...	Policy Type	Policy Parameters	Initial Stock, units
1	CDC Outbound		Order on demand	Order on demand	5,176
2	CDC Inbound		Order on demand	Order on demand	1,294
3	RDC2		Min-max policy with safety stock	s=2,377, S=4,754, safety stock=4,680	7,057
4	RDC1		Min-max policy with safety stock	s=2,156, S=4,312, safety stock=4,229	6,385

Figure 2- Inventory control policy data

(ii) Performance metrics- In accordance with research by (Dolgui et al., 2020a; Hosseini & Ivanov, 2021; Namdar et al., 2021; Singh et al., 2021), we employ the following performance metrics for analysis: Three factors determine a company's performance: financial (profit), customer (ELT) (anticipated lead time) service level, and operational (alpha) service level. The difference between total revenue and total SC expenses which include costs for materials, manufacturing, transportation, inventory keeping, and fixed facilities is used to calculate profit.

EFFECTS OF THE LENGTH OF THE BLACKOUT

Now, we examine the outcomes of many scenarios with regard to the duration of the blackout. It is evident that in the event of localised blackouts, the significant magnitude occurs even with a brief outage (see, for example, lines 1, 2, and 3). The length of the blackouts adds a large amount to the impact, making it a contributing component to the instant effect.

Note 1- The model's reorder time is one week, making it longer than the duration of a brief blackout but less than that of a medium- and long-term lockdown.

In multi-echelon situations, the length of the blackout is crucial, particularly when there are consecutive blackouts at several echelons. Lower product unavailability is the result of longer blackouts (e.g., compare lines 5 vs. 6 and 23 vs. 29). Regarding the brief consecutive blackouts, their spread among several SC strata does not result in further detrimental performance effects (refer to lines 1, 7, and 23); nevertheless, greater durations do exacerbate the adverse effects (lines 3 and 29). The longer durations in the event of multi-echelon, successive blackouts lead to worse viability and resilience performance. If many layers have simultaneous blackouts, this effect is somewhat lessened.

Insight 1- The length of the blackout affects the sustainability of the ecosystem, particularly for essential and perishable goods. Longer periods of product unavailability are caused by longer blackout durations, particularly when there are several, consecutive blackouts at various SC levels. One way that the increasing demand helps SC's economic performance is through better earnings. However, there is a decline in both ELT and alpha service levels, which has a detrimental impact on the sustainability and resilience of SC. Due to shorter overall blackout lengths and high demand, panic purchasing is less effective when there are simultaneous blackouts at various echelons (see lines 38 vs. 44 and 16 vs. 22).

Insight 2- High demand can boost profitability, but panic buying reduces product supply and delays in delivery. When creating preparation plans for blackout situations, take into account the impacts of panic buying.

TEST-PLAN DESIGN

Two categories of scenarios sequential and simultaneous blackouts are taken into consideration for study. We further vary our analysis in each of these two categories by taking into account both reasonable and irrational (i.e., panic buying) client behaviours during the blackout periods. Lastly, we evaluate how the SC responds under various scenarios and make inferences about how the blackout affects the SC's survivability, resilience, and performance. Three methods were employed for verification: output log file analysis, visualisation analysis, and tracking of the simulation runs. Replications are used in comparison and variation experiments for testing. It is thought that there should be a two-month warm-up phase before the interruption, or blackout. With a steady lead time and balanced inventory dynamics, SC achieves a profit of $28,021 million by operating at 100% ELT and alpha service levels. Now that we have simulated the various blackout scenario circumstances (refer to Figure 2), we can see the gaps in the SC performance when compared to the disruption-free mode. March 1 is when blackouts at the RDCs start in all of the tests. January 1 through December 31 is the simulation period. When a blackout spreads, the blackout at the stage upstream (CDC, for example) starts the day after the blackout at the stage downstream (RDC, for example) ends. Blackout overlap is not taken into account. To determine the effect on performance and if a blackout's propagation has a ripple effect in the SC, we ran and compared scenarios for both localised and propagated blackouts in this set of simulations. Lines 1/7/23 vs. 17/39 and lines 3/29 vs. 19/41 show that simultaneous blackouts have less of an effect on viability, performance, and resilience than sequential blackouts. Furthermore, these impacts become more pronounced the longer the interruption lasts.

Insight 3- The ripple effect in SCs is caused by the blackout propagation. Compared to sequential blackouts, simultaneous blackouts cause less harm to the SC's viability, resilience, and performance.

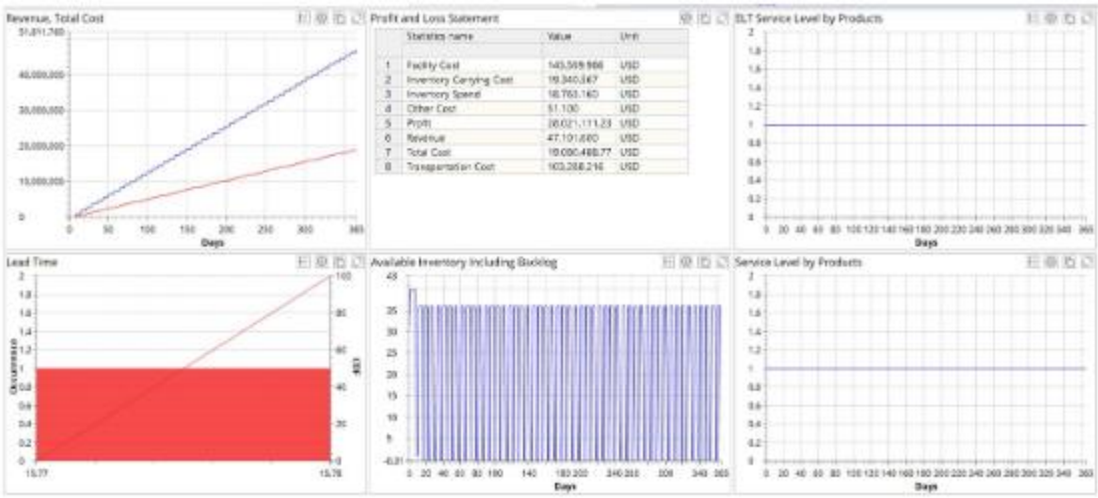

Figure 3- SC performance in disruption-free scenario

CONCLUSION

Disruption risks in material flows, such as the effect of supplier interruptions on performance and resilience, have frequently been the focus of uncertainty in SCs. The dangers associated with energy supply disruptions and geopolitical conflicts have made energy-related hazards more prominent, giving rise to new sources of uncertainty. Furthermore, when energy systems change to new sources with unpredictable or weather-dependent output, resilient SC operations face new difficulties because without energy, materials would disappear. The SC management viewpoint still has to be established, despite the fact that research on energy-efficient manufacturing and logistics has been thriving in the technical literature for the previous 20 years. Furthermore, the energy aspect is often absent from studies on SC resilience. The outcomes of a simulation research on the effects of blackouts on SC performance, resilience, and viability were reported in this publication. Our work may be expanded in a number of ways in further investigations. We looked at how blackouts spread upstream, but downstream propagation is also of relevance. Analysis of the effects of additional sourcing control and inventory control rules is possible. Products that prohibit backordering may be examined. As suggested in (Ivanov, 2017; Ivanov & Rozhkov, 2021), alternative recovery plans for the blackout periods may be implemented that alter inventory and sourcing control during and after the interruption, adjusting it to structural dynamics.

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