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# Fragility of oil as a critical infrastructure problem

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ABSTRACT

Interdependences between critical infrastructures are becoming increasingly apparent. The 21st century has been defined by events that have changed perceptions about critical infrastructures and their fragility in the face of the inherent risks and vulnerabilities. A major critical infrastructure is the energy sector, of which oil is an important component. This paper explores the systemic interrelationships between oil and other infrastructures and the implications for future design, analysis and development of oil systems within the energy critical infrastructure. The paper argues that the relationships between oil and other elements of the critical infrastructure have significant implications for the structure of the oil industry due to increasing interdependence. Understanding how to manage the new oil industry structure is an emerging issue that can be examined from a systems view. Whether oil is in its crude or refined form, its value cannot be minimized due to its numerous applications and global importance as an energy source. However, oil and its derivatives do not exist as an independent infrastructure and cannot be considered in isolation from other critical infrastructures. Indeed, oil is inextricably interconnected to other forms of energy and other infrastructures. These interconnections introduce increased risks and vulnerabilities. The conclusion is that oil is – for the foreseeable future – critical to the wellbeing of society. It is a fragile interdependent component of the energy sector and, regardless of political proclivities and the desire for alternative forms of energy, oil must be viewed as a primary energy asset of the fossil-fuel-based global economy.



## 1. Introduction

Economies that were once thought of as being independent and resilient are now susceptible to a number of threats. Current economic uncertainties, the events of 9/11 and numerous cyber attacks have exposed many interdependent weaknesses in infrastructures that were once thought to be resilient and well protected. The 21st century has experienced many events whose occurrence in one part of the world can have significant consequences for the global community (e.g., the Fukushima nuclear disaster, Cyprus banking crisis, BP oil spill and Arab Spring). Prior to these events, understanding and dealing with the interconnectedness of critical infrastructures were not top priorities [1]. However, issues related to the interdependences existing among critical infrastructures are currently moving to the forefront, especially the determination of the risks and vulnerabilities stemming from critical infrastructure interdependences and the development of tools for better governance of critical infrastructure interrelationships. This paper illustrates how various critical infrastructure systems are interconnected with the oil infrastructure, especially in terms of security, susceptibility and consequences.

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We are in the midst of a continuing revolution in computing technologies, which offers easy access, inexpensive acquisition and computing power. The technological advances have increased interconnections and interdependences while reducing the autonomy of critical infrastructures [2–5]. The inevitable consequence is that if one infrastructure fails, the failure can cascade to other infrastructures, eventually crippling services provided by the intertwined "system of systems" of critical infrastructures. As such, a failure can no longer be thought of as: (i) controlled within the purview of a single "independent" critical infrastructure sector; (ii) easily defined in terms of simple cause–effect relationships; and (iii) predictable and anticipated from historical patterns in data. According to Hollnagel et al. [6] "[f]ailure is simply the absence, temporary, or permanent, of [an] ability." Failures in interdependent infrastructures are subject to high levels of complexity, uncertainty, emergency and ambiguity [7,8]. The failures are of two primary forms:

- *Manmade failures*. These failures are attributed directly to human actions. They include events such as human factors (physiological and psychological), terrorism, operator knowledge/execution and malicious activities (i.e., cyber attacks). Human-induced failures can have an enormous impact on the interconnected web of financial, legal, transportation, healthcare, education, defense/security and water systems. The failures can threaten societal wellbeing, cause panic and disrupt civil societies.
- *Natural failures*. These failures are not attributed to human actions. They include hurricanes, volcanoes and other natural hazards. Although their sources may be different, the failures can have similar disruptive consequences as manmade failures. The potential human contributions to these disasters (e.g., global warming) are currently the subject of political and scientific debate, but are outside the scope of this paper.

Although oil and energy might be considered to be independent of other critical infrastructures, this separation is limited in reality. For example, oil interfaces with multiple other critical infrastructures in everything from identification (oil exploration technologies and supporting research infrastructures) to extraction (other energy, financial and water), refinement (chemical, information technology and commercial facilities) and distribution (transportation and communications). Increasing interdependence requires that oil be considered in relation to other supporting infrastructures.

In the final analysis, whether or not a failure is manmade or natural, the same critical infrastructure is at risk from the independent and interdependent perspectives. Thus, it is necessary to move beyond considerations based on the reductionist cause–effect paradigm to a more "systemic" paradigm. The systemic paradigm is based on holism and the appreciation of the associated complexity that may be beyond the grasp of our current capabilities to address adequately. The interdependence of oil with other critical infrastructures suggests the need for a different level of thinking and expanding the boundaries for the examination of potential failure modes. These failure modes exist beyond the isolation of oil within narrow boundaries that exclude the consideration of interrelationships with other critical infrastructures. Thus, a systemic view of oil that invokes a holistic perspective can be instructive in understanding and responding to the fragility that emerges from interrelationships with other critical infrastructures. This paper adopts the classical meaning of the term "fragility" – easily broken, damaged or otherwise made incapable of performing the intended functions. This meaning is consistent with other articulations [9,10].

To better understand the purpose of this paper, consider Perrow's [11] suggestion of "normal accidents" as occurring in complex systems (high risk systems) where multiple failures can occur. These normal accidents occur due to the high level of interactions between entities that create complex and uncertain risk problems. Several of these normal accidents relate to organizations rather than technology. Perrow suggests using the term "system accidents" to explain that these failures might cause a trivial impact in the beginning, but can spread widely and produce long-lasting effects. System accidents are emergent, stemming from conditions of complex systems such as high levels of uncertainty, ambiguous boundaries, contextual influence, rich interactions and interdependences among entities [12–17]. Since the "oil system," as an element within the energy critical infrastructure, is complex in nature, we argue that "oil system accidents" can cause severe consequences to other related critical infrastructures. As shown in the following examples and discussion, many of the failures in the oil system relate more to organizational issues where people are essential, if not dominant, contributors to the failures. These failures stem from technical and social (human) elements as well as from the interactions between the two elements. An excellent example is the oil embargo of 1973, where technical issues related to oil production and distribution levels and human (policy/political) issues contributed to the failures that had a global impact.

The oil industry and its related systems are certainly critical to the security of nations and the wellbeing of residents of industrialized nations and nations that are dependent on industrialized nations. However, the U.S. oil infrastructure will serve as the focus of this paper. The next section provides a review of the related literature, the intent being to explore why oil and its related infrastructure services constitute a critical system within the energy sector. Section 3 provides examples of the oil infrastructure and its interdependences to demonstrate that the infrastructure sector does not operate in isolation, but is interdependent with other critical infrastructures. Next, the risks and vulnerabilities inherent in oil systems are discussed. This establishes the fragility of the sector based on interdependences. Following this, governance principles are specified that can provide utility in designing, maintaining and developing successful critical oil systems in the face of the inherent interdependences. The paper concludes with a discussion of the implications of the research and avenues for future research.

This research provides a foundation that is readily extended to other critical infrastructures. It can help decision makers and other critical infrastructure stakeholders by: (i) encouraging the consideration and re-evaluation of the interdependences that exist between critical infrastructures; (ii) stimulating informed decision making based on an