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A Framework for Assessing the Impact of Potential Disruptive Technologies in Business

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ABSTRACT

Today's competitive world prompts businesses with increased challenges, spanning from the need for a post-pandemic recovery to the hardship driven by world conflicts, energy prices, and inflation among others. The resulting competition forces businesses to look for new ways to innovate and gain a competitive edge. Technology has been a major driver for competitiveness, and business leaders across industries shall make tough choices on how to react to technological threats which may affect their businesses survivability. Oftentimes some apparent technological advantage my prompt business leaders to choose among alternative technological paths, without having an adequate framework or pragmatic approach to assess such potentially disruptive technologies. This paper proposes an alternative framework for assessing the impacts of potential disruptive technologies. This research followed a critical thinking approach supported by alternative analysis techniques. The framework comprises five dimensions: strategic, operational, tactical, technical, and organizational. The strategic dimension considers political, economic, cultural, and legal factors as variables. The operational dimension evaluates performance, congruence, and opportunity. In the tactical dimension, the variables are secrecy, as well as tactics, techniques, and procedures. The technical dimension takes into account performance, maturity, and interconnectedness. Finally, the organizational dimension includes internal support, pacing gap, and cost as variables. Examples of disruptive technologies are provided. By analysing the impact of a specific technology on these dimensions, the framework can determine whether the impact is null, moderate, high, or revolutionary. The suggested framework serves as a valuable decision support tool for informing policymakers, business leaders, concerning technology investment, capability development, and other strategic initiatives.

Keywords: Business competitiveness, Disruptive technologies, Framework, Impact, Innovation

INTRODUCTION

The current era is commonly referred to as the "age of chaos", characterized by a brittle, anxious, nonlinear and incomprehensible (BANI) world (Cascio, 2020). Advancements in technology, such as data, artificial intelligence, space, materials, quantum computing, and biotechnology, are rapidly transforming society. Initially, the disruptive potential of a technology may

not be apparent until it is utilized or combined in innovative ways. However, scientific breakthroughs can also lead to immediate or ongoing disruptions (NAS, 2010). Disruptions may present challenges and negative consequences, yet moments of dramatic change also provide opportunities. The impact of disruptive technologies varies based on the perspective and distribution across affected groups (Boucher et al., 2020).

Technological change not only affect business at large, but also government and multinational organizations. This is so important that organizations such as NATO has requested its Science and Technology Group - a network of nearly 5,000 scientists, engineers and analysts - to watch for technology changes, as well as identify and document disruptive potential for the Alliance (NATO, 2018). The European Union (EU) is also concerned with the impact of disruptive technologies as evidenced from a conference held in Lisbon in 2021 (Portuguese Presidency of the Council of the EU, 2021). Therefore, while not straightforward, assessing the impact of disruptive technologies is of upmost importance.

As part of the methodological approach the Five Whys diagnostic approach which helps in identifying the root causes of problems was used. It starts with the definition of the problem of interest, after which initial causes are identified, followed by the question "Why is this a problem?" for each initial cause and "why" as many times as needed. Table 1 demonstrates the utilization of the Five Whys technique in evaluating the effects of potentially disruptive technologies. This paper focuses on technologies that have widespread applicability and examines potential solutions for addressing the underlying causes of an issue. As they already focus on the problem, no further delimitations are specified.

The objective of this study is to establish a framework which can assess the impact of potentially disruptive technologies on all relevant dimensions. To

Table 1. Assessing the impacts of potentially disruptive technologies: problems and possible root causes. Adapted from Bartolomeu and Água (2022).

Focus problem	**Assessing the impacts of potentially disruptive technologies is complicated.**	
Initial causes	Some disruptive technologies are unknown or unexpected	Existing assessments focus on a limited factors
Why is this a problem?	It triggers sudden and unexpected effects or inability to respond	Assessments are not the most adequate
Why?	Inability to adjust operational concepts to face it adequately	Critical thinking, innovation, and "out of the box" factors are not included in the analysis
Why?	Lack of technological foresight, intelligence, training, will, doctrine, and/or equipment	Assessments, as well as planning, tend to follow "business as usual"
Why?	Lack of / bad planning processes, motivational objectives, investment in R&D and / or capabilities	It is easier to follow known and tested procedures than to create new ones
Why?	Business leaders are not enough aware about the impact of potentially disruptive technologies across all relevant dimensions (Root cause)	Missing academic or business frameworks to make adequate assessments (Root cause)

achieve this, the specific objectives (SO) of the research are: 1) Identification of the common characteristics of disruptive technologies; 2) Evaluation of the main factors that enable or hinder the utilization of disruptive technologies.

This paper comprises four sections, besides this introduction and the conclusion. The second section presents the background information and outlines the methodology used in this research. The third section evaluates the common features, enablers, and constraints for utilizing potentially disruptive technologies, and proposes a framework for assessing their impact. The fourth section offers concluding remarks and recommendations for future research.

BACKGROUND AND METHODOLOGY

Key Concepts

Numerous definitions of disruptive technologies could be found from the literature. NAS (2010) defines it as "An innovative (although not necessarily new) technology that triggers sudden and unexpected effects". Drawing from a defence approach to technology Brimley et al. (2013, p. 4) argued that "*What makes a technology "game changing," "revolutionary," "disruptive" or a "killer application" is that it both offers capabilities that were not available – and were in many ways previously unimaginable – a generation earlier* (…)."

Disruptive effects can have significant impact within a limited timeframe, compelling businesses to adapt and revise their goals, concepts, strategies, and planning. Several factors, such as a scientific breakthrough, a new manufacturing method, a novel power source, a game-changing weapons system or platform, can unleash potential for transformative technologies (Brimley et al., 2013).

In effectively assessing the potential impact of disruptive technologies, it is critical to take current and future threats, legal and policy constraints, political factors, investment decisions, and the potential for organizational entrepreneurial drive and risk tolerance (NATO STO, 2020). However, other factors also play a significant role, such as congruence, perspectives, societal values, organizational culture, time. The synergies among these factors are known as "convergence" (Brimley et al., 2013). In the defence technology domain, Andås (2020) defines convergence as the merging of existing technologies to create new and better possibilities, enabling further development and maturity. The former approach intends to successfully create and implement game-changing technologies, while the latter aims to drive the technological development cycle.

Methodology

In order to navigate a BANI environment with emerging and disruptive technologies, it is essential to employ critical thinking and alternative analysis methodologies. Therefore, this paper adopts a research approach that emphasizes critical thinking. The approach follows a structured reasoning process, as proposed by Paul & Elder (2009), which includes purpose, key questions,

assumptions, key concepts, facts and experiences to support conclusions, personal viewpoints, as well as conclusions and implications. Additionally, the Five Whys technique is employed to determine the root causes of the problem by iteratively asking "why", while the Concept Mapping technique is applied to create tables illustrating suggested relationships between concepts.

BUILDING THE FRAMEWORK

This section employs the Concept Mapping technique to identify pertinent dimensions and factors, and consolidates insights from disruptive military technologies to refine the framework's indicators.

Concept Mapping

Tables 2 and 3 illustrate the connections between concepts from the reviewed literature and concepts proposed by the authors, which were used to identify factors and dimensions for the framework. Focus Issue 1, presented in Table 2, is related to SO 1. Through the process of constructing, revising, and interpreting the concepts, various factors and dimensions emerged for this focus issue, including:

1) Congruence and performance: operational dimension
2) TTP and secrecy: tactical dimension
3) Interconnectedness and performance: technical dimension

Table 2. Concept mapping for focus issue 1. Adapted from Bartolomeu and Água (2022).

Focus Issue 1: What are the common characteristics of disruptive technologies?			
Concepts		**Emerging Factors**	**Emerging Dimensions**
From Literature Review	**Authors' Suggestions**		
Hard to foresee or identify; never seen before; unforeseen; sudden and unexpected effects	Surprise, lack of countermeasures	Secrecy	Tactical
Used in a different way		Tactics, techniques & procedures (TTP)	Tactical
Revolutionary effect; change the competition paradigm	Production output, quality, waste, customer satisfaction, response time, productivity	Operational performance	Operational
Innovative technology; merging of existing technologies; congruence		Congruence and interconnectedness	Operational and technical
A scientific breakthrough or a new manufacturing method, power source, system or platform	Best performance, top-rated	Technical performance	Technical

Table 3. Concept mapping for focus issue 2. Adapted from Bartolomeu and Água (2022).

Focus Issue 2: What are the main factors that enable or hinder the utilization of disruptive technologies?			
Concepts		**Emerging Factors**	**Emerging Dimensions**
From Literature Review	**Authors' Suggestions**		
Current and future threats; limited time frame	Operational environment, competition, demand, trends, failure into adoption	Opportunity	Operational
	Current tactics and counter-tactics; organization, doctrine and training	TTP	Tactical
Policy, law and regulatory constraints; perspectives; potential for organizational entrepreneurial drive and risk tolerance; organizational culture; and time	Oversight mechanisms, support, resources and infrastructure	Pacing gap, internal support and cost	Organizational
Political factors; investment decisions; societal values; ethics; and legal constraints		Political, economic, cultural and legal	Strategic
	Maturity of technology	Maturity	Technical

Table 3, Focus Issue 2, is centred on the topic of SO2. The resulting factors and dimensions that have emerged from this focus issue are as follows:

1) Political, economic, cultural and legal: strategic dimension
2) Opportunity: operational dimension
3) TTP: tactical dimension
4) Internal support, pacing gap and cost: organizational dimension
5) Maturity: technical

Facts and Experiences From Disruptive Technologies

The strategic, operational, tactical, technical and organizational dimensions, along with the relevant factors, serve as the primary structure for analysis and framework. The strategic dimension specifically emphasizes political, economic, cultural, and legal factors that may impact the organization's overall strategy and decision-making. Printing press, radio, steam engine, nuclear weapons and ssocial media, are examples of disruptive technologies with political impact because they managed to achieve strategic objectives or change perceptions. The stability of requisite institutions to sustain innovation and being (or not) a regional or global player are also relevant indicators for assessing the political impact. Railroad, Global Positioning System (GPS) and Office Software are examples of the economic impact from disruptive technologies due to their adoption rate and diffusivity. The availability of

financial and human resources, scientific, technical, and engineering capabilities, infrastructure capacity, and level of investment in R&D are critical factors in determining a business' technological progress. For example, in 1846, the French were the first to adopt steam propulsion and screw propellers on auxiliary ships, marking the beginning of the Naval Revolution. However, it was the British's economic power that allowed them to take the lead in applying these technologies effectively (Krepinevich, 1994). The extent to which certain technologies and applications are deemed acceptable or resisted due to cultural, religious, or ethical reasons is a crucial factor to consider. While certain technological advancements such as the railroad were easily accepted by society, others like artificial intelligence today are raising significant ethical, moral, and legal concerns. The legal factor is related to the ineffectiveness or effectiveness of limitations from regulations or norms. While product safety and potential environmental damage are considered red lines that no conscious business dares to cross, there are other legal and ethical considerations that are relevant to any business, such as intellectual property, privacy, antitrust, product liability, and accessibility.

The operational dimension focuses on performance, congruence and opportunity. Operational performance in a business refers to the extent to which day-to-day tasks and processes are carried out efficiently and effectively to achieve the organization's objectives. It encompasses the evaluation and measurement of operational activities such as production, logistics, quality control, and customer service. Depending on the nature of the business and its objectives, operational performance can be assessed in a variety of ways. For instance, a manufacturing company might evaluate performance by monitoring production output, quality levels, and waste reduction. In contrast, a service-based business might prioritize metrics like customer satisfaction, response time, and productivity. Congruence in business refers to the integration of technology with a concept for its use in a timely and relevant situation. For example, using social media platforms to increase brand awareness and engagement is a congruent technology solution because it is well-integrated with the company's marketing goals and the current market situation. The technology itself (social media platforms) is relevant and timely for the task at hand and helps achieve the intended outcome of increased brand awareness and engagement. The adoption of technology in high operational tempo environments presents opportunities for businesses. Cloud computing, for instance, has been a disruptive technology that has enabled businesses to quickly scale up, adapt to changing market conditions, and compete effectively with larger companies. It has also provided a range of tools and services to improve operations, such as project management software, collaboration tools, and data analytics platforms. Another example is the massive adoption of Microsoft software packages, which triggered the adoption of additional packages and sometimes became de *facto* standards.

The tactical dimension focuses on secrecy and TTP. Secrecy can be measured by the level of surprise of the market disruption, or lack of countermeasures and / or counter-countermeasures. For instance, Apple is

known for surprising the marketplace with outstanding innovative products. The impact motivated by technology can also be revealed by changes in TTP, including changes in size, organization and training of teams and whole companies; boosting of R&D; and contribution for operations performance.

The technical dimension includes performance, maturity and interconnectedness. Technical performance can be measured using metrics and key performance indicators, testing, observations, reviews and audits, comparisons, and feedback. The choice of method depends on the specific context and objectives of the measurement. The nine technology readiness levels (TRL) pioneered by John C. Mankins at NASA in the 1980s are commonly used to measure the maturity of a particular technology (Mankins, 1995). For instance, Blockchain technology has the potential to enhance supply chain processes and streamline contract transactions between businesses. However, the specific requirements for implementing this technology have not yet been clearly defined, indicating that it is at TRL 1. In contrast, in 2020, the US Navy successfully tested a high-energy laser weapon that is capable of destroying aircraft mid-flight (The Economic Times, 2020). This technology is more advanced and has reached TRL 6. Interconnectedness allows for the evaluation of the possibility of integrating two or more established technologies that were previously thought to have no correlation. For instance, the Predator system was developed in 1995 but only became a significant tool for US counterterrorism after being integrated with GPS technology. Similarly, while the concept of AI dates back to the early 1950s, its widespread use was limited until the emergence of microprocessors, the proliferation of mobile and connected devices, and the advancement of machine learning algorithms. These developments have propelled AI forward and made it more accessible for practical applications.

The organizational dimension is influenced by internal support, pacing gap, and cost. To evaluate the level of internal support, various indicators, including senior leader top cover, small team participation, junior personnel promotion pathways, and disguising disruptive innovations as sustaining ones (Scott et al., 2019), can be used. For example, the Barbie creator at Mattel had to wait two years to convince senior management of the potential of the product. Nowadays more than 100 dolls are sold every minute. A similar story could be told about Nespresso, which faced some initial resistance as it would compete with other Nestlé products, however, at some point and with senior management sponsorship it became one of the most successful products of Nestlé ever, with over 14 billion capsules sold every year (Light, 2020). The pacing gap is the time needed to create laws, regulations, and oversight mechanisms that ensure the secure development and successful implementation of a new technology. The impact indicators used to evaluate the cost of a specific technology include the size and type of investment, human capital, necessary infrastructures, and the ability to replicate the product after development. While software development and computational biology require minimal investment in infrastructure beyond computing power, advanced materials, nanotechnology, biotechnology, and systems require a significant investment that may not be available to many (NAS, 2010).

Table 4. Framework for assessing the impacts of potentially disruptive technologies.

Dimensions	Variables	Indicators	Impact
Strategic	Political	Strategic objectives partially attained, attained or overcame; sustainable innovation; having a marketplace edge	Null Moderate
	Economic	Level of business development; market quota; number of new markets; new technology emerging; financial and human resources; scientific, technical, and engineering capabilities; infrastructure capacity; level of investment in R&D; and diffusivity / adoption rate	High Revolutionary
	Cultural	Level of acceptability or resistance to certain technologies, and applications for cultural, religious or ethical reasons	
	Legal	Effectiveness of limitations from regulations or norms	
Operational	Performance	Production output, quality levels, waste reduction, customer satisfaction, response time, and productivity	
	Congruence	Level of integration of the technology itself with an innovative concept for its effective deployment	
	Opportunity	Timing; failure into adoption; and/or adopted first by competition	
Tactical	Secrecy	Levels of surprise *vis-à-vis* competition	
	TTP	Level of changes in tactics, techniques and procedures; changes in size, organization, and training; boosting of R&D; and contribution for the effects on the marketplace	
Technical	Performance	Key performance indicators, testing, observations, reviews and audits, comparisons, and feedback.	
	Maturity	TRL 1 - Basic principles observed and reported; TRL 2 - Technology concept and / or application formulated; TRL 3 - Analytical and experimental critical function and / or characteristic proof-of-concept; TRL 4 - Component and / or breadboard validation in laboratory environment; TRL 5 - Component and / or breadboard validation in relevant environment; TRL 6 – System / subsystem model or prototype demonstration in a relevant environment; TRL 7 - System prototype demonstration in operational environment; TRL 8 - Actual system completed and qualified through test and demonstration;	

Continued

Table 4. Continued.

Dimensions	Variables	Indicators	Impact
		TRL 9 - Actual system proven through successful mission operations (Mankins, 1995)	
	Interconnectedness	Potential for integration with other technologies of two or more well-understood technologies where no correlation had previously been identified	
Organizational	Internal support	Credible senior leader sponsorship; small team participation; junior personnel promotion pathways; disguising disruptive innovations as sustaining ones (Scott *et al.*, 2019)	
	Pacing gap	Time required to establish laws, regulations and oversight mechanisms for the safe development or implementation of a new technology	
	Cost	Size and type of investment (initial and maintenance); human capital required; infrastructure required; replication viability of a product once is developed	

Outputs and Assessments

This study's findings on the impact of technology on selected variables are summarized in Table 4, which displays the individual indicators. By evaluating the impact of all variables along a specific dimension, one can determine the effects of a particular technology on such dimension. The impacts on each dimension and variable are then classified as null, moderate, high, or revolutionary. By combining the impacts from multiple dimensions, one can evaluate the overall impact of a particular technology.

CONCLUSION

Technology has been a major driver for business competitiveness, and companies shall envision new technologies and innovation in order to sustain their competitive edge. The question of which technology to pursue starts by questioning how to asses a specific technology potential for disruption. This research focused on designing a framework to help decision makers in assessing the disruptive potential of technologies vis-a-vis the marketplace. Obviously a technology will only provide and advantage until competition copies it, develops an improved version, or creates a substitute technology with even more disruptive attributes. The proposed framework is comprehensive and applicable across different industries, as it considers five critical dimensions that technology can impact on businesses: strategic, operational, tactical, technical, and organizational. Each dimension is carefully examined with respect to its main variables, making the framework both systematic and pragmatic. By analysing the impact of a specific technology across

these dimensions, the framework can determine whether the impact is null, moderate, high, or revolutionary. This valuable decision-making tool enables business leaders to assess the potential impacts of technology investments and strategic initiatives on their competitiveness.

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