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Covid-19 attacks the body of purchasing and supply management: A medical check of the immune system

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ABSTRACT

Much like the immune system of the body, the 'immune system' of purchasing and supply management (PSM) is also affected by the Covid-19 virus. Medicine must hinder the spread of the virus and outbreak of disease, just as PSM must prevent risk events and handle supply disruptions. The existing debate on supply resilience and robustness can be demonstrated using this medical analogy. The purpose of this article was to perform a medical check of the 'PSM immune system' to identify lessons and research gaps when confronted with a low-frequency-high-impact event such as the pandemic. As a provocative note, this article identifies research gaps in elements of the immune system of PSM (e.g., helper cells – consultancy support or memory cells – feedback loops). The results call for a more holistic debate on the immune system of PSM. Two approaches for research on 'conventional' or 'alternative' risk management schools of thought are presented as a basis for future discourse on how to improve the PSM immune system.

1. Setting the stage: Covid-19 and immune-system response

A pandemic is an epidemic of an infectious disease that has spread over large regions, continents, or the world. It is a rare event that severely affects humankind. Examples include the plague in the 14th century, 1918 flu pandemic, 1980 HIV/AIDS, and today's Covid-19. There have been 140 million Covid-19 cases and three million deaths within only one year of its first outbreak. This pandemic has forced people to take numerous and strict measures to fight the disease.

The pandemic and all measures to counter the crisis have deeply affected national economies. Many organizations have suffered severe supply disruptions, with strategic implications. Public procurement has been harshly criticized for failing to secure medical equipment and buy sufficient vaccines in a timely manner: 'The European Union has bought wrong' (Sueddeutsche, 2021) was the glaring conclusion. The Covid-19 pandemic has highlighted the need for a resilient and robust supply chain (Ivanov and Dolgui, 2020; El Baz and Ruel, 2021).

One might think that the Covid-19 pandemic is a unique event; it can be classified as a low-frequency-high-impact (LFHI) catastrophic event (Knemeyer et al., 2009; Ivanov and Das, 2020). How procurement and supply management (PSM) deals with such an event and if the current knowledge is enough to be prepared for future LFHI events is the big question of the hour.

Over several decades, PSM research has addressed various facets of risk management (RM), such as bottlenecks, supply risks, and supply disruptions. For example, Christopher and Peck (2004) distinguished various types of supply disruptions and mentioned five areas of risks, one of which– environmental risk – reflects the pandemic, because the risk origin is external to the supply network. Wagner and Bode (2006) examined sources of supply chain vulnerability and identified a number of relevant characteristics (e.g., customer or supplier dependencies, single sourcing, and reliance on global supply sources) that drive risk exposure. Hendricks and Singhal (2003, 2005a, 2005b) found that supply disruptions have severe effects on several dimensions of performance and that businesses do not quickly recover from negative economic consequences. Their call for more research on the prediction and prevention of supply disruptions (Hendricks and Singhal, 2005b) has been, in part, addressed recently with enhanced measures to analyze the effects of different supply risks on performance (e.g., Baghersad and Zobel, 2020; Ambulkar et al., 2015), evidence on how disruptions affect supply network actors and their relations (Kim et al., 2015), and development of decision-making models for investments for greater

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flexibility and agility in response to disruptions (Shekarian et al., 2020). Christopher and Peck (2004) put forward propositions for fortifying the resilience that aligned with research findings on activities that help mitigate risk events (e.g., Rice and Caniato, 2003; Revilla and Saénz, 2014).

A broad stock of knowledge on supply disruptions and how to address them has been developed, but is it sufficient for supply systems to resist an LFHI event, such as the Covid-19 pandemic? This question raises the need to determine how supply disruptions are managed in PSM. For this purpose, we applied a medical analogy of the human immune system to PSM, where sufficient research has shown how a body stays healthy or recovers after sickness. The use of the analogy was also inspired by Christopher and Peck (2004, p.12) who stated that there is a need to "sacrifice short-term cost optimization in favor of improved and sustainable supply chain wide resilience." In other words, a "healthy supply system" requires more than a short-term treatment of single disruptions, and the aim should be to achieve a lasting status of resilience. The analogy aligns with PSM research on supply disruptions in the overarching aim to safeguard and achieve "health" (body/supply system). Thus, the ability of PSM to treat supply disruptions could be structured and evaluated from a new perspective.

The immune system consists of existing and adaptive components that are interlinked with each other. External treatments, such as medicine or vaccines, can support the body's immune system. The human immune system has evolved over time to withstand infectious disease attacks. Evolution prioritizes 'survival of the fittest'; therefore, it can be assumed that nature has developed an immune system that balances effectiveness with the effort required to build up, execute, and maintain it.

PSM in organizations and supply networks can be seen as a system (Helou and Caddy, 2006). Similar to the human body, PSM is confronted by Covid-19. Using analogical reasoning (Cornelissen and Durand 2014), we couple them together, because both require effective responses when under attack, for which they rely on strong immune systems.

There were two aims to this study. First, we wanted to determine whether the PSM sub-systems (components) that address supply RM could be mapped onto the sub-systems of the human immune system. Second, we tried to identify gaps in immune system components, while considering component interplay. With this effort, we wanted to contribute to the debate on how PSM reacts in an LFHI event such as the Covid-19 pandemic. The general aim was to check the "healing process".

2. Refining the pandemic problem and introducing analogical thinking

Currently, the world is facing a pandemic that puts healthcare, social, and supply systems under stress. The full impact of Covid-19 on supply chains is still unknown, but it is expected that medium-to long-term economic effects will hit most industries (Deloitte, 2020; PwC, 2020; Accenture, 2020; McKinsey, 2020). Ninety-five percent of Fortune 1000 companies have seen supply chain disruptions caused by Covid-19 (Accenture, 2020). Not surprisingly, observations have shown that "some companies are better prepared than others to mitigate the impact [… or to …] respond to this event" (Deloitte, 2020). The recommendations for managing the pandemic are numerous (e.g., 25 measures in Deloitte, 2020) and address heterogeneous fields. Examples include the identification of alternative sources, transport of inventory away from quarantine zones, and buying ahead to procure material that will be in short supply in impacted areas (PwC, 2020). It seems as if practice responds to the crisis in a hectic and unconsolidated manner, which is no surprise considering the following perception of Covid-19: 'As a typical black swan event, Covid-19 took the world by complete surprise' (Deloitte, 2020).

This NOTES AND DEBATE contribution follows that statement and examines what PSM research already has in its portfolio to respond to an LFHI event, such as Covid-19. Similar events have been discussed in PSM literature. Wagner and Bode (2006) explicitly mention the SARS epidemic in Southeast Asia in their discussion of supply chain vulnerability, and Zsidisin et al. (2005) reference the 9/11 terror attacks. However, information on how to respond to such LFHI events is fragmented. Several PSM contributions mention LFHI events (earthquakes, tsunamis, hurricane Katrina, 9/11 terrorist attacks) (Zsidisin, 2003; Wagner and Bode, 2006) but most other studies on supply disruptions do not and only refer to risk or disruption in general. Furthermore, recent contributions to supply RM focus on very specific aspects (e.g., backshoring, supply chain finance, or sustainability risks), which will be presented below. The stock of knowledge is dispersed and lacks aggregation. In other words, PSM immune system must be viewed holistically.

The systems view supports an understanding of the holistic approach behind it (Caddy and Helou 2007) and this article reports on an analogy method that supports holistic analysis. Briefly, an analogy is a comparison between things that have similar features. Literature is full of colorful analogies and that it is used for many purposes, as per Ketokivi et al. (2017). Therefore, to spark a debate, we used an analogy to help recapitulate and assess the PSM literature linked to LFHI events. We compare the body's immune system with the PSM immune system, because there are some obvious similarities: (1) both systems are now attacked by a virus; (2) although Covid-19 is a new attack, there have been similar attacks on PSM in the past; (3) both systems are hardwired to respond to such attacks; (4) both systems are sophisticated and built with a number of interrelated components evolved over time.

Ketokivi et al. (2017) named the following purposes for using analogies, with example sources: analogies allow researchers to convey novel ideas (Bacharach, 1989), to make abstract and complex subjects comprehensible (Cornelissen, 2005), to formulate explanations (Williamson, 1971), to highlight something non-obvious (Alvesson and Spicer, 2012), and to spark conversation or debate (Astley and Zammuto, 1992). The latter purpose matches our intention; we refer to the immune system to prompt debate about how PSM reacts to severe supply disruptions.

Typically, analogies are quite close to metaphors but according to Cornelissen and Durand (2014) the difference is negligible, because the difference is in the degree of comparison and not in the comparison between things per se. Analogical thinking is a research practice that involves a comparison between a domain of knowledge that researchers already understand and another target domain that they cannot yet fully understand or explain or that they are keen to revise (Cornelissen and Durand, 2014). The comparison, in turn, may provide new vocabulary, insights, and inferences, and thus aid in theorizing. Analogies principally function as a way of understanding a particular subject in terms traditionally associated with another subject or domain of knowledge (Gentner et al., 2001). Thus, analogy helps in different ways: it gives the researcher permission to focus on the relevant part of the problem, to exclude other parts, and to suppress discrepancies (Ketokivi et al., 2017).

In this article, we highlight the functions and interplay of components in the immune system. Therefore, we observe PSM from a medical perspective. Due to the nature of NOTES AND DEBATE, we do not further explain the methodology of analogical thinking, but we refer to recent publications based on their relevance to business research (Ketokivi et al., 2017). Further, we acknowledge several limitations of analogies, which are presented in the conclusion section. Overall, this study follows the idea that analogies are methodological tools that lie at the foundation of some of the most important research programs (Ketokivi et al., 2017). This NOTES AND DEBATE article is also relevant to researchers who perceive medical research (standards and methodologies) as an inspiration for PSM (e.g., Harland and Qatami, 2007).

3. Medical view of the elements of the immune system

Our analogy follows the body's immune system described by

Neumann (2008) and Brodin and Davis (2017). It is a multicellular system that protects an individual from danger, such as an infection. To protect the body, the immune system reacts to pathogens, such as viruses, bacteria, parasitic worms, cancer cells and even objects such as wooden splinters. If an infection is left unchecked, these pathogens can harm our body, leading to progression of the infection into a disease. Fig. 1 illustrates the main elements of the immune system according to the timeline of infection.

The first major component of the immune system is the physical barrier against the entry of pathogens into the body. Skin, membranes, and endothelial cells form a barrier to obstruct the flow of substances in and out of tissue and blood. This barrier reduces the probability of pathogens reaching sufficient numbers to cause illness.

The second major component is the innate, unspecific immune system. Its major aim is to stem the dispersion of pathogens. The infection response is non-specific, but it starts immediately. Cells of the innate immune system use pattern recognition receptors to identify pathogens. Granulocytes (leukocytes, commonly referred to as white blood cells) and natural killer cells, together with macrophage cells, identify pathogens and eliminate them. Usually, they engulf and digest pathogens.

Macrophage cells also play a coordinating role. Through a chemical process, macrophages attract other macrophages and granulocytes. Macrophages can also "read" the pathogen and provide this information to the adaptive immune system, which is the third component of the immune system. This component starts several hours to several days after infection begins. The response is specific to the pathogen. B cells (also a type of leukocyte) identify pathogens when antibodies on their surface bind to a specific foreign antigen. This antigen/antibody complex is taken up by the B cells. Together with helper cells, B cells begin to divide, and their offspring (plasma cells) secrete copies of the antibody that recognizes the antigen. The antibodies go through blood vessels and mark antigens for destruction. Killer T cells recognize antigens and kill infected cells. Additionally, other scavenger cells can respond more efficiently to pathogens if they are attached to antibodies. B/T cells can further develop into memory cells, which save information. If the body is treated with the same antigen, memory cells can be activated quickly, which increases the adaptive immune system reaction speed.

To complement this analogy, we added aspects of external support. Morale and ethics (e.g., the Hippocratic oath) provide a framework for how external support is provided. Protective clothing (masks) helps prevent pathogens from reaching the skin/endothelium barrier. Social rules (lockdown, quarantine) are another means of preventing infection, while a vaccine would also reduce the need for an immune response. During the healing process, technical support (medical equipment), professional support (doctors/nurses), and other external support (medication) are often recommended.

The use of a biological timeline in business and economics research is not new (Eliasson 2005). In addition, this note matches PSM research content to the immune system in the following section, aiming to discover whether the analogy could provide insight for further improvements.

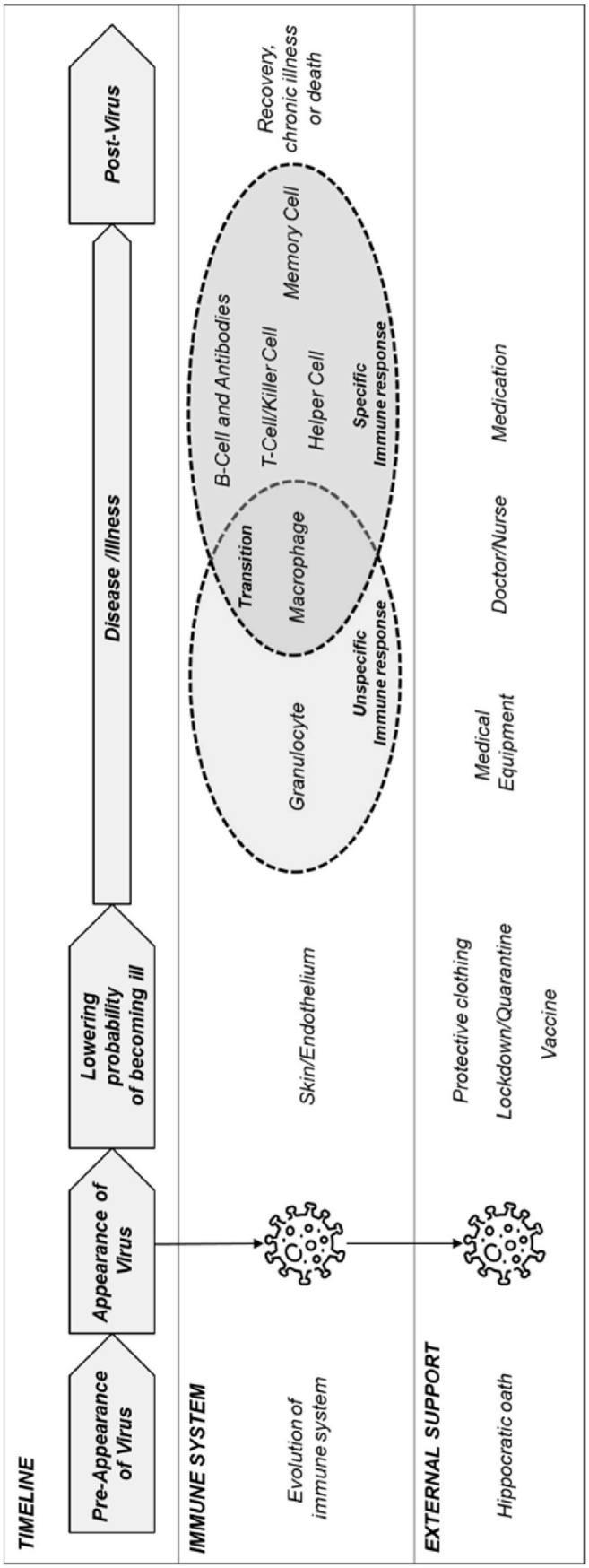

Fig. 1. Can we learn something from the human immune response?.

4. Insights from PSM research and analogy application

4.1. The stock-of-knowledge

The basis for the analogy was built on sample journal articles on supply vulnerability and disruption. To ensure completeness and reproducibility, we conducted a semi-structured literature search in a manner similar to review methodologies (Easterby-Smith et al., 2015; Tranfield et al., 2003). The search was executed within the *Journal of Purchasing and Supply Management* (JPSM) for articles published from 2000 to 2020. The search string contained the keywords '*Event*' OR '*Disruption*' OR '*Emergency*' OR '*Bottleneck*' OR '*Disaster*' OR '*Crisis*' OR '*Supply Risk*' OR '*Supply Chain Risk*' OR '*Risk*'. The initial search resulted in 70 publications. The search focused only on publications from JPSM,

which is a limitation of our study. Through the filtering process, several publications were excluded due to their titles, keywords, abstracts, or full texts if they did not consider supply risk/disruption-related topics. Therefore, 41 publications remained in the sample.

Fig. 2 provides an overview of the publication years and the methodologies used. The number of publications addressing supply risk-related topics within the JPSM has grown continuously since the discussion started in 2003 (Zsidisin, 2003; Harland et al., 2003). The methodology of the examined articles was diverse, but it was dominated by case study research (34%), simulations (20%), and surveys (20%). Additionally, the authors used interviews (7%), experiments (7%), action research (2%), conceptual approaches (2%), and other methods (7%), such as public data analyses or historical retrospectives.

Most identified publications approached the topic from the perspective of the buying organization (33 publications), followed by analysis of the supply network (three publications), the supplying organization (two publications), and the dyad (two publications).

Only 18 out of 41 publications used a theoretical approach, which supports the findings of Spina et al. (2016) that PSM research has a relatively lower theoretical maturity than other disciplines. The theories used included transaction cost economics (three publications), grounded theory (two publications), agency theory (two publications), resource dependency theory (two publications), and contingency theory (two publications). Publications also used prospect theory, decision theory, organizational justice theory, utility theory, stakeholder theory, service triad theory, normal accident theory, internationalization theory, institutional theory, human capital theory, and contracting theory.

The first publication out of these 41 that considers an LFHI risk (e.g. SARS pandemic, terror attacks), also known as disaster or catastrophic risk, appeared in 2006 (Wagner and Bode, 2006). Overall, 16 publications considered LFHI risks either explicitly or implicitly. Five publications used a theoretical approach, such as transaction cost theory, contingency institutional theory, resource dependency theory, and normal accident theory. Compared with the theories used in humanitarian supply chain management (Tabaklar et al., 2015), which often addresses catastrophic risks, several theories, such as inventory control theory, system theory, resource-based view, and stakeholder theory, are completely missing, which indicates a need for further research to adapt existing knowledge to industrial purchasing.

4.2. Content matching between PSM and medicine

Overall, the publications dealing with supply disruption address a broad range of different phenomena. First, we were able to identify appropriate content matches from PSM research for most elements of the immune system. Content matching is presented in Table 1. The first two columns of Table 1 show the medical elements of the immune system, which are then matched with the corresponding PSM elements. Many analogies are quite obvious, but we explain the aggregate themes and introduce content regarding supply RM, which will be needed later in the discussion.

Basic constructs: The basic constructs of the immune system analogy are the virus, illness/disease, the immune system, and its evolution. The virus is the initial cause of an infection that obviously corresponds to a risk or risk event in PSM. Zsidisin (2003) defines supply risk as 'the probability of an incident (event) associated with inbound supply from individual supplier failures or the supply market occurring, in which its outcomes result in the inability of the purchasing firm to meet customer demand or cause threats to customer life and safety'. PSM research has similarly provided several classifications for risks (e.g., Zsidisin, 2003; Micheli et al., 2009), which are the topic of ongoing discussion, as risks are perceived differently from individual to individual (Harland et al., 2003). Similarly, threats to the human body vary, and new ones (Covid-19) regularly emerge. Nevertheless, risks can be quantified using the probability of the occurrence (frequency) of a specific event and the significance of the loss (impact; Harland et al., 2003). Even if this understanding of risk is quite mechanistic, it matches the medical understanding of infections. A response to risk/infection could reduce the probability of infection (via skin/endothelium) or reduce its impact (via immune response). If and how easily a supply system is disrupted is demonstrated by its vulnerability. Wagner and Bode (2006) examined supply vulnerability, which is the 'exposure to serious disturbance'. Drivers of vulnerability are single- and global-sourcing, supplier concentration, and dependency. Events in PSM, such as pandemics, might lead to supply disruptions, causing a state of reduced performance. The possible analogy to the human body is unmistakable, because illness/disease stands for a state of reduced performance (Ribbert, 1912). Supply disruptions are treated by supply chain RM, which represents the immune system, while prevention, robustness, and resilience management might be better suited to single components of the immune system, as outlined below.

Entry (physical) barriers: Prevention corresponds to the physical barriers of the immune system, as prevention minimizes the probability of a supply disruption, such as issues with supplier selection process (Schoenherr et al., 2008; Micheli et al., 2009). An analogy to the body's skin/endothelium can be drawn, as these barriers minimize the possibility of virus penetration into the human body. Prevention management is also supported by instruments and technology, such as tools for supplier selection or supply chain finance analysis, analyzed by Jolai et al. (2011) or Moretto et al. (2019). These instruments correspond to the

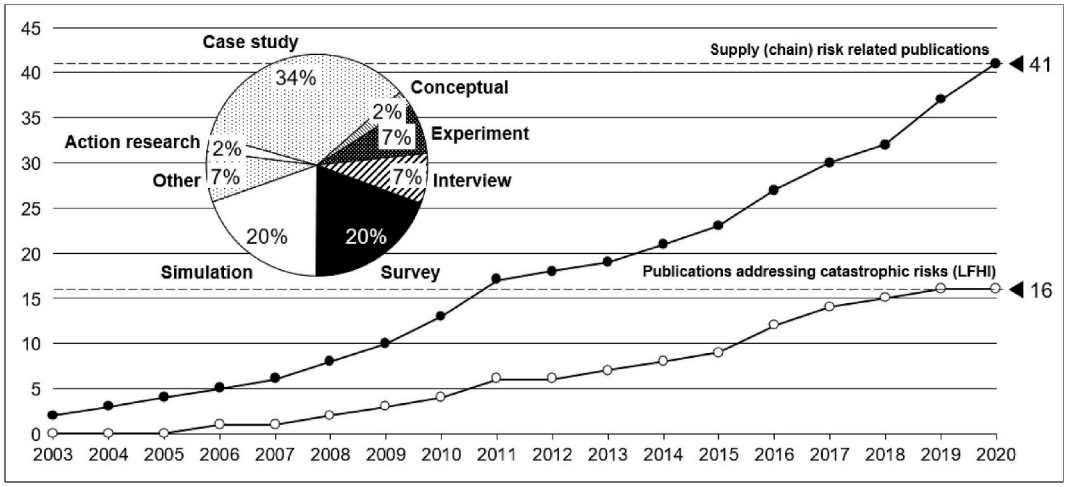

Fig. 2. Supply chain risk-related research within JPSM.

Table 1
Analogy matching.

	Medical term	Function/Description (medical [sub-] system)	PSM Analogy/Translation (PSM [sub-] system)	Articles Addressing the Topic	Comment on Content
Basic constructs	Virus	Initial cause	Event/Risk	Zsidisin (2003)	Definition of supply risk as a multi-faceted concept.
				Wagner and Bode (2006)	Examination of supply chain vulnerability (risks) that includes catastrophic risks.
	Illness/Disease	State and process of reduced performance	(Supply) Disruption	Knight et al. (2015)	Supply side risks (uncertainty) hinder innovation.
				Blackhurst et al. (2018)	Visualization of disruption effects on a supply network.
	Immune system	Defense mechanism	Holistic view on RM ***Gap 7: PSM RM is an integrated system.***	Harland et al. (2003)	Alternatives for an instrument to help execute RM are proposed.
				Hoffmann et al. (2013)	Analysis of efficiency and effectiveness of RM.
	Evolution of immune system	Long-term development of system to fit better to conditions	(Organizational) Development of RM in PSM	Tchekogué (2011)	Long-term development of PSM organization swings from one state to another and back, depending on the situation.
				Padhi et al. (2012)	Improved positioning of commodities in Kraljic matrix.
				Juha and Pentti (2008)	Supply risks are examined from the perspective of buying center (organizational) perceptions.
Entry barrier	Skin/endothelium	Protection/prevention against penetration of virus	Prevention management	Schoenherr et al. (2008)	Support of sourcing decision considering 17 risk factors with the use of AHP methodology.
				Micheli et al. (2009)	Risks are measured in a total cost of ownership model and, thus, support decision making.
	Protective clothing (mask)	Technical support for protection against penetration of virus	Technical support for prevention management	Jolai et al. (2011)	Instrument for supplier selection to address uncertainties.
				Moretto et al. (2019)	Instrument to use more supply chain data to evaluate financial risk with a rating model.
Non-specific immune response	(Innate) Non-specific immunity	General defense mechanism	Robustness management	Costantino and Pellegrino (2010)	Effect of risk is reduced due to appropriate sourcing allocation decision.
				Kirilmaz and Erol (2017)	Shift orders between suppliers to mitigate supply side risks.
				Lee (2017)	Pre-allocation of emergency capacities and build-up of back-up suppliers.
				Di Mauro et al. (2020)	Risk aversion leads to higher orders, thus safety stocks.
	Granulocyte	General defense from further spread	RM for typical (routine, operational) risks.	Gaudenzi et al. (2018)	Treatment of commodity price risk (=routine RM for PSM).
				Foerstl et al. (2010)	Treatment of sustainability risk (=routine RM for PSM).
				Pellegrino et al. (2019)	Reaction mode of switching suppliers or substitution of commodities in case of price volatility (= typical PSM situation).
	Macrophage	Identification, alerting, coordination	Risk perception, risk evaluation, and information	Pereira et al. (2019)	Perception of risks and situation impacts how outcomes are achieved. (Risk perception is highly relevant.)
				Li et al. (2017)	Disruption information is critical but is uncertain and, thus, must be assessed efficiently.
				Padhi et al. (2012)	Assessment of risks according to Kraljic matrix.
				Chen (2016)	Divergent perceptions, over/underestimations that can lead to wrong behavior.
Specific immune response	(Adaptive) Specific immunity	Specific defense mechanism	Resilience management ***Gap 4: Current research possesses only a fine-grained understanding.***	Whitney et al. (2014)	Temporary sourcing diversification in case of LFHI risks (earthquake).
				Lee (2017)	Pre-allocation of emergency capacities and back-up suppliers.
	B-cells and antibodies	Defense mechanism outside cell (blood flow)	Defense mechanism addressing logistics	***Gap 1: Logistics issues are hardly addressed and often unmentioned in risk categories.***	
	T-cell and killer cells	Defense mechanism that destroys existing ill cell structures	Defense mechanism addressing structures	Gelderman et al. (2016)	Global sourcing as a reaction to disruptions.
				Barbieri et al. (2019)	Consider relocation of manufacturing activities in times of crisis.
				Knudsen and Servais (2007)	Different supply structures (global, local, etc.) have different supply risks and vulnerability.
				Ateş et al. (2015)	Interplay of category strategies and supply base structures.
	Helper cell	Service and support that enable a specific reaction.	External help (e.g., consultant/ service provider)	***Gap 2: Specialized service providers are not addressed.***	
	Memory cell (B & T)	Increase of reaction speed through learning	Feedback/perceptions, best practices	***Gap 3: Feedback loops and learning from supply disruptions are hardly addressed.***	
	Doctor/nurse		PSM profession/HR competencies		

(*continued on next page*)

Table 1 (*continued*)

	Medical term	Function/Description (medical [sub-] system)	PSM Analogy/Translation (PSM [sub-] system)	Articles Addressing the Topic	Comment on Content
External support and outcomes		Personnel help/ competencies		Feisel et al. (2011)	Development of specific competencies to treat risks through education and training is necessary.
	Medical equipment	Technical support of healing process	Technical support	Tazelaar and Snijders (2004)	Risk decisions by experts often fall behind algorithms.
				Giannakis and Louis (2011)	Development of IT support for supply disruption management.
	Medication/vaccine	External means for prevention or response	Economic/external help	***Gap 5: External help for existing and future LFHI risks is not addressed.***	
	Lockdown/ quarantine	Prevention of spread by social means	Collaboration/relational initiatives	Selviaridis and Spring (2010)	Proposition to address uncertainties with (relational) contracting.
				Uenk and Taponen (2020)	Distribution of risk in service triads.
				Hallikas et al. (2004)	Focus on critical supplier relationships.
				Grudinschi et al. (2014)	Risks influence trust and collaboration (i.e. collaboration fluency).
	Hippocratic oath/ triage	Ethical guidelines	Morals, ethics, and opportunistic behavior	Matopoulos et al. (2019)	Perceived justice is relevant to crisis management.
				Gelderman et al. (2020)	Opportunism of the buyer leads to changed collaboration mode in case of uncertainties.
				Cheng and Chen (2016)	Influence of moral orientations on RM in relationships.
	Healing process: recovery, chronic illness, or death	Failure to recover	Enduring supply limitations **Gap 6: Long-term and side-effects of recovery after supply disruption management are neglected.**	Chae et al. (2019)	Global trade is permanently limited and leads to adjustment of supply base.
				Kinkel and Maloca (2009)	A relatively high percentage of companies change their supply structure (offshoring/ backshoring) in quite a short time, without drawing lessons from previous decisions.
				Park et al. (2016)	High RM propensity helps organizations overcome supply disruptions and gain competitive advantage.

protection clothing/masks that improve the penetration barrier.

Non-specific immune response: The immune response is discussed in two alternative streams: strategies for minimizing the impact of the supply disruption include robustness and resilience (management). Robustness minimizes the extent of a supply disruption, and measures to increase robustness involve keeping safety stock (Di Mauro et al., 2020) or enacting multiple sourcing (Costantino and Pellegrino, 2010). Therefore, an analogy to the human non-specific immune response can be drawn, as it keeps viruses from spreading further within the human body.

Specific immune response: Resilience, on the other hand, represents 'adaptive capability' (Lee, 2017) and, therefore, the reactive approach of supply systems to a specific disruption through the use of backup suppliers (Whitney et al., 2014). An analogy within the human body involves the specific immune response by T cells and B cells. While B cells address the pathogen in the blood, similar to logistics, T cells address ill or infected structures. The adaptive immune response requires exact analysis by macrophages, which can be interpreted as risk perception, information, and evaluation. Furthermore, the immune system is supported by helper T cells, which regulate both the innate and adaptive immune responses and help determine which immune response the body initiates toward a particular pathogen. These cells do not kill pathogens by themselves, but they coordinate the immune response by directing other cells to perform these tasks. We see the use of consultancy and other services as matching counterparts for helper cells.

External support **and outcomes:** External help can also be provided to minimize disruption risks, such as lockdowns or quarantine for infected persons. Overall, these approaches could be seen within the supply system as collaborative or inter-organizational efforts to minimize the occurrence of disruptions. This could be achieved by building trust and adequate risk sharing. Similarly, ethical guidelines, professionalism, and recovery process can be transferred to PSM through analogical thinking as morale/behavior, PSM competencies, and long-term supply effects.

This brief explanation might help retrace how we matched PSM constructs and elements with the immune system model. The discussion refers to the identified PSM literature and how its knowledge suits the analogy and was also used to identify the research gaps (Table 1).

5. The stock of knowledge and gaps in research on the PSM immune system

5.1. Analogy overview

Overall, 41 publications were included in this study, which is an unexpectedly low number. First, we examined a smaller time range, because we expected a far higher number of publications. An event such as Covid-19 makes previous research on supply risk/disruptions appear insufficient, at least from a quantitative point of view. However, we observed a steady growth curve of related publications over time. Almost every year, a small number of new contributions address supply risk/disruption management. Furthermore, it is worth noting that explicit work on LFHI events is scarce.

We must acknowledge that the considered publications addressed many aspects from the perspective of medical analogy. In addition, there were other underdeveloped themes. Altogether, seven topics were identified as the main research gaps. The PSM immune system is shown in Fig. 3.

5.2. Analogy evaluation for matched content

The basic constructs that constitute the immune system are aptly addressed in the relevant PSM literature. The virus, or supply risk, is defined, conceptualized (Zsidisin, 2003), and connected with supply chain vulnerability (Wagner and Bode, 2006). Illness, the manifest supply disruption, is also discussed. Blackhurst et al. (2018) proposed a visualized mapping of disruption effects along supply chains, while Knight et al. (2015) focused on specific risks and their effects on

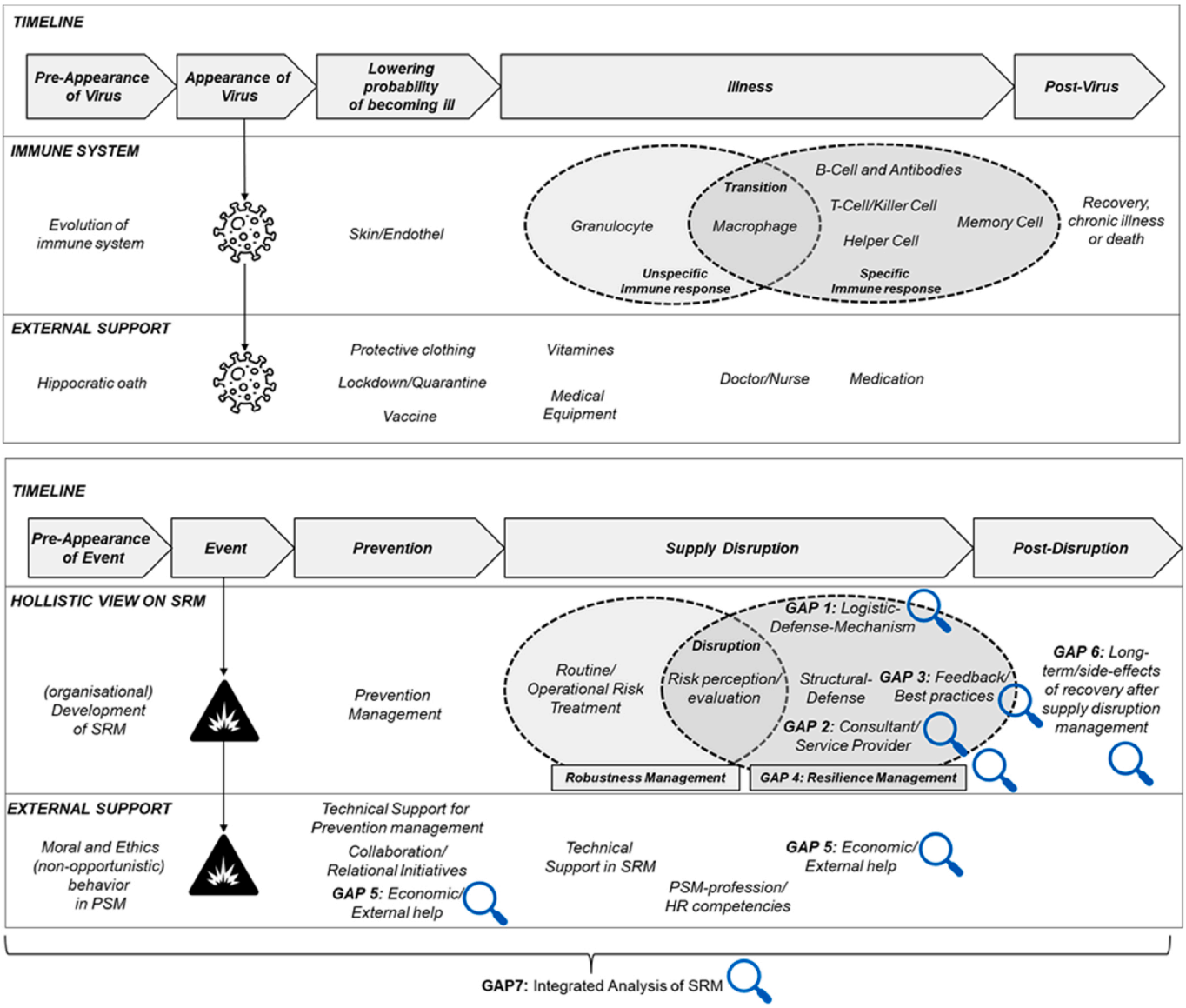

Fig. 3. PSM immune system and research gaps.

innovation. At least two contributions took a holistic view of risk management, similar to the immune system as a whole (Harland et al., 2003; Hoffmann et al., 2013). Overall, there is a conceptual basis of further developing RM, which several contributions have addressed (e.g., Tchekogué 2011; Padhi et al., 2012; Juha and Pentti, 2008). This corresponds to the evolution of the immune system over time. There is always room for more fine-grained research on basic constructs. For example, research on disruptions might benefit from a more stringent typology of PSM disruptions, similar to how L'Hermitte et al. (2014) classified logistics-relevant disasters. However, the basic terms and elements are sufficiently defined.

Based on the three main components, surface entry barriers, unspecific immune response, and adaptive immune response, we see that all areas are addressed at an aggregated level. However, only some elements have more than two matched contributions, and some elements lack corresponding contributions.

Prevention management corresponds to surface barriers and protection clothing/masks in four sources. Schoenherr et al. (2008) and Micheli et al. (2009) evaluated risks to improve decision-making, which prevents supply disruption. Moretto et al. (2019) and Jolai et al. (2011) provide additional technical support to further evaluate the relevant risks. Altogether, the examined studies correspond to prevention management and the necessity to evaluate and prevent risks.

Compared to the nonspecific immune response, we see several contributions that reduce supply risk impact through appropriate sourcing, ordering back-ups, and supplier back-ups (Costantino and Pellegrino, 2010; Kirlmaz and Erol, 2017; Lee, 2017). Demand allocation is a general measure to reduce risk impact, which fits as an unspecific response to supply risk. Other contributions address the more fine-grained and typical PSM risks. Price risks (Gaudenzi et al., 2018), sustainability risks (Foerstl et al., 2010), and price volatility risks (Pellegrino et al., 2019) are threats that are not LFHI and, therefore, could be treated with a general treatment strategy. Macrophages are the connection between the unspecific immune response and the adaptive response. These cells identify the risks and alert the adaptive immune response. We matched four contributions that analyzed the perception or assessment of risk (Pereira et al., 2019; Chen, 2016; Padhi et al., 2012) and related information (Li et al., 2017). These sources examined the influence of risk perception on outcome. Overall, managing robustness is seen as the predominant unspecific immune response, and the major elements of robustness management are addressed.

Next, we discuss the adaptive immune response. Overall, we saw two

contributions that explicitly address a specific response to risk events. Whitney et al. (2014) addressed LFHI risks (i.e., earthquakes) and recommended temporary sourcing diversification. Lee (2017) recommended placing back-up suppliers and activating these backups in emergency situations. Next, we also saw contributions that addressed disrupted supply structures. Similar to T cells and killer cells that destroy infected cells, four articles discussed how supply structures should be reorganized in the case of disruptions and supply risks (Gelderman et al., 2016; Barbieri et al., 2019; Knudsen and Servais, 2007; Ateş et al., 2015).

5.3. Research gaps in resilience management

Unfortunately, we did not see references to B cells or antibodies. Thus, an immune response explicitly addressing "flow," i.e. logistics, is missing. There are some logistics aspects mentioned in other contributions, but there is no article that has this as a core focus. We identify this as research gap #1, because there are some obvious practices that might reduce supply disruption impact: Transport of inventory away from quarantine zones is mentioned in practice (PwC, 2020).

Next, we did not find a match for external help provider. No articles focused on specialized consultancy or service providers that could provide assistance during supply disruptions. Falagara and Wakolbinger (2019) analyzed outsourcing in times of crisis, including the examples of *ad hoc* consultants that schedule aircraft. In addition, a "new service provider" is a viable option, as seen in the logistics discussion on 3 PL, 4 PL, and xPL (Vinai et al., 2009). Nevertheless, it seems that the use of internal/external enablers is hardly addressed, which we see as research gap #2.

Similarly, we did not find a paper that explicitly matched with 'memory cells'. We did not discuss what we learned from previous LFHI events. Wagner and Bode (2006) mention that more attention is paid to catastrophes, disasters, and crises, due to their increased intensity and frequency on a global scale. This is remarkable, because LFHI are rare, but considering earthquakes, tsunamis, pandemics, and other events worldwide, they have been repeatedly confronted. For this reason, we identify this area as research gap #3 and recommend further research to obtain a closer and more focused look at how previous LFHI events have been counteracted.

In addition, we saw some generally under-researched topics. Considering how deeply medicine has examined the immune response at the molecular level, going far beyond our brief description, we see resilience management as an overarching research gap #4. We require a more in-depth theory on how organizations can respond to supply risks and disruptions. Whitney et al. (2014), with their proposition to make temporary sourcing diversification in case of earthquakes, or Lee (2017), who proposed the activation of back-up suppliers in case of disruptions, are positive examples of literature in this field. However, there is no single article that focuses on how to adapt to different LFHI events. Currently, it seems as if many RM sources treat an earthquake in the same way as a tsunami, a terrorist attack, or a pandemic. Understanding what is necessary to develop agile and adaptive resilience management is key to improving the treatment of supply disruptions. It seems as if PSM research on resilience management still has potential, compared to the deep medical understanding of the adaptive immune system, which even describes the cell-interplay at the molecular level.

5.4. Research gap in external support

We assessed external help, including whether medical equipment, professional competencies, and behavioral responses were addressed. For these components, we only saw a few contributions. Feisel et al. (2011) discussed the development of specific competencies to treat risks, which we matched with specific roles, such as doctors or nurses. However, a broad discussion of which competencies are necessary in PSM, and how they are established through training and education does not exist. Tagelaar and Snijders (2004) and Giannakis and Louis (2011) analyzed how technical support could help supply disruption risk management. Surprisingly, we only saw these decision support instruments, while additive manufacturing was not discussed. Additive manufacturing has the potential to reduce the risk impact in cases of supply disruptions (Meyer et al., 2020; Boer et al., 2020), which was not discussed in the sampled articles. Thus, technical discussion on disruption management could be expanded.

Behavioral supply management is a rising field of interest. Therefore, it is not surprising that collaborative initiatives to solve supply disruption risks are discussed in several contributions. Selviaridis and Spring (2010) addressed uncertainties in relational contracting, Uenk and Taponen (2020) examined risk distribution in triads, Hallikas et al. (2004) distinguished critical supplier relationships, and Grudinschi et al. (2014) examined latent constructs, such as trust and collaboration fluency. Ethical guidelines were examined by a match of three contributions, who examined the influence of morals, justice, and opportunism on behavior in times of uncertainty and crisis (Matopoulos et al., 2019; Gelderman et al., 2020; Cheng and Chen, 2016). Joint means of disruption response are considered in COVID-19 lockdown and quarantine, as well as in PSM, where collaborative, behavioral approaches are proposed to treat supply disruptions.

What is clearly missing is the debate on external help for supply chains. Similar to medicine for the human immune system, we see economic support programs for firms, but not for supply chains. If an n-tier member of a supply chain does not recover from the crisis, this could severely impact all involved firms in the supply chain and the whole economy. This is why we see this topic as research gap #5, with the core unaddressed question being what the best 'medicine' for PSM would be.

5.5. Research gap in healing results: long-term effects

Three contributions were matched with the end of the infection/disease. Two of them more or less address a state of chronic illness. Chae et al. (2019) considered global trade as permanently limited, while Kinkel and Maloca (2009) observed a back and forth between offshoring and backshoring in a short time without improving on previous decisions. Only Park et al. (2016) mentioned how full recovery could look: RM could help organizations overcome supply disruptions and gain a competitive advantage. However, it could be inferred that PSM research only addressed three out of the four phases of disaster management (Safran, 2003). Prevention management, disaster occurrence, and disaster response have been addressed sufficiently, but only some contributions discuss the recovery phase. This is identified as research gap #6, because the long-term and side effects of disruption management may be more relevant in the future. In a static case, the aim of supply RM would be to recover from the supply disruption and to bring performance back to or above pre-disruption levels. This goal may be insufficient in the future, when several risk events around the globe overlap, leading to permanent supply disruption. In this case, the ability to estimate the long-term effects of disruptions on business models is key for the strategic management of supply networks.

5.6. Research gap in holistic view

Finally, the analogy revealed that the interaction between the different sub-elements or subsystems of supply RM was not adequately addressed. Although we did see some early evidence of an integrated risk management approach (Hoffmann et al., 2013), medicine has taught us that the immune system fully works only when all subsystems are linked in a systematic (and possibly self-steering) way ('power of interplay'). Therefore, we list research gap #7 as a missing understanding of supply risk management as an integrated system, maybe even as a 'system of systems'. This gap refers to the existing idea of a network-based sourcing approach (Hines 1996).

This gap also guides us back to the quote by Christopher and Peck

(2004), who mentioned the vision of an improved and sustainable supply chain wide resilience, which we referred to in the introduction. This could be realized by leaving behind conventional thinking and goals (e.g., short-term cost optimization). In comparison, this would refer to the need to treat an illness with unconventional medicine.

Under the umbrella term "alternative" medicine, we see a wide range of healing practices that take a different perspective from "conventional" medicine. Many practices use unproven or even disproven methods and stand close to pseudoscience or quackery. However, "alternative" medicine also encompasses approaches like acupressure, acupuncture, homoeopathy, or detoxification via dieting. While some of these treatments are fraudulent, others are established elements in the medical canon and are available in almost every pharmacy and at least partially paid by health insurance (Linde et al., 2014).

A holistic view of the PSM immune system is yet underdeveloped. Therefore, an obvious approach could be to better understand and orchestrate all elements of supply RM. This approach would also encompass the previously mentioned research gaps, as conventional RM addresses supply disruption with a range of specific mechanisms. Therefore, a holistic view of RM must also improve understanding of the interplay of different immune system elements, including hitherto missing aspects of external support or logistics defense mechanisms.

On the other hand, the analogy to conventional and alternative medicine also shows the long-lasting tradition to confront existing medical treatment with new approaches. Similar to conventional medicine, which aims to reveal pseudoscientific or fraudulent practices, PSM research should be careful with new RM approaches. However, PSM should identify, discuss, and critically evaluate other grand "schools of thought" on how to treat supply disruptions. Typically, "alternative medicine' focuses not on the illness and short-term effects, but on sustainable holistic health. This is quite similar to Christopher and Peck (2004) and their claim that more research is needed to establish a sustainable well-working supply system with low vulnerability to supply disruptions. Fig. 4 contrasts "conventional" with a possible "new"/"-alternative" RM.

A dynamic viewpoint on the two identified approaches identified in Fig. 3 shows that research efforts following approach 1 will result in a better RM, which can better prevent or respond to supply disruption. This is somehow the historic path that RM originates from, which has led to current system designs. A more vulnerable supply chain requires better RM, but a performant RM could make managers design supply systems with a higher level of risk exposition. Approach 1 might result in vulnerable or 'ill' supply systems, hopefully with a performant RM immune system.

However, if research verifies approach 2, this might help to construct a "new or alternative RM" that focuses on forming "healthy" supply systems. Approach 2 is not a singular entity, as other concepts, such as circular economy, also question the conventional economic model. Circular economy is often related to a complete reform of human (economic) activity and aims for an extremely efficient (closed-loop) economy that reduces, reuses, and recycles materials and energy (Yuan et al., 2006). Circular economy contrasts conventional "sell-consuming" economy with a resource-saving alternative. Another concept that advocates an alternative economic model is the "Economy for the Common Good" (Felber, 2018). One aspect of this concept is to confront conventional financial balance sheets with a common good balance sheet that considers factors such as solidarity and ecological sustainability. Generally, there are a number of "alternative" approaches discussed in economic literature that envision a "healthier" economy. These attempts to develop solutions for "systemic illness" are less centered on single risk factors or disruption events. Similarly, research in the PSM domain could lead to the development of alternative approaches.

6. Concluding call for a more intense debate for a healthier PSM: limitations and outlook

This study examined how PSM research has addressed the area of supply disruption risk over the last 20 years. The guiding aim of this article was to check whether the PSM response to an LFHI event such as Covid-19 is appropriate and whether something is missing or underdeveloped. The medical analogy to the immune system helped illustrate current knowledge and identify seven areas for future research.

Covid-19 and hectic responses from the practice and media suggest that PSM is not well prepared, but we found the major elements of an immune system mirrored in PSM literature. Basic constructs and terms have been defined for a long time, and prevention management and unspecific and adaptive responses to supply disruptions are discussed in terms of robustness and resilience management. Therefore, our initial finding is that PSM is generally prepared for supply disruptions following the overarching approaches of prevention, robustness, and resilience.

However, we found that PSM research does not focus sufficiently on LFHI events, such as Covid-19. In many contributions, the RM approach considers other threats. Therefore, this study proposes a distinguished analysis of routine high-frequency low-impact risks and extraordinary LFHI risks.

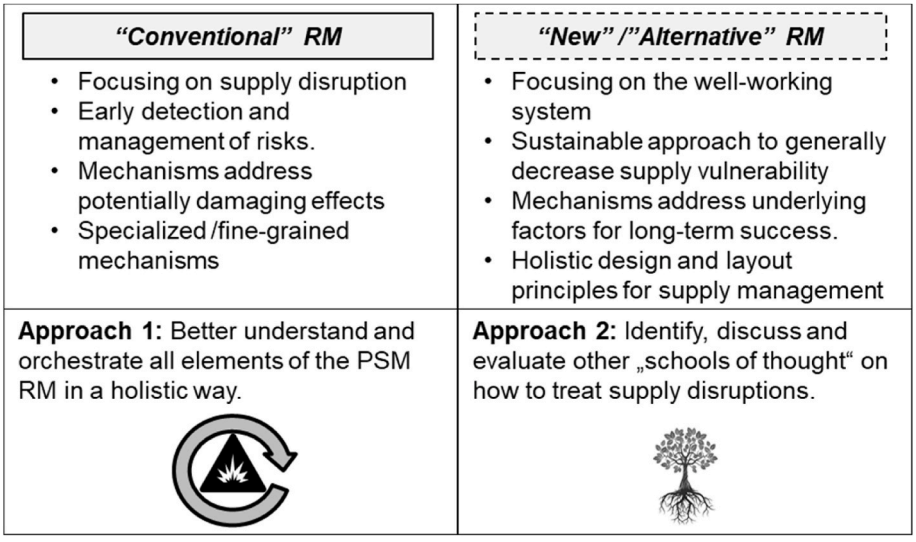

Fig. 4. Proposed approaches to strengthen the PSM immune system.

Furthermore, we saw how precise the medical examination of biochemical processes is through our search on the human immune system. This is far beyond what we can present in our analogy. Therefore, the seven research gaps mentioned above were the only obvious gaps. Other specific components seem to be under-researched, even if some contributions have been matched.

It is remarkable that only a few contributions take a holistic RM perspective. Thus, this note is also a call for a more intense and general debate on how PSM could be established in a 'healthier' way. A debate on different schools of thought, such as conventional or alternative medicine, has not been identified. A more intense academic dispute on how to strategically address supply disruptions is desired.

Finally, we are fully aware of several important limitations. First, the pandemic is still ongoing, and one limitation is clearly the intermediate phase of observing and deriving insights. Second, analogical thinking bears a number of risks for transferring knowledge between disciplines (Witt, 1988). It is perceived as a problem if analogies are taken for granted and no longer scrutinized (Ketokivi, 2017). Third, the authors were not immune biology experts. Therefore, we would like to thank two medical professionals who were helpful in assessing our analogy for major faults. Their primary feedback focused on the aggregated presentation of immunology research, as the introduced subsystems and their coherence could be broken down in more detail. This provides an additional field of research, from which more knowledge could be transferred using analogies to the human immune system.

Author statement

Individual contributions to the paper:

Andreas H. Glas: Conceptualization; Methodology; Investigation; Project administration; Roles/Writing - original draft; Writing - review & editing. **Matthias Meyer:** Conceptualization; Data curation; Formal analysis; Roles/Writing - original draft; Visualization. **Michael Essig:** Supervision; Validation;

Declaration of competing interest

None.

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