

## ENHANCING PHYSICAL ASSET RESILIENCE IN APPAREL MANUFACTURING: INSIGHTS FROM INDUSTRY EXPERTS

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**Abstract:** Apparel manufacturing organisations heavily rely on a wide range of physical assets, such as machinery, equipment, and infrastructure, to maintain continuous operations, meet production demands, and ultimately achieve organisational objectives. Ensuring the resilience of these physical assets, referred to as Physical Asset Resilience (PAR), is crucial for sustaining operational continuity, particularly in the face of potential disruptions such as physical asset failures, blackouts, deterioration, and supply chain delays. Though literature identifies four key capacities of PAR as anticipative, absorptive, restorative, and adaptive capacity, which determine the total PAR capacity of an organisation, there is limited evidence on how these capacities can be enhanced for improved PAR. To address this gap, this study explores the practices that can be integrated into physical asset management practices in order to enhance PAR in the apparel manufacturing organisations. A qualitative research approach was employed using semi-structured interviews with five industry experts who have extensive knowledge and experience in facility operations, physical asset management, and physical asset resilience. The findings confirmed the relevance of the four PAR capacities and identified key practices, including maintaining a skilled workforce, maintaining backup physical assets, allocating required financial resources, conducting risk assessments, conducting scenario planning and others that strengthen resilience in apparel organisations. Experts also highlighted context-specific practices unique to the apparel sector, providing an evidence-based foundation for improving physical asset resilience.

**Keywords:** *physical assets, physical asset resilience, physical asset resilience capacities.*

### 1. Introduction

Physical assets are tangible resources that provide both economic and operational value to an organisation, and include equipment, machinery, tools, and infrastructure (Hayes, 2022). These assets are considered essential resources that allow the delivery of core services and outputs (Trojanowski, 2015). As mentioned by Hayes (2022), depending on the organisation and its operations, a wide range of physical asset types can be found. However, regardless of the type, these assets play a key role in conducting overall organisational processes, contributing to increased profitability within organisations (Schuman and Brent, 2005). However, physical assets are affected by different disruptions, including operational failures, supply chain disruptions, breakdowns, deterioration, to name a few. In order to minimise the negative impacts of such disruptions on organisations' operations, enhancing PAR has become an essential need (Bryant, 2021). PAR is how well a physical asset can withstand disruptions so that it keeps working during the disruptions, or how quickly it can fully recover if it stops (Ayyub, 2014). As Puri & Mishra (2020) pointed out, compared to other organisations, apparel manufacturing organisations are highly reliant on physical assets when driving their operations. Therefore, enhancing resilience in physical assets is especially significant for maintaining continuity, meeting production targets, and ensuring long-term competitiveness in apparel manufacturing organisations. However, extant literature or empirical findings do not discuss the practices that can be used to enhance PAR in apparel manufacturing organisations. Therefore, to address this gap, this study pursues the following objectives. Identifying the practices that can enhance PAR in an organisation, examining the relevance and applicability of literature-based PAR practices within the apparel sector, and categorising these practices under the four PAR capacities. Accordingly, the next sections of the paper discuss the literature review, research method, and expert findings, and analysis, respectively, while the final section concludes the findings of the study with implications for further research directions.

### 2. Literature review

This section of the paper discusses the key literature findings related to PAR and key practices for enhancing PAR in an organisation.

#### 2.1. INTRODUCTION TO PHYSICAL ASSET RESILIENCE

Physical assets are the backbone of an organisation's operations, supporting efficiency, productivity, and organisational success (Schuman & Brent, 2005; Trojanowski, 2015). However, physical assets are also faced with various disruptions, such as breakdowns, natural disasters, deterioration, operational disruptions, and unexpected natural disruptions (Gardoni et al., 2021; Heckmann et al., 2015; Linkov et al., 2013). Therefore, to eliminate or minimise the negative impact of disruptions on

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organisational performance, it is essential to enhance the resilience of physical assets. The word ‘resilience’ originated from the Latin word ‘resiliere’ (Hosseini et al., 2016), and it indicates the meaning of bouncing back. The term resilience was first defined by Ecologist Holling (1973), providing a strong foundation for resilience (Rehak et al., 2018). Moreover, definitions of resilience vary depending on the object of analysis and even when attention is focused on the content of analysis (Carlson et al., 2012). The definition of resilience has evolved and been expanded from several disciplinary perspectives by numerous researchers (Rosowsky, 2020). Among the different contexts in which resilience is studied, PAR is important. The primary focus of PAR is to emphasise the capacity of physical assets to withstand disruptions. i.e., return to the primary design condition or state after an adverse condition can be made by PAR. Rosowsky (2020) also came up with a similar view that PAR refers to the ability of these assets to withstand, adapt to, and recover from disruptions. Moreover, according to the National Infrastructure Advisory Council [NIAC] (2010), PAR is the capacity to predict, absorb, recover, and adapt quickly to disruptions. These reveal that these distinct capacities can collectively characterise PAR.

### 2.2. DETERMINANTS/COMPONENTS OF PHYSICAL ASSET RESILIENCE

An investigation into the literature identified four capacities, i.e., Anticipative, Absorptive, Restorative, and Adaptive, on which the PAR is dependent (Rathnayaka et al., 2024; Kozine et al., 2018). Anticipative capacity refers to the capacity of physical assets to foresee the potential adverse conditions and provide proactive measures (Kozine et al., 2018). Whereas Absorptive capacity, on the other hand, is the degree to which a physical asset can absorb the negative impact of system disturbances and minimise consequences with much effort (Richter, 2015). According to Mottahedi et al. (2021), restorative capacity is the degree to which the physical assets can effectively restore their damaged performance. It incorporates the vital ability to restore complete functionality efficiently and effectively based on disruptions (Rahi, 2019; Yang et al., 2023). The fourth capacity is the adaptive capacity, which is the ability of physical assets to quickly and effectively adapt to changing conditions and respond to the adverse events that could impact their functionality (Comes and Van De Walle, 2014; Kim et al., 2024; Rathnayaka et al., 2022; Engle, 2011).

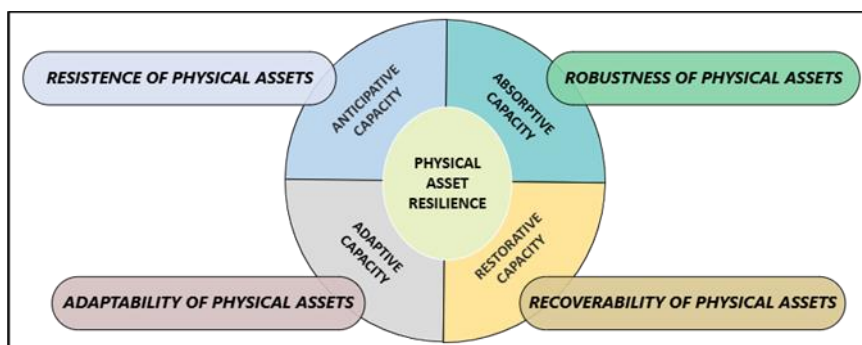


Figure 1: Key Determinants of PAR in an Organisation, Developed by Authors

Apart from the above classification, NIAC (2020) introduced four components of PAR, namely, Resistance, Robustness, Recoverability, and Adaptability, which also comply with the four capacities discussed above. As discussed by Guo et al. (2021), resistance involves preparedness and prevention, whereas robustness offers strength to absorb shocks without the performance degradation of physical assets (Mazur et al., 2019). Moreover, recoverability refers to the capacity of physical assets to return to their initial or necessary performance level following the impact of disruptive events (Francis & Bekera, 2014). In addition, adaptability involves adapting to new changes and continuous improvement (Francis & Bekera, 2014; NIAC, 2020). These align closely with the four capacities, i.e., anticipative, absorptive, restorative, and adaptive, which characterize PAR as it is shown in Figure 1.

### 2.3. ENHANCING PHYSICAL RESILIENCE IN AN ORGANISATION

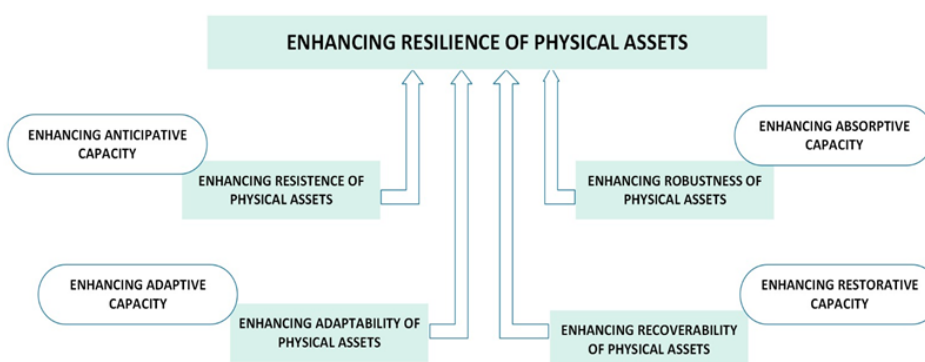


Figure 2: Conceptual framework for enhancing PAR in an organisation

Hence, based on the above discussion (Section 2.2), it can be concluded that the PAR is dependent on four determinants, i.e., resistance, robustness, recoverability, and adaptability (anticipative, absorptive, restorative, and adaptive), and therefore, enhancing PAR means enhancing those four physical asset resilience capacities/ components, as shown in Figure 2.

### *2.3.1 Enhancing resistance of physical assets (Enhancing anticipative capacity)*

According to Osei-Kyei et al. (2022), resistance is the ability of a physical asset to protect itself from a disruptive event, which is prevention. Therefore, it focuses on preventing. Its enhancement depends on disruption preparedness, anticipation ability, and implementing security measures (Splichalova et al., 2020; Rehak et al., 2022). Resistance can therefore be enhanced by improving risk identification, conducting proactive threat assessments, and implementing protective measures that minimise exposure to disruptions.

### *2.3.2. Enhancing robustness of physical assets (Enhancing absorptive capacity)*

According to Stochino et al. (2019), robustness is the capacity of physical assets to absorb the impacts of a disruptive event without experiencing variations in the provision of services, i.e., absorption. According to Rehak et al. (2022), robustness can be enhanced by strengthening redundancy, detection ability, and responsiveness. Hence, improving robustness involves introducing backup physical assets, enhancing mechanisms for early disruption detection, and developing efficient response strategies to limit disruption impacts.

### *2.3.3. Enhancing recoverability of physical assets (Enhancing restorative capacity)*

As mentioned by Slivkova et al. (2017), recoverability is the ability of physical assets to restore their operation to its primary level of service after the effects of a disruptive event have ceased. i.e., recovery or restore. Enhancing recoverability involves establishing standardised restoration procedures, improving repair and replacement processes, and ensuring the availability of necessary recovery resources. These practices allow faster restoration of physical asset functionality following disruptive events.

### *2.3.4. Enhancing adaptability (Enhancing adaptive capacity)*

According to Rehak et al. (2019), adaptability is the capacity to adjust or adapt to shifting conditions. This capacity can be enhanced through continuous learning, innovation, and development processes that allow assets and their supporting systems to evolve based on past disruptions (Mostafavi et al., 2017). Risk management practices, technological upgrades, training, and development initiatives support the improvement of adaptive capacity (Rehak et al., 2018).

## 2.4. PRACTICES FOR ENHANCING PHYSICAL ASSET RESILIENCE IN AN ORGANISATION

The following practices, identified through literature, play a significant role in enhancing PAR within organisational settings.

According to the literature, a technically skilled workforce is one of the most significant factors for managing physical assets in order to enable timely inspection, maintenance, and repair activities (Razak et al., 2012). Experienced workers can effectively manage disruptions, maintain operational continuity, and support rapid recovery (Macharia & Paul, 2024). Furthermore, workforce awareness of disruption risks strengthens preparedness by enabling early identification and response strategies (Thomas et al., 2019). These reveal that maintaining a skilled workforce is essential for enhancing PAR. Senior leadership support is also highlighted in literature as an enabler for embedding PAR within organisational priorities. Without active involvement from leadership, resilience strategies may lack direction, resources, and institutional commitment (Baptiste, 2024). Leadership engagement strengthens preparation by prioritising resilience in planning, fostering a proactive culture, and enabling strategic decision-making that aligns with long-term physical asset sustainability goals (Australian Government, 2024). Also, preparing physical asset operators through targeted training is significant for enhancing resilience. Operators must be consistent with the necessary skills and knowledge to respond effectively to disruptions (Labaka et al., 2015). On the other hand, maintaining backup physical assets increases PAR by providing a continuous supply during disruptions. Hence, Backup systems, redundancies, or alternative resources provide immediate replacements for affected major physical assets, supporting continuous operations (Kim et al., 2024; Ouyang, 2014). Thus, this practice strengthens PAR capacities by improving flexibility, responsiveness, and effective resource allocation in times of crisis (Cutter et al., 2013; Yang et al., 2022).

Besides, the integration of new technology into physical assets enhances resilience by improving monitoring, control, and adaptability under disruptive conditions. As physical asset complexity increases, the risks and failure modes associated with it intensifies correspondingly (Mayfield et al., 2023). For instance, advanced technologies, such as smart sensors, smart grids, or automated systems, support PAR capacities by enabling early detection of issues and real-time response, thereby improving asset performance during disruptions (Argyroudis, 2022). Similarly, budgetary support allows pre-disruption mitigation efforts, a targeted maintenance programme, and timely improvements of physical assets (Gordan, 2023). Simultaneously, sufficient funding enhances anticipative and adaptive capacities by allowing organisations to identify risks early and invest in long-term resilience planning (Center for Climate and Energy Solutions, 2019). Hence, providing adequate financial resources is significant for enhancing PAR. Another important practice is monitoring the performance of physical assets. This practice involves tracking physical asset reliability, including durability, maintenance efficiency, and design robustness, which directly link with the likelihood of continuing operation during disruptive events (Comes & Van De Walle, 2014). Moreover, it is associated with maintainability, or the ability to conduct timely repairs and restore functionality

(Dhillon, 2002). By systematically monitoring physical asset performance before the disruptions, organisations can detect early signs of degradation, identify potential failure points, and implement preventative actions. Thus, practices allow early risk identification and reduce the severity of disruption impacts (Liu et al., 2022). Even though physical assets are monitored before the disruptions, conducting the post-event damage assessments helps to identify the vulnerabilities within physical assets and systematically assess the extent and nature of damage caused by disruptions (Comes & Van De Walle, 2014; Cutter et al., 2013; Kim et al., 2024; Yang et al., 2022). It provides critical data to guide restoration efforts, ensuring they go beyond simply restoring previous conditions and instead strengthen long-term resilience (Eakin et al., 2018). It directly supports restorations by informing recovery strategies and providing evidence-based decision-making for further planning in resilience. On the other hand, predictive stocking strategies, informed by previous data and failure patterns, help certify that major components are readily available when needed (Heckmann et al., 2015). Additionally, strong supplier relationships and efficient procurement processes enable timely access to quality parts (Sharma & Gupta, 2022). Hence, this practice positively affects repairing and supporting rapid asset recovery. These reveal that maintaining and optimising the inventory of spare parts is a key practice for reducing downtime and sustaining physical asset functionality during disruptions. However, as mentioned by Thomas et al. (2020), to properly identify, evaluate, and priorities potential disruptions affecting asset performance, conducting physical asset risk assessments is essential. In line with ISO 31000, this process involves analyzing vulnerabilities, assessing the likelihood of disruptions, and measuring potential impacts. Furthermore, comprehensive risk assessments support the development of mitigation strategies, contingency planning, and effective resource allocation (Nightingale et al., 2018). Hence, this practice enhances PAR capacities by allowing proactive decision-making, promoting cross-functional communication, and fostering a culture of resilience (Leite & Akinci, 2012).

Scenario planning involves developing and analysing potential future disruption scenarios, including worst-case conditions, to enhance organisational preparedness (Hosseini et al., 2016; Jamali et al., 2023). By preparing a range of possible disruptive events and priorities and appropriate responses, organisations can strengthen their ability to manage uncertainty. Thus, this practice directly supports anticipative and adaptive capacities by improving strategic foresight, guiding contingency planning, and enabling more flexible responses to unexpected disruptions in physical asset operations. As mentioned by Mayfield et al (2023), PAR has been impacted by external pressures such as environmental changes and demands in operational. According to Smith and Jones (2021), climate-based disruptions, such as floods, can damage physical assets. Hence, monitoring environmental and climate considerations is essential for enhancing PAR capacities. Nevertheless, robust communication allows timely and effective coordination (Ashrafi et al., 2022). Furthermore, roles and responsibilities during adverse events are made known to all relevant parties by transparent and proper communication channels, response times are reduced, and adverse impacts are mitigated (Lee et al., 2020). According to Smith (2022), clear communication between asset managers and users about potential disruptions is needed to assure that users know how best to utilise physical assets, considering all challenges. This reveals the need for maintaining effective communication. Conducting structured problem-solving, particularly using root cause analysis techniques such as the 5 Whys, plays a key role in enhancing physical asset resilience. By identifying the underlying causes of disruptions, organisations can implement corrective actions that prevent recurrence and ensure long-term asset reliability (Linkov et al., 2018). This approach moves beyond surface-level issues and addresses systemic weaknesses, thereby improving the assets' ability to withstand future disruptions. It supports restorative and adaptive capacities by enabling continuous improvement and reducing the likelihood of repeated failures (Carpenter et al., 2012).

Hence, the literature identified different key practices that can be incorporated into organisations in general for enhancing their PAR. Thus, these practices help to enhance the identified capacities/components mentioned in Figure 02.

### 3. Research Methodology

This study employed a qualitative research approach, allowing for in-depth exploration of expert perspectives on PAR in apparel manufacturing organisations. This approach is particularly suitable when investigating complex and context-specific phenomena that are not easily quantified (Creswell & Poth, 2018). A comprehensive literature review was conducted to determine the PAR capacities and key practices for enhancing PAR in an organisation. Subsequently, an expert interview was conducted to get confirmed the applicability of the identified PAR capacities and practices for enhancing PAR in apparel manufacturing organisations, and to explore whether additional context-specific practices are there which can also be integrated to enhance PAR in apparel manufacturing organisations. Furthermore, expert interviews focused on classifying the identified practices under the respective capacities to which they directly related. Semi-structured interviews were employed to collect data, which allows flexibility in key topics (Gill et al., 2008). Purposive sampling was used to select participants with specialised knowledge of asset operations, resilience planning, and maintenance processes. Five experts were selected from four leading apparel manufacturing organisations in Sri Lanka. These individuals held senior positions in physical assets maintenance, engineering, with more than seven years of industry experience in the asset management field. The selection of certified representation from divisions directly responsible for managing physical assets and PAR. Experts from general operational roles were excluded from the data collection, as the study required input from individuals with specific knowledge and understanding of PAR practices. Table 1 presents an overview of the expert profiles. The interview guideline was organised based on the four PAR capacities identified through the literature review. Questions were developed: (1) the relevance of literature-based practices and (2) the contribution of each practice to the respective PAR capacities. Interviews were conducted individually, and each interview lasted between 45–60 minutes. Prior permission

was gained for audio recording, and all recordings were transcribed for analysis. Further, interviews were analysed using manual content analysis, which is effective in systematically identifying patterns, themes, and insights within qualitative data (Bengtsson, 2016).

Table 1: Profile of Experts

Expert	Designation	Overall Industry Experience in Years
E1	Manager Maintenance	10
E2	Deputy General Manager, Engineering	16
E3	Manager Maintenance	08
E4	Manager Engineering	12
E5	Manager Maintenance	10

#### 4. Data Analysis and Research Findings

The following sections present the data analysis and the main findings of the research.

##### 4.1. PHYSICAL ASSETS USED IN APPAREL MANUFACTURING ORGANISATIONS

The experts highlighted that apparel manufacturing organisations utilise a wide range of physical assets that can be categorised into two main types. i.e., physical assets used for core business (directly used in the production process) and physical assets used for supportive activities (facilitate or support the smooth functioning of production and other organisational operations).

As explained by E2, the machinery used in the apparel production process can be broadly classified into three categories: small-scale, medium-scale, and heavy-scale machinery. E2 further elaborated that *“small-scale machines include machines like hand-cutters and scissor-cutters. Medium-scale machines include fabric inspection machines, band knives, fusing machines, sewing machines, etc. Heavy-scale machines are relatively heavy machines like fabric spreaders and auto-cutters.* This classification highlights the diversity of physical assets involved in production, each playing a unique role in allowing workflow efficiency and product quality. Similarly, E3 provided a detailed explanation of the production process and the corresponding physical assets used at each stage. E3 described that *“in the cutting section, fabric relaxation machines, spreaders, loaders, auto cutters, and manual cutters are used.”* E3 further added that *“cutting tables with vacuum and blowing options are also physical assets.”* This indicates that even supporting equipment, such as worktables with specific functionalities, plays an important role in the efficiency of the cutting process. As pointed out by E3, in the production stage, E3 noted that *“sewing machines are the main physical assets, along with heat seal machines, ironing tables, pocket setters, and loop setters.”* These machines contribute directly to product assembly and finishing accuracy.

Supportive physical assets include utility systems and infrastructure that allow production continuity. As E1, *“generators, chillers, compressors, dryers, AC units, as well as the electrical distribution systems and their components, including transformers and breakers. As well as passenger lifts, goods hoisters, IT equipment, and network components,”* are part of the physical asset section. E2 referred to *“heavy-duty utility machines”* such as *“generators, air compressors, and boilers (diesel boilers and biomass boilers)”*. Further, AC units, but do not use chillers.” Similarly, E3 and E5 mentioned major utility assets such as *“chillers with centralised AC systems, air handling units (AHUs), cooling towers, boilers (diesel, biomass, and furnace oil), generators, and air compressors.”* In addition to the machinery and utility systems, buildings and infrastructure were also recognised as critical supportive physical assets. E5 highlighted that *“buildings and infrastructures are also considered physical assets. This includes the walls, roofs, gutters, airways, and fire lines.”* E3 further added, *“that they have kitchen equipment and furniture in their physical asset list.”*

##### 4.2. IMPORTANCE OF PAR IN APPAREL MANUFACTURING ORGANISATIONS

Experts identified several disruptions that commonly affect physical assets in apparel manufacturing organisations. These include electrical failures, mechanical breakdowns, fire incidents, and lightning-related damage. Such events disrupt production continuity and can lead to costly downtime. For instance, E1 mentioned *“fire incidents, lightning disruptions for electrical systems, generator breakdowns, and transformer failures”* as major disruptions. Similarly, E3 and E4 highlighted that *“mechanical and electrical failures”* are the most frequent disruptions encountered in operations. E5 also reported *“lightning issues and a past fire incident”* as significant events that affected asset performance. These disruptions highlight the significant need for PAR in the apparel manufacturing industry. All experts emphasised that business continuity, productivity, and profitability depend heavily on the resilience of physical assets. E1 stated that *“the total operation of a manufacturing organisation depends upon its physical asset resilience,”* stressing that physical asset protection is essential for both business and customer assurance. E2 pointed out the financial implications, explaining that *“the cost of the physical assets and the negative effect on production if the machine failed”* can be substantial. Similarly, E3 noted that *“production is designed as line-wise, so if any machine breaks down, the whole output stops.”* This highlights that resilient physical assets allow uninterrupted production and reduce losses. E4 concisely summarised this by saying, *“Without resilience, how to run the business?”*. In addition, the experts’ views reaffirmed that PAR not only supports operational stability but also

strengthens an organisation's long-term competitiveness and reputation. For instance, E2 explained that maintaining resilience helps ensure *"on-time delivery and customer satisfaction, even during unexpected breakdowns,"* highlighting the time-sensitive nature of apparel production. Similarly, E3 mentioned that resilient physical assets *"reduce repair costs and help continue operations without frequent interruptions,"* highlighting that resilient physical assets extend their useful life.

#### 4.3. KEY PRACTICES FOR ENHANCING PAR IN APPAREL MANUFACTURING ORGANISATIONS

Practices listed in Table 2 were derived through a two-step process. First, a comprehensive literature review identified a set of established practices associated with enhancing PAR. Second, during content analysis: whether each literature-based practice was relevant to the apparel sector (✓ in Table 2), whether modifications were required to align the practice with apparel sector-specific, and whether new practices were suited from expert insights that had not been discussed in the literature. As summarised in section 2.2, PAR is characterised by four major capacities. i.e., anticipative, absorptive, restorative, and adaptive capacities. As affirmed by all five experts, these four capacities are important for enhancing PAR in any organisation. E1 emphasised the importance of anticipative capacity, noting that preparedness practices or proactive planning are needed to address potential adverse events before they occur. Further, E2 also confirmed this by mentioning that *"anticipative capacity involves anticipating risks and proactively preparing for them. In the apparel manufacturing industry, this is crucial to minimise the downtime and ensure continuous operations."* E2 also stressed the importance of absorptive capacity. According to him, *"absorptive capacity helps to stay competitive."* As E4 highlighted, restorative capacity is essential to recover from disruptions quickly. It is *all about taking physical assets back to the previous performance level as quickly as possible after a disruption.* E3 further stressed its importance by mentioning that adaptability is closely linked to continuous improvement. E3 also specifically highlighted the significance of enhancing restorative capacity, saying, *"restorative capacity is crucial as it allows us to bounce back from adverse events, which reveals effective restoration plans to reduce downtime and prevent major losses"*. As E5 emphasised, *"adaptability is what helps us stay ahead in the ever-changing market, and it involves constant training, feedback, and technological upgrades"*. This revealed that all experts agreed on the four capacities identified in section 2.2.

All the experts agreed with the majority of PAR practices identified through the literature. However, experts refined some practices to better suit, especially for the apparel manufacturing organisations. i.e., E1 stated that the practice *"monitoring the physical asset performance before the disruption is similar to the practice physical assets condition monitoring of any machine, and equipment is necessary."* E1 further highlighted that *"conducting periodic audits on physical assets to identify weak points"* is important for improving PAR. Additionally, E1 noted that *"maintaining emergency response teams is essential,"* and also, E2 suggested that organisations should focus on *"monitoring reliable service providers"* and *"repairing and replacing parts to extend physical assets' life."* E3 introduced another practice, highlighting the environmental and climate monitoring, which, it is not widely used yet in the sector, however, *"providing a suitable working environment for physical assets, such as maintaining the desired humidity level,"* can significantly enhance PAR. A common key practice that emerged across all experts was the importance of continuous training for employees involved in physical asset operation and maintenance. As E2 noted, *"continuous training is a must."* Supporting this, E1 suggested the need to *"establish a separate research section for conducting research regarding the physical assets,"* indicating a proactive approach to resilience improvement through learning and innovation. E1, E2, and E5 also discussed the role of technology integration in strengthening PAR. E2 cautioned that *"every new technology cannot be used because they need to be suited for the company,"* while E5 emphasised that *"the use of new technological detection systems is essential for physical asset resilience."* In addition, all experts agreed that conducting post-event damage assessments is not fully aligned with this apparel manufacturing sector. Hence, based on the above the PAR practices that are applicable for enhancing PAR in apparel manufacturing organisations were determined and they are presented in Table 2.

Table 2: Relevance of Identified Practices for Enhancing PAR in Apparel Manufacturing

Practice	Experts Responses				
	E1	E2	E3	E4	E5
Maintaining a skilled workforce		✓		✓	✓
Providing support by senior leadership	✓	✓	✓	✓	✓
Preparing physical asset operators			✓	✓	✓
Maintaining backup physical assets	✓		✓	✓	✓
Incorporating new technology into physical assets (This practice is modified to using a new technological detection system)	✓		✓	✓	✓
Allocating required financial resources	✓	✓		✓	✓
Monitoring the physical assets' performance before the disruptions (This practice is modified to Conducting physical assets condition monitoring)	✓		✓	✓	✓
Maintaining and optimising the inventory of spare parts	✓			✓	✓

Conducting physical asset risk assessments		✓	✓	✓	✓
Conducting scenario planning		✓	✓	✓	✓
Monitoring environmental and climate considerations (This practice is modified to providing a suitable working environment for physical assets)			✓	✓	✓
Maintaining effective communication	✓		✓	✓	✓
Maintaining a proper risk management process	✓		✓	✓	✓
Conducting problem-solving.	✓			✓	✓
<b>Practices identified as irrelevant and removed by Experts</b>					
Conducting post-event damage assessments	Removed as it is not fully aligned with the apparel manufacturing sector				
<b>New practices added by Experts</b>					
Conducting periodic audits on physical assets	✓		✓	✓	✓
Maintaining an emergency response team	✓	✓	✓	✓	✓
Conducting new research on physical assets' resilience	✓	✓			✓
Monitoring reliable service providers		✓	✓	✓	✓
Repairing and replacing parts of the physical assets		✓	✓	✓	✓

## 5. Discussion

The findings from the literature review and expert interviews confirmed four key capacities of PAR, which are essential for preparedness, absorption, recovery, and adaptation to disruptions. Similarly, the components of PAR, resistance, robustness, recoverability, and adaptability, identified by NIAC (2020) and Francis and Bekera (2014), are closely aligned with these capacities. In line with the literature, resistance and robustness reflect the organisation’s ability to prevent and withstand disruptions through audits and technological systems (Labaka et al., 2015; Argyroudis, 2022). Recoverability aligns with response and restoration practices such as maintaining emergency teams and reliable service providers (Ouyang et al., 2012), while adaptability focuses on learning, innovation, and flexibility through continuous training and technology alignment (Woods, 2015; Mayfield et al., 2023). Expert insights confirmed that these components are essential for ensuring productivity and competitiveness in apparel manufacturing, where disruptions like mechanical failures and supply chain interruptions are common.

The findings from expert interviews further confirmed that PAR is a significant requirement to maintain productivity, business continuity, and competitiveness within apparel manufacturing organisations that depend heavily on uninterrupted physical asset performance (Puri & Mishra, 2020). Disruptions such as mechanical failures, fire incidents, electrical breakdowns, and supply chain disruptions were identified by experts, highlighting the importance of enhancing PAR to minimise downtime and operational losses. For instance, technologies such as smart sensors, smart grids, and automated systems support resilience by enabling early detection of issues and real-time responses, thereby improving asset performance during disruptions (Argyroudis, 2022). Similar to this, the experts specified that “*incorporating new technology*” should be interpreted as “*utilising a new technological detection system,*” stressing how sector-specific insights align with wider technological recommendations from the literature. According to Comes and Van De Walle (2014), monitoring physical asset performance is essential for enhancing PAR. This practice involves tracking physical asset reliability, including durability, maintenance efficiency, and design robustness. In the expert interviews, this practice was modified, “*conducting physical asset condition monitoring,*” reflecting a practical and context-specific approach to maintaining asset resilience. Further, as mentioned by Mayfield et al. (2023), PAR is influenced by external pressures, including environmental changes and operational demands. In the expert interviews, the literature practice of “*monitoring environmental and climate considerations*” was contextualized for the apparel manufacturing sector as “*providing a suitable working environment for physical assets.*” Furthermore, the expert interviews identified several new practices specific to apparel manufacturing. These include conducting periodic audits on physical assets, maintaining an emergency response team, monitoring safety systems for physical assets, monitoring reliable service providers, repairing and replacing parts of physical assets, and conducting new research on physical assets' resilience. Accordingly, Figure 3 illustrates the final output of the expert interview findings, showing the practices that contribute to enhancing physical asset resilience capacities specifically in apparel manufacturing organisations. Hence, Figure 3 illustrates the final framework of practices that

contribute to enhance PAR in apparel manufacturing organisations. The practices are grouped according to the four PAR capacities: anticipative capacity, practices focus on preparedness. Absorptive capacity includes practices that help to reduce the negative impact of disruptions. Restorative capacity represents practices that allow rapid recovery after disruptions. Adaptive capacity practices focus on supporting learning, continuous improvement, and future adaptability. These findings extend existing literature by evidence that PAR practices are not only technically but also organisational and behavioural. These include human considerations, such as continuous training, leadership involvement, and research-based improvement, aligning with prior studies (Labaka et al., 2015; Baptiste, 2024) that view PAR as an outcome of both technological and organisational capabilities. The expert emphasis on establishing dedicated research sections for PAR represents a forward-thinking initiative to set learning and innovation within the operational environment, signifying a transition from a general to a resilient environment. Overall, this illustrates that the integration of both literature-based and expert-identified practices contributes to a holistic approach for enhancing PAR in apparel manufacturing organisations. The combining of these insights suggests that PAR can be effectively strengthened through a combination of preventive, adaptive, and learning-based practices.

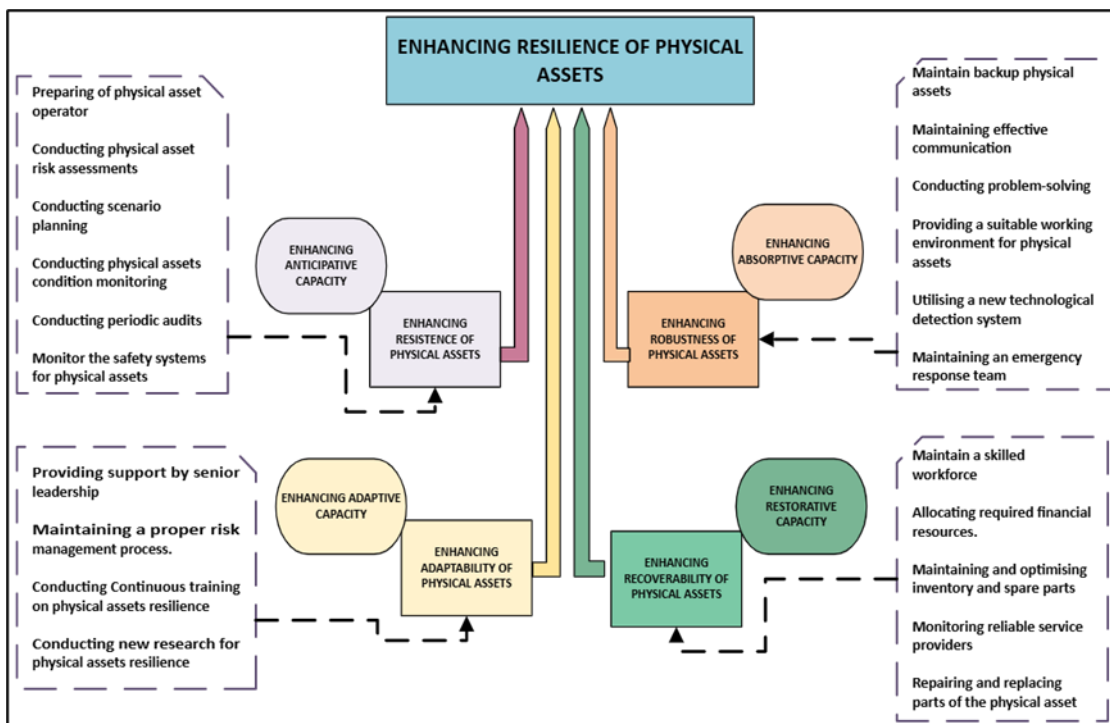


Figure 3: Practices Contributing to Enhance PAR in an Apparel Manufacturing Organisation

## 6. Conclusion

This study explored the enhancement of PAR in apparel manufacturing organisations, a sector that heavily depends on physical assets for operational continuity and production efficiency. Through a comprehensive literature review and expert interviews, four key capacities, i.e., anticipative, absorptive, restorative, and adaptive, were confirmed as the foundation of PAR. These capacities align with the broader resilience components of resistance, robustness, recoverability, and adaptability, thereby providing a structured foundation for strengthening PAR within the apparel sector as well. The findings revealed that while many practices have been identified in literature and through expert insights, the study identified relevant and practically applicable practices that strengthen each capacity within apparel operations. Further, this research provides valuable insights into how apparel manufacturing organisations can practically apply these practices within their physical asset management processes to strengthen each PAR capacity. By adopting practices that enhance anticipative, absorptive, restorative, and adaptive capacities, organisations can improve their ability to foresee potential disruptions, minimise their negative impact, recover efficiently, and adjust to future challenges. Strengthening these individual capacities collectively contributes to enhancing overall PAR. Thus, enhanced PAR allows these organisations to reduce downtime, sustain production flow, and respond effectively to such disruptions. Future research focuses on empirically assessing the effectiveness of these practices across apparel manufacturing organisations in Sri Lanka to strengthen the validity and practical applicability of the findings.

## 5. References

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