CHAPTER 7

BPMN as a tool for adaptive support of pattern recognition and digital diagnostic results in remediation and post-crisis recovery

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Abstract

In the monographic study, a comprehensive analysis of the potential of BPMN 2.0 (Business Process Model and Notation 2.0) as a tool for adaptive support of pattern recognition results and digital diagnostics in the processes of remediation and post-crisis recovery of objects and territories is presented. The relevance of the topic is due to the fact that modern systems of monitoring, remote sensing, computer vision, and intelligent analytics are capable of promptly identifying the consequences of emergency events of natural and technogenic nature, namely: damage to infrastructure objects, contamination of territories, and other crisis consequences. However, at the same time, a managerial and organizational-technological gap often remains between the digital detection of a problem and the actual implementation of reconstruction and remediation measures. In this context, BPMN (Business Process Model and Notation) is proposed to be considered as a process tool that is capable of ensuring the formalization, routing, as well as coordination of further managerial actions based on the results of digital diagnostics. In the monograph, the concept of adaptive support is substantiated, within the framework of which pattern recognition results are interpreted as a basis for launching a managed process of identification, verification, refinement, expert evaluation, selection of an appropriate response protocol, as well as resource and logistical support with subsequent verification of the results of the implemented remediation measures. The authors pay particular attention to the process of handling information with varying degrees of uncertainty, which is associated, among other things, with the probabilistic nature

DOI: 10.21303/978-9908-845-05-0.ch7

of AI (Artificial Intelligence) outputs, including the use of confidence thresholds, escalation mechanisms, as well as repeated data collection and feedback. The monograph substantiates that the application of BPMN (Business Process Model and Notation) makes it possible to link the analytical layer of digital diagnostics with the operational layer of remediation into a unified process logic, thereby increasing the level of transparency, traceability, as well as coordination of actions of key agents and stakeholders.

Keywords

Business process model and notation (BPMN), pattern recognition, digital diagnostics, remediation, post-crisis recovery, computer vision (CV), decision model and notation (DMN), case management model and notation (CMMN), human-in-the-loop (HITL), digital passport of territory.

7.1 Introduction

It should be noted that in the first quarter of the XXI century post-crisis recovery of territories is increasingly determined by the ability of management systems to operationally transform fragmented data into coordinated managerial actions. This is due to the fact that modern risks have a systemic and cascading nature, simultaneously affecting infrastructure, the natural environment, supply chains, institutional mechanisms, and social resilience.

For this reason, the tasks of remediation and post-crisis recovery can no longer be considered as a set of disparate organizational and technical measures. On the contrary, they imply the integration of diagnostic, analytical, organizational, and execution contours into a unified logic of developing and implementing effective managerial decisions. Thus, in the published documents of UNDRR (United Nations Office for Disaster Risk Reduction), in particular in the Global Assessment Report, it is emphasized that modern risks propagate across sectors and territories, and effective loss reduction requires the evolutionary development of management systems and a transition to more coordinated models of coordination [1]. In this context, the search for such instruments that are capable of ensuring a controlled transition from the digital identification of damage to the actual implementation of recovery and remediation measures acquires particular significance.

Additional relevance to the topic is provided by the rapid development of remote sensing, satellite monitoring, computer vision, and intelligent analytics. Modern operational observation systems already make it possible to map natural and technogenic threats, identify damage to buildings and other objects, assess the condition of infrastructure, and record crisis changes across large territories. NASA (National Aeronautics and Space Administration) emphasizes that Earth satellite data are used to map natural hazards and reduce damage from floods, fires, and other disasters, while ARSET (Applied Remote Sensing Training) programs demonstrate their practical application for disaster risk assessment, resilience provision, and humanitarian monitoring. In turn, CEMS (Copernicus Emergency Management Service) already provides cartographic support for the management of natural and anthropogenic emergencies, humanitarian crises, as well as tasks of post-conflict recovery and reconstruction planning. This indicates that the technological base for the operational acquisition of digital information on the nature of damage and the spatial distribution of consequences has already been formed. At the same time, the availability of diagnostic data in itself does not yet guarantee their effective transformation into a sequence of managerial and logistical actions [2–5].

Practice shows that one of the key barriers in the management of crises and emergencies remains the gap between the stages of damage detection and the implementation of managerial decisions for consequence elimination and remediation. Even in the presence of high-quality results of pattern recognition, a number of unresolved issues still remain, related to their verification, prioritization, alignment with regulatory protocols, allocation of actually available resources, involvement of experts in selecting the optimal scenario, and re-validation of results after the completion of the remediation work complex.

The situation is further complicated by the fact that the outputs of AI (Artificial Intelligence) models often retain a probabilistic nature and are quite sensitive to domain shifts, the type of disaster, the specific features of the territorial distribution of damaged objects, and the characteristics of the input data. Thus, studies based on xBD/xView2 confirm that automated damage assessment of buildings using satellite imagery is a significant direction for disaster response and recovery, however, it requires unified damage scales and more precise interpretation of results. The analysis of recent scientific works also demonstrates the fact that the generalization capability of models to new challenges and threats of a hybrid nature still remains limited, whereas adaptive methods yield better results when the disaster context is taken into account. Consequently, for remediation tasks, not only the recognition algorithm itself is of fundamental importance, but also the process mechanism of supporting its result under conditions of uncertainty [6–10].

It is precisely in this, in the opinion of the authors of the monograph, that the study and practical significance of BPMN (Business Process Model and Notation) lies. According to the specification of Object Management Group (Object Management Group), BPMN is a formal standard for business process modeling that combines clarity for stakeholders with a level of precision sufficient for translating diagrams into software process components.

This makes BPMN potentially suitable for constructing an end-to-end logic of coordination in complex interagency and multivector remediation processes, especially in situations of elimination of emergencies of natural and technogenic nature, where it is necessary to manage not only the sequence of actions, but also exceptions, multivariant scenarios, events, the alignment of various organizational, economic, technical and other decisions, as well as the necessity of direct participation of authorized persons within the management loop. Studies on process organization in crisis situations indicate the BPMN advantages and the expediency of its combination with CMMN (Case Management Model and Notation) and DMN (Decision Model and Notation) for the purpose of supporting more flexible knowledge-intensive scenarios. Therefore, an in-depth study of BPMN not as a recognition tool, but as a tool for adaptive support of digital diagnostics results appears logical and methodologically justified. The practical value of such an approach consists in overcoming the fragmentation of digital crisis management contours through process logic that allows for data refinement, repeated data collection, expert verification, and context-dependent case routing. No less important additional advantage remains the possibility of its validation based on open data from Copernicus Emergency Management Service, xBD/xView2, and SpaceNet 8 [11–14].

The objective of the study is to substantiate BPMN as a tool for adaptive support of pattern recognition results and digital diagnostics in remediation and post-crisis recovery processes. To achieve the stated objective, it is necessary to solve three interrelated tasks. Firstly, to reveal the specifics of the managerial gap between the digital identification of consequences of emergencies of various nature and scale and the actual implementation of recovery measures, as well as to determine the place of Pattern Recognition results and digital diagnostics within the overall architecture of managerial decision-making in the remediation of affected objects and territories. Secondly, to substantiate the possibilities of using BPMN for the purpose of formalizing routes of verification, escalation, coordination, and control under conditions of uncertainty of AI outputs. Thirdly, to identify the practical applicability of the proposed approach for constructing controllable digital response contours and to outline the possibilities of its verification based on the composition of open benchmark datasets, crisis geodata, and process metrics for evaluating orchestration.

The solution of these tasks will make it possible to clarify the theoretical foundations of process orchestration of digital diagnostics and, at the same time, to enhance the practical applicability of BPMN in complex scenarios of remediation and post-crisis recovery.

7.2 State of the study of the problem and literature review

First of all, it should be emphasized that the state of the study of the problem under investigation is characterized by a fairly high degree of fragmentation. Thus, the scientific literature widely presents studies on process modeling, digital diagnostics of the consequences of emergency events of a crisis nature, remote sensing, and automated assessment of incurred damage; however, their integration into a unified logic of adaptive support of recognition results for the tasks of remediation and post-crisis recovery remains rather limited. It should be noted that the theoretical and methodological layer directly related to BPMN as a standard for business process modeling has been studied and developed in sufficient depth. The OMG specification establishes BPMN as a generally accepted notation oriented simultaneously toward comprehensibility for all key agents and stakeholders and, at the same time, toward sufficient formal precision for translation into software process components. According to the conviction of the authors of the monograph, it is precisely this dual nature of BPMN, as well as the combination of visual transparency and formal certainty, that has determined its wide dissemination in the tasks of regulation, automation, and coordination of processes in various subject areas [8, 11].

At the same time, studies show that classical BPMN is most effective in cases where the process can be represented as a relatively structured flow of actions. Under conditions of emergencies and weakly predictable scenarios of event unfolding, procedural logic alone often proves insufficient, which has led to increased interest in the combined use of BPMN, CMMN, and DMN. Within such a combination, BPMN makes it possible to ensure flow orchestration, CMMN provides case-oriented flexibility, and DMN supports managerial decision-making. As noted in their scientific work by Niemz, Gehrke, and Ruhland, it is precisely such an integrated architecture that is better adapted to the changing conditions of crisis situations than the isolated application of a single notation. A similar conclusion is also contained in studies on adaptive case management in emergency response, where it is emphasized that hybrid process models make it possible to adapt execution more rapidly to the development of an incident while simultaneously preserving controllability under conditions of increasing uncertainty [8].

Another significant body of the study is associated with the digital diagnostics of the consequences of crisis phenomena of natural, technogenic, and military nature based on remote sensing, computer vision, and Pattern Recognition methods. In recent years, this direction has advanced substantially due to the development of open datasets and benchmark platforms. Of particular importance is the xBD dataset, created as a large-scale open resource for change detection and building damage assessment in the interests of humanitarian assistance and disaster recovery. The authors of xBD emphasize that after the occurrence of emergency events, rapid assessment of the actual condition and incurred damage, as well as logistical planning of evacuation, delivery, and distribution of resources, are critically important. In this context, satellite imagery in combination with computer vision is capable of significantly reducing the burden on physical verification through inspection. Additionally, SpaceNet 8 makes it possible to expand this approach by integrating tasks of recognition of buildings, roads, and other objects, thereby extending the horizon of functional capabilities not only to damage detection but also to the analysis of post-crisis response and the successful remediation of affected territories [11].

In contemporary science, the capabilities of tools for the primary digital identification of damage and environmental changes associated with the occurrence of emergency events have been studied in considerable depth. Thus, operational platforms such as CEMS confirm that, in practice, a mature infrastructure for obtaining open geospatial data for emergency response, risk, and recovery mapping has already been formed. In particular, Copernicus Emergency Management Service explicitly indicates that recovery mapping is used for the purposes of supporting recovery process management, reconstruction planning, agricultural and natural area recovery, as well as the formation of post-crisis resilience [15]. The above makes it possible to conclude that the layer of digital diagnostics and spatial documentation of damage is, in general, significantly more developed than the layer of subsequent process support of the obtained results [16, 17].

A separate direction of scientific literature is associated with the study of the problems of applying remote sensing and spatial methods for the assessment of pollution and environmental monitoring, which are directly related to the processes of elimination of contamination of various nature and the implementation of remediation measures. Publications of USGS (United States Geological Survey) and contemporary review studies show that remote sensing can be used for the identification of residual contamination, the assessment of vegetative stress as a proxy indicator of pollution, the mapping of hotspot zones, and the support of environmental decision-making in affected territories. Recent works on monitoring soil contamination and technogenic impacts confirm that geodata and machine learning methods significantly expand the horizon of environmental diagnostics capabilities; however, in most cases they still remain tools of observation and analytics rather than elements of a formalized process for translating results into specific managerial actions. Consequently, within the environmental and remediation contour, the same pattern manifests as in the field of disaster damage assessment: diagnostics develops faster than the process orchestration of its results [18–22].

In addition, one of the significant directions of in-depth scientific research is constituted by publications on process mining and data-driven approaches in the context of process execution analysis. The BPI Challenge and the open event logs associated with it have effectively formed a benchmark environment for testing methods of process mining, predictive monitoring, and bottleneck analysis. According to the view of the authors of the monograph, the significance of this direction within the raised problem lies in the existence of an already established apparatus of metrics and approaches for evaluating the actual behavior of processes, including delays, deviations, repeated actions, and bottlenecks in the implementation of operations. At the same time, a comprehensive survey of publications on this topic has revealed the fact that available benchmark logs, as a rule, relate to banking, administrative, medical, and other organizational processes, rather than to the elimination of the consequences of emergency events and subsequent remediation, and not to the support of AI results in crisis systems. Consequently, the methodological toolkit for evaluating orchestration already exists, whereas the domain-specific event base for remediation remains practically undeveloped [23, 24].

An important layer of contemporary research is constituted by publications reflecting issues related to HITL (Human-in-the-Loop) and human oversight in high-risk AI systems. Thus, studies emphasize that in high-stakes domains a human must retain control over critical decisions, while AI acts as a means of supporting them. Within the logic of the present monographic study, this is of fundamental importance, since the results of pattern recognition in crisis diagnostics often have a probabilistic nature and require verification, refinement, and contextual interpretation. At the same time, the literature on HITL predominantly develops within the framework of AI governance, explanation, reliability, and decision support, rather than within the framework of formalized BPMN orchestration of the full incident life cycle – from recognition to the completion of the remediation case [25–28].

Thus, a comprehensive analysis of literary sources makes it possible to draw several generalizing conclusions. In contemporary science, such directions as process modeling based on BPMN, hybrid crisis management models BPMN/CMMN/DMN, digital damage assessment based on satellite data, open crisis geodata, and process mining methods have already been sufficiently well developed. To a significantly lesser extent, the question of how the probabilistic result of Pattern Recognition and digital diagnostics can be transformed into an adaptively supported, verifiable, and controllable process of remediation and post-crisis recovery has been studied. At least four bottlenecks remain that require in-depth investigation: the absence of a domain-specific orchestration model of recognition results for remediation, insufficient elaboration of process handling of uncertainty of AI outputs, weak integration of HITL into executable process contours, and the absence of a direct open benchmark for the verification of such hybrid systems. It is precisely the combination of these gaps that forms a research niche for further substantiation of BPMN as a tool for adaptive support of pattern recognition results and digital diagnostics in remediation and post-crisis recovery [8, 11, 17, 25].

The results of the problem-oriented analytical cross-section are presented below in **Table 7.1**.

Table 7.1 Degree of study of the problem by blocks across research directions

Research Direction Block	Representative Sources	What Has Been Studied to Date	Bottlenecks / What Has Been Insufficiently Studied	Theoretical Maturity (0–5)	Practical Development (0–5)
1	2	3	4	5	6
BPMN as a process modeling standard	OMG BPMN 2.0 (2010–2013)	Formal notation, semantics of elements, modeling and automation of processes	The role of BPMN in supporting probabilistic AI outputs is insufficiently disclosed	5	5
BPMN in crisis and weakly predictable scenarios	Niemz, Gehrke, Ruhland (2021)	Application of BPMN for crisis situations and coordination of actions	Insufficient number of cases for remediation and post-crisis recovery	3	2
Integration of BPMN + CMMN + DMN for adaptive management	Niemz et al. (2021) and related works	Hybrid management of structured and unstructured scenarios, decision support	Insufficient adaptation to supporting Pattern Recognition results	4	2
Pattern Recognition / Computer Vision for damage assessment	Gupta et al., xBD (2019)	Damage recognition, change detection, building damage assessment	Recognition results are not translated into formalized process support	4	4
Open benchmark datasets for crisis visual diagnostics	xBD, xFBD, SpaceNet 8	Benchmark evaluation of damage detection, changes, infrastructure disruptions	No benchmark linkage with decision orchestration and closure of remediation cases	4	4

Continuation of Table 7.1

1	2	3	4	5	6
Open crisis geodata and recovery mapping	Copernicus EMS	Emergency, preparedness, and recovery mapping, damage assessment products	Geodata are weakly integrated into executable BPMN contours of adaptive support	4	4
Process mining and benchmark culture of event logs	BPI Challenge, Process Mining Task Force	Methods of execution analysis, bottlenecks, rework, deviations, process performance	Absence of open remediation / case-orchestration event logs	5	4
HITL in high-stakes AI	Contemporary HITL studies	Human control, expert verification, oversight	Weak formalization of HITL integration into BPMN remediation contours	3	2
Integration of AI diagnostics and process orchestration	Related works on workflow and crisis management	Partial linkage of analytics, workflow, and decision support	No stable end-to-end model of adaptive orchestration	2	1
Adaptive support of pattern recognition results and digital diagnostics in remediation and post-crisis recovery	Direct scientific sources not identified	Only related conceptual and applied foundations are available	Absence of an integral model, mature terminology, and direct benchmark	1	0–1

Note: Evaluation scale: 0 – practically not represented; 1 – isolated formulations; 2 – fragmentarily studied; 3 – moderately studied; 4 – well studied; 5 – comprehensively studied / standardized / supported by developed practice. Representative blocks of the table are based on the BPMN standard of the OMG, open disaster benchmarks xBD and SpaceNet 8, recovery mapping of the Copernicus Emergency Management Service, and the benchmark culture of process mining

7.3 Conceptual foundations of adaptive support of pattern recognition results by BPMN means

The conceptual idea of adaptive support of Pattern Recognition results by BPMN means should be presented based on the distinction between the very fact of digital recognition and the subsequent management based on these results. It refers to the fact that in crisis and post-crisis scenarios, pattern recognition forms a diagnostic conclusion regarding the nature and scale of damage, contamination, change of an object and/or territory, as well as other anomalies; however, such a conclusion is not yet identical to a managerial decision. It is precisely for this reason that the result of Pattern Recognition should be considered not as the final point of analytics, but as an input to a subsequent process of verification, routing, and coordination of further managerial actions undertaken. In this sense, adaptive support means the organization of a controlled life cycle of the recognition result – from its initial fixation to the closure of the case after the implementation of remediation, reconstruction, and other recovery measures [11, 17, 29].

The basic logic of the proposed approach is grounded in the BPMN perception as a formal standard for process description that combines comprehensibility for all agents and stakeholders with semantic precision sufficient for software implementation. By virtue of this, BPMN may be considered as a process framework which, based on the results of digital diagnostics, makes it possible to structure an organized logic of subsequent managerial actions. The first conceptual foundation of the approach thus lies in the differentiation between the analytical layer and the orchestration layer; at the same time, BPMN does not substitute the AI model, but ensures the management of the subsequent remediation process within the decision-making system [29, 30].

The second foundation is related to the probabilistic nature of Pattern Recognition results. As demonstrated by publicly available benchmark datasets, in particular xBD, post-crisis damage assessment based on satellite data depends on the quality of input data, the disaster context, and the structure of damage classes. Consequently, the recognition result must be interpreted not only in terms of its content, but also in terms of the level of confidence, completeness, and contextual relevance, and the process support system must distinguish at least three situations: sufficient confidence for automatic transition to action, intermediate confidence – for additional verification, and insufficient confidence – for escalation, repeated data collection, or deferred decision-making [11].

The third conceptual foundation lies in the fact that adaptive support should not be reduced to a linear workflow as such. Thus, if the result of pattern recognition enters the system as a signal of a potential incident (for example, a destroyed infrastructure object, a contaminated territory, etc.), then in this case the subsequent logic must take into account not only the type of detected pattern, but also the context of its occurrence, key priorities, temporal and resource constraints, regulatory requirements, as well as the necessity of participation of specific actors (including experts, military personnel, and other specialists). Consequently, at the center of the model there should be not a rigid scenario, but a controlled case routing that provides for deviations, returns to previous stages and operations, possible branching options, as well as repeated verification cycles. Within this logic, BPMN acts as the core of the structured part of orchestration, whereas adaptability is ensured through event-based logic, gateways, as well as subprocesses and tasks of specific actors of the remediation process and stakeholders with the integration of external rules. From this perspective, adaptive support is interpreted by the authors as a process mode in which the result of pattern recognition is not automatically accepted as a final basis for a specific managerial action, but passes through a contour of additional refinement, evaluation and forecasting, as well as selection of the further path and control of execution of a specific remediation scenario.

It should be noted that a key principle of the model proposed by the authors is the event-driven nature of interaction between the diagnostic and execution contours. Thus, within this logic, the Pattern Recognition result should enter the BPMN process not in the form of an abstract report, but as a structured event that reflects the type of pattern with geospatial reference, determination of the confidence level based on actual data sources, time of detection, and a preliminary assessment of the priority class. It is precisely this that makes it possible to automatically initiate the process of elimination of the consequences of an emergency event, trigger the corresponding subprocess, or embed a new case into an already operating management contour.

According to the authors of the monograph, the principle of multi-level data verification is no less important. Thus, in high-risk and post-crisis domains, it is unacceptable to build the entire management cycle on a single digital output without verifying its level of reliability. Therefore, in the proposed model, at least automatic verification according to a set of rules is provided, as well as the possibility of verification through the use of additional data sources and/or expert evaluation. In this regard, Human-in-the-Loop (HITL) occupies a special place in this logic as an institutionalized point of process escalation, namely: human participation acts as an embedded element of adaptive support of the remediation process management.

In addition to the above, no less significant is the principle of context dependency of the post-crisis management process. Thus, the same recognition result may require different responses depending on the type and scale of contamination, characteristics of the territory, accessibility of the area for the implementation of remediation measures, weather conditions, availability of laboratories, reagents, secondary risks of contamination or its scaling, as well as existing regulatory constraints. In this regard, the BPMN process must not only record the presence of identified patterns, but also correlate them with the parameters of the domain context. This determines the expediency of the architecture proposed by the authors, in which BPMN is responsible for the entire complex of remediation measures, while the decision layer or rule-based logic determines the conditions for route selection, threat level, and type of response protocol. For the domain of remediation and post-crisis recovery, such logic is of particular importance, since the corresponding processes are multistage and, in a number of cases, rather long-term. Consequently, BPMN as a tool of adaptive support must ensure not a one-time switch to a specific managerial action, but the maintenance of the management case throughout several phases – from the initial assessment of contamination to confirmation of the effect of the implemented remediation measures complex.

From this follows the principle of a closed loop, which consists in the fact that adaptive support of the remediation management process must be completed by repeated acquisition of digital data, their comparison with the initial state of the affected object, and fixation of the achieved result. In generalized form, such a model includes six basic stages, namely: registration and structuring of the Pattern Recognition result; initial assessment of the level of its confidence and criticality; selection of the verification route; assignment of tasks and coordination of response/remediation actions; monitoring of the execution of the complex of works for elimination of the consequences of the emergency event; repeated digital verification and case closure.

As a result of a comprehensive analysis, the authors of the monograph have established that the availability of open benchmark datasets for recognition of damage incurred as a result of emergency events, geospatial recovery products, and process metrics for evaluating the execution of remediation operations makes it possible to consider this model as not only theoretically substantiated, but also potentially verifiable within a compositional research framework [8, 29, 31].

The scheme presented above reflects an architecture in which the result of pattern recognition is presented not as a final analytical product, but as an input to a controlled process of supporting the remediation of an affected object or territory. Thus, at the initial levels, data from heterogeneous sources are accumulated and integrated, after which the Pattern Recognition layer generates a primary digital output regarding the characteristics of damage, its parameters, associated risks, etc. This output is then transformed into a structured event containing the type of pattern, geospatial reference, determination of the confidence level, a list of data sources, as well as key priorities and constraints, which makes it possible to embed digital diagnostics into an executable management contour.

The central element of the model is the BPMN contour of adaptive support of the remediation process, within which case registration, assessment of the level of its criticality and data reliability, selection of the scenario/route of further actions, additional verification, or expert evaluation are carried out. As mentioned earlier, Human-in-the-Loop in the proposed architecture acts as an embedded component rather than an external addition, since the participation of experts (including military personnel, technical specialists, etc.) ensures confirmation, refinement, or rejection of the obtained AI output. After that, the BPMN contour makes it possible to link the analytical data layer with practical actions for the elimination of the consequences of an emergency event, while ensuring the selection of an optimal remediation scenario with subsequent coordination of process participants and control of its execution.

The execution layer encompasses all participants of the remediation process who interpret the data of digital diagnostics, namely: contractors, regulators, military personnel, technical specialists, logistics operators, laboratory staff, expert groups, etc. Of fundamental importance is the feedback verification layer, which closes the architecture into a complete controlled cycle. Thus, after the implementation of the complex of remediation measures, repeated monitoring and comparison of the state of the affected object/territory according to the "before/after" scheme are carried out. At the same time, full case closure is permitted only after confirmation of the achieved restoration effect, which ensures the result-oriented nature of the model. Finally, the concluding level is the formation of a digital passport of the object/site, reporting, as well as the accumulation of lessons learned. In this context, process mining and process analytics create the basis for subsequent final evaluation of orchestration effectiveness and improvement of the remediation management system.

The conceptual architectural scheme is presented below in **Fig. 7.1**.

It should be emphasized that the Digital Passport of the affected object or territory is one of the central results of the architecture proposed by the authors, since it is precisely it that makes it possible to interlink digital diagnostics, remediation/recovery actions, the results of repeated data verification, institutional memory, and the reuse of the body of information from various sources upon the occurrence of new emergency events. Within the framework of this model, it is advisable to interpret it as an integral digital artifact of the state, the entire history of interventions, and the verified result for a specific spatial remediation unit. In other words, it is a specific structured, spatially referenced digital object in which both its initial and current state are recorded, the results of digital diagnostics, the entire history of interventions related to the elimination of the consequences of an emergency situation, information on the implemented remediation scenarios, the results of the conducted post-verification, as well as the current status of operational suitability, level of risk and/or restrictions. Thus, the Digital Passport ensures full digital traceability of all stages of management, namely: from the identified damage or contamination to the confirmed result of the implemented complex of remediation measures, accumulates institutional memory, supports intersystem exchange between GIS and the BPMN platform, as well as monitoring systems and analytical contours. At the same time, it also forms the basis for repeated monitoring, reassessment of the level of risk, and the initiation of a new remediation process cycle in the event of emergency situations.

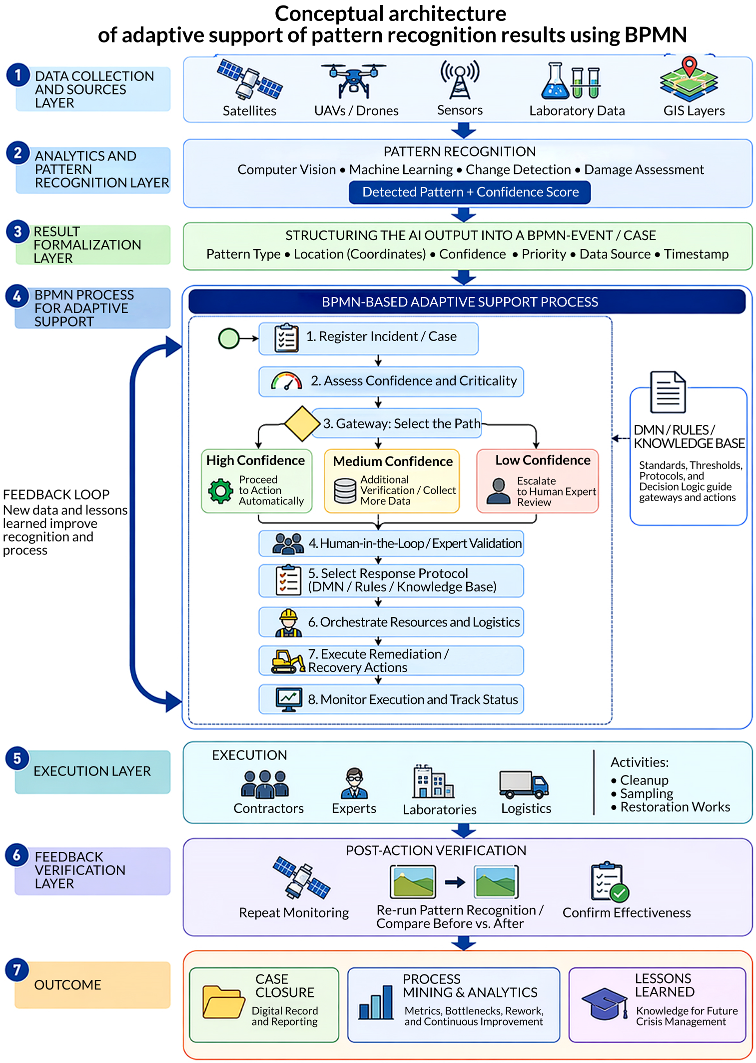

Fig. 7.1 Conceptual architecture of adaptive orchestration of pattern recognition results using BPMN

Note: images, photorealistic images, diagrams, drawings, figures that have been generated by artificial intelligence should be labeled "Imagined with AI".

Digital Passport of the territory as the final artifact of the BPMN contour of adaptive support of the remediation management process

From the perspective of the architecture of BPMN contours, the Digital Passport of the territory is interpreted by the authors as the final artifact of the closure stage of the remediation process of the affected object, which is formed after the completion of the full cycle of adaptive support. At a minimum, it should include the identifier of the object or affected territory, the type and nature of consequences, geometry and coordinate reference, the results of Pattern Recognition and digital diagnostics, the confidence level and verification status, information on the BPMN support route, as well as the list of implemented cleaning and recovery measures, the results of repeated verification, the current status of the remediation object, the presence of operational risk, as well as related digital artifacts. In the context of practical implementation, the basic format of its representation may be GeoJSON with an extended set of attributes, which it is advisable to supplement with structured JSON schemas for the purpose of integration with external services. For these purposes, it is also possible to use JSON-LD (JavaScript Object Notation for Linked Data) or RDF (Resource Description Framework). Unlike a one-time report, the Digital Passport should be considered as a dynamically updated digital object with its own life cycle – from creation and phased enrichment to final validation, reuse, and revision under new crises.

Thus, it acts not as a secondary appendix to the BPMN contour, but as its substantively significant outcome and, at the same time, as a mechanism for consolidating the verified state of the territory. The generalized vision of the structure of the Digital Passport of the territory is presented in **Table 7.2**.

The structure presented above demonstrates the fact that the Digital Passport of the territory should be considered as a final digital artifact that makes it possible to integrate spatial, diagnostic, process-related, and verification information about the affected object, including the site on which it is located. It records not only the initial incident, but also the full cycle of adaptive support – from case registration to confirmation of the result of the complex of implemented operations – while ensuring traceability of managerial decisions made, transparency of implemented measures, and accumulation of institutional memory. Due to the possibility of phased updating, the Digital Passport may be suitable not only for reporting, but also for reuse in the event of other crisis situations.

Summarizing all of the above, it may be argued that the most significant aspect, in the opinion of the authors, is the possibility of managing the level of uncertainty, namely: the presence of a confidence score means that the system can change the case route depending on the level of confidence, context, and criticality of the incident, rather than being limited to the binary scheme "recognized/not recognized". Therefore, in the case of an insufficient confidence level, the process must provide for additional verification, expert involvement, and/or repeated data collection. Such an approach makes it possible to bring the case from the recognition stage to the selection of a protocol, the launch of the resource-use process, repeated verification, and formation of the Digital Passport of the site, which gives the idea of end-to-end orchestration both theoretical and practical validity. The next logical step of the study is the routing scheme by confidence level (**Fig. 7.2**).

Table 7.2 Structure of the digital passport of the territory

Passport Element	Characteristics / Composition of Information	Source of Formation	Stage of Update
Identification Block	Identifier of the passport and the site, type and functional purpose of the territory	BPMN-system, GIS, object registries, planning documentation	Creation of the passport; upon status change
Spatial Block	Coordinates, contour, geometry, and spatial localization of the site	GIS, satellite data, Copernicus Emergency Management Service, local geodata	Creation; refinement during repeated verification
Crisis Impact Block	Type of incident, date of detection, source of the primary signal	Event layer, AI/ML system, UAVs (Unmanned Aerial Vehicles), sensors, external reports	Initial case registration
Diagnostic Block	Type of identified pattern, class of damage/contamination, results of digital diagnostics	CV pipeline, AI/ML-model, analytical layer	Initial registration; repeated diagnostics
Confidence and Verification Block	Confidence level of the output, confirmation status, expert conclusions	CV pipeline, BPMN/DMN, expert verification	Verification; repeated assessment
Prioritization and Routing Block	Case criticality, selected BPMN support branch, assigned response protocol	DMN, rule engine, BPMN engine, expert decisions	After initial assessment; upon route revision
Execution Block	Involved participants, resources, list of implemented measures, implementation timelines	Operational systems, BPMN tasks, case records, contractor reports	During execution
Re-verification Block	Results of post-remediation control, comparison of "before/after" states	Repeated monitoring, GIS, CV pipeline, laboratory data	After completion of measures
Current Status of Territory Block	Current state of the site, residual risk, usage restrictions	BPMN closure logic, monitoring layer, expert assessment	Upon case closure; upon repeated update
Archival-Documentary Block	Versioning, chronology of updates, case opening/ closure/reopening	BPMN engine, event log, metadata layer	At all stages of the life cycle
Historical-Analytical Block	Versioning, history of changes, case status, analytical notes and conclusions	Event log, metadata layer, process mining outputs, expert analysis	At all stages; especially upon case closure

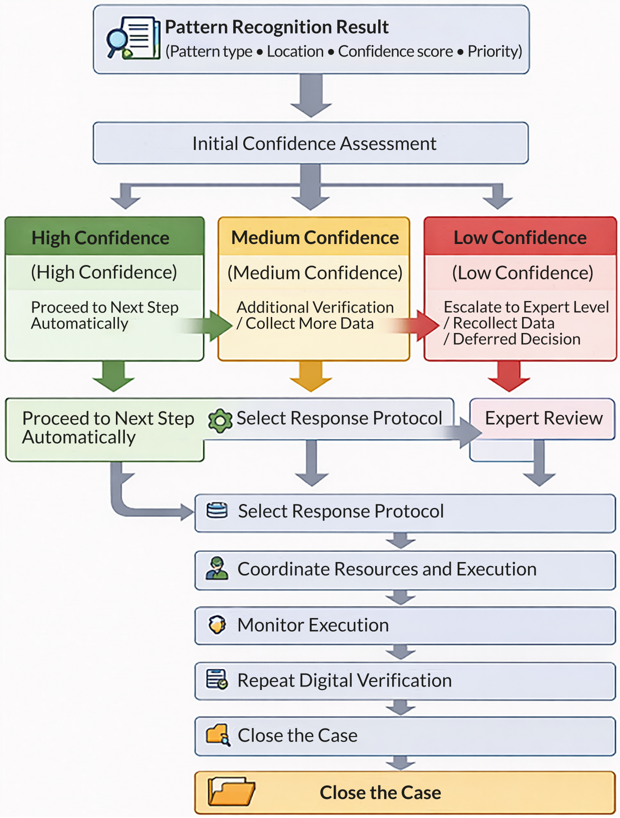

Fig. 7.2 Routing scheme of pattern recognition results by confidence level

This scheme reflects the key principle of adaptive support of Pattern Recognition results, which consists in the fact that the subsequent routing of the case is determined not only by the type of identified pattern, but also by the level of confidence of the digital output. In this sense, the confidence score acts as a central process trigger that determines the nature of subsequent managerial actions.

Thus, at a high level of confidence, the recognition result may serve as a basis for an automated transition to the selection of a response protocol, coordination of allocated resources for the elimination of consequences of the emergency event, and the initiation of remediation/recovery actions. A medium level of confidence reflects an intermediate zone of uncertainty, within which procedures of additional verification are initiated – re-analysis of data, involvement of alternative data sources, as well as additional data collection and comparison with the geocontext. After that, the case is transferred either to the automated or to the expert branch. A low level of confidence excludes the automatic initiation of actions and requires urgent response: expert escalation, repeated data collection and/or additional diagnostics, that is, the transition of the process into a more controlled mode. Regardless of the initial routing branch, the process must remain closed-loop, and the result – strategically oriented toward priorities. After the selection of the response protocol, coordination of resources, and execution of the complex of remediation measures, monitoring must be carried out, followed by repeated digital verification, and only then – case closure. This makes it possible to shift management from the mode of reaction to a signal to the mode of confirmation of the achieved effect, which is especially important for remediation and post-crisis recovery.

Thus, the scheme not only illustrates branching by confidence levels, but also fixes the central idea of the study: the recognition result must be supported in a process-driven and adaptive manner up to the moment of confirmed case completion.

7.4 Synthesis of open benchmark foundations for verification of the proposed model

It should be noted that the panoramic scientific exploration conducted by the authors of the monograph revealed that no direct separate benchmark specifically for BPMN orchestration in remediation was identified. However, a strategy for proving the authors' concept through a composite benchmark consisting of three open contours is entirely realistic: a benchmark for damage recognition, open crisis geodata, and benchmark/event logs for process mining.

Thus, the three-layer composite benchmark consists of:

– a benchmark for damage/contamination recognition;

– an open contour for crisis/recovery geomonitoring;

– a benchmark/event log for process orchestration, adaptation, and execution analysis.

Direct Layer for Pattern Recognition. One of the most relevant benchmarks is xBD/xView2. xBD is positioned as a large open dataset for change detection and building damage assessment in humanitarian response and disaster recovery. Thus, the article on xBD [11] directly emphasizes the connection with damage assessment, logistics/resource planning, and post-crisis use. The xView competition series by DIU (Defense Innovation Unit) was generally created as a series of competitions that benchmark computer vision algorithms for real humanitarian and disaster tasks, which correlates with the input layer "pattern recognition results" [32].

The second comprehensive source is the description of SpaceNet 8 [33–35]. It was collected as a benchmark for identifying flooded roads and buildings, and combines building detection, road extraction, and flood detection; the challenge provides a unified scoring logic for buildings and roads. For the authors' hypothesis, this is especially important because it makes it possible to move from object recognition/damage identification to the need to orchestrate recovery operations and logistics. For the crisis and recovery layer, there is a powerful open operational contour – Copernicus Emergency Management Service. Copernicus EMS is a service that provides mapping support for natural hazards, man-made emergencies, and humanitarian crises, and among the types of activations there is not only emergency response, but also recovery. It has damage assessment logic, methods of interpretation based on remote sensing, and open vector geodata. This is especially important for confirming the authors' concept, because it makes it possible to connect visual diagnosis with subsequent geospatial actions and managerial routes [16, 36–38].

Thus, if xBD/SpaceNet 8 provides the input diagnostic benchmark, then Copernicus EMS provides the operational-geospatial reference layer on which it is possible to model how BPMN transforms a recognition result into processes of verification, routing, notification, resource allocation, and subsequent closure. As a methodological benchmark for process evaluation, the official resources of the Process Mining Task Force may be used, as they publish event logs and BPI Challenge datasets, while the BPI Challenges themselves constitute a recognized benchmark class for analyzing real event logs. There are also catalogs of event data / logs for process mining. This means that the layer of "how to measure process behavior, deviations, delays, rework, bottlenecks, escalations" can rely on an already existing benchmark culture. That is, they confirm that the process layer can be evaluated according to the rules of process mining.

A separate block consists of a number of scientific sources confirming that in crisis situations and emergency response, namely in unpredictable and weakly structured crisis scenarios, procedural BPMN alone is often insufficient and the combination of BPMN + CMMN + DMN is useful. This is especially important for confirming the authors' hypothesis, because the proposed approach essentially requires:

– a procedural framework;
– flexibility by case;
– a decision layer [8, 39–41].

Thus, BPMN is the core of orchestration, while adaptive support is implemented through the composition of BPMN + rules/DMN + HITL + external services.

7.5 Possibilities of operationalization and verification of the architectural model

The architectural model proposed in the monograph is not an exclusively theoretical construction, since its key elements can be operationalized on the basis of open datasets, process modeling standards, and modern BPM (Business Process Management) platforms. In methodological terms, this is not a full-scale empirical approbation of an implemented system, but a proof of evaluability, that is, evidence that this concept can be formalized, implemented in an executable contour, and verified on open benchmark foundations. As a basic scenario for applying the model, the following chain may be considered: damage assessment based on xBD/xView2 data → formation of a structured event → launch of a BPMN contour with confidence-based routing → passage through one of three branches → selection of a response protocol to contamination and/or damage → monitoring of the remediation scenario execution → repeated digital verification → case closure.

At the first stage, the CV pipeline processes pre- and post-event images and forms a primary diagnostic output, including the type, class, and scale of contamination/damage, spatial reference of the object, and a confidence-like indicator. However, this output is not yet a managerial decision, since it must be transformed into a structured BPMN event that contains the case identifier, coordinates of the object/territory, pattern type, confidence level, list of data sources, and key priorities. It is precisely such an event that becomes the input for the executable remediation process contour.

Next, a BPMN process is initiated, within which an initial assessment of the criticality and confidence level of the verification result is carried out. It should be noted that at this stage a decision-making layer based on DMN may be used, since this standard is specifically intended for the formalization of repeatable decisions with the possibility of their automated execution. Accordingly, rules of the type "if the damage class of the object/territory is severe and the confidence level ≥ the established threshold, then initiate the automatic route of emergency consequence elimination" or "if the confidence level is within an intermediate range, then route this case for additional verification" may be applied. In the proposed model, as described earlier, it is advisable to provide for three routing branches, namely: a high level of confidence, which assumes the possibility of automatic transition to the selection of an emergency consequence elimination protocol/remediation scenario; a medium level of confidence, which assumes additional verification through repeated data analysis, aggregation of alternative information sources, as well as manual verification of attributes or refinement of the geocontext; a low level of confidence, which provides for the transition of the case into the mode of expert review, repeated data collection if necessary, or deferred decision until confirmation is obtained.

Further, after the route selection, the system proceeds to the assignment of a response protocol/remediation scenario, where the previously described damage assessment service of the Copernicus Emergency Management Service may be used as a reference operational layer. Then, BPMN ensures full coordination of all participants of the remediation process within the implementation of the specifically selected scenario by means of service tasks for the purpose of intersystem information exchange and coordination of the execution of subprocesses and tasks for the elimination of the consequences of the emergency situation. After the initiation of the remediation scenario implementation, the architecture must provide for monitoring of the status and repeated digital verification of the result through the acquisition of new data, repeated recognition, or updating of the geospatial layer and comparison of the "before/after" state. Consequently, this step transforms the process into a closed-loop cycle of comprehensive management of the remediation process.

For the purpose of verifying this architectural model, it is advisable to use not domain-specific remediation event logs, which are currently practically absent in open access, but the methodological logic of process mining benchmark culture. In this case, it is not a specifically selected remediation scenario that will be evaluated, but the parameters of process execution, namely: lead time, rework rate, escalation frequency, expert intervention rate, false auto-routing rate, closure time, and post-verification success rate. Such a set of metrics makes it possible to assess how effectively the model manages the level of uncertainty of AI outputs and how rationally it distributes cases between automatic and expert branches. From a practical point of view, the most realistic implementation stack includes: CV pipeline + BPMN/DMN engine + persistence/event layer + monitoring/analytics layer.

Thus, as a CV pipeline, a damage assessment model trained or fine-tuned on xBD/xView2 may be used. As the process core, Camunda 8 or Flowable may be applied, since both platforms support BPMN and DMN, while Flowable is additionally oriented toward the integration of BPMN/CMMN/DMN within a unified set of engines. Camunda is particularly convenient in scenarios where confidence thresholds, criticality levels, and response protocols are defined not within the process code, but in the decision layer through DMN and FEEL (Friendly Enough Expression Language). Flowable, in turn, is of interest for further expansion of the model toward case-oriented logic and less structured scenarios.

In other words, adaptive support here does not require a special set of elements, since it emerges from the meaningful combination of events, gateways, tasks, decision management, as well as exception-handling mechanisms. The recommended structure of the technical stack is presented below in **Table 7.3**.

Table 7.3 Recommended technical stack for implementation

Layer	Recommended Components	Purpose
Visual diagnosis layer	xBD/xView2-trained CV model; satellite imagery preprocessing	Building damage assessment, class prediction, confidence output
Event formalization layer	Python/Java service, API gateway, JSON event schema	Transformation of AI output into a structured BPMN
Process orchestration layer	Camunda 8 or Flowable BPMN engine	Execution of the BPMN routing contour
Decision layer	DMN engine, FEEL expressions, decision tables	Threshold rules, selection of response route and protocol
Case / expert layer	User tasks, task lists, notification service	HITL, expert verification, escalation
Operational geospatial layer	Copernicus EMS products, GIS services, map layers	Spatial context, recovery/damage reference
Persistence and integration layer	Event store, relational DB, REST / message broker	Storage of cases, statuses, results, and intersystem exchange
Monitoring and analytics layer	Process monitoring dashboard, event log export, process mining tools	Lead time, rework, escalation, closure and post-verification metrics

It should be emphasized that the above-presented stack describes an implementable, but not the only possible platform configuration. Its significance lies primarily in confirming the consistency of the authors' architecture, since it translates the concept into the plane of operationalization: it shows what data are required, which elements must be formalized, where the decision logic is located, and how the evaluation of process effectiveness may be organized.

7.6 Conclusion

The conducted study makes it possible to conclude that BPMN in the context of remediation and post-crisis recovery should be considered much more broadly – as a process framework for adaptive support of Pattern Recognition results and digital diagnostics. The authors substantiate that the key problem of modern digital management contours of emergency situations of natural, technogenic, and military nature lies in the gap between the obtained diagnostic conclusion and its transformation into a sequence of verifiable, coordinated, and controllable managerial actions for consequence elimination and subsequent remediation of the object/territory.

The proposed concept forms an integral architectural model in which the recognition result is transformed into a structured event, passes through a BPMN contour of confidence-based routing, is complemented by decision logic and expert verification, and is brought to the stage of execution of the remediation scenario, repeated digital verification, and case closure. Thus, it is substantiated that adaptive support of AI outputs may be considered as an independent process mode of managing the level of uncertainty and reducing the risk of erroneous automation. An important outcome of the study is the conclusion regarding the fundamental operationalizability of the proposed model based on open benchmark datasets of visual diagnostics, geospatial recovery products, and process mining metrics. At the same time, the analysis of literature and practice has confirmed the presence of a study gap: despite the high maturity of individual directions – BPMN, disaster damage assessment, recovery mapping, and process evaluation – their integration into a unified contour of adaptive support of digital diagnostics results for remediation tasks remains insufficiently developed.

The limitations of the concept consist in its predominantly architectural and conceptual nature, the absence of full-scale empirical approbation, and the fact that existing benchmark foundations make it possible to verify only individual contours of the model. The prospects for further study are associated with scenario-based testing of the model on real crisis datasets, the construction of domain-specific event logs for process mining, testing of confidence-based routing rules, as well as the creation of a pilot BPMN/DMN prototype integrated with geospatial and computer vision services.

Conflict of interest

The authors declare that there is no conflict of interest in relation to this paper, as well as the published research results, including the financial aspects of conducting the research, obtaining and using its results, as well as any non-financial personal relationships.

Financing

The study was performed without financial support.

Data availability

The data underlying the conclusions of this study, including the used open benchmark datasets (xBD/xView2, SpaceNet 8, Copernicus EMS) and methodological materials, may be provided by the authors upon reasonable request.

Use of Artificial Intelligence statement

The authors employed artificial intelligence technologies solely for auxiliary purposes that do not affect the scientific novelty or reliability of the results. In particular, ChatGPT (OpenAI) was used for verifying the academic English translation and generating illustrative materials. All conceptual, methodological, and architectural contributions, as well as the study's conclusions, were developed exclusively by the authors.

Acknowledgments

The authors express their gratitude to the reviewers of this study and the publisher for providing the opportunity to publish the results of their scientific activity.

Authors' contributions

Bohdan Cherniavskyi: Conceptualization of the study, Development of the theoretical and methodological framework, Formation of the architectural model of adaptive support, Formal analysis, Preparation of the initial manuscript draft, Scientific editing, Integration of the research results.

Oksana Drozd: Methodology, Analysis of literary sources, Participation in the development of the research logic, Interpretation of theoretical provisions, Preparation of individual manuscript sections, Text editing.

Anatolii Nadtochyi: Methodology, Formal analysis, Participation in the development of the logic of model operationalization, Analysis of benchmark foundations, Participation in the formation of the concept of the Digital Passport of the territory, Validation of results, Editing of the final version of the text.

Viktor Nadtochii: Methodology, Development of the technical logic of operationalization and verification of the architectural model, Formation of the technical implementation stack, Visualization, Preparation of diagrams, Tables, and Architectural solutions, Participation in the writing and editing of the manuscript.

Maksym Matviienko: Analysis of data and sources, Research on process mining and process orchestration in the applied context, Systematization of process metrics and open benchmark ecosystems, Participation in the development of model verification scenarios, Preparation of visualizations as well as analytical materials for the manuscript.

Ivan Kalinichenko: Research on the applied aspects of the context of remediation and post-crisis recovery, Analysis of geospatial data and recovery mapping, Participation in the development of practice-oriented provisions of the study, Validation of the substantive structure of the work, Development of visual content, Editorial refinement, and Approval of the final version of the manuscript.

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