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Resilience of Urban Public Utilities in Belarus to External and Internal Shocks

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Description of the System and Internal Interdependencies

The urban housing and communal services system (HCS) of the Republic of Belarus represents a complex set of interrelated organizational, technical, economic, and social elements that ensure the functioning of cities and settlements.

It includes:

- **Housing management and maintenance services** – management of multi-apartment housing stock, routine and capital repairs, and maintenance of adjacent territories.
- **Communal infrastructure** – water supply and wastewater disposal, heat supply, electricity supply, gas supply, and the collection, utilization, and processing of municipal solid waste.
- **Urban amenities and sanitation** – street cleaning, landscaping, lighting, and maintenance of roads and sidewalks.
- **Other services** – public baths, laundries, hotel services, funeral services, and household services.

System management involves national authorities (the Ministry of Housing and Communal Services), regional HCS associations, city and district enterprises, as well as specialized organizations (water utilities, district heating networks, etc.). In large cities, the structure is more specialized and technologically advanced; in medium-sized cities, functions are combined within a single enterprise; and in small towns, the system is highly centralized with limited resources.

The functions of HCS include providing housing and communal services to the population, maintaining sanitary and living conditions, modernizing infrastructure, quality control of services, social support for vulnerable groups, crisis response, and public awareness activities in the fields of energy efficiency and environmental protection.

Internal Dependencies of the System

The HCS operates as an integrated network in which each element depends on the condition and performance of others.

Key dependencies include:

- **Technological chains.** Water supply depends on the uninterrupted operation of sources (wells, surface water bodies), water treatment plants, pumping stations, and distribution networks. Heat supply relies on the stable operation of CHP plants and boiler houses, fuel supply, and trunk and distribution heat networks. Wastewater systems require reliable sewer networks, pumping stations, and treatment facilities.
- **Energy dependence.** Almost all technological processes (water pumping, heat circulation, wastewater treatment) require electricity, and failures in power grids lead to cascading disruptions.
- **Human resources dependence.** Service quality is directly linked to the qualifications and availability of personnel. Shortages of engineers, electromechanics, and system operators increase the risks of failures and accidents.
- **Financial interdependence.** Non-payments by households and enterprises reduce the ability to finance repairs and modernization. Cuts in budget funding lead to increased network wear and declining service quality.
- **Material and technical dependence.** Worn-out networks and equipment increase accident frequency and repair costs. Delays in the supply of spare parts or materials can paralyze entire subsystems.
- **Information flows.** Dispatch services, monitoring, and metering systems ensure coordination and control of network parameters. Disruptions in data transmission may delay emergency response.

Thus, Belarus's HCS is a multi-level interconnected structure in which internal dependencies form a chain: **resource → technology → personnel → financing → consumer**. Failures at any link lead to cascading disruptions, requiring integrated management, continuous monitoring, and preventive measures.

Description of External Stakeholders Influencing the System

The urban HCS system in Belarus does not operate in isolation but interacts with a wide range of external stakeholders that directly or indirectly affect its resilience, efficiency, and crisis response capacity. These stakeholders can be grouped into government authorities, the socio-economic environment, the natural environment, international interaction, and infrastructure partners.

1. Government Authorities and Regulatory Bodies

- **National level** – ministries responsible for housing and communal services, energy, natural resources and environmental protection, healthcare, architecture, and construction.
  These bodies establish the regulatory framework, define tariff policy, quality standards, labor safety and environmental requirements, and oversee compliance with sanitary and hygiene norms.
- **Local authorities** – regional, city, and district executive committees.
  They approve local HCS development programs, form budgets, and set priorities for capital repairs, urban improvements, and modernization.

2. Socio-Economic Environment

- **Population and service consumers** – shape demand and payment capacity and provide feedback on service quality. Mass non-payments or rising social expectations directly affect the financial stability of enterprises.
- **Business and industry** – industrial enterprises, as major consumers of water, heat, and electricity, create significant network loads and influence system operating modes.
- **Private sector and contractors** – construction companies, service firms, and suppliers of equipment and materials, on whom the speed and quality of repairs and modernization depend.

3. Natural and Climatic Environment

- **Climatic factors** – extreme cold, heat waves, droughts, heavy precipitation, and storm winds affect infrastructure wear, accident rates, and operating regimes.
- **Natural resources** – the condition and availability of drinking water sources, water quality, and the presence of natural filtration systems (forest belts, wetland ecosystems) influence water supply systems.
- **Environmental threats** – pollution of rivers and groundwater, waste accumulation, and technogenic accidents.

4. International Interaction

- **Neighboring countries and transboundary water bodies** – Belarus relies on water resources partly formed outside its territory, making the system vulnerable to external changes in water quantity and quality.
- **International programs and donors** – participation in EU, UNDP, and World Bank projects brings funding, technologies, and best practices in energy efficiency, environmental protection, and waste management.

- **Foreign policy and economic environment** – sanctions, trade restrictions, and energy price fluctuations affect access to equipment, technologies, and financing.

5. Infrastructure Partners

- **Energy companies** – suppliers of electricity, heat, and gas, on which the operation of most HCS systems directly depends.
- **Transport enterprises** – ensure logistics for fuel, reagents, and construction materials.
- **Telecommunications and IT infrastructure** – operators providing communication channels for dispatch centers, SCADA systems, and remote monitoring.

External stakeholders may act both as sources of support and as risk factors for the HCS system. Their influence manifests through changes in regulatory requirements, resource availability, operating conditions, and the investment climate. To enhance system resilience, it is necessary to:

- build stable cooperation with key public and private partners;
- incorporate climatic and environmental factors into planning;
- actively participate in international programs that provide access to modern technologies and funding sources.

Principles for Forming the List of Shocks (Internal and External)

The formation of a list of potential shocks capable of affecting the resilience of the housing and communal services (HCS) system is a key stage of risk management. This process is based on a comprehensive analysis of both the internal characteristics of the system and the external factors with which it interacts.

A **shock** is understood as a sudden, often unpredictable event or change in conditions that can lead to significant disruptions in system operations, deterioration in service quality, threats to public health, or economic losses.

In this study, sources of shocks are divided into two groups.

Internal shocks arise within the system and are related to its structural and functional characteristics:

- technological accidents (equipment failures, network accidents),
- disruptions in energy supply,
- human resource crises (mass departure of specialists),
- financial shortages,
- information failures (breakdowns of dispatching and monitoring systems).

External shocks originate outside the system and exert an impact on it:

- climatic extremes (frosts, heat waves, floods, droughts),
- economic crises, inflation, and rising energy prices,
- epidemics and pandemics,
- geopolitical conflicts and sanctions,
- changes in legislation and tariff policy,
- environmental disasters.

The following principles were applied when selecting shocks:

- **Impact significance** – the list includes shocks capable of causing substantial consequences for system operability and resilience.
- **Probability of occurrence** – historical frequency and trends of similar events are taken into account.
- **Response time** – the less time available for preparation, the higher the priority of the shock.
- **Complexity of impact** – shocks affecting several subsystems simultaneously (water, heat, electricity, waste) are prioritized.
- **Consideration of interdependencies** – assessment of whether one shock can trigger a chain reaction of disruptions (e.g., power outage → pump shutdown → water supply interruption).
- **Scenario realism** – highly unlikely hypothetical threats are excluded if their occurrence is not supported by data or expert assessments.

Sources of information used to form the list included statistical data on past accidents and crises; monitoring of the technical condition of facilities; climatological and hydrological forecasts; expert interviews with HCS specialists; analysis of regulatory changes and economic forecasts; and reviews of international experience in HCS risk management.

The principles for forming the list of shocks make it possible to structure potential threats, identify priorities, and create a foundation for further risk assessment and the development of response measures. This approach ensures consistency, transparency, and reproducibility in the risk management process.

Methodology for Assessing the Risk of Shock Realization. Ranking of Shocks

Risk assessment and ranking of shock events are key elements of the risk management system in housing and communal services. The purpose of the methodology is to determine the likelihood of each shock, assess the scale of its consequences, and establish priorities for response measures.

1. Definition of Assessment Indicators

For each shock, two basic parameters are evaluated:

Probability of occurrence (P) – an assessment of the frequency or likelihood of the event within a given period, expressed in points:

- 1 — extremely rare (once every 20 years or less),
- 2 — rare (once every 10–20 years),
- 3 — possible (once every 5–10 years),
- 4 — frequent (once every 1–5 years),
- 5 — very frequent (annually or more often).

Severity of consequences (S) – an integrated assessment of the scale of impact on the system:

- 1 — minor (local disruptions, recovery < 1 day),
- 2 — moderate (partial disruptions, recovery 1–3 days),
- 3 — serious (failures in individual subsystems, damage up to 1% of the annual budget),
- 4 — significant (large-scale disruptions, damage of 1–5% of the budget, threats to public health),
- 5 — catastrophic (system-wide failure, damage > 5% of the budget, prolonged disruption of essential services).

2. Calculation of the Integrated Risk Indicator

Risk is calculated using the formula:

$$\mathbf{R = P \times S}$$

where **R** is the integrated risk score.

The maximum value is 25 (highest risk), and the minimum value is 1 (lowest risk).

3. Classification of Risk Levels

- **High risk (R = 16–25)** – requires immediate preventive measures and the preparation of response plans.
- **Medium risk (R = 9–15)** – requires continuous monitoring and inclusion in preparedness plans.
- **Low risk (R = 1–8)** – requires periodic reassessment and observation.

4. Ranking Method

For each shock, experts (technical specialists, managers, analysts) assign values for P and S based on data, experience, and forecasts. The integrated risk score R is then calculated, and shocks are sorted in descending order of R. Shocks with the highest scores are identified as priorities for the development of response measures.

5. Application of the Methodology

This approach makes it possible to:

- objectively compare heterogeneous threats;
- justify the allocation of resources for prevention;
- plan infrastructure upgrades and staffing needs;
- adapt priorities as external and internal conditions change.

Ranking shocks based on probability and severity of consequences provides a foundation for building an adaptive risk management system in HCS. Such a system allows efforts to be focused on the most dangerous threats and ensures efficient use of limited resources.

List of the Most Dangerous Shocks and Description of Their Impact, Vulnerability, and Potential Losses

Based on the conducted risk assessment and ranking by probability of occurrence and severity of consequences, the most critical shocks for the housing and communal services (HCS) system in Belarus have been identified.

1. Large-scale power outage

Impact: shutdown of pumping stations, boiler houses, wastewater treatment plants, and dispatching systems. Leads to disruptions in water and heat supply, failures in wastewater disposal, and malfunctioning of stormwater drainage systems.
Vulnerability: high, due to the complete dependence of key processes on electricity.
Potential losses:

- **Economic** — damage of up to 5% of the enterprise's annual budget in the case of prolonged disruption.
- **Social** — interruptions in essential services for the population and increased sanitary and epidemiological risks.

2. Accidents on main heating networks during the winter period

Impact: mass disconnection of heating, sharp temperature drops in residential and social facilities, and the need for emergency repairs under severe weather conditions.

Vulnerability: elevated, due to the high level of network wear (up to 60–70% in some cities).
Potential losses:

- **Economic** — significant expenditures on emergency repair and restoration works.
- **Social** — risk of hypothermia among the population, especially vulnerable groups.

3. Contamination or shortage of water in water supply sources

Impact: suspension of potable water supply, increased incidence of disease, and the need for urgent water delivery through alternative means.
Vulnerability: medium to high, especially in cities relying on surface water sources or shallow groundwater horizons.
Potential losses:

- **Economic** — costs associated with additional treatment, logistics, and chemical reagents.
- **Social** — widespread public dissatisfaction and increased sanitary risks.

4. Extreme weather events

Impact: damage to infrastructure, flooding of residential areas, failure of power grids and pumping equipment.
Vulnerability: high for areas with outdated stormwater drainage systems and insufficient drainage capacity.
Potential losses:

- **Economic** — repair of roads, networks, and pumping stations.
- **Social** — evacuation of residents and damage to property, including buildings and structures.

5. Mass departure of qualified personnel

Impact: reduced management efficiency, longer response times for аварий, and loss of competencies in servicing complex equipment.
Vulnerability: medium, but increasing due to demographic trends and labor migration.
Potential losses:

- **Economic** — costs related to recruitment and training of new staff.
- **Social** — deterioration in service quality and increased accident rates.

6. Sharp increase in prices and shortages of fuel/energy resources

Impact: disruption of boiler house operation schedules, restrictions on heat and hot water supply, and increased tariff pressure on households.
Vulnerability: high, due to dependence on external fuel supplies.
Potential losses:

- **Economic** — cost increases amounting to 10–20% of the annual budget.
- **Social** — rising non-payments and reduced affordability of services.

These shocks pose the greatest threat to the resilience of the HCS system. Their impact may be complex, triggering cascading failures in related subsystems. Each of them requires dedicated prevention and response plans that take into account both technical and organizational measures.

List of Measures to Minimize Consequences

To reduce the impact of the most dangerous shocks and enhance the resilience of Belarus's housing and communal services system, a comprehensive set of measures is proposed, covering technical, organizational, and managerial solutions.

1. Large-scale power outage

- Equipping key facilities (pumping stations, boiler houses, dispatch centers) with autonomous power sources (diesel and gasoline generators).
- Creating fuel reserves sufficient for at least 72 hours of autonomous operation.
- Developing priority power supply schemes for critical infrastructure facilities.

2. Accidents on main heating networks

- Conducting preventive diagnostics of heating pipelines (thermal imaging surveys, acoustic monitoring).
- Replacing the most worn sections during the non-heating season.
- Establishing mobile emergency repair teams with round-the-clock readiness.

3. Contamination or shortage of water supply sources

- Monitoring water quality at sources with automated detection of deviations.
- Preparing reserve wells or alternative water supply sources.
- Ensuring emergency delivery of drinking water during crisis situations.

4. Extreme weather events

- Rehabilitation and cleaning of stormwater drainage systems.
- Creation of local drainage systems in flood-prone areas.

- Establishment of reserve bases for emergency response services and stockpiling of equipment and materials.

5. Mass departure of qualified personnel

- Staff retention programs (wage increases, social benefits, training).
- Establishment of mentoring systems for young specialists.
- Development of personnel reserves and cooperation agreements with educational institutions.

6. Sharp increase in prices and shortages of fuel/energy resources

- Diversification of suppliers and fuel types (transition to alternative fuels, biomass).
- Energy saving measures and modernization of boiler houses to improve efficiency.
- Creation of seasonal fuel reserves.

These measures are aimed at reducing the probability of critical events and minimizing their consequences, enabling the HCS system to maintain functionality even under severe external and internal shocks. Their implementation requires systematic planning, allocation of resources, and continuous monitoring of effectiveness.

Organization of Activities to Minimize the Most Dangerous Shocks

Effective reduction of the impact of critical shocks on the housing and communal services (HCS) system requires not only the development of measures, but also a clear organization of their implementation. This calls for the establishment of a multi-level risk management system covering planning, allocation of responsibilities, monitoring, and response.

1. Establishment and Operation of a Coordination Center

Purpose: strategic and operational management of risk mitigation activities.
Composition: representatives of enterprise management, technical departments, dispatch services, human resources, and finance departments, and, where necessary, representatives of local authorities and civil defense and emergency services.
Functions: development of annual and seasonal preventive work plans; allocation of resources and control over the implementation of measures; analysis of the effectiveness of implemented actions and adjustment of plans.

2. Emergency Repair Units

- Organization of round-the-clock teams operating on a shift basis and equipped with transport, tools, and materials.
- Response plans for each priority shock (power outages, ruptures of heating mains, water supply failures, etc.).
- Alert system — automatic notification of teams via the dispatch center upon detection of an emergency event.

3. Resource Logistics and Material and Technical Support

- Reserve storage of equipment and materials: pipes, fittings, pumps, cables, generators.
- Fuel storage for autonomous power sources in compliance with safety standards.
- Contracts with suppliers for emergency delivery of materials within 24 hours.

4. Monitoring and Early Warning System

- **Technical monitoring** — installation of sensors for pressure, temperature, flow rates, and water quality with data transmission to dispatch centers.
- **Climatic monitoring** — use of weather forecasts to prepare in advance for extreme conditions (storms, frost, floods).
- **Data analysis** — monthly reports on incidents and potential threats.

5. Personnel Training and Drills

- Annual exercises based on scenarios of the most dangerous shocks (e.g., “Power outage during the winter period” or “Rupture of a main water pipeline”).
- Training programs on new technologies and equipment.
- Mentoring systems for young specialists to accelerate adaptation and improve qualifications.

6. Interaction with External Stakeholders

- **Local authorities** — coordination of evacuation measures and resource allocation.
- **Civil defense and emergency services** — joint response plans for major accidents and natural disasters.
- **International and national partners** — exchange of experience and attraction of additional funding and technologies.

7. Documentation and Audit

- Written action plans for each shock, with designated responsible persons and implementation deadlines.
- Response regulations — standardized instructions for personnel.
- Readiness audits — annual inspections of equipment, resources, and procedures.

The organization of shock mitigation activities should be based on the principles of proactive management, flexibility, and integration of resources. Continuous interaction between internal departments and external stakeholders is a critical element, enabling timely response to crises, damage minimization, and maintenance of HCS system resilience.

Assessment of the Potential Influence of External Stakeholders on the Effectiveness of the Proposed Measures

The implementation of measures to mitigate the consequences of critical shocks in the HCS system is highly dependent on external stakeholders, which may either enhance or hinder their effectiveness. These stakeholders include government bodies, business partners, international organizations, and the natural and climatic environment.

1. Government Bodies and Local Authorities

Positive influence: provision of funding, simplification of project approval procedures, rapid adoption of regulatory acts, and support for infrastructure projects.
Negative influence: delays in approving plans and budgets, limitations on budget funding, and bureaucratic barriers in procurement and contracting.

2. Resource Suppliers and Contractors

Positive influence: timely delivery of materials, equipment, and fuel; flexibility in adjusting contract terms during force majeure events.
Negative influence: supply disruptions, price increases, and dependence on a limited number of suppliers.

3. International and Donor Organizations

Positive influence: provision of grants, technical assistance, and training; access to advanced technologies and best practices.
Negative influence: lengthy project approval procedures and funding tied to complex requirements and conditions.

4. Population and Service Consumers

Positive influence: participation in energy-saving programs, responsible payment behavior, and prudent use of communal resources.
Negative influence: mass non-payments, resistance to tariff changes, and low tolerance for temporary service restrictions during works.

5. Natural and Climatic Conditions

Positive influence: favorable weather during repair and preventive works.
Negative influence: extreme weather events that may disrupt schedules or negate the effects of preventive measures.

The effectiveness of the proposed measures directly depends on the level of interaction and coordination with external stakeholders. To minimize negative impacts, it is necessary to:

- conclude long-term partnership agreements with suppliers and contractors;
- actively involve the population in joint resilience-enhancing programs;
- build resource reserves to compensate for supply disruptions;
- establish continuous information exchange with government bodies and international partners.

Results of the Analysis of Potential Shocks and System Preparedness

The analysis identified a wide range of potential shocks capable of significantly affecting the operation of the HCS system in Belarus. Assessment of their probability and severity indicates that the greatest threats are posed by large-scale power outages, accidents on main heating networks during the winter period, contamination or shortages of water supply sources, extreme weather events, personnel crises, and sharp fluctuations in fuel and energy prices.

System vulnerability is driven by the high degree of interdependence among its elements—failure in one component may trigger cascading disruptions in related subsystems.

- **Internal shocks** are most often associated with infrastructure wear, shortages of personnel, and insufficient financing.
- **External shocks** are mainly shaped by climatic, economic, and geopolitical factors, as well as changes in the regulatory framework.
- The most critical threats are complex in nature, simultaneously affecting multiple essential services (water supply, heating, electricity, wastewater).

Assessment of Preparedness

- **Technical preparedness:** limited, due to significant equipment wear and insufficient reserve capacity.
- **Organizational preparedness:** basic response mechanisms exist (emergency teams, dispatch services), but further development is required, particularly in proactive planning and interagency coordination.
- **Resource preparedness:** insufficient for long-term autonomous operation under large-scale shocks; reserves of fuel, materials, and equipment need to be expanded.
- **Human resources preparedness:** critical, given the risk of losing experienced specialists and the inadequate development of personnel reserves.

Conclusion

Belarus's HCS system possesses basic capabilities for responding to emergency situations; however, its overall resilience remains limited. Enhancing preparedness requires comprehensive measures aimed at infrastructure modernization, diversification of energy supply sources, strengthening human capital, and developing risk monitoring systems. The success of these measures depends directly on effective interaction with external stakeholders and the availability of stable financing.