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Optimizing Regeneration Energy Usage on Railways: Innovative Approaches to R&D Project Management

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Abstract:

Purpose: *The purpose of the article is to identify specific aspects of managing innovative projects in railway transport for the rational utilization of regenerative energy.*
Design/Methodology/Approach: *The article includes analysis of scientific literature and industry documents regarding the management of innovative projects in railway transport and the utilization of regenerative energy. The phenomenon of regeneration is described, and the energy balance of the train is presented. It is noted that the utilization of regenerative energy in the railway transport structure is an example of specific renewable energy and thus fits best with the Green Deal. The specificity of managing innovative projects in railway transport is identified. Recommendations are provided regarding the preparation of funding applications to increase the chances of obtaining funds for the implementation of R&D projects.*
Findings: *The article emphasizes the importance of identifying specific aspects of innovative project management in railway transport in the context of effective utilization of renewable energy. This is a step towards sustainable development of the transport sector through the reduction of greenhouse gas emissions and increased energy efficiency. The phenomenon of regeneration and the energy balance of the train are key elements of analysis in terms of the potential utilization of renewable energy in railway transport. Understanding them is essential for developing effective implementation strategies for modern solutions. The utilization of renewable energy in the railway transport structure has been recognized as an excellent example of specific renewable energy sources that align with the goals of the Green Deal, highlighting its strategic importance for the future of the transport sector. The specificity of innovative project management in railway transport requires an approach based on risk analysis, flexibility, and continuous adaptation to changing technological and market conditions.*
Practical Implications: *The article provides significant knowledge for individuals and institutions involved in the development of innovative projects in railway transport, encouraging the use of renewable energy as an effective means of improving energy*

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efficiency and reducing greenhouse gas emissions. Discussed issues, such as regeneration and the energy balance of the train, can be directly utilized by railway designers and engineers to design more sustainable and environmentally friendly solutions. The specificity of innovative project management in railway transport indicates the need for continuous improvement of management processes and resource allocation to effectively achieve sustainable development goals.
Originality/Value: *The article provides a new perspective on innovative project management in railway transport, focusing on the rational utilization of renewable energy as a key factor in improving energy efficiency and reducing emissions. The analysis of the phenomenon of regeneration and the energy balance of the train constitutes a unique contribution to understanding the potential benefits and challenges associated with the implementation of renewable technologies in the railway sector.*

Keywords: *Regeneration, project management, research and development projects, railway transport, project proposal, funding.*

JEL codes: *M14, L15.*

Paper type: *Research article*

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1. Introduction

In the 21st century, innovation has become a significant goal of policy for every modern state. The issue of innovation holds an important place in the development documents of the European Union. The term "innovation" appears in European strategic programs, projects designed for scientific institutions, and entrepreneurs.

The ability to implement innovative solutions is one of the key driving forces for the development of businesses and the entire national economy. Research and development (R&D) projects are intended to create innovations, resulting in the development of enterprises by significantly improving existing solutions or creating entirely new breakthrough market solutions. An important characteristic of highly innovative R&D projects is that they are associated with a high risk of failure.

Hence, partial minimization of this risk can be provided through support from national and European funds.

Projects aimed at increasing the utilization of recuperative energy on railways perfectly align with the goals of the Green Deal (Pomykała and Raczyński, 2020), which is a key element of the European Union's strategy for sustainable and green development. Energy derived from regeneration is a particular type of renewable energy. It is a significant concept in the field of railway transport, aiming for the efficient use of energy during train braking.

The essence of recuperative energy lies in the recovery and reuse of kinetic energy generated during train braking. Recuperative energy on railways is crucial for the efficiency and cost-effectiveness of railway transport, while also helping to reduce the sector's negative impact on the environment and operational costs.

Regenerative braking is widely used in electrified railway networks as a means to ensure train safety and improve energy efficiency in railway transport (Kuznetsov, Hubskyi, and Skrzyniarz, 2021). It serves as a measure to ensure train safety and enhance the energy efficiency of railway transport.

Theoretical studies and field experiments have identified factors influencing the possibility of regenerative braking application and the use of recovered energy, developed methodological foundations for assessing the potential of regenerative braking by sections, and determined the energy efficiency of railway transport.

Recuperative energy can be used for various purposes. Some of the recovered energy is consumed for the traction of other trains, and when energy is returned to traction substations, it is used for the traction of other trains. Energy supplied to traction substations is used for their own needs as well as by railway consumers and external areas powered by the supply network and longitudinal lines.

The aim of the article is to identify selected specific aspects of managing projects co-financed by the EU using a case study of an R&D project conducted by the Institute of Rail Transport. The research methods employed in the article include: case study, analysis of source materials, descriptive method, critical analysis of selected literature.

It should be noted that there is a large number of publications on technical aspects of maximizing the use of recuperative energy in metros and railways.
However, there are not many works dedicated to the management aspects of innovative R&D projects focused on energy recovery. This publication addresses precisely these issues.

When considering the implementation of a project aimed at increasing the utilization of recuperative energy, attention should be focused on selected aspects of the project planning phase: opportunities to obtain funding for its implementation, the type of research to be conducted during the project, human resources, budget, and indicators.

Precisely defining indicators at the project preparation stage is extremely important and allows for the correct progress of project tasks and the delivery of reports (deliverables) in the further perspective of the implementation process.

2. Energy from Regeneration on Railways as a Form of Renewable Energy

From a technical standpoint, energy regeneration on railways results from the recovery of kinetic energy from trains during braking. This process involves transforming the train's motion energy into electrical energy or another form of energy that can be later utilized or stored.

Recuperative energy can be used for various purposes, such as powering other electrical systems onboard the train, supplying other trains, or feeding energy back into the electrical grid. In this way, the recovery of electrical energy can reduce energy consumption by the vehicle and also decrease wear on braking system components.

In Poland, in direct current (DC) railway traction power systems, energy flows from the system (AC) to the traction network (DC) through its power supplies. The return of regenerative braking energy from trains occurs within the traction network (DC). Therefore, regenerative braking energy can be consumed by another vehicle if traffic conditions allow or converted into heat in braking resistors and dissipated. Due to the design of traction network power supplies, this energy cannot return to the distribution system (AC).

Requirements for utilizing recuperative energy in traction power systems are outlined in section 4.2.6 of the TSI ENE [4]: direct current (DC) power systems should be designed to allow for the use of regenerative braking at least in the range of power exchange with other trains.

In the case of direct current (DC) power supply, onboard energy measurement systems (EMS) are used to measure the electrical energy drawn from the traction network and returned (during regenerative braking) to the traction network by the electric railway vehicle. At present, this scenario applies to the entire railway traction network in Poland.

According to the standard PN-EN 50388-1:2023 [5], the rolling stock should discontinue regenerative braking when there is a voltage drop in the network or a short circuit on the section, the network ceases to be receptive (absorbing braking energy), and the network voltage exceeds Umax2. Conversely, the rolling stock should activate undervoltage protections for the voltage range: 85÷95% Umin2 (Szeląg, 2019).

The potential of recuperative energy depends on several factors:

1. Train speed and mass: The higher the train's initial braking speed and mass, the more kinetic energy it possesses during motion. Therefore, reducing speed over a large range can recover more energy;
2. Type of braking systems: Regeneration efficiency also depends on the type of brakes used. For example, electric trains with electrodynamic brakes may more efficiently convert kinetic energy into electrical energy than trains with traditional mechanical brakes, which do not recuperate energy at all;
3. Route geometry: On sections with steep gradients, regeneration may be more effective because changes in altitude can affect the train's kinetic energy;
4. Level of technological development and equipment: Regeneration efficiency also depends on the state and modernity of train equipment and infrastructure;
5. Weather conditions: Weather conditions such as wind, rain, and snow can affect friction and aerodynamic resistance, which can also impact regeneration efficiency.

The electrical energy drawn by the vehicle from the traction network during vehicle travel for time T, on section W, is calculated according to the formula:

$$W = \int_0^T U(t)I(t)dt \tag{1}$$

where:
U(t) - voltage at the pantograph
I(t) - train current
T - travel time of the section

Electric energy is used for mechanical work performed by electric traction motors to move the vehicle, power circuits for internal needs, and cover energy losses in electro-energetic devices. During the movement of the traction vehicle, energy drawn from the traction network is used to perform work against the forces resisting motion and accumulate kinetic energy.

After the acceleration phase, motion is continued thanks to the accumulated kinetic energy, which is expended to overcome resistive forces on the track. In the general case, the energy balance equation for the motion of the traction vehicle is as follows (EN 50388-1:2022):

$$W=Ws+Ww+Wh+\Delta W+Wwp-Wrek \tag{2}$$

where:
Ws - energy losses in the devices initiating the traction vehicle,
Ww - energy losses to overcome the main resistances to the motion of the traction vehicle, resistances on curves and gradients,

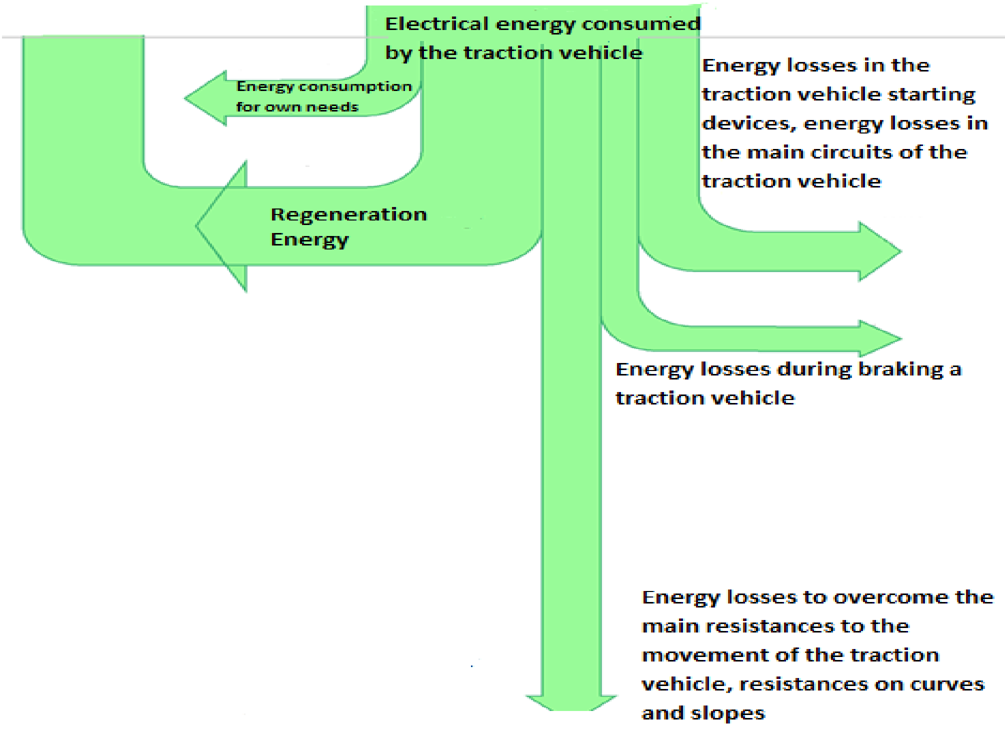
Wh - energy losses during braking of the traction vehicle,
ΔW - energy losses in the main circuits of the traction vehicle,
Wwp - energy consumption for internal needs,
Wrek - energy regeneration.

Figure 1 illustrates the energy balance of the train movement.

Considering, therefore, from an energy point of view, the traction power supply process can be distinguished into the following stages:

1. generation of electrical energy at power plants;
2. transformation of electrical energy to parameters corresponding to the needs of traction vehicles;
3. conversion of electrical energy into kinetic energy of the traction vehicle;
4. conversion of kinetic energy of the vehicle into:
   a) energy dissipated due to friction and resistances to motion;
   b) thermal energy of brake pads;
   c) electrical energy returned to the traction network (regeneration).

Figure 1. *Energy balance of trains' movement*



Source: *Own elaboration.*

The individual stages of this process will be described below.

The energy accumulated in primary sources, at power plants, is converted into electrical energy. Then, this energy is transmitted through the power system to traction substations.

The traction substation converts the electric current supplied from the power plant (AC) into a current suitable for feeding the traction network (DC). Vehicles draw a certain amount of energy from the traction network and, through a series of energy transformations, convert it into kinetic energy.

However, this does not happen without losses. Due to friction, gearbox efficiency, and the motor itself, a small part of the energy is dissipated as heat to the surroundings.
Kinetic energy is one form of mechanical energy possessed by bodies in motion. It is directly related to velocity.

Because regional rail traffic is characterized by short distances between stops, in the case where a traction vehicle travels on a flat and straight section, it is advisable for the driver, after accelerating the vehicle to cruising speed, to use the so-called "coasting" for further travel. "Coasting" involves zero electrical energy consumption for traction purposes.

This means that a vehicle with previously accumulated kinetic energy will be slightly slowed down by the resistive forces encountered. Thus, a small portion of its kinetic energy will be expended due to overcoming the vehicle's resistive forces during traction.

In the final stage of the journey, the braking phase occurs. Vehicles equipped with regenerative brakes have the ability to recuperate energy. During regeneration, kinetic energy is once again converted into electrical current, and also, due to the use of friction brakes, a portion of the kinetic energy is consumed by the traction vehicle (dissipated into the surroundings as heat).

3. Selected Aspects of R&D Project Management in Rail Transport

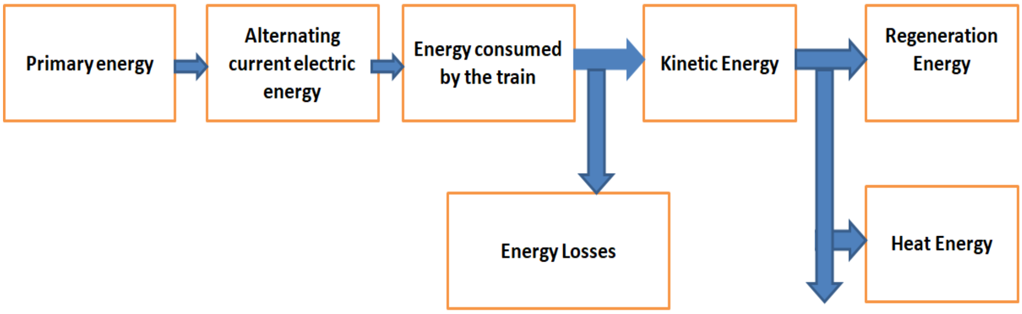
There are many methodologies for project management. Each project goes through a lifecycle, which in most methodologies consists of groups of processes: project initiation, planning, project execution, monitoring and control, project closure. The specific aspects in managing innovative railway projects aimed at rational energy recovery include:

- Seeking financial instruments to finance the project,
- Identifying research and development activities,

- Human resource management,
- Project budget planning in case of funding from multiple financial institutions,
- Identifying indicators to assess the degree of achievement of project results and objectives (Gryzik and Knapińska, 2012).

These aspects are discussed below.

Figure 2. *Energy transformation process*



Source: *Own elaboration.*

Managing an innovative project is a complex and intricate process. Many factors influence the successful course of a project, such as predictability, planning, organization, control, and risk minimization. In many cases, scientific projects go beyond the framework of standard management methods.

However, they must possess basic elements regarding the implementation of various initiatives, including defined human resources, budget, timeframes, communication means, and control forms. Often, R&D projects require the use of various management systems.

Selecting a financial instrument for implementing a research initiative is a crucial element in managing research projects. In the European Union, funding for research and innovation projects (R&D) is provided through the Framework Programs (FP).

Investments in research and innovation in the railway sector are essential for achieving EU environmental goals, as well as necessary for maintaining and strengthening the European railway industry's competitiveness in the global market and for preserving and creating highly skilled jobs in railway transport.

In the current EU financial perspective, the Horizon Europe framework program includes the "Europe’s Rail Joint Undertaking." The partnership was established at the end of 2021 for a ten-year period, with a total budget of €1.2 billion. The budget consists of funds provided by the Horizon Europe Framework Programme up to €600 million and the initiative members' own contribution.

The goal of Europe’s Rail is to accelerate the development and implementation of innovative railway technologies. The program focuses on digital innovations and automation to transform the railway system necessary to achieve the goals of the European Green Deal.

By improving competitiveness, it aims to support Europe's leading role in railway technology. Research topics focus on seven key flagship areas (FA) and cross-cutting actions:

- FA1 Planning and control of network management and mobility management in a multimodal environment,
- FA2 Digital, automated, and eventually autonomous trains;
- FA3 Intelligent and integrated asset management;
- FA4 Sustainable and ecological railway system;
- FA5 Sustainable and competitive freight transport services, ecological and digital;
- FA6 Regional railway services – innovative railway services for the revitalization of branch lines;
- FA7 New or emerging technologies for land transport, cross-cutting issue: digital data and activators (Barcikowska, Wawrzyn, 2023).

In the flagship project FP4 – Sustainable and ecological railway system, acronym Rail4Earth, in which the Railway Institute participates, works related to the development of solutions for holistic management of electrical energy for traction purposes and for buildings, including broader use of energy storage for railway purposes, supporting regeneration, are planned.

Another way to obtain funding for R&D projects related to increasing the use of regeneration energy on railways is the participation of research units with entrepreneurs in consortia in competitions announced by the National Centre for Research and Development (NCBR).

In the financial perspective for the years 2014-2020, funds for R&D projects in the railway transport area, in cooperation with NCBR, could be obtained in the following programs: Operational Program Innovative Development, Joint Ventures, and Strategic Research and Development Programs.

NCBR and PKP PLK S.A. implement the so-called Research and Development Joint Venture acronym BRIK – Research and Development in Railway Infrastructure.

The main goal of the program is to increase innovation and competitiveness in railway transport. Its implementation is to contribute to the increase of R&D activity in the area of railway infrastructure, increase the number of innovative solutions in this area, improve the efficiency of railway infrastructure operation and management, and reduce the negative impact of railway transport on the environment.

The program is dedicated to scientific units and companies from the railway industry (Barcikowska and Wawrzyn, 2023).

The Railway Institute has received funding for a project aimed at increasing the use of regeneration energy on railways within the Europe's Rail initiative in the flagship area FA4 Sustainable and ecological railway system, acronym Rail4Earth. In the new financial perspective, the Railway Institute actively collaborates with PKP S.A., which has obtained the status of a direct member of EU-Rail.

The Railway Institute participates in the project as a related entity within the Research and Development Ecosystem led by PKP S.A. Project activities concern environmentally friendly solutions at railway stations, development of modular construction, and use of closed-loop economy.

An important aspect developed within the FA4 Flagship Area is also the development and application of digital representations of station buildings in a virtual environment, where BIM standards will be used as a basis for determining construction standards, and guidelines for tendering procedures related to selecting a contractor for services related to the preparation and implementation of the construction process will be developed.

Moreover, within the FA4 Flagship Area, activities related to the development of solutions for holistic management of electrical energy for traction purposes and for buildings, as well as the creation of a universal interface for hydrogen refuelling, ensuring appropriate safety standards, with the shortest refuelling time are planned.

The Railway Institute participates in the WP11 package of works in the execution of tasks 11.1. Implementation of energy hubs in specific traction conditions (subtask 11.1.2. Energy hubs in specific railway network conditions) and task 11.2 Implementation of the Energy Hub as an advanced element of the railway system (subtask 11.2.2. Energy storage on the side (AC).

An important stage in the process of applying for a grant for a research and development project is identifying activities and tasks of the project that have the character of R&D work. It is also necessary to determine whether the planned work concerns industrial research or development work.

This is important because it differentiates activities in terms of funding – greater support can be obtained for industrial research. During project planning, it is also necessary to determine at what level of technological readiness the researched technology or developed product currently stands, and what further levels are intended to be achieved at various stages of project implementation.

In this regard, the nine-level TRL (Technology Readiness Level) scale is helpful, where the first level indicates the lowest degree of technological advancement, and the last one full maturity and readiness for implementation.

Research and development activities require the involvement of many human, technical, and intellectual resources by companies and scientific units. Therefore, an important aspect at the stage of preparing for the implementation of the project subject to the application for funding is to demonstrate the ability to properly implement it.

In particular, it is necessary to demonstrate that the company, scientific unit, or consortium has the appropriate human resources, i.e., a team that will be involved in project work.

It is important for the team to have the knowledge and experience necessary to carry out the project, and the skills possessed by them should be adequate and correspond to the areas of work undertaken in the project. The relationship between individual resources and the scope of planned R&D work in the project must be clearly demonstrated.

The human resource management aspect plays a significant role in project management. At the Railway Research Institute (RRI), which has an organizational structure in the form of a matrix, project teams are organized to carry out projects based on the Director's Regulation on detailed rules for organizing teams to implement projects/undertakings and determining the amount of the supplementary fee for members of project teams.

Before starting each project, a Project Team is appointed, composed of: a project manager, an R&D manager, an R&D specialist, research and technical staff. The Coordination of Projects and International Cooperation Department is responsible for coordinating project work.

In RRI, the person responsible for managing and supervising the entire project work, both substantive and administrative, is the project manager. All persons involved in the project are subordinate to him. Teams are created as needed for each project.

The project budget is an important element to prepare at the project planning stage. It contains information about the costs that will be incurred during its implementation. It should be well thought out, consistent with the schedule and scope of project activities, and include real costs necessary for project implementation and achievement of the planned effects.

In the analysed project, the so-called lump sum financing scheme, operating within the Horizon Europe program, is obligatory. Since 2018, the European Commission has gradually introduced this type of settlement. Lump sum amounts are determined at the stage of submitting the project proposal and are specified in the financing agreement.

Due amounts are paid after the completion of activities in individual work packages. The level of funding for the analysed project looks as follows: the European Union co-finances up to 60% of the eligible project costs, and for the remaining 40% of the eligible costs, support can be obtained under the Ministry of Science and Higher Education Program (https://www.kpk.gov.pl/ [accessed on February 19, 2024]).

The last element in the development of an R&D project is to determine indicators that allow measuring the extent to which the project's intended goal has been achieved. The above aspects at the project preparation stage depend entirely on the type, specificity, and nature of the project. However, considering the above-mentioned elements will help structure the research and development project and facilitate the planning and preparation process of its basic assumptions.

3. Conclusions

Based on the obtained results, the following conclusions have been formulated:

1. The utilization of regeneration energy in railway transport is an example of rational energy use in the transportation sector. The electric energy resulting from regeneration is not obtained through the burning of fossil fuels or other chemical processes, thus not constituting the conversion of primary energy into secondary energy.

   The technological process of energy regeneration essentially originates from the recovery of previously generated energy taken by the railway vehicle and stored in the form of kinetic energy. Therefore, regeneration energy in railways is significant for the efficiency, equivalence, and economic viability of railway transport, simultaneously helping to reduce the sector's negative impact on the environment and operational costs.

2. R&D projects in railway transport are elements of innovation and key factors in increasing efficiency and creating new jobs. A project is a complex process comprising design, testing, and improving new products, services, and processes to enhance their value, quality, or reliability.

3. Choosing the appropriate financial instrument is crucial for the effective implementation of research projects in the railway sector. In the case of research and innovation initiatives in the European Union, such as Europe's Rail, NCBR competitions, and the BRIK joint venture, there are numerous opportunities for obtaining funding.

   This allows for accelerating technological development, improving competitiveness, and achieving sustainable development goals in railway transport. The diversity of these funding sources enables effective collaboration between research institutions and companies, contributing to the transformation of the railway sector and meeting market needs.

   In order to implement environmentally friendly research projects aimed at increasing the use of regeneration energy in railways, Railway Research Institute participates in the Europe's Rail initiative in the flagship area FA4 Sustainable and ecological railway system under the acronym Rail4Earth.

4. A crucial element in the preparation stage of a research and development project is demonstrating the ability to implement it properly by having the appropriate human resources. In the case of the Railway Institute, project teams are organized based on a matrix structure and are appointed before the start of each project.

   They consist of a project manager, R&D manager, R&D specialist, research, and technical staff. Project coordination is handled by the Department of Project Coordination and International Cooperation, while overall project supervision rests with the project manager. It is essential to ensure that the skills possessed by the team are adequate for the scope of R&D work in the project.

5. The R&D project budget must reflect the real costs necessary to achieve the project's objectives, ensuring its effective implementation. In the analysed project, which uses a lump-sum financing scheme under Europe's Rail in the flagship area FA4, the European Commission covers up to 60% of eligible costs, while the remaining 40% are covered from the Ministry of Science and Higher Education Program.

   Utilizing a lump-sum financing scheme under the Horizon Europe JU program brings several benefits to the research unit: no need for detailed monitoring and settlement of each expense allows the research unit to fully focus on achieving the project's research goals, instead of spending time on complex financial procedures, the lump-sum model eliminates the need for detailed settlement of each cost, significantly simplifying administrative and accounting procedures.

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