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АНОТАЦІЯ

У даній роботі розглядається тема «Інформаційні технології на основі алгоритму Дейкстри в металургійних залізницях». Обговорюється застосування алгоритму Дейкстри для оптимізації вибору маршрутів залізничного транспорту в металургійній промисловості з метою підвищення ефективності транспортування, зниження витрат і полегшення робочого навантаження внутрішніх працівників залізниці на металургійних підприємствах. З постійним розвитком металургійної промисловості зростання обсягів виробництва призвело до значного збільшення частоти транспортування розплавленого чавуну, що робить роль залізничного транспорту все більш важливою. Однак складне розташування залізничних колій у межах металургійних комбінатів, численні стрілочні переводи в поєднанні з високою швидкістю маневрових робіт і різноманітністю транспортних вимог створюють значні проблеми для планування залізничних шляхів.

Алгоритм Дейкстри, як ефективний інструмент для пошуку найкоротшого шляху, продемонстрував значну ефективність у вирішенні питань планування маршруту. Його ефективність випливає з його здатності керувати проблемами найкоротшого шляху з одного джерела, його механізму запису шляху та його переваг у графічному представленні. Суть цього алгоритму полягає в його поступовому розширенні: починаючи з початку, він відвідує вузли на графі один за іншим і обчислює найкоротший шлях від початкової точки до кожного вузла. Алгоритм Дейкстри не тільки ефективно визначає найкоротший шлях, але й записує конкретні деталі шляху, надаючи повну довідкову інформацію для подальшого вибору шляху.

У цьому документі спочатку викладаються основні концепції алгоритму Дейкстри та його застосування в області планування маршруту. Після цього розроблено стратегію оптимізації маршруту на основі алгоритму Дейкстри, адаптовану до конкретних характеристик металургійного залізничного транспорту. Ця стратегія враховує не лише аспект відстані

маршруту, але й всебічно розглядає численні виміри, включаючи безпеку, економічні витрати, ефективність часу та потенціал розширення, намагаючись знайти оптимальне транспортне рішення. Шляхом побудови математичної моделі та її поєднання з конкретними практичними випадками перевіряється прикладна цінність і практична ефективність алгоритму.

У практичних застосуваннях алгоритм Дейкстри може ефективно вирішувати різні проблеми, що виникають у металургійному залізничному транспорті. Наприклад, він може допомогти диспетчерам вибрати оптимальний шлях шляхом точного розрахунку вартості кожного маршруту, тим самим зменшуючи непотрібні відстані подорожі та економлячи час і ресурси. Крім того, цей метод демонструє чудову гнучкість і адаптивність, здатний регулювати відповідні параметри відповідно до різних транспортних вимог, забезпечуючи ефективне та стабільне рішення для залізничного транспорту в металургійній промисловості. Наприклад, коли потрібне швидке реагування на надзвичайні ситуації або коригування транспортних планів, алгоритм Дейкстри може швидко перерахувати шлях, щоб забезпечити плавне виконання транспортних завдань.

Крім того, застосування алгоритму Дейкстри також закладає основу для побудови наступних інтелектуальних систем диспетчеризації. Завдяки інтеграції з аналізом великих даних, технологією Інтернету речей (IoT) і штучним інтелектом (AI) алгоритм Дейкстри може досягти динамічної оптимізації шляху в більш складних середовищах. Наприклад, за допомогою моніторингу даних у режимі реального часу та прогнозного аналізу можна заздалегідь визначити потенційні вузькі місця транспортування, що дозволить вжити запобіжних заходів; за допомогою алгоритмів машинного навчання стратегії вибору шляху можна автоматично коригувати, що ще більше підвищує інтелектуальність і точність планування шляху.

Таким чином, оптимізація маршруту за допомогою алгоритму Дейкстри не тільки підвищує точність і ефективність планування маршруту, але й забезпечує більш гнучку та надійну технічну підтримку для

залізничних перевезень у металургійній промисловості. Це сприяє підвищенню конкурентоспроможності підприємств та сприянню сталому розвитку всієї галузі. У майбутньому, з постійним розвитком інформаційних технологій, алгоритм Дейкстри відіграватиме більшу роль у металургійних залізничних перевезеннях, сприяючи диверсифікованому розвитку алгоритму вибору найкоротшого шляху.

Ключові слова: алгоритм Дейкстри; Металургійна залізниця; Оптимізація шляху; застосування інформаційних технологій; Інтелектуальне планування

ABSTRACT

This paper explores the theme of "Information Technology Based on Dijkstra Algorithm in Metallurgical Railways." It discusses the application of the Dijkstra algorithm to optimize the selection of railway transportation paths in the metallurgical industry, aiming to enhance transportation efficiency, reduce costs, and alleviate the workload of internal railway employees in metallurgical enterprises. With the continuous advancement of the metallurgical industry, the growth in production volume has led to a significant increase in the frequency of molten iron transportation, making the role of railway transportation increasingly important. However, the complex layout of railway lines within metallurgical plants, numerous switches, coupled with the high speed of shunting and the diversity of transportation demands, pose considerable challenges for railway path planning.

The Dijkstra algorithm, as an efficient tool for shortest path searches, has demonstrated significant effectiveness in addressing route planning issues. Its potency stems from its ability to manage single source shortest path problems, its path recording mechanism, and its graphical representation advantages. The essence of this algorithm lies in its gradual expansion process: starting from the origin, it visits nodes in the graph one by one and calculates the shortest path from the starting point to each node. The Dijkstra algorithm not only effectively identifies the shortest path but also records the specific details of the path, providing comprehensive reference information for subsequent path selection.

This paper initially outlines the core concepts of the Dijkstra algorithm and its applicability in the field of route planning. Following that, a path optimization strategy based on the Dijkstra algorithm is designed, tailored to the specific characteristics of metallurgical railway transportation. This strategy takes into account not only the distance aspect of the path but also comprehensively considers multiple dimensions, including safety, economic cost, time efficiency, and expansion potential, all in an effort to find the optimal transportation solution.

By constructing a mathematical model and combining it with specific practical cases, the algorithm's application value and practical effectiveness are verified.

In practical applications, the Dijkstra algorithm can effectively tackle various issues encountered in metallurgical railway transportation. For instance, it can assist dispatchers in selecting the optimal path by accurately calculating the cost of each path, thereby reducing unnecessary travel distances and saving time and resources. Moreover, this method exhibits excellent flexibility and adaptability, capable of adjusting relevant parameters according to different transportation requirements, providing an efficient and stable solution for railway transportation in the metallurgical industry. For example, when rapid response to emergencies or adjustments to transportation plans are needed, the Dijkstra algorithm can quickly recalculate the path to ensure the smooth progress of transportation tasks.

Furthermore, the application of the Dijkstra algorithm also lays the groundwork for the construction of subsequent intelligent dispatching systems. By integrating with big data analysis, Internet of Things (IoT) technology, and Artificial Intelligence (AI), the Dijkstra algorithm can achieve dynamic path optimization in more complex environments. For example, using real time data monitoring and predictive analysis, potential transportation bottlenecks can be identified in advance, allowing for preventive measures; through machine learning algorithms, path selection strategies can be automatically adjusted, further enhancing the intelligence and precision of path planning.

In summary, path optimization using the Dijkstra algorithm not only enhances the precision and efficiency of path planning but also provides more flexible and reliable technical support for railway transportation in the metallurgical industry. This contributes to enhancing the competitiveness of enterprises and promoting the sustainable development of the entire industry. In the future, with the continuous advancement of information technology, the Dijkstra algorithm will play a greater role in metallurgical railway transportation, promoting the diversified development of shortest path algorithm selection.

Keywords: Dijkstra Algorithm; Metallurgical Railway; Path Optimization; Information Technology Application; Intelligent Scheduling

CONTENT

INTRODUCTION

Compared to passenger railways, metallurgical railways have shorter lines, more switches, frequent shunting, and harsh working conditions. These characteristics have led to a decreasing number of young people willing to engage in this type of work, while at the same time, the aging of the workforce is severe, necessitating an urgent upgrade to the existing system to alleviate the work pressure on employees.

Currently, the computer interlocking system, when dealing with long distance shunting, requires multiple short distance shunting operations to be realized, which is not only inefficient but also increases the number and complexity of manual operations. In metallurgical enterprises with frequent shunting, this inefficient operation significantly increases the workload of employees.

The Need for the Introduction of the Shortest Path Algorithm

To improve shunting efficiency and reduce manual operations, we are considering the introduction of a shortest path algorithm to optimize shunting paths. When selecting the algorithm, we mainly consider the following key factors:

Accuracy and Safety: The algorithm must be able to provide the most accurate shortest path and ensure the safety of the shunting process.

Single Source Problem: Shunting is from one location to another, which is a single source shortest path problem.

No Negative Weights: When the locomotive needs to reverse, it presses the signal machine opposite to the shunting direction, so there is no problem with negative weight edges.

Good Extensibility: The algorithm should have good extensibility and be able to integrate well with existing data, providing a foundation for future intelligent unmanned dispatching.

Considering the above requirements, Dijkstra's algorithm is a very suitable choice. Here are the advantages of Dijkstra's algorithm in the application of metallurgical railway shunting:

Determinism and Reliability:

Dijkstra's algorithm can guarantee to find the shortest path from the source point to all other vertices, provided there are no negative weight edges in the graph. This determinism makes it very reliable in practical applications.

Efficiency: For sparse graphs (such as metallurgical railway networks), with the use of priority queues, the time complexity of Dijkstra's algorithm is $O((V + E) \log V)$, making it suitable for large scale graphs. This makes it perform well in handling frequent shunting tasks.

Easy to Understand and Implement: Dijkstra's algorithm is based on a greedy strategy, where the vertex with the smallest known distance is selected for expansion each time until all vertices have been visited or cannot be expanded further. This intuitive principle makes the algorithm easy to understand and implement. Good Combination with Data Structures:

Dijkstra's algorithm is usually combined with priority queues (such as binary heaps, Fibonacci heaps, etc.) to efficiently manage the collection of candidate vertices. This combination ensures that the algorithm remains efficient when dealing with large scale data.

Our research focuses on the application of railway dispatching, aiming to optimize path selection from the origin to the destination using Dijkstra's algorithm. By identifying suitable entities as nodes and weights, we are committed to finding the optimal solution among all possible paths to ensure that trains can complete shunting tasks in the shortest time and at the lowest cost.

To achieve the aforementioned objective, the following numbered tasks must be completed:

1. Overview of Railway Transportation within Metallurgical Enterprises
   - Analyze the characteristics, current situation, and primary challenges faced by internal railway transportation within metallurgical enterprises.
   - Evaluate the criteria for selecting existing transport routes and their impact on efficiency.

2. Overview of Applying Dijkstra’s Algorithm to Railway Modeling in Metallurgical Enterprises
    - Investigate the fundamental principles of Dijkstra's algorithm and its suitability.
    - Explain how Dijkstra's algorithm can be applied to modeling the railway network within metallurgical enterprises.
3. Analysis of Dijkstra’s Algorithm Application in Metallurgical Enterprise Railways
    - Discuss the advantages of applying Dijkstra’s algorithm in metallurgical railways.
    - Conduct an in-depth analysis of specific scenarios where Dijkstra’s algorithm is used in the railway transportation of metallurgical enterprises.
4. Modeling Analysis of Metallurgical Enterprise Railways Using Dijkstra’s Algorithm
    - Construct a railway network model for metallurgical enterprises, setting weights for nodes and edges.
    - Apply Dijkstra’s algorithm to calculate the optimal path and compare the outcomes with traditional route selection methods.
5. Demonstration of Dijkstra’s Algorithm Program
    - Implement Dijkstra’s algorithm using software tools.
    - Showcase the actual operation process of the algorithm and demonstrate its application effects in the railway transportation of metallurgical enterprises through case studies.

1. RESEARCH BACKGROUND AND OBJECTIVES

1.1 Research Background

Amidst the pressures of the global economy, the metallurgical sector is grappling with challenges that are truly one of a kind. To surmount these hurdles and sharpen its competitive edge, streamlining the railway routes for shipping metallurgical goods has become a priority [1]. Pinpointing the most direct routes not only boosts the efficiency of logistics but also cuts down on shipping expenses. This streamlining effort is key to bolstering the sector's shipping prowess and gives companies a leg up in a fiercely competitive landscape.

Within the realm of rail dispatching, choosing the right shunting routes is essential for the smooth and secure management of train traffic. The way we select these routes has transformed over time from manual processes to automated and smart systems.

In the infancy of rail transport, the selection of shunting routes was predominantly a manual task. Dispatchers had to visually inspect, manually jot down, and verbally pass on instructions to carry out shunting jobs. This approach was not just inefficient but also error prone, particularly in intricate yard settings where dispatchers were inundated with information, often resulting in miscalculations [2].

As rail technology progressed, the incorporation of mechanical and electrical tools in shunting operations became more prevalent. Tools like mechanical arms, signal lights, and relays helped dispatchers in the route selection process. While these advancements increased the precision and safety of shunting, their efficiency was still hampered by the need for human intervention.

With the dawn of the 21st century, the advent of Centralized Traffic Control (CTC) systems marked a significant step forward in the smart selection of shunting routes. CTC systems, utilizing a network of decentralized autonomous computers [3], ensured the reliable separation of shunting and train routes in terms of both timing and spatial distribution. The system was capable of automatically determining the most efficient shunting route based on train schedules and live data. However, due to the intricacies of rail transport within metallurgical companies and the fluctuating nature of production tasks, there remain challenges with manually initiating rail signals for route selection, and lengthy shunting operations may not always identify the most direct path.

1.2 Research Objectives

In the contemporary era, with the rapid advancement of artificial intelligence technology, the field of metallurgical railway dispatching has encountered unprecedented opportunities for development. To seize this trend, we must keep pace with technological advancements and fully utilize the latest scientific achievements to drive innovation and continuous progress in the metallurgical railway dispatching industry. By integrating advanced algorithms and data analysis tools [4], we can achieve intelligent management of transportation processes, making real time adjustments and optimizations to dispatch plans, effectively responding to the ever changing market demands.

The core strengths of intelligent dispatch systems lie not only in enhancing operational efficiency but also in promoting energy conservation and emission reduction in metallurgical enterprises. By scientifically planning transportation routes, we can minimize unnecessary travel distances [5], thereby reducing energy consumption. Moreover, more accurate scheduling helps to avoid traffic congestion during peak hours, lessening the additional emissions caused by such congestion. This strategy, which focuses on both efficiency and environmental protection, aligns with the global trend of sustainable development and also assists enterprises in easing economic cost pressures, positioning them advantageously in the competitive market [6].

In this context, the application of Dijkstra's algorithm becomes particularly significant. As a classic and efficient graph theory algorithm, Dijkstra's algorithm excels in solving single source shortest path problems. The algorithm is deterministic, meaning that it will always yield consistent results given the same input conditions. This reliability makes Dijkstra's algorithm highly suitable for scenarios that demand high reliability and safety, such as railway systems.

In railway dispatch applications, Dijkstra's algorithm can help identify the optimal path among all possible paths from the starting point to the destination, ensuring that trains complete shunting tasks at the fastest speed and lowest cost. Moreover, the introduction of Dijkstra's algorithm not only enhances the efficiency of path selection but also improves the adaptability and flexibility of the system. In the face of complex railway networks and varying transportation demands, Dijkstra's algorithm can quickly respond and provide solutions, making railway dispatch more intelligent and automated. This intelligent dispatch system not only improves the quality of railway transportation services but also enhances the competitiveness of the entire metallurgical industry [7].

Introducing Dijkstra's algorithm into computer interlocking systems is essential. The aim of this study is to examine how Dijkstra's algorithm can be integrated into these systems.

Dijkstra's algorithm, introduced by Dutch computer scientist Edsger W. Dijkstra in 1956, addresses the single source shortest path problem within graph theory. This algorithm effectively identifies one or more shortest paths from an origin to a destination and has been extensively used in traffic navigation and network routing [8].

Incorporating Dijkstra's algorithm into railway dispatch systems leverages its deterministic nature, ensuring consistent outcomes for the same input, which is crucial for the reliability required in railway operations, adhering to the failsafe principle.

Metallurgical railway transportation is characterized by its complexity and dynamism, involving numerous train dispatches, route planning, and emergency responses [9]. As technology advances, employing Dijkstra's algorithm offers a robust tool for optimizing internal railway routes in metallurgical enterprises. Known for its efficient shortest path calculations, Dijkstra's algorithm excels in managing large scale network graphs, swiftly determining the optimal path from start to end.

In practical applications, Dijkstra's algorithm not only effectively solves path optimization problems under static conditions but also demonstrates excellent dynamic adjustment capabilities. When construction, maintenance, or unexpected accidents render existing paths unusable, the algorithm can quickly recalculate the optimal path based on the latest line conditions, ensuring that dispatch plans remain timely and accurate even in the face of unforeseen circumstances. This flexibility is crucial for ensuring the continuous production of metallurgical enterprises.

Dijkstra's algorithm not only shows great potential in current railway dispatching but can also be easily extended to support future intelligent dispatching. By integrating big data, the Internet of Things (IoT), and artificial intelligence (AI) technologies, the intelligence level of railway dispatching can be further enhanced, achieving more efficient, safer, and more environmentally friendly transportation management.

2. OVERVIEW OF RAILWAY TRANSPORTATION IN METALLURGICAL ENTERPRISES

2.1 Domestic and international analysis of metallurgical enterprises

The metallurgical industry, as a crucial pillar of the national economy, covers several areas including steel, nonferrous metals, and precious metals. Its development level directly affects industrial modernization and national economic growth. China is the largest metallurgical producer globally, especially in terms of steel production, where it has consistently led other countries in recent years. According to the latest data, China's crude steel production accounts for more than half of the global total. With the advancement of the "dual carbon" policy, domestic steel enterprises face increasingly fierce competition in the market, particularly in terms of price, quality, and technological innovation.

Globally, the metallurgical industry is also undergoing continuous transformation. Metallurgical enterprises in Europe, America, and Japan have significant advantages in research and development and technological innovation, especially in the production of high end steels and special alloys. These countries' enterprises not only lead in technology but also adhere to stricter environmental standards. In response to increasingly stringent environmental regulations, metallurgical enterprises worldwide are accelerating the implementation of clean production and circular economy practices to reduce their environmental impact and improve resource utilization efficiency.

Overall, whether domestically or internationally, the metallurgical industry is experiencing profound changes. Technological innovation and green development have become important drivers for industry growth. This is not only reflected in the progress of production processes but also in the optimization of the entire supply chain management, especially in the improvement of transportation.

2.2 Overview of metallurgical enterprise railway transportation

Internal railway transportation in metallurgical enterprises is a critical component of the industrial production process, including metal smelting and rolling. The efficiency of internal railway transportation not only directly affects production costs but also relates to key factors such as the transportation time and temperature control of molten iron.

The efficiency of internal railway transportation also significantly impacts the input of raw materials and the output of finished products, directly affecting the overall operational efficiency of the enterprise. An efficient internal railway transportation system ensures that raw materials are delivered to the production line in a timely and accurate manner, ensuring that molten iron can be quickly delivered to the ironmaking and steel rolling departments at the optimal temperature, thereby improving production continuity and efficiency.

After production, finished products can also be rapidly transferred from the production line to storage or external transportation, enhancing the company's competitive edge in the market by reducing inventory costs and improving capital turnover rates.

In the internal railway transportation of metallurgical enterprises, the optimization of the shortest path is particularly important. Through scientific planning and scheduling, determining the shortest transportation path not only significantly reduces transportation time and increases the flow rate of materials but also effectively lowers energy consumption and labor costs during the transportation process. Such optimization measures not only enhance economic benefits but also promote efficient resource utilization, reduce unnecessary waste, and drive the enterprise toward green and sustainable development.

In the context of global economic integration and Industry 4.0, the metallurgical industry, as a crucial pillar of the national economy, plays a vital role in enhancing the country's overall competitiveness through its production efficiency and economic performance.

With the continuous changes in the global market and rapid technological advancements, along with increasingly strict environmental policies and ongoing technological innovations, metallurgical enterprises face dual pressures of energy conservation, emission reduction, and cost reduction while pursuing efficient production. They are confronted with unprecedented challenges and opportunities.

To address these changes, enterprises are placing greater emphasis on internal management and technological innovation, particularly in the optimization of railway transportation routes. By optimizing railway transportation paths, enterprises can not only improve logistics efficiency and reduce energy consumption but also significantly enhance safety and response speed, thereby achieving a greener and more efficient operational model.

Therefore, the metallurgical railway dispatch system, in response to increasingly complex production demands and reform trends [10], has gradually undergone a major upgrade from traditional 6502 electrical centralized interlocking to fully electronic computer interlocking. This modern, fully electronic computer interlocking system not only offers better scalability and flexibility but also provides a solid physical equipment foundation and modern technological support for intelligent dispatching and shortest path selection, effectively driving technological innovation in the entire industry [11].

Drawing on the capabilities of a fully electronic computer interlocking system, incorporating both drag shunting and shortest path algorithms can markedly enhance the efficiency of logistics transportation [12]. This sophisticated method not only diminishes energy usage but also bolsters the safety and swiftness of the transportation process.

By refining intelligent dispatching systems, metallurgical companies can attain more productive and sustainable transportation procedures, ensuring the punctual satisfaction of production demands while optimizing the efficiency of resource utilization. This evolution not only amplifies the competitiveness of these enterprises but also establishes a pivotal groundwork for the entire metallurgical sector to progress towards a more efficient and friendly trajectory.

3. OVERVIEW OF USING DIJKSTRA ALGORITHM IN RAILWAY MODELING FOR METALLURGICAL ENTERPRISES

3.1 Advantages of Dijkstra's algorithm in railway dispatching systems

Dijkstra's algorithm, a cornerstone and potent tool in the realm of computer science, brings considerable benefits to railway dispatch systems due to its predictable outcomes and swift performance. As a deterministic process, Dijkstra's algorithm guarantees that the output will remain consistent for the same set of input data, no matter the time or location of execution. This trait is essential in railway transportation systems [13], aligning with the stringent reliability demands under the failsafe principle and offering dependable decision making support amidst intricate dispatch challenges.

Within the context of metallurgical railway transportation, the network's structure is often intricate and subject to change, necessitating immediate adjustments to shifts in production schedules and external factors. Implementing Dijkstra's algorithm can significantly streamline the internal railway transportation routes of businesses. For instance, when dealing with various parallel tracks or intersecting paths, Dijkstra's algorithm can accurately identify the shortest route, ensuring optimal transportation efficiency.

Additionally, the algorithm has excellent dynamic adjustment capabilities. When railway lines change due to construction, maintenance, accidents, or other emergencies, Dijkstra's algorithm can quickly recalculate the optimal route to adapt to these dynamic changes. This capability not only ensures the timeliness and accuracy of dispatch plans but is also a key factor in improving the safety and efficiency of railway transportation.

The significant potential of Dijkstra's algorithm in current railway dispatch systems is also reflected in its good scalability. This algorithm provides a solid technical foundation for future intelligent unmanned dispatch. With the continuous development and integration of advanced technologies such as big data, the Internet of Things (IoT), and artificial intelligence (AI) [14], Dijkstra's algorithm is expected to further enhance the intelligence level of railway dispatch, achieving more efficient, safer, and more environmentally friendly transportation management. This comprehensive application will bring new development opportunities to the railway transportation of the metallurgical industry, driving its transformation toward a more intelligent direction .

Moreover, the efficiency of Dijkstra's algorithm means that it can quickly provide solutions when dealing with large scale railway networks. This is particularly important for metallurgical enterprises that need to respond rapidly to market changes and internal dispatch demands. By reducing unnecessary transportation time and costs, enterprises can improve their market competitiveness while having a smaller environmental impact.

3.2 Modeling analysis of Dijkstra's algorithm in metallurgical railways

In the process of optimizing shunting paths in internal railway transportation within metallurgical enterprises, using Dijkstra's algorithm to determine the optimal path is a highly effective method. This approach not only improves the efficiency of shunting operations but also enhances the overall safety and reliability of the process.

Specifically, in building the model, we set the first shunting signal on the train's shunting direction as the starting point (or source) for Dijkstra's algorithm. This design choice is based on practical considerations: shunting operations typically start at the signal, and only after the signal opens the appropriate indication can the train start and proceed according to the received information. This mechanism ensures the order and safety of the shunting process, avoiding operational chaos and potential safety hazards caused by unclear or incorrect signal indications [15].

Furthermore, to comprehensively cover all possible shunting paths, we include all codirectional shunting signals that need to be passed through as nodes in Dijkstra's algorithm. Each node represents a critical decision point where the train can change its route or continue along the current path. In this way, we establish a complex network composed of multiple nodes, where the connections between nodes represent feasible transition paths between different tracks. The weights of these connections are usually based on actual distances or specific factors (such as track congestion, maintenance status, etc.).

It is noteworthy that this modeling method strictly follows the basic principle of shunting signal opening, which is that a train is only allowed to move along a path when all relevant signals on that path are open.

Therefore, when using Dijkstra's algorithm to find the shortest path, any track known to be occupied or blocked by obstacles will be considered impassable, and the previous node (i.e., the nearest signal) will automatically become the endpoint of that segment. This ensures that every recommended path found is safe and reliable, supporting more efficient and safe shunting operations.

The deployment of Dijkstra's algorithm also permits the seamless integration of increased complexity and detail within our model. For instance, we can enrich each node and edge with supplementary characteristics, such as signal opening times, train priority levels, and specific shunting operation requirements, thereby enhancing the model's practical applicability and accuracy. Consequently, the algorithm not only determines the shortest path but also takes into account a variety of constraints and optimization goals present in real world operations.

By leveraging Dijkstra's algorithm to address the shunting path optimization challenge within the internal railway transportation systems of metallurgical enterprises, we can markedly enhance the efficiency of shunting operations and significantly mitigate the risks of uncertainty stemming from human errors or environmental fluctuations. This offers a technically sound and feasible solution for businesses. The adoption of this approach will render shunting operations more intelligent, optimize resource allocation, lower operational expenses, and ultimately bolster the enterprise's competitive edge in the market [16].

3.3 Mathematical model analysis of Dijkstra's algorithm in

metallurgical railways

In the metallurgical railway shunting system, the mathematical model of Dijkstra's algorithm is based on the shortest path problem in graph theory. Specifically, we abstract the metallurgical railway network into a weighted directed graph, where nodes represent shunting signals, and edges represent track segments between signals. The weights of the edges represent the length or shunting time of the track segments.

Mathematically, let the graph ($G = (V, E)$), where (V) is the set of nodes, and (E) is the set of edges. Each node ($v \in V$) corresponds to a shunting signal machine, each edge ($(u, v) \in E$) corresponds to a track segment between two signal machines, and the weight of the edge ($w(u, v)$) is the length or shunting time of the track segment. The goal of Dijkstra's algorithm is to find the shortest path from the starting signal machine (source) (s) to all other signal machines.

The mathematical model of Dijkstra's algorithm can be formalized into the following steps:

1. **Initialization:** Set the distance of the starting signal machine (s) to 0, i.e., ($d(s) = 0$), and the distance of all other signal machines to infinity, i.e., ($d(v) = \infty$) for all ($v \neq s$). Create a priority queue (Q), containing all signal machines, with distance as the priority.
2. **Iteration:** When the priority queue (Q) is not empty, perform the following operations:
    - Remove the signal machine (u) with the smallest distance from (Q).
    - For each adjacent signal machine (v) of (u), calculate the distance to (v) through (u) ($d(u) + w(u, v)$). If this distance is less than the currently recorded distance ($d(v)$), update ($d(v)$) to ($d(u) + w(u, v)$), and update the priority of (v) in (Q).
3. **Termination:** When (Q) is empty, the algorithm ends. At this point, the distance of each signal machine ($d(v)$) is the shortest path length from the starting signal machine (s) to that signal machine.

In the metallurgical railway shunting system, the mathematical model of Dijkstra's algorithm needs to consider the actual railway network structure and the specific requirements of shunting operations.

By employing mathematical modeling and algorithmic implementation, integrating Dijkstra's algorithm into the metallurgical railway shunting system can notably enhance the efficiency and safety of shunting maneuvers. This approach can reduce the time taken for shunting, decrease transportation expenses, and boost the overall productivity of the metallurgical enterprise. As computer technology advances and algorithms are further optimized, the utilization of Dijkstra's algorithm within the metallurgical railway shunting system is poised to expand and deepen. This will offer robust technical backing for the smart and automated evolution of metallurgical enterprises.

4 APPLICATION OF DIJKSTRA'S ALGORITHM IN METALLURGICAL ENTERPRISE RAILWAYS

4.1 Analysis of the Application of Dijkstra's Algorithm in Metallurgical Railways

Dijkstra's algorithm, proposed by the Dutch computer scientist Edsger W. Dijkstra in 1959, is an algorithm for calculating the shortest path in a graph, specifically designed to solve the shortest path problem in weighted graphs. This algorithm can accurately calculate the shortest path from one vertex to all other vertices, and is suitable for directed and undirected graphs with nonnegative weights. The key to Dijkstra's algorithm lies in its greedy strategy, which gradually expands the nearest unprocessed node and updates the distance of its neighboring nodes, ultimately determining the shortest path for all nodes [17].

In the railway marshalling operation process, Dijkstra's algorithm plays a crucial role, situated at the key link between the operator issuing marshalling commands and the computer interlocking system accepting and executing these commands.

When carrying out long marshalling operations, the locomotive must move from its current track (the starting track) to another target track (the destination track). In this process, there are usually multiple parallel routes to choose from, each of which may include multiple signal machines as important navigational markers. The operator triggers the entire marshalling plan formulation process by dragging the locomotive icon from the starting position to the expected arrival position through the graphical interface.

Figure 4- 1 D88 to D91

When it is necessary to marshal the locomotive from signal D88 (located on the right side of the interface) to signal D91, the operator needs to perform intuitive operations through the Graphical User Interface (GUI). Specifically, the operator will drag the icon representing the locomotive from the right side of signal D88 to the left side of signal D91, thereby clearly indicating the starting point and destination of the marshalling task.

Once the operator has completed the above operation, once the operator has completed the dragging operation of the locomotive icon, the system will automatically trigger the execution of Dijkstra's algorithm. The algorithm will take signal D88 as the starting point (or source) and calculate the best marshalling path from D88 to D91. It first takes the first signal machine in the direction of departure as the starting point, the so called source point of Dijkstra's algorithm;

Next, all signals in the same direction are considered as nodes in the graph. For any two adjacent signal machines, the length of the track they connect constitutes the weight value of the edge between these two nodes. Based on such a network graph composed of signal machines, Dijkstra's algorithm can calculate the shortest of all feasible paths from the initial position to the final destination.

It is worth noting that during actual operation, if a section of the path is occupied by other trains or obstacles, the nearest signal machine in front of that section of the track will be considered as the end point in an impassable state. This means that any scheme attempting to continue forward through this path will be excluded.

Therefore, during the processing of Dijkstra's algorithm, when encountering such a situation, the relevant signal machine marks the end of the path where it is located, indicating that it is no longer possible to advance from here.

In this way, even facing complex track layouts and constantly changing actual conditions, Dijkstra's algorithm can still efficiently identify a best marshalling route that is both safe and fast. Once the shortest path is determined, the computer interlocking system will open the corresponding marshalling signal machines along this path, ensuring that the locomotive can smoothly travel along the planned route until it safely arrives at the designated destination. This not only improves the efficiency of marshalling but also greatly enhances the safety of the entire process.

In addition, the application of Dijkstra's algorithm in the railway transportation system is highly adaptable and flexible. It can not only handle static network structures but also adapt to dynamically changing environments [18].

For example, in the event of emergencies or line maintenance, the algorithm can quickly recalculate the path and provide alternative solutions, ensuring the continuity and stability of railway transportation. This ability makes Dijkstra's algorithm an indispensable tool in the railway transportation system, especially in the complex internal railway network of metallurgical enterprises, its role is particularly significant.

4.2 The Position of Dijkstra's Algorithm in the Computer Interlocking System

Figure 4- 2"Metallurgical Railway Shunting System Structure" illustrates the structure of the metallurgical railway shunting system, which depicts the overall process of dispatching operations in detail and clearly points out the specific position of Dijkstra's algorithm within the computer interlocking system. This diagram not only provides an intuitive perspective for understanding the entire shunting process but is also crucial for identifying how each key component works together to achieve efficient and safe shunting operations.

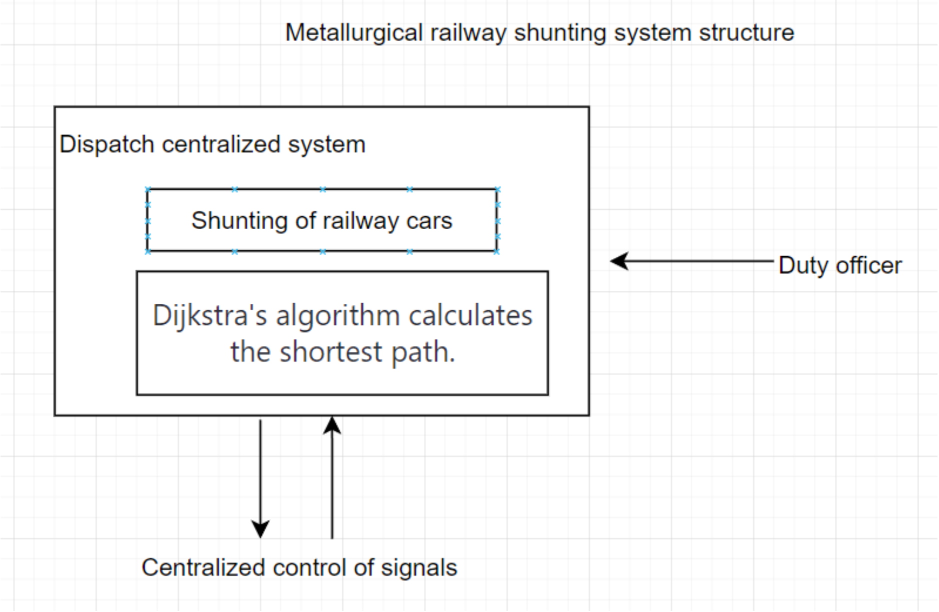

Figure 4- 2 Metallurgical railway shunting system structure

In the Figure 4- 2"Metallurgical Railway Shunting System Structure", we can observe a complete operational process: starting from the operator issuing shunting commands, through a series of complex decision making and calculation processes, and finally to the computer interlocking system executing these commands [19]. Dijkstra's algorithm occupies a central position in this process, serving as a key bridge between manual instructions and automated control, ensuring the efficiency and safety of shunting operations. When the operator drags the locomotive icon from the starting position to the expected destination through the graphical interface, expressing the shunting requirements, the system will automatically initiate Dijkstra's algorithm to calculate the optimal path. This process not only reflects the practicality of Dijkstra's algorithm but also demonstrates how the computer interlocking system intelligently responds to manual instructions.

It should be highlighted that Dijkstra's algorithm is distinctly marked in the diagram, underscoring its vital part in facilitating the seamless execution of shunting operations and highlighting its strategic importance within the broader scope of railway transportation management for metallurgical enterprises. This emphasis allows metallurgical companies to pursue more nuanced and intelligent shunting operation management, substantially enhancing operational efficiency and service standards.

Further analysis reveals how Dijkstra's algorithm interacts with other components of the system in Figure 4-2 "Metallurgical Railway Shunting System Structure." For example, the algorithm requires real time updated track layout and signal status information, which is provided by sensors and monitoring systems alongside the tracks.

Moreover, the algorithm must collaborate closely with the train control system and signal control system to ensure that the determined route is not just the shortest but also practical and secure. This integrated system effort is pivotal for achieving effective shunting operations.

Furthermore, the Figure 4-2 "Metallurgical Railway Shunting System Structure" also shows how Dijkstra's algorithm adapts to the dynamic changes in the railway system. In actual operations, railway lines may change for various reasons, such as maintenance, emergencies, or other unexpected events.

Dijkstra's algorithm is adept at swiftly adjusting to alterations, recalculating routes, and maintaining the continuity and adaptability of shunting operations.

Figure 4-2, "Metallurgical Railway Shunting System Structure," underscores the capacity of Dijkstra's algorithm to optimize resource distribution and enhance energy efficiency. By precisely determining the shortest path, the algorithm minimizes the locomotive's travel distance and time, consequently reducing fuel usage and emissions. This is highly beneficial for meeting the environmental objectives of metallurgical enterprises and bolstering their societal responsibility.

Figure 4-2, "Metallurgical Railway Shunting System Structure," aids in grasping the application and significance of Dijkstra's algorithm within the metallurgical railway shunting system. Utilizing this algorithm, metallurgical enterprises can attain more efficient, secure, and intelligent railway transportation management, boost operational efficiency, increase corporate competitiveness, and support sustainable development [20]. As technology continues to evolve, the integration of Dijkstra's algorithm in the metallurgical railway shunting system will expand and deepen, with its value and potential being further explored and realized.

5 APPLICATION OF DIJKSTRA'S ALGORITHM IN MODELING AND ANALYSIS OF METALLURGICAL ENTERPRISE RAILWAYS

5.1 Dijkstra's Algorithm in Modeling and Analysis of Metallurgical Enterprise Railways

When staff drag the locomotive from a starting point to a destination on the display interface of the computer interlocking system, and there are multiple parallel routes, Dijkstra's algorithm can effectively select the route with the shortest path. It then opens the signals and switches along the path to achieve the selection of the shortest path.

In building the shunting network model, we consider all the shunting signals that need to be passed in the same direction as key nodes in Dijkstra's algorithm. Each of these nodes represents a potential shunting path selection point, and the connections between these nodes form a complex shunting path network. This design not only complies with the basic principles of signal opening for shunting but also ensures the safety and orderliness of the entire shunting process. By setting signals as nodes, we can effectively simulate the actual operation of trains under different signal controls, thus providing a solid foundation for finding the optimal path.

It's important to highlight that within this model, we employ the effective track length as the edge weight in Dijkstra's algorithm's graph. This allows for a more precise evaluation of the costs associated with various shunting paths, enabling the selection of the most optimal shunting plan. Such an approach not only enhances the overall efficiency of shunting operations but also significantly diminishes potential safety risks during the shunting process, ensuring the safety and fluidity of railway transportation. The effective track length is defined as: the maximum segment of the track's total length that can safely accommodate locomotives and vehicles without causing interference to adjacent tracks [21]. This definition takes into account a variety of factors from real world operations, including but not limited to train size, parking safety distances, and the safety buffer between adjacent tracks. The benefit of using effective length as a weight is that it prevents shunting challenges due to overly short tracks and maximizes the utilization of existing resources, thereby improving shunting efficiency. Additionally, this method ensures that even during peak shunting activities, the parking positions for locomotives and vehicles can be organized in an efficient and rational manner, preventing potential safety hazards.

The use of effective length as a weight also helps to sidestep difficulties in shunting due to tracks that are too short and maximizes the use of existing resources. This not only boosts shunting efficiency but also minimizes unnecessary waiting times and waste of resources. Furthermore, this approach allows for the efficient and rational arrangement of parking positions for locomotives and vehicles, even in the most congested or space constrained scenarios, further bolstering operational safety.

Specifically, when determining the effective length of the track, it is also necessary to consider the maximum length of the train or vehicle that can be safely parked on the effective length of the track. This not only helps to accurately calculate the cost of each path but also reflects the limitations under actual operating conditions. Using effective length as a standard is particularly important. Another advantage of doing this is that it promotes the optimal allocation of resources, ensuring that even with limited space resources, efficient shunting operations can be achieved.

5.2 Case Study of Dijkstra's Algorithm in Metallurgical Enterprise Railways

The application of Dijkstra's algorithm in the modeling and analysis of metallurgical enterprise railways takes the slag and iron station of Anyang Iron and Steel Co., Ltd. as an example to specifically illustrate the effectiveness of Dijkstra's algorithm in practical applications.

For example, in the process of transporting from the iron mouth of the blast furnace to the iron and steel rolling department, when shunting from signal D128 to signal D2, there are usually multiple feasible paths. To ensure that the transportation process is both efficient and safe, it is crucial to select the shortest and optimal path. According to the basic principles of Dijkstra's algorithm, by calculating the total length of each path (i.e., the sum of the effective lengths of each section of the track), the optimal solution can be found.

To ensure the accuracy and comprehensiveness of the experiment, we divide the long shunting route into two sections, one long and one short, for analysis. This segmented treatment not only helps to more finely evaluate the characteristics and potential problems of each section of the path but also provides more reliable data support for finally determining the overall shortest path.

Specifically, in the shunting process from signal D128 to signal D2, we first divide the entire path into two parts: Path A, the shorter path from signal D128 to signal D88; Path B, the longer path from signal D88 to the intermediate signal D2. The purpose of this is to better understand the specific situation of each section of the path, including its length, the status of the signals, etc.

In Path A: the shorter path, we use Dijkstra's algorithm to calculate all feasible paths from signal D128 to signal D88 and find the shortest one. Although this section of the path is relatively short, it also needs careful analysis. In this way, we can ensure that even within a shorter distance, the best path can be selected, thereby improving the efficiency of the overall shunting operation.

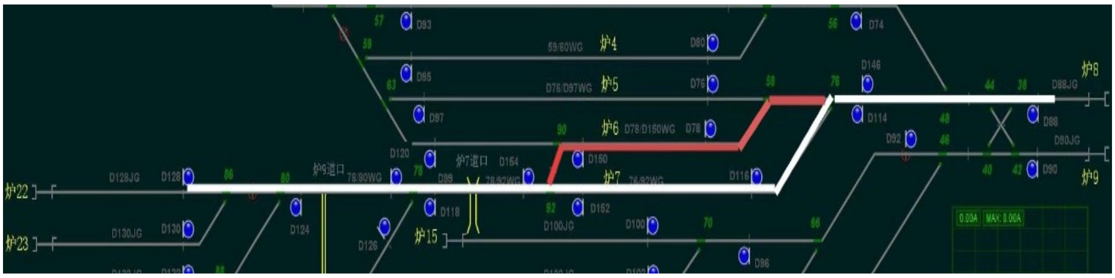

Figure 5- 1 Path A

In Path B: the longer path, we use Dijkstra's algorithm to calculate all feasible paths from signal D88 to signal D2 and identify the shortest one. This section of the path typically involves more signals and tracks, thus requiring more complex calculations. By doing so, we can ensure the selection of the optimal path during long distance shunting, avoiding the impact on efficiency that might be caused by excessively long paths or the presence of too many obstacles.

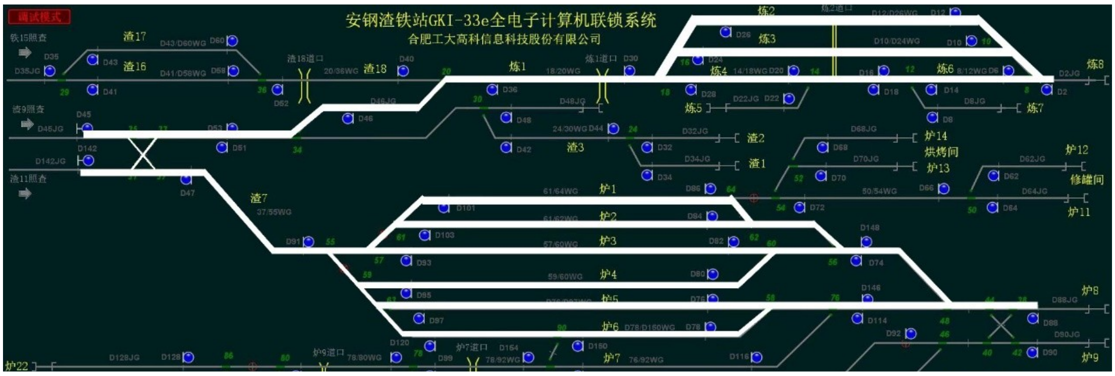

Figure 5- 2 Path B

Finally, we combine these two shortest paths to form the overall shortest path from signal D128 to signal D2. By using this segmented processing method, we can not only analyze the characteristics of each section in more detail but also ensure the accuracy of the final result. This approach not only improves the overall efficiency of shunting operations but also enhances safety, reducing the potential issues that may arise from improper path selection.

Moreover, segmented processing also helps to deal with emergencies. If new obstacles or changes occur during the shunting process (such as a section of track being temporarily occupied), we only need to recalculate the affected section of the path without having to recalculate the entire path. This greatly improves the system's response speed and flexibility.

By dividing the long shunting route into one long and one short section for analysis, and applying Dijkstra's algorithm to determine the shortest path for each section, we can not only more accurately evaluate the situation of each section but also ensure that the total path ultimately chosen is the optimal solution. This method not only improves the efficiency of shunting operations but also enhances safety, providing strong support for the optimization of the internal railway transportation system in metallurgical enterprises.

Specifically, assuming there are two main shunting paths to choose from when starting from signal D128:

- Path A: Starting from signal D128, passing through intermediate signals such as D120, D154, and finally arriving at signal D88.

- Path B: Starting from signal D88, passing through intermediate signals such as D47, D30, and finally arriving at signal D2.

In actual operations, the effective length of each section of track has been preset and serves as the weight value of the graph edges in Dijkstra's algorithm. These effective lengths take into account not only the actual physical length of the track but also factors such as the safety distance for train parking and the safety interval with adjacent tracks.

When the operator drags the locomotive icon from signal D128 to signal D88 through the display interface of the computer interlocking system, the system automatically initiates Dijkstra's algorithm to evaluate all possible paths. The algorithm sets signal D128 as the source point, signal D88 as the target node, and traverses all possible intermediate nodes, calculating the total length of each path. By comparing the total lengths of these paths, Dijkstra's algorithm can quickly determine the shortest path.

Figure 5- 1 "Path A" illustrates Path A: starting from the D128 signal, passing through intermediate signals such as D120 and D154, and ultimately arriving at the D88 signal.

Figure 5- 3 D128 to D88 path analysis

When there are two parallel routes, Dijkstra's algorithm can effectively select the shortest route. Taking the slag and iron station of Anyang Iron and Steel Co., Ltd. as an example, as shown in Figure 5- 3 "D128 to D88 path analysis", during the transportation process from the iron mouth of the blast furnace to the iron and steel rolling department, there are two possible paths when shunting from signal D128 to signal D88. According to Dijkstra's algorithm, the shortest path can be accurately calculated and identified. Assuming that the white route is the shortest path calculated by Dijkstra's algorithm, the system will open all the signals on this path, allowing the locomotive to complete the transportation task within the shortest and effective distance.

In this Figure 5- 3 "D128 to D88 path analysis", the two paths are represented in different colors for easy distinction and understanding. Specifically, assuming the total length of one path (Path A, represented in white) is 359 meters, and the total length of the other path (Path B, represented in red) is 377 meters. According to the calculation results of Dijkstra's algorithm, Path A is determined to be the shortest path. Therefore, the computer interlocking system will automatically open all the signals on Path A and adjust the relevant switches, ensuring that the locomotive can complete the transportation task within the shortest effective distance.

Figure 5-2 "Path B" illustrates Path B: starting from signal D88, passing through intermediate signals such as D47, D30, and finally arriving at signal D2.

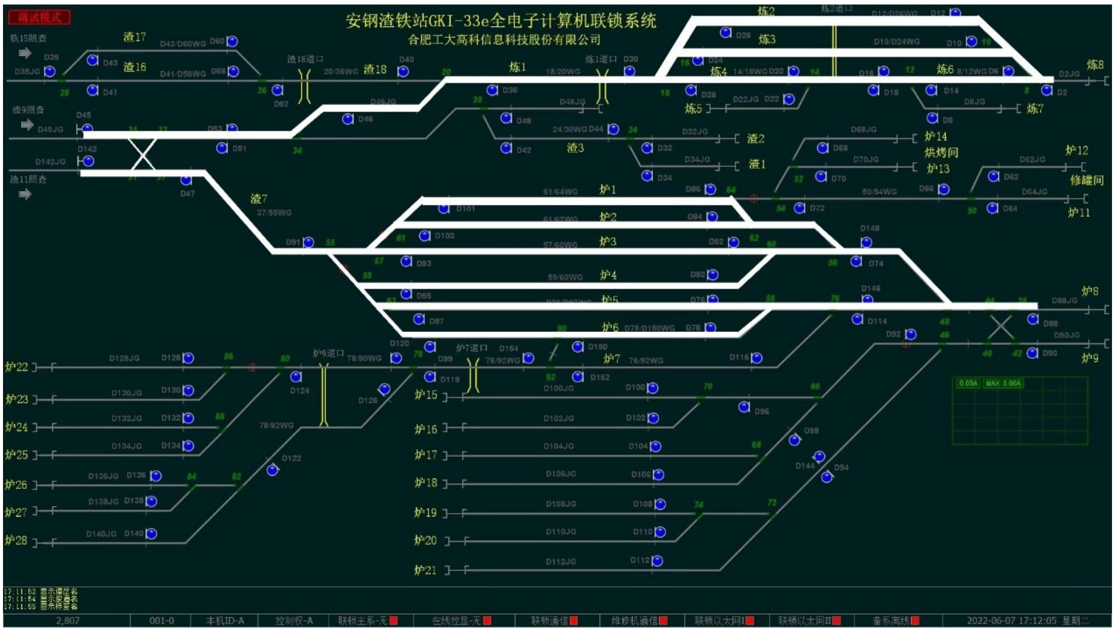

Figure 5- 4 D88 to D2 path analysis

Entering the second phase, our focus shifts to Path B, which starts from signal D88, passes through intermediate signals such as D47, D30, and finally arrives at signal D2. As shown in Figure 5- 4 "D88 to D2 path analysis", in the process of transporting molten iron from signal D88 to the iron and steel rolling department for smelting and processing, we face a variety of possible route choices. In this situation, in order to maximize transportation efficiency, we will rely on Dijkstra's algorithm to accurately calculate the shortest path. The application of this method not only ensures the rapid transportation of molten iron but also greatly enhances the overall efficiency of logistics operations.

Specifically, when it is necessary to transport molten iron from the blast furnace area through signal D88 to the iron and steel rolling department, there are multiple parallel routes to choose from. These routes may pass through different signals and tracks, each with varying lengths and conditions. To ensure that molten iron can reach its destination at the fastest speed and in the safest manner, we need an efficient and reliable method for route selection.

Dijkstra's algorithm is precisely such a powerful tool. It constructs a complex network model by setting all relevant signals as nodes and using the effective length of the tracks as the weight of the graph edges. In this model, each node represents a point of choice for the shunting path, and the connections between nodes constitute the entire network of shunting paths. In this way, Dijkstra's algorithm can fully consider the actual situation of each path, including track length, signal status, and possible obstacles.

In actual operations, Dijkstra's algorithm will first set signal D88 as the source point and signal D2 as the target node. Then, the algorithm will traverse all possible intermediate nodes, calculate the total length of each path (i.e., the sum of the effective lengths of each section of track), and quickly determine the shortest path by comparing the total lengths of these paths.

Once the shortest path is determined, the computer interlocking system will immediately respond by opening all the signals on the path and adjusting the relevant switches [22], ensuring that the train can travel smoothly along the planned route. The benefits of this are obvious: first, it reduces unnecessary travel distance and improves the efficiency of shunting operations; second, since the path selection fully considers safety factors, it greatly reduces the possibility of accidents and ensures the safety of railway transportation.

5.3 Comparison of Dijkstra's Algorithm with Existing Methods in Optimizing Metallurgical Enterprise Railways

In the metallurgical industry, an efficient logistics and transportation system is one of the key factors to ensure continuous production and cost control. With the expansion of enterprise scale and technological progress, traditional path planning methods have gradually exposed problems such as low efficiency and high costs [23]. Dijkstra's algorithm, as a classic and efficient shortest path calculation method, has shown significant advantages in solving such problems. This report aims to discuss the performance of Dijkstra's algorithm compared to traditional methods in optimizing the internal railway transportation network of metallurgical enterprises through comparative analysis.

Starting with efficiency, traditional approaches often depend on manual expertise or straightforward rules to map out transportation routes. While this method is uncomplicated and straightforward to apply, it falls short when dealing with intricate and fluctuating transportation demands. For instance, when determining the best paths to multiple destinations simultaneously, manual calculations are not only laborious but also error prone. Dijkstra's algorithm, on the other hand, can swiftly and precisely identify the shortest path between any two points, significantly enhancing the pace and precision of route planning [24]. This benefit is especially noticeable in vast and intricate railway networks.

Moving on to cost effectiveness, employing Dijkstra's algorithm for route optimization can substantially cut down on transportation expenses. Under traditional methods, the absence of a comprehensive view may lead to unnecessary detours, increasing fuel and maintenance costs. Dijkstra's algorithm, by accurately assessing the cost of each potential path and choosing the one with the lowest overall cost, directly minimizes superfluous spending. Moreover, it can assist enterprises in more effectively scheduling train operations, preventing delays due to congestion, and further saving on time costs.

Lastly, safety is a critical metric for assessing the quality of a transportation system. Traditional methods, constrained by factors such as slow information updates, struggle to respond promptly to emergencies (like track failures, adverse weather, etc.). With Dijkstra's algorithm, in the event of an anomaly, the system can swiftly reroute, bypass affected areas, and maintain traffic safety. Additionally, by incorporating real time monitoring data, the algorithm can anticipate potential risk points and take preemptive actions, further bolstering the overall safety of the system.

However, it is important to note that although Dijkstra's algorithm has many advantages, it also has certain limitations in practical applications. In some specific scenarios, higher level dynamic planning technology may be required if path information needs to be updated frequently [25]. Therefore, while adopting Dijkstra's algorithm, it is also necessary to combine other auxiliary means to overcome these limitations.

Dijkstra's algorithm has shown superiority over existing traditional methods in optimizing the railway transportation paths in metallurgical enterprises. Its efficiency, reliability, and flexibility make it an important tool to improve railway transportation efficiency. Despite some challenges in practical application, with the combination of technological means and the improvement of data processing capabilities, Dijkstra's algorithm is expected to bring new breakthroughs to the transportation management of metallurgical enterprises. In the future, with the advancement of technology and the improvement of intelligent levels, Dijkstra's algorithm will play a more important role in the field of railway optimization, providing strong support for the long term development of enterprises.

5.4 Graph Theoretical Analysis of Dijkstra's Algorithm in Metallurgical Enterprise Railways

Combining Path A and Path B constitutes a complete process of transporting from the iron mouth of the blast furnace to the iron and steel rolling department. Specifically, from signal D128 to signal D88, and then to signal D2, the entire shunting process uses signals in the same direction as nodes for Dijkstra's algorithm, and the effective length of the tracks between signals as the weight of adjacent nodes for modeling and analysis. In this way, we have constructed a complex network composed of multiple nodes, where each connection between nodes represents a feasible transition path between different tracks. We have been able to construct a graph theoretical model as shown in Figure 5-5 "D128 to D2 path analysis". Dijkstra's algorithm will traverse this network, calculate the total length of each path (i.e., the sum of the effective lengths of each section of track), and ultimately determine the shortest path. Figure 5-5 "D128 to D2 path analysis" shows in detail the process of path selection from signal D128 to signal D2.

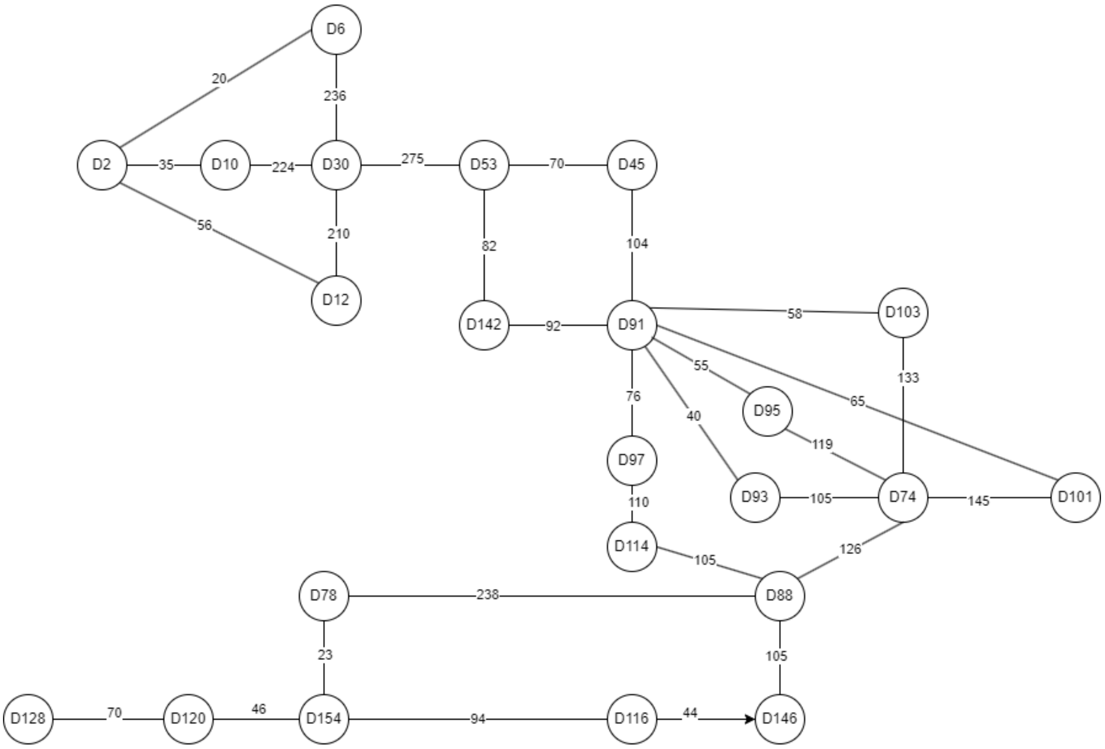

Figure 5- 5 D128 to D2 path analysis

5.5 Dijkstra's Algorithm in the Evaluation of Optimized Railway Paths in Metallurgical Enterprises

Dijkstra's algorithm is one of the famous graph theory algorithms, commonly used to calculate the shortest path between two nodes in a graph. Through the aforementioned experiments, we have found the feasibility of the experimental theory, and Dijkstra's algorithm indeed has advantages in long distance shunting.

This algorithm has significant application value in the evaluation of optimized railway paths in metallurgical enterprises, effectively improving transportation efficiency, reducing operating costs, and enhancing the overall level of logistics management. Railway transportation is an indispensable part of metallurgical enterprises, and its efficient operation is crucial for the enterprise's production and economic benefits. Therefore, using Dijkstra's algorithm to optimize the railway network can help enterprises plan transportation routes reasonably, ensuring rapid cargo transportation in complex railway networks, even during peak periods.

Through the analysis of the slag and iron station case, we can also analyze the advantages of Dijkstra's algorithm in optimizing paths for raw material transportation. Dijkstra's algorithm accurately calculates the shortest path from the marshalling station (the starting station for material transportation into the factory area) to the raw material system, effectively reducing transportation distance, thereby lowering fuel consumption, time costs, and the leasing costs of train cars. This is of great significance for controlling production costs. Secondly, in the product distribution phase, using Dijkstra's algorithm can quickly determine the best route combination from the production line to different destinations, ensuring that goods can reach customers as quickly as possible, thus enhancing the enterprise's market competitiveness.

Dijkstra's algorithm can also compare multiple transportation routes in metallurgical enterprises to assess the advantages and disadvantages of different transportation methods. This is particularly important for enterprises that need to achieve flexible scheduling. In actual operations, metallurgical enterprises often face the choice of multiple railway networks. If the optimal route can be selected, it will undoubtedly significantly enhance the enterprise's distribution capacity and resource utilization rate. By applying Dijkstra's algorithm, enterprises can not only calculate the shortest transportation time but also evaluate the economic aspects of different choices, including the transportation costs, resource consumption, and potential risks of each route.

However, the application of Dijkstra's algorithm in railway path optimization also faces some challenges. First, the dynamics of the railway network make the transportation environment constantly changing, so how to update data in real time and quickly recalculate the optimal path becomes crucial. Second, when the number of nodes and edges in the railway network is very large, the computational efficiency of the traditional Dijkstra's algorithm may not meet real time requirements. Therefore, it is necessary to consider algorithm optimization during implementation to enhance its applicability in large network environments. In addition, dealing flexibly with unexpected events, such as equipment failures and weather changes, also needs to be considered in the path optimization model to adjust transportation plans and ensure the sustainability and stability of transportation.

In summary, Dijkstra's algorithm has shown broad application potential in the evaluation of optimized railway paths in metallurgical enterprises. By reasonably constructing mathematical models and adopting precise data analysis and algorithm optimization, enterprises can effectively improve the overall efficiency of railway transportation, reduce operating costs, and achieve reasonable allocation and utilization of resources. Despite facing various challenges in practical applications, with the development of technology and the enhancement of data processing capabilities, the application of Dijkstra's algorithm will become more in depth and become an important tool for railway transportation management in metallurgical enterprises [26], providing stable and low cost transportation guarantees for enterprises. Through continuous exploration and practice, the research and application of Dijkstra's algorithm will bring new opportunities and challenges to the optimization and management of logistics in the metallurgical industry.

6 DIJKSTRA'S ALGORITHM PROGRAM

6.1 Programming

```
import networkx as nx
def find_shortest_path(G, source, target):
    try:
        # Use Dijkstra's algorithm to find the shortest path and
its length
        path = nx.dijkstra_path(G, source=source, target=target)
        length = nx.dijkstra_path_length(G, source=source,
target=target)
        return path, length
    except nx.NetworkXNoPath:
        return None, float('inf')  # Return None and infinity if
no path exists
    except nx.NodeNotFound:
        return None, None  # Return None if the node does not
exist

# Create an empty undirected graph
G = nx.Graph()

# Add nodes and edges along with edge weights
edges = [
    ('D128', 'D120', 70),
    ('D120', 'D154', 46),
    ('D154', 'D78', 23),
    ('D154', 'D116', 94),
    ('D116', 'D146', 44),
    ('D146', 'D88', 105),
    ('D78', 'D88', 238),
    ('D88', 'D114', 105),
    ('D88', 'D74', 126),
    ('D114', 'D97', 110),
    ('D74', 'D93', 105),
    ('D74', 'D95', 119),
    ('D74', 'D103', 133),
    ('D74', 'D101', 145),
    ('D97', 'D91', 76),
    ('D93', 'D91', 40),
    ('D95', 'D91', 55),
    ('D101', 'D91', 65),
    ('D103', 'D91', 58),
    ('D91', 'D142', 92),
    ('D91', 'D45', 104),
```

```
    ('D142', 'D53', 82),
    ('D45', 'D53', 70),
    ('D53', 'D30', 275),
    ('D30', 'D6', 236),
    ('D30', 'D10', 224),
    ('D30', 'D12', 210),
    ('D6', 'D2', 20),
    ('D12', 'D2', 56),
    ('D10', 'D2', 35)
]

# Add edges to the graph
G.add_weighted_edges_from(edges)

# Example: Query the shortest path from D128 to D88
source_node = 'D128'
target_node = 'D88'
path, length = find_shortest_path(G, source_node, target_node)

if path is not None:
    print(f"Shortest path from {source_node} to {target_node}:
{path}")
    print(f"Shortest path length from {source_node} to
{target_node}: {length}")
else:
    print(f"No path found from {source_node} to {target_node} or
the nodes do not exist.")

# Example: Query the shortest path from D88 to D2
source_node = 'D88'
target_node = 'D2'
path, length = find_shortest_path(G, source_node, target_node)

if path is not None:
    print(f"Shortest path from {source_node} to {target_node}:
{path}")
    print(f"Shortest path length from {source_node} to
{target_node}: {length}")
else:
    print(f"No path found from {source_node} to {target_node} or
the nodes do not exist.")

# Example: Query the shortest path from D128 to D42 (Note: There
is no node D42 in the given edges list)
source_node = 'D128'
target_node = 'D2'  # Changed from 'D42' to 'D2' because there
```

```
is no 'D42' in the provided edges.
path, length = find_shortest_path(G, source_node, target_node)

if path is not None:
    print(f"Shortest path from {source_node} to {target_node}:
{path}")
    print(f"Shortest path length from {source_node} to
{target_node}: {length}")
else:
    print(f"No path found from {source_node} to {target_node} or
the nodes do not exist.")

# Example: Query the shortest path from D2 to D128
source_node = 'D2'
target_node = 'D128'
path, length = find_shortest_path(G, source_node, target_node)

if path is not None:
    print(f"Shortest path from {source_node} to {target_node}:
{path}")
    print(f"Shortest path length from {source_node} to
{target_node}: {length}")
else:
    print(f"No path found from {source_node} to {target_node} or
the nodes do not exist.")
```

6.2 Output Results

```
Shortest path from D128 to D88: ['D128', 'D120', 'D154', 'D116',
'D146', 'D88']
Shortest path length from D128 to D88: 359
Shortest path from D88 to D2: ['D88', 'D74', 'D93', 'D91',
'D142', 'D53', 'D30', 'D6', 'D2']
Shortest path length from D88 to D2: 976
Shortest path from D128 to D2: ['D128', 'D120', 'D154', 'D116',
'D146', 'D88', 'D74', 'D93', 'D91', 'D142', 'D53', 'D30', 'D6',
'D2']
Shortest path length from D128 to D2: 1335
Shortest path from D2 to D128: ['D2', 'D6', 'D30', 'D53', 'D45',
'D91', 'D93', 'D74', 'D88', 'D146', 'D116', 'D154', 'D120',
'D128']
Shortest path length from D2 to D128: 1335

The process has ended with an exit code of 0
```

7 SUMMARY AND ANALYSIS

Through the research on the information technology of optimizing the internal railway transportation paths in metallurgical enterprises based on Dijkstra's algorithm, we have found that Dijkstra's algorithm is significantly feasible in the selection of the shortest path in metallurgical railways. This method not only effectively reduces transportation distance and improves transportation efficiency but also solves the problems of low efficiency and proneness to errors in traditional manual scheduling methods, thus ensuring the safety of the transportation process. By scientific path planning, Dijkstra's algorithm provides strong support for the efficient production and safety management of metallurgical enterprises.

Dijkstra's algorithm constructs a complex graph theory model by setting all signals in the same direction in the shunting network as nodes and using the effective length of the track between signals as the weight value. This modeling approach enables the algorithm to accurately calculate the cost of each path and find the shortest path from the starting point to the destination. In practical applications, this method greatly reduces unnecessary travel distance, saves time and resources, and avoids safety hazards caused by improper path selection.

In this way, Dijkstra's algorithm not only improves the overall efficiency of shunting operations but also enhances safety. It ensures that each shunting task can be completed efficiently and safely, thereby increasing the efficiency of the entire production process. For metallurgical enterprises, efficient transportation management is one of the key factors in ensuring continuous production and product quality. The application of Dijkstra's algorithm not only reduces transportation costs but also improves production efficiency, bringing significant economic benefits to enterprises.

Moreover, the flexibility of Dijkstra's algorithm enables it to adapt to different transportation demands and environmental changes. In metallurgical enterprises, railway transportation is often affected by various factors, such as equipment maintenance, weather changes, and fluctuations in transportation demands. By updating the railway network data in real time, Dijkstra's algorithm can quickly adjust path selection, ensuring that the optimal transportation path can still be found in a dynamic environment. This adaptability not only improves transportation efficiency but also reduces potential risks caused by environmental changes.

In the future, with the continuous advancement of technology, combined with advanced technologies such as big data, the Internet of Things, and artificial intelligence, Dijkstra's algorithm will play a greater role in metallurgical railway transportation. For example, through big data analysis, transportation demands and potential obstacles can be more accurately predicted, thereby further optimizing path selection; the Internet of Things technology can monitor the state of the railway system in real time, providing more accurate data support; and artificial intelligence can further enhance the level of intelligent path planning by learning historical data and pattern recognition.

In summary, the application of Dijkstra's algorithm in optimizing the internal railway transportation paths in metallurgical enterprises has demonstrated its powerful capabilities and broad application prospects. By scientific path planning, Dijkstra's algorithm not only improves transportation efficiency but also enhances safety, providing strong technical support for the efficient production and safety management of metallurgical enterprises. As technology continues to develop and improve, Dijkstra's algorithm will play a more important role in future metallurgical railway transportation, achieving more efficient, safer, and more environmentally friendly transportation management. This will not only help enhance the competitiveness of enterprises but also promote the sustainable development of the entire industry. With the continuous advancement of technology, metallurgical enterprises in the future will be able to stand out in fierce market competition and become industry leaders.

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