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After machines began to "learn to think" - the boundaries of automation and the repositioning of the labor force in the transformation of manufacturing

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ABSTRACT

Along with industry 4.0 advancement, Intelligent Manufacturing becomes an important trend of manufacturing industry. As a key component in intelligent manufacturing, intelligent control system can not only improve production efficiency, product quality, but also define labor's function and value. In this paper, a deeper discussion is made on the design framework, multi-level framework and application effect of intelligent control system for machinery and equipment in manufacturing enterprises. Through building integrated intelligent control system, a new automated production model is put forward, which aims at intelligent management of production equipment, automatic optimization of production process, and efficient redeployment of labor force. With advanced sensor technology, AI algorithm and big data analysis, this system is able to significantly enhance production efficiency, reduce cost and provide powerful support to manufacturing industry in the future. As technology advances and manufacturing requirements continue to change, Smart Control System is expected to play an important role under broader industrial scenarios, driving manufacturing towards intelligent, efficient and sustainable development.paper applies the Bayesian method to the parameter estimation of the Fama-French five-factor model, aiming to address the limitations of the traditional Ordinary Least Squares (OLS) method, such as sensitivity to extreme values and reliance on large sample sizes. Using monthly data of U.S. stocks spanning from 1963 to 2024, sourced from the Center for Research in Security Prices (CRSP) and the Fama-French Data Library, we specify normal prior distributions for the risk premium parameters (MKT-RF, SMB, HML, RMW, CMA) and estimate their posterior distributions through the Markov Chain Monte Carlo (MCMC) method. The results reveal two key findings: First, compared to OLS, Bayesian estimation reduces the standard error of parameters by 10%-15%, with a particularly notable improvement for the HML factor, where the standard error decreases from 0.18 to 0.15. Second, in small-sample scenarios (e.g., 5-year data subsets), Bayesian estimation exhibits a smaller deviation from the true parameter values. This study contributes to the literature by providing a more stable estimation method for asset pricing models, which is especially valuable in situations with limited data availability.

1. Introduction

Manufacturing faces unprecedented challenges and opportunities in the global economy. For one thing, the market competition becomes fiercer day by day, consumers demand more and more high quality products and delivery speed. On the other hand, rising labor cost and skilled labour shortage become more prominent. In order to meet these challenges, the manufacturing industry must seek technological innovation and change production models[1]. As a new production mode, Intelligent Manufacturing provides a new way to transform and upgrade manufacturing industry with advanced information technology and automation technology. As an important part in intelligent manufacturing, intelligent control system can realize intelligent management of production equipment, automatic optimization of production process, and efficient repositioning of labor force. In recent years, as sensor technology, artificial intelligence technology, big data technology and cloud computing technology continue to develop continuously, the research and application of machinery intelligent control system has become a hot topic.

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In this paper, we discuss this system from three aspects: system framework, system architecture and main function application, so as to provide useful reference and inspiration, and promote wide application of Intelligent Control System[2].

2.Smart transformation of manufacturing enterprises

2.1.Potential and Challenge of Machine Intelligent Control

As a kind of production model integrating AI and traditional automation technology, intelligent control has shown great potential. The intelligent system is able to take on some production tasks, such as automatic fault diagnosis and production scheduling optimization. It provides real time production data and decision support to managers so that they can better understand production situation and optimize production strategy. However, it faces many challenges such as how to make sure its production proposal is consistent with manager's management concept, how to maintain manager's leading position in human-machine interaction, and how to deal with technology and production well[3]. These problems need to be solved by working together among manufacturing professionals, technology developers and policy makers in order to develop a smart control path for machines and equipment that takes full advantage of technology while preserving the essence of production.

2.2.Manufacturing Transformation: Automation Boundaries

As the manufacturing industry becomes intelligent and automated, it becomes a focus for both academia and industry to focus on how to define the scope and boundaries of automation technology, and how to reposition labor structure and role. As industry 4.0 advances, automation technology becomes more and more widely used in manufacturing. Automation systems can be found everywhere, from simple repetitive tasks on production lines to complex production scheduling and quality monitoring. But automation isn't all-powerful. While pursuing production efficiency and cost control, we should clearly define reasonable application boundaries so as to maximize the synergy between technology and human resources[4].

When determining automation boundary, it is necessary first to balance technical feasibility with economical cost. Although AI and ROBOTICS could theoretically carry out more production tasks, some complex manual skills or tasks requiring high creativity and flexibility could not be completely replaced by machines. For example, when producing high-end customized products, automated systems cannot replicate the exquisite craftsmanship and personalized design skills of artisans. Moreover, purchasing, installing, maintaining and upgrading automated equipment will require high investment. For some SMEs, excessive automation may result in tight or even broken capital chains. Therefore, in order to make a reasonable decision about the application range and depth of automation technology, manufacturing enterprises should comprehensively evaluate its feasibility and cost effectiveness[5].

2.3.Reorienting Labor Force in Manufacturing Industry Intelligent Transformation

Reorienting the labor force is another important issue which cannot be neglected in the transformation of manufacturing industry. Along with the widespread use of automation technology, many workers engaged in repetitive and low-skill jobs in traditional manufacturing industries risk being replaced by machines. However, from a different perspective, automation is also an opportunity to re-position workers. For one thing, automation technologies have given rise to new jobs such as programming, debugging, maintenance and data analysis[6]. On the other hand, automation technology makes production process more efficient and accurate, which provides more space for enterprise to innovate and develop. Enterprises can invest their savings on products R&D, market expansion, customer service with high added value, thereby creating more jobs. As a result, manufacturing enterprises should actively guide labor transfer to highly skilled and high-added jobs. By providing training, education and career development planning, they help employees improve skill levels, adapt to new job requirements, and achieve positive interactions between reorienting labor and enterprise development[7].

2.4.Development of Intelligent Control System for Machinery and Equipment Design Goals

Based on the above mentioned development trends and challenges of manufacturing industry, our research team is committed to development of intelligent control systems for machines and equipment. This system has been developed with the aim of satisfying the requirement of intelligent manufacturing and intelligent control in manufacturing industry[8]. Through the integration of AI, Big Data, Cloud Computing and other advanced information technologies, the company provides efficient, intelligent and personalized production and management platform. In practice, the system can help managers to manage production activities better and improve productivity and quality[9]. At the same time, it provides intelligent production support and rich production resources to stimulate their enthusiasm and creativity. From long term point of view, its application will drive innovation and transformation of production models and provide powerful support for cultivating qualified workers who will adapt to future social development.

3.Machine Equipment Based on Intelligent Manufacturing Intelligent Control System

3.1.Overall System Design

In order to construct intelligent machinery system, Integrated Development Environment (IDE) is adopted, C + + and Python programming languages are used. A relational database is MySQL and a non-relational MongoDB database. The system uses artificial intelligence (AI) and big data technology to assist production, such as analyzing production data and production efficiency data to produce intelligent production scheduling and equipment maintenance advice. Through deep learning model, this system is able to identify operation mode and fault characteristic of production equipment to provide more precise maintenance advice[10]. Data processing and analysis are carried out using big data technology, including production equipment operation records and production process data. The system is able to extract valuable information through data mining and analysis in order to provide production decision-making support for managers while optimizing intelligent production scheduling algorithm. In addition, this system provides an interaction platform between the manager and the intelligent production system. On the platform, managers are able to plan and implement production activities using smart tools. At the same time, this intelligent system is capable of providing real time production advice and assistance based on production objectives and feedback[11]. It takes full advantage of manager's professional advantage and makes full use of intelligent system's high efficiency and precision to improve production efficiency and workshop management efficiency. Moreover, HMI features powerful online collaboration capabilities that support resource sharing and sharing of experience among managers, as well as innovation and improvement of production methods[12].

3.2.System Main Levels

3.2.1.Design of Data Layer Design

The data layer is the base of the whole system in intelligent control system based on intelligent manufacturing. Whether its design is reasonable or not relates directly to system running stability and data processing efficiency. Data layer is mainly in charge of storing and managing operation data of production equipment, management personnel's production data, and various kinds of information generated in operation process. In order to guarantee data integrity and security, data layer adopts distributed database structure, which combines the merits of relational database and non-relational database[13]. A relational database is used to store structured data such as production equipment basic information, productivity and production schedule. These data are clearly structured and related[14]. Through the relational database, it is convenient to carry out data query and transaction processing. The non-relational database is used for storing unstructured data such as production equipment operation log, image data in production process, operation record of production personnel. These data are flexible and scalable[15]. They can adapt well to large amounts of complicated data produced during intelligent manufacturing. Data encryption technology is adopted in data storage process to protect the privacy of production equipments and managers. At the same time, in order to deal with data loss or damage risk, a comprehensive backup and recovery mechanism was designed in the data layer. Regularly backing up data, it can be restored quickly if necessary to ensure that system functions normally.

3.2.2.Design of Logic Layer Design and Its Application

Logic layer plays a key role in data processing, business logic realization and intelligent production scheduling. In logic layer design, OOP is used to divide system functions into multiple independent modules, each responsible for specific business logic. For example, Intelligent Production Scheduling Module can generate intelligent production scheduling and equipment maintenance suggestions through analyzing operational data of production facilities. In this module, we need to take multiple factors into account such as operating conditions, production efficiency, maintenance requirements, and so on. Collaborative Production Module is in charge of interaction logic between management personnel and intelligent systems to achieve planning, execution and monitoring. This module helps managers better manage workshops, evaluate production efficiency, and adjust production strategies based on real-time feedback through intelligent production tools and support functions. Take the auxiliary production for example. Using Python program, an operational data set of production equipment has been established, including features of production equipment and operation efficiency. Data set format: [operating times, production efficiency, failure rate, maintenance requirements]. Use big data analysis technique to predict failure in production equipment and provide management advice. The code example is:

```
new_data = pd.DataFrame({
"Device ID" : [" Device 1 ", "Device 2"]
"Running time" : [10, 15]
"Failure rate" : [0.05, 0.03]
"Maintenance Requirements" : [1, 0]
})
schedule = scheduler.generate_schedule(new_data)
print(" Generated production scheduling suggestion: ",
schedule)
```

At the same time, the logic layer is designed to optimize algorithm and improve performance. Through efficient algorithm design and code optimization, the system is able to react quickly and operate stably when processing large amount of data and complicated business logic. Furthermore, a high efficient data interaction interface between data layer and application layer has been established in logic layer to ensure smooth data flow among different layers in order to realize overall cooperative operation.

3.2.3.The Application Layer Design of Applications

Application layer is an interface for direct interaction between system and user. Its user experience and promotion effect are directly affected by its friendly and user-friendly design. Application layer provides different user interface for production staff, manager and system manager. Each interface can be customized according to users' role and requirements. The application layer provides a visual interface for production personnel, including equipment operation, production task reception and production progress tracking. These functions lead the production personnel to complete the production task easily through simple and clear interface design process, and provide real-time feedback of the production results. Management interface places greater emphasis on production management functions and provides tools such as production planning, resource allocation, productivity analysis, and online production interaction. With these tools, the manager can conveniently plan production activities and adjust production strategy according to the production data. System administrator interface provides advanced functions such as system configuration, user management, data backup and recovery. Application layer design also emphasizes to optimize user experience. Through user interface friendly design, simplified operation process, variety of interaction methods to improve user satisfaction. At the same time, an application layer supports access from a variety of terminal devices including computer, tablet computer, mobile phone and so on, so that users can manage production and operation at any time.

3.3.System Database Design

The storage layer plays an important role in intelligent manufacturing intelligent control system. Its rationality and efficiency have a direct impact on performance, reliability and scalability. The storage layer takes charge of management and maintenance of large quantities of data generated during operation, including production equipment operation records, management personnel production materials, system configuration information, etc. Considering the variety of data types and usage requirements, it adopts hierarchical storage strategy that integrates multiple storage technologies in order to ensure efficient data storage, fast access, and secure protection. According to structure degree, access frequency and importance of data, different storage media and technology are used respectively. As for structured data such as production facilities, production efficiency, production plan etc., this system uses relational database Management System (RDBMS) to organize and store these data in form. A relational database has powerful data integrity constraints, transaction processing capabilities, and a mature Query Language (SQL) to efficiently support complex data operations and query requirements. For example, through relational databases, it is easy to perform statistical analysis of production equipment operational efficiency, equipment failure rate calculations, and query operations under multiple conditions, providing precise data support for intelligent production scheduling.

With respect to non-structured data such as production equipment operation logs, image data during production process, and production personnel operations records, the system adopts a storage solution combining non-relational databases (NoSQL) and distributed file systems (DFS). Unstructured data is typically characterized by large volumes and various formats, which makes it difficult for efficient storage in conventional relational databases. With its flexible data model, high scalability and high performance, NoSQL database is suitable for such data storage. As a popular NoSQL database, for example, MongoDB supports document storage mode, which makes it easy to store and retrieve the operation log of production equipment and the operation records of the production personnel. On the other hand, for large-capacity multimedia files such as production equipment operating image data, distributed file system is used to store them. A distributed file system can enhance storage capacity scalability, improve data reliability and access speed by distributing files between nodes. The Hadoop Distributed File System (HDFS), for example, ensures high data availability through multiple replica storage mechanisms for data blocks in unexpected situations like hardware failure. At the same time, its efficient parallel I/O capability can satisfy the requirement of fast accessing multimedia resources.

From the data security point of view, we design multi-layer protection mechanism to guarantee data confidentiality, completeness and availability. First of all, the system uses encryption technology to encrypt sensitive information during data storage. For sensitive data such as production equipment operation data and management personnel's personal information, encryption algorithm is used to encrypt data, which can only be decrypted and accessed by authorized users. Moreover, the system strictly restricts access rights of data through access control mechanism so as to make sure that only authorized users and applications have access to data resources. At the same time, in order to prevent data loss and damage, the system implemented regular data backup policy. The backup strategy includes both full backup and incremental backup. Full backup performs full backup on a regular basis throughout the database and file system, ensuring full recovery of all data during a disaster recovery. Incremental backup will backup newly added or modified data between two full backups in order to increase backup efficiency and reduce storage space usage. Backup data is stored on remote backup servers to avoid losing data if local data centers go down. Furthermore, the system conducts periodic recovery tests of backup data to ensure its validity and integrity, enabling rapid recovery of system data when required.

In order to improve storage layer performance, many optimization measures are taken in this system. With regard to relational database, through reasonable database design, including table normalization, index creation and query statement optimization, data storage efficiency and query speed are increased. For example, creating an index for a frequently queried field can significantly speed up a query's response time. At the same time, database caching technology is adopted to cache frequently accessed data into memory, which further improves the speed of data reading. For distributed file system, through optimizing data block size, copy number, layout of storage nodes, etc., the storage performance is improved greatly. For example, adjusting block size according to actual application requirements can strike a balance between storage space utilization and access speed. The reasonable number of replica can ensure data reliability and avoid unnecessary waste of memory space. Moreover, load balancing technology is adopted to allocate data access requests rationally among different storage nodes in order to avoid overload of individual nodes and enhance concurrent processing capability and stability.

As far as data scalability is concerned, as intelligent manufacturing advances and system users grow, data volume will continue to increase. Therefore, it is essential to design scalable storage layer. Distributed storage technology is used in the system's storage structure. The architecture could easily expand the storage capacity and improve the performance of the system through the addition of storage nodes.

3.4.The System Security Design of Software

Data security and privacy protection are indispensable to the design of system in today's digital era. Security layer is designed so as to provide comprehensive security protection for the whole system so as not to leak, tamper or abuse the data of production equipments and managers. Security layer adopts multiple layers of security protection measures including network firewall, intrusion detection system, data encryption technique and user identity authentication. A network firewall and an intrusion detection system have been set up on network boundary for real-time monitoring of network traffic so as to guard against malicious attacks and illegal intrusion. Data encryption technology is used in data storage and transfer process. It is used to encrypt sensitive information during storage and transfer. In order to prevent unauthorized access, User Identity Authentication Mechanism strictly verifies user identity by user username, password, SMS authentication code. Additionally, Security Layer conducts regular security audits and security scans to promptly identify and correct security vulnerabilities in the system, ensuring its security and stability. Through these multi-level security protection measures, security layer provides safe and reliable working environment for machine intelligent control system.

4.The application of main system functions

4.1.Smart Production Support and Collaborative Manufacturing

One of the key innovations of the system is its intelligent production assistant and human-machine cooperative production function. Its aim is to achieve efficient, intelligent production processes through the integration of AI technologies and professional production capabilities of managers. The intelligent system provides rich production tools and assistant functions such as intelligent Production Planning Assistant, Production Process Monitoring Tool, Real-Time Production Data Analysis Dashboard. Intelligent Production Planning Assistant is able to recommend appropriate production plans and scheduling plans based on production objectives and resource constraints to help managers formulate high quality production plans. Production process monitoring tools help managers to monitor key indicators such as production equipment operating status, production progress, production efficiency during production process to increase control and transparency. Real-Time Production Data Analysis Dashboard gives managers real-time feedback on production data including production efficiency, failure rate, production rate, etc. Moreover, the intelligent system provides personalized production advice to managers according to production data so as to help them focus their attention on every link in production process. It takes full advantage of manager's professional advantage and makes full use of intelligent system's efficiency to improve production quality and workshop management efficiency.

4.2.The Optimization of Intelligent Production Scheduling Generation

The generation and optimization of Intelligent Production Scheduling System based on Intelligent Manufacturing System is key to realize fine management. By deeply analyzing operation data of production equipment, including production efficiency, failure rate, maintenance requirement, production priority, Python programming, advanced machine learning algorithms and data mining techniques are used to tailor unique production scheduling plans for each production phase. A training model is generated in order to realize the intelligent construction of production scheduling plan. The code example is:

```
self.data = self.data.dropna()
self.data = pd.get_dummies(self.data, columns=[' device ID']) # encode the device ID as a hotcode

# Separate features from target variables
X = self.data.drop(columns=[' productivity '])
y = self.data[' productivity ']

# Divide the training set and the test set
self.X_train, self.X_test, self.y_train, self.y_test = train_test_split(X, y, test_size=0.2, random_state=42)
print(" Data preprocessing completed, training set size: ", self.X_train.shape, "test set size: ", self.X_test.shape)
def train_model(self):
"" "
Train the production scheduling model
"" "
self.model.fit(self.X_train, self.y_train)
print(" Model Training Completed ")
```

For example, if equipment performs well on one production task, the system automatically assigns more production tasks. For equipment that may fail or fail, the system would arrange maintenance ahead of time so as to avoid disruption of production. Moreover, this system is able to optimize production scheduling schedule based on real time feedback of production data so as to ensure the scientificity and validity of production scheduling. The intelligent production scheduling can improve production efficiency and equipment efficiency as well as reduce production cost and waste of resources. Thus, it provides powerful support to enterprises' sustainable development.

4.3.Real-Time Production Evaluation and Feedback

The real-time evaluation and feedback function is important to guarantee the validity of intelligent production. The function conducts comprehensive and objective evaluation of students' learning outcomes through various assessment methods, including evaluation of operational efficiency of production equipment, completion of production tasks, and evaluation of production quality. An intelligent evaluation engine is designed in this system, which can analyze operation data automatically and generate detailed analysis reports according to evaluation indexes. These reports cover not only operational efficiency and failure rate of production equipment, but also the bottleneck link and optimization space in production process. The system provides automatic quality inspection tools for inspection and assessment of production quality and supports managers to add personalized evaluation criteria and recommendations. Moreover, the system provides real-time feedback based on evaluation results, including reminders of production progress, improving efficiency of production, adjustment of production strategy, etc. The timely and accurate feedback mechanism helps managers to understand production status quickly, adjust production methods and production plans so as to achieve production objectives. At the same time, production staff will be able to get a better understanding of their operational competence through assessment results, adjusting working methods and plans to enhance working skills and productivity.

4.4.Sharing and Production Resource Management

Production resource management and sharing functions are important bases in supporting intelligent manufacturing and intelligent control systems. The function provides abundant production resources to managers and production staff, including production equipment operation manual, production process optimization plan, production quality inspection standard, production case analysis etc. Intelligent resource management system is designed to automatically classify production resources according to production goals and plans to facilitate managers and production staff to search for and use quickly. According to production plan, managers can select suitable production resources from resource base and integrate them into production activities. At the same time, the system allows managers to upload their own production resources so as to enrich their resource library. In order to promote sharing of resources and exchange of experience between managers, a platform for sharing resources is provided. On this platform, managers can share production resources and management experience, interact and discuss with other managers. The resource sharing mechanism enhances the utilization efficiency of productive resources, promotes managers' professional growth and management methods innovation. Furthermore, according to production personnel's skill level and job requirements, the system recommends personalized production resources so as to help them complete production tasks better and improve their skills and productivity.

4.5.Compatibility Design and System Scalability

With the rapid development of intelligent manufacturing system, its scalability and compatibility is key to ensure its long-term stability and continuous optimization. During the design process, the system takes full account of future technology developments and changes in production requirements. Its modular architecture and open standards guarantee easy expansion and upgrade of functions of the system. Modular structure makes each function module relatively independent. When it is necessary to add a new function or optimize an existing function, it is possible to develop and test these modules independently without affecting others in the system. The design not only improves the system development efficiency, but also reduces maintenance cost. Furthermore, the system follows internationally accepted open standards and protocols such as HTML5, CSS3, JavaScript, etc., ensuring stable operation on various operating systems and browsers, and supporting multiple terminal devices such as PC, tablet, mobile phone etc. The excellent compatibility makes the system adapt to different users' usage habits and equipment conditions. It provides powerful guarantee for wide application.

5.System application case analysis

5.1.Case Summary

In order to validate the application effect of intelligent manufacturing intelligent control system (hereinafter referred to as "Production System"), two manufacturing workshops from one manufacturing enterprise were selected. The two workshops do not differ significantly with respect to production equipment, skill levels, and production plans, so there is a high degree of comparability. Among them, a workshop has been appointed as an observation group, using this production system to carry out production activities. Another workshop was used as a control group, adopting traditional production methods. Research period is a quarter and aims at evaluating the efficiency of production system through comparison between two workshops.

5.2.Application Methods

The control group adopted the traditional production method, i. e., management personnel carried out production scheduling according to uniform production schedule and production target. During the process of production, managers mainly monitor production progress and quality by means of on-site inspection, production records and periodic evaluation. The production model emphasizes on completion of production task and obedience of production personnel, lack of real-time monitoring of production equipment operation status and intelligent optimization of production process.

By contrast, the observation group used the production system fully. At the beginning of the quarter, management personnel created individual operation files to record the basic information, operation condition and initial maintenance requirements. On the basis of these data, intelligent production scheduling is generated for each production facility, and corresponding production resources are recommended. During the production process, managers make use of intelligent production assistance functions to monitor production status and production progress, promptly adjust production strategy based on feedback from system. For example, for equipment which does not perform very well in certain production tasks, managers may assign more appropriate tasks or perform equipment maintenance according to intelligent production recommendations. At the same time, production team members will be able to independently select production tasks, conduct self-assessment, and track production progress through online production platforms. The production model fully embodies the features of intelligent manufacturing and intelligent control, which can satisfy production requirements, improve efficiency and quality.

5.3.Results

The result showed that the workshop of observation group was better than the control group on production efficiency and product quality after one quarter. To be more specific, the average production efficiency increased 15% compared with control group, the failure rate decreased 20% and the pass rate increased 10%. These data show that production systems are effective in improving production efficiency, reducing equipment failures, and improving product quality. Moreover, the observation group workshop demonstrated that the utilization rate of production resources and work enthusiasm of production personnel was higher, and the transparency and controllability of production process had been significantly improved. These non-quantitative indicators have further demonstrated that production system plays an important role in improving production management level.

Table 1. Production Conditions for Two Workshops

Evaluation index	**Control Group (Traditional production**	**Observation Group (Traditional Production)**	**Difference (Observation group - Control Group)**
Average production efficiency (%)	80	95	15
Equipment failure rate (%)	10	8	-2
Product quality pass rate (%)	90	98	8

6.Conclusion

Building and applying intelligent control system based on intelligent manufacturing provides a new way to develop modern manufacturing. Through system framework design and function realization, the system is able to satisfy the intelligent requirements of production process effectively, improve production efficiency and product quality, and enhance production management level. However, we should clearly realize that research and application in this area is still being developed and perfected. As artificial intelligence, big data, cloud computing, and other technologies are further developed, along with continuous changes in manufacturing requirements, it is expected that Intelligent Control System will play an even bigger role in the future. We are looking forward to continuously improving system functions and optimizing production model through continuous research and practice so as to contribute more to intelligent, efficient and sustainable development in manufacturing industry.

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