To Improve the Environmental, Economic and Safety Benefits of Coal Terminals: The Research of Train Collection Strategy and Silo Storage System

Xu Xinglu, Wang Wenyuan, Peng Yun, Song Xiangqun, and Guo Zijian

***Abstract*—In order to solve the problem of dust pollution in coal terminals, this paper introduces the application of silo storage system, and analyzes the handling operation process of silo-type export coal terminals. Then, in order to improve the economic and safety benefit in coal terminals with silo-storage system, a model is built to simulate the operation process of the coal terminals, under different scenarios of the train collection strategy and the single silo volume. The annual throughput, port time of trains and ships are used as the evaluation index of economic benefit. And the storage time and the numbers of silo-changing operations, are used to evaluate the safety benefit. After running the simulation model, the results show that when the single silo volume changes from 20,000 tons to 30,000 tons, the economic benefit improves while the safety benefit declines. When the single silo volume is 20,000 tons, as the train collection period increases from 3 days to 7 days, the annual throughput decreases 0.7% and the average port time of ships can be increased by 16.9% respectively. Besides, the average port time of trains gains a marked improvement of 78.8%. As for the safety benefit, the coal storage time has decreased 23.4%, and the number of silo-changing times increases from 9 times to 26 times.**

***Index Terms*—Coal terminals, environmental protection of ports, dust control, coal silo, logistics simulation.**

I. Introduction

With the increasing demand of coal energy, there comes a serious dust pollution problem when expanding the scale of coal ports, since the coal ports are important nodes of coal storage and transportation. In traditional open yard, the dust pollution problem which caused by wind and handling operation seriously affects not only the health of the staff, but the living conditions around [1]. Moreover, flying dust causes a great coal loss which is unrecoverable. Thus, control flying dust should clearly be a high priority. In this background, coal silo storage system, which needs less land and can observably reduce dust pollution, has been used in many coal terminals, such as Jakarta port in Indonesia and Huanghua port in China, etc. Carson J W [2] introduced the unique advantage and the silo storage system's application and significant results of application of silo system in coal storage. Qiao [3] introduced environmental protection in Huanghua Port. According to the engineering practice, 90% dust pollution had been reduced which greatly improved the benefit of environmental protection.

On this basis, in order to improve the economic benefit, system simulation technology is used to find out the best operation strategies in the coal terminals with silo storage system. Most researchers focused on the operation strategies, U. Bugaric [4] developed a simulation model to Fig. out the way to improve the bulk cargo terminal by introducing the strategy of unloading devices. Tang [5] and Meng [6] studied stacking strategy by built a simulation model of silo storage coal terminal`s handling production process. Teus van Vianen *et al*. [7] used simulation tool to determine the required storage size for dry bulk terminals. Song [8] put forward a new mixed operation mode, Li [9] focused on the relationship between the single volume of silos and port throughput capacity.

Another challenge in using coal silo storage is the safety problem. Fierro *et al*. [10] dealt with oxidation and spontaneous combustion of coal piles laid in coal storage yard and the measures to avoid the heat losses produced. Zhang [11] aimed at the spontaneous combustion of coal stored in large silos, and found out the spontaneous combustion periods of three coal samples. Lv. [12] analyzed the causes of fire in coal ports and expounded the safety managerial methods of silo.

With an overview of the previous studies of the silo storage system in the coal ports, the researchers either studied the economic benefit, or stated the safety management measures, almost no one combined the two. In addition, when it came to the impact of operation strategies, most researchers confined the studies in stacking and reclaiming strategies, and ignored the train collection strategy. In export coal terminals, the coal is transported by trains, and stores in ports in advance according to the ships' arrival time and the amount of demand. Thus, the train collection strategy, especially the train collection period which directly impacts the daily operation of the ports is the key strategy.

In this context, this paper chooses the export coal ports with silo storage system as research objects. The train collection strategy and the single volume of silos are taken into consideration to improve the environmental, economic and safety benefits export coal terminals. A simulation model is built to Fig. out how the train collection strategy impacts the benefits under different single silo volumes.

II. The Simulation Model of the Operation System in Export Coal Terminals

A. Model Establishment

1) Modeling assumptions

1) The arrival time of ships, the type and the quantity of

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coal demand have been known;
2) Silos are regarded as closed environments;
3) Do not start Silo-change when the silo is loading or unloading;
4) Coal flows into silos evenly;
5) The belt conveyer and other machines work at a uniform velocity.

2) Model formulation

The simulation software Arena 14.0 is applied to establish the model in this paper, and the flow chart of this model is shown in Fig.1. The simulation model of the operation system for the silo-type coal terminal consists of three parts: uploading and warehousing submodule, shipment submodule and safety monitoring submodule.

1) Uploading and warehousing submodule: Generate train entities in accordance with the specified rule. Besides, assign appropriate silos according to the stacking strategy. And manage the unloading and warehousing equipment.
Stacking strategy: Different types of coal are stored in different silos. Give priority to the silo which has already stored the same type of coal and has sufficient capacity to accommodate the coal just arrived. If there are several silos meeting the requirement, then give priority to the silo whose residual capacity is minimum. Choose an empty silo if none of these fits the need. If there are no empty silos available, pick silos according to its residual capacity from largest to smallest.
2) Shipment submodule: Generate arrival ship entities in accordance with the specified rule. Besides, assign appropriate silos according to the reclaiming strategy. And manage the shipment equipment.
Reclaiming strategy: Choose silos from largest to smallest according to its stock.
3) Safety monitoring submodule: Monitor the security situation, and manage the process of the silo-changing operation.
As for coal storage security, the key problem is the spontaneous combustion in closed environment. In order to prevent the fire accidents, the real-time temperature of coal in the silos is monitored in reality. Safety measures would be taken before reaching the critical temperature of spontaneous combustion. According to the experiment by Zhang [11], the period of coal spontaneous combustion which means the time from the standard initial temperature heating to the critical temperature of spontaneous combustion, have been obtained. Therefore, we convert the complex temperature control into the control of the storage time. Monitor the storage time in real time, carry out the silo-changing operation immediately once the storage time exceeds the limit. Transfer the coal to the open yard to cool down and prevent the occurrence of fire and explosion accidents

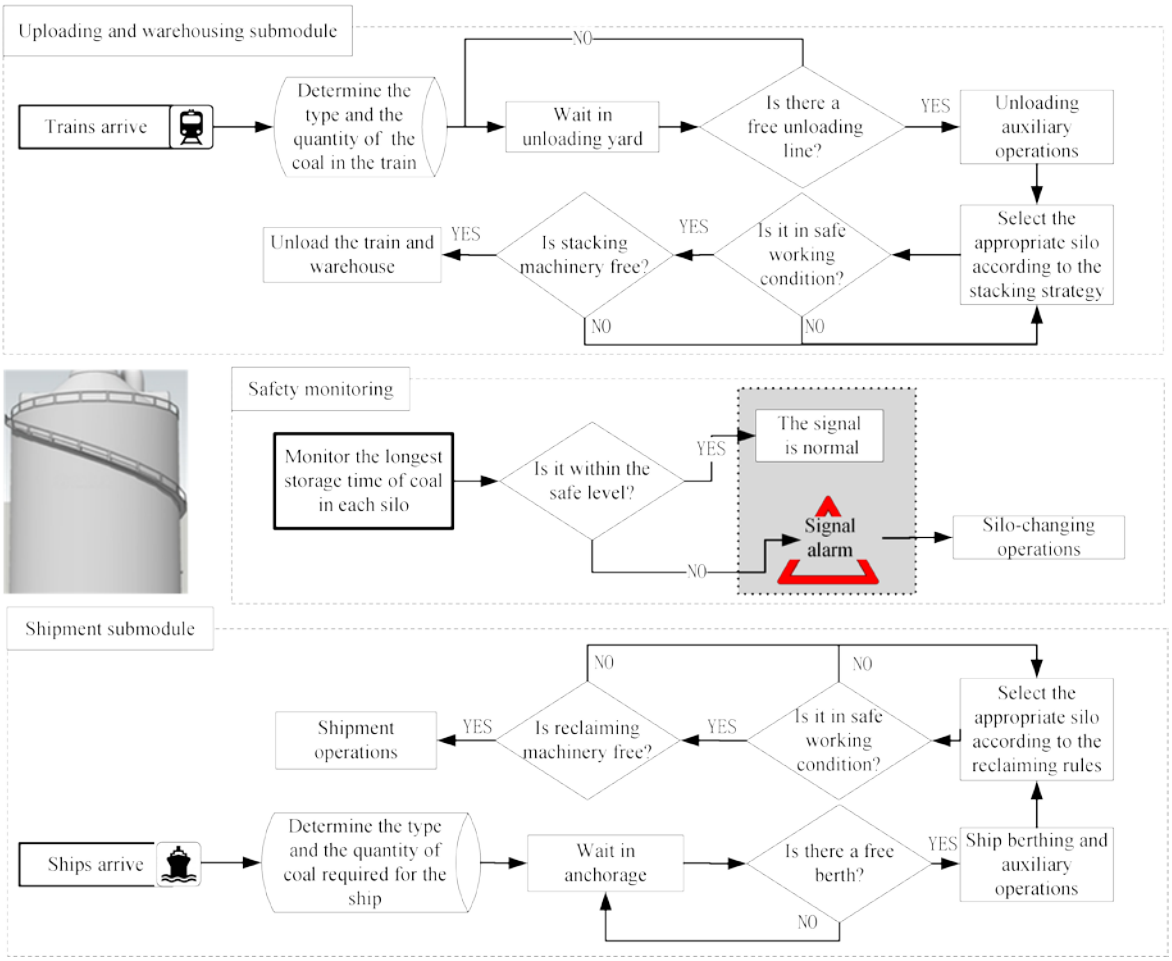

Fig. 1. The simulation flow chart of export coal terminal operation system.

B. Parameters of the Model

1) Input parameters

The arrival pattern of ships and trains; ship tonnage; the carrying capacity of trains; the number of silos; single silo volume; the period of coal spontaneous combustion; natural conditions of port, etc.

2) Output parameters

In order to do a quantitative research on the impact of train collection strategy and single silo capacity on the economic and safety benefits, some indicators, such as the annual throughput and the port time of ships and trains, are applied to measure the economic benefits of the port in this paper. Meanwhile, some other indicators, like the times of silo-changing operation and the average storage time, are applied to measure the safety benefits.

1) Economic benefit: The economic benefit gets better with the decrease of the port time of trains and ships. Greater annual throughput indicates the better the economic benefit. Moreover, the strict requirement of sail schedule makes it more important to focus on the port time of ships.
2) Safety benefit: The more average storage time goes by, the more times the silo-changing operation happens, which means the higher probability of security incidents.

C. Model Validations

The model was validated by a real case in China. The data including the number of arrival ships, ship tonnage and cargo required and so on were input as the parameters. The comparison between the simulation model results and the real data was made: The actual throughput of this port was 38 million tons while the result of simulation was 36.9 million tons, the relative error is 2.89%. Besides, the actual average storage time of coal is 3.5 days while the result of simulation is 3.43 days, the relative error is 2%. In conclusion, the simulation model can reflect the actual operation conditions factually.

III. Case Study

An export coal terminal in northern China was taken as an example to analyze the impacts of the train collection period and the single silo volume on the economic and safety benefits.

A. Case Inputs

The design annual throughput of this export coal terminal is 34 million tons. 24 silos are divided into 4 rows and 6 columns. There are 2 unloading operating lines whose rated capacity is 7700t/h, 4 berths are linked with the silo system by 4 ship-loading lines whose rated capacity is 8000t/h. A silo-changing operation line exclusively serves for silo-changing.

The key parameters of three main types of coal are given in Table I. The loading capacity of the train is 9,000 tons. The ship tonnage and arrival proportion are shown in Fig. 2.

TABLE I: The Throughput and Spontaneous Combustion Period of Different Varieties of Coal

Coal type	1#	2#	3#
Design annual throughput (million tons)	17.31	12.56	4.07
spontaneous combustion period(Days)	15	8	10

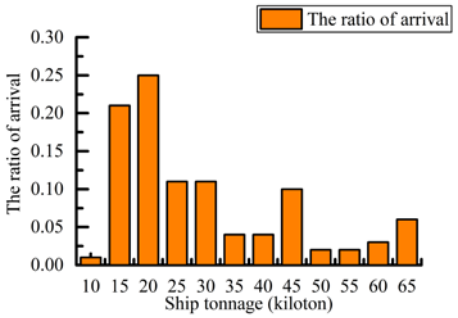

Fig. 2. The tonnage and arrival proportion of ships

B. Experiments and Results

The simulation time was one year, and every program ran 5 times to eliminate errors. The train collection period changed from 3 days to 7 days. Two scheme of the single silo's volume had been designed according to the engineering experience, ships' tonnage and the capacity of the trains. The volume of single silo is 20,000 tons in case I, and 30,000 tons in case II. The annual throughput, the average port time of ships and trains, the average storage time and the times of silo changing were outputted as shown in Fig. 3~6.

The impact of train collection period is more obvious. Take the case I as example: when the train collection period increased from 3 days to 7 days, as shown in the Fig. 3, the annual throughput of this port slightly decreased 0.7%, the average port time of ships reduced 16.9%, the average port time of trains gained a marked improvement of 78%. Moreover, the storage time and the silo-changing operations improved as the collection period increased. The silo-changing operation changed from 9 times per year to 26 times per year with a growth rate of 65.4%. Thus, Long train collection period meant poor safety benefit.

When the single silo volume increasing from 20,000 tons to 30,000 tons, as we can see from the output results: the annual throughput increased 1.1% on average; and he port time of ships and trains declined, when the train collection period was 3 days, the port time of ships declined from 14.69 hours to 13.30 hours, and the port time of trains had a 13.5% decrease. As for safety benefit, with the single silo volume increasing, the average storage time had a significant increase of 21.2% at the condition of 7 days collection period, and the silo-changing times increased from 26 times to 28 times per year which meant the higher risk of safety accident.

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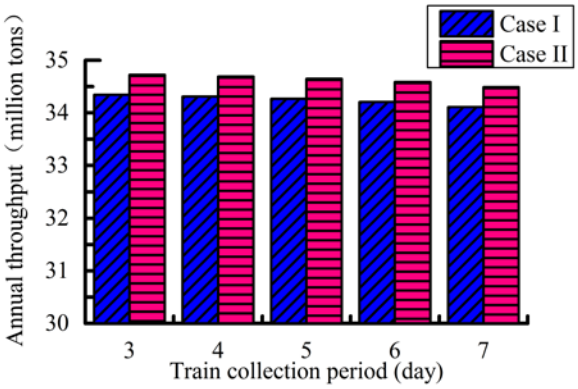

Fig. 3. The annual throughput.

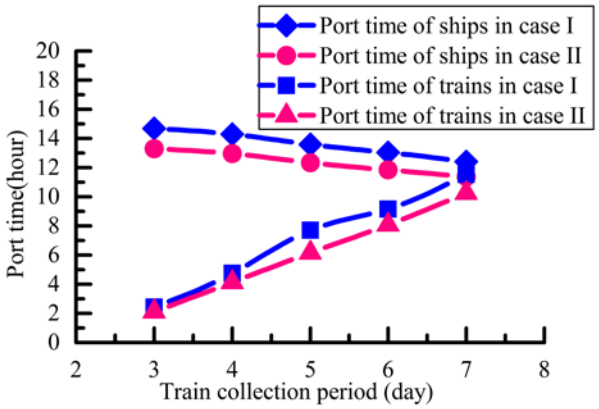

Fig. 4. The average port time of train and ship.

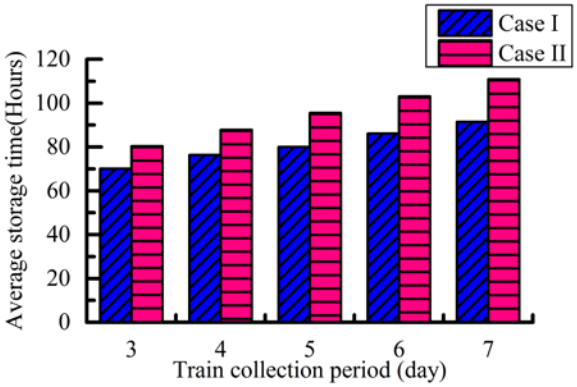

Fig. 5. The storage time of coal under different testing program.

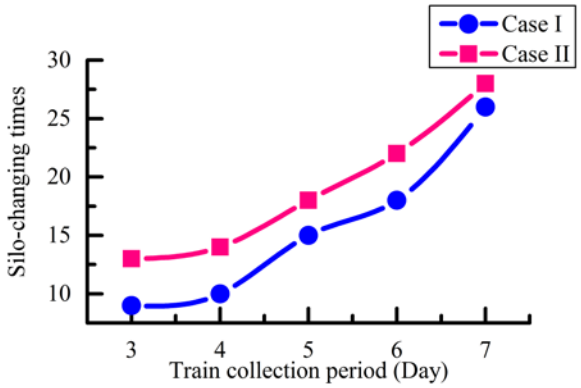

Fig. 6. The silo-changing times under different testing program.

IV. Conclusions

This paper took the export coal terminal with silo storage system as a research object which is much more environmentally friendly. A simulation model was built by Arena software 14.0 to do a quantitative study on the impact of the train collection strategy and the single volume of silos, on the operation benefits. Silo storage system can solve the dust pollution at the source, and the engineering experience shows the environmental protection benefit has been increased substantially. On the basis of the simulation results, we can reach the following conclusions:

For the economic benefit, with the single volume increased from 20,000 tons to 30,000 tons, the improvement of annual throughput and the decrease of port time, mean that the increase of the single volume would enhance the economic benefit of ports. The impact of the train collection strategy on economic benefit is relatively complex. When the train collection period increasing from 3 days to 7 days, the average port time of ships reduced which was good for economic benefit, while the index of the annual throughput and port time of trains was just the opposite.

For the safety benefit, we can conclude from the average storage time and the number of silo-changing operations that the improvement of the single silo volume and the decrease of the train collection period are helpful to enhance the safety benefit. When the train collection period increased from 3 days to 7 days, the silo-changing operation had a growth rate of 65.4% in case I. And with the single volume increased from 20,000 tons to 30,000 tons, the storage time had a significant increase of 21.2%, at the condition of 7 days collection period.

In conclusion, in precondition of satisfying safety requirements, the port`s economy will benefit when choosing bigger silo. The train collection period shouldn`t be too short in order to make sure the ships can arrive at the port according to the sail schedule. However, cutting down the train collection period is conducive to the annual throughput of coal terminals, the port time of trains and the safety benefit. Further researches can be studied on the impact of various assembled forms of operation lines in coal terminals with silo-storage system.

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