Techno-economic analysis of selecting the aggregate supply system based on optimal equipment layout in ready-mixed concrete plants

Milad Ghanbari, Armin Monir Abbasi and Mehdi Ravanshadnia

Production of 100 million cubic meters of concrete and an annual turnover of US$ 3.5 billion indicate the significance of concrete in the economy of construction projects in Iran. As concrete consumption in this country is more than the world average by 28 percent, improvement of the production lines is one of the steps to reduce energy consumption in this section. Just ten percent increase in the efficiency of concrete production, could economize and return US$ 350 million annually. In recent years, theoretical and operational issues concerning concrete production have been very considerable. However, little notice has been paid to the process of concrete production particularly supplying aggregate. Clearly, apart from mixing concrete in a batching plant, the most important process is the supply of aggregate which is carried out in a linear or star system. Removing loaders from this process as well as taking advantage of the proposed funnel-conveyor system could decrease the initial required capital by 70 to 90 % and maximize the continuous efficiency of production.

1. INTRODUCTION

Ready-mixed concrete (RMC) is used in most of the construction projects in private or state sectors today. 70 % of the produced cement and 43 % of the produced sand in the United States in 2012 were used in concrete production (Kramer, 2013) [1]. The amount of ready-mixed concrete used in construction projects in Iran in the same year was one third of the whole produced concrete. Approximately 100 million cubic meters of concrete is annually produced in Iran. Less than 40 % of this is RMC which is used in construction projects such as bridges and large buildings. The annual turnover of concrete production in Iran is estimated to be US$ 3.5 billion.

The per capita annual consumption of cement in Iran in 1978 was 220 kilograms which rose to 600 kilograms in 2013. Thirteen percent of the energy of the country is spent on cement production. In addition, the annual production of concrete in Iran is three times as big as the world average which indicates inappropriate consumption of concrete. As Iran is consuming concrete 28 percent more than the world average, improving RMC production lines is one of the steps to decrease energy consumption in this sector. The most important part in these plants which influences energy consumption and production largely, is depots and aggregate supply [2].

The purpose of this paper was to technically and economically analyze the supply of aggregate in ready mixed concrete plants. To do so, the depot and supply facilities such as dragline, distribution weighing feeder, trucks, loaders, and mini-loaders were studied.

2. REVIEW OF LITERATURE

A ready-mixed concrete plant is such a vast site that there is a gap for study in all its parts particularly inventory control, resources supply, production planning, updating the equipment and technology, etc.

Accordingly, Lu and Lam in December 2005 worked on optimizing concrete delivery planning with genetic algorithms (GA) [3]. Their study tried to find out the optimal number of mixers for any type of concrete with the optimal delivery schedule on different working days. Bellés et. al. [4] studied production planning and transportation of RMC. In this research, the number and capacity of the production stations, the number of the production lines in each station, and loading time were some of the parameters considered. Considering the loading time and the volume of the concrete required, planning production and transportation was done. Zayed and Nosair studied cost management in RMC production centers by means of stochastic mathematical models [5]. This study considering efficiency, cost, and delay as the most important factors in concrete production demonstrated the influence of delay on the cost of a concrete unit. It also considered the cost of equipment in the production of a cubic meter of concrete in the cost bill.

Feng et. al. [6] attempted to optimize planning RMC truck mixers by means of GA. They studied the duration of transportation, concrete placement, mixing, and the number of truck mixers required as the input of the model. The optimal planning of concrete delivery is considered as the output. However, in their study, transportation and concrete placement duration were not precise. There is need to use functions of distribution probability for these factors. Cao et. al. [7] optimized the operations in batching plants. They planned the required truck mixers by means of simulation and GA. They also considered critical resources, production planning, of demand of the plants on working days, minimum cost, and maximum efficiency.

Srichandum and Rujirayanyong also studied concrete production planning and dispatching of truck mixers by means of a bee colony algorithm [8]. They considered the same parameters and model as the ones done by Feng et. al. However, the means of optimization used by them was different. Eventually, they planned delivery and production by considering the time and volume of the required concrete. Zayed and Minkarah in 2004 worked on planning and resources allocation in batching plants [9]. They considered optimization of production in terms of maximum benefit and income in their model which was a linear one. In this model, different types of concrete were considered, and the optimal number of truck mixers considering the volume of concrete were estimated. The space for storage of critical resources could also be estimated by introducing their types and volume in this model. Naso et. al. [10] studied the application of GA in supply planning in batching plants. They attempted to optimize delivery and production of concrete in ready-mixed concrete plants considering time through algorithm. Zayed and Halpin simulated concrete production in batching plants [11]. In their study, they worked on management of planning production and transportation of concrete considering the distance, minimization of production cost, and decrease of time. The function of their purpose was quantitative. All the studies mentioned above are summarized in Table 1.

Accordingly, studies concerned with batching plants could be categorized according to the following scenarios:

1. Optimizing the concrete mixture design
2. Planning concrete production
3. Planning delivery and distribution
4. Optimizing the concrete production equipment
5. Quality control [13]
6. Batching plant equipment layout and etc.

The study of the Table 1 demonstrates the significance of resource allocation, inventory management, planning production, transportation and delivery in ready-mixed concrete plants. The set of these factors together bring about optimization of production and prevent delay. To achieve all this, we have to choose an optimal system for feeding aggregate in the plant.

3. INTRODUCING AGGREGATE SUPPLY SYSTEMS

Depot and supply of aggregate in concrete plants are usually in a star or linear system. In a star model, a dragline is used while in a linear model, weighing feeders are used. Both systems require loaders to load and supply aggregate. Therefore, feeding process, in terms of equipment and machinery, is defined by the batching and loaders sections. Batching is all the equipment including weighing, conveyor lines, dragline, control room, cement silos, and etc. In a star system, loaders are used to organize or relocate the depot, and help the dragline to load aggregate, while in a linear system, they are used to load and transfer aggregate from the depot to the feeder.

In some batching plants, mini-loaders so-called Bobcats are used instead of loaders as they have lower provision cost (initial investment). However, they suffer more depreciation than loaders in batching plants. This is caused by high internal friction of wet aggregate which increases the weight of sand which requires a more powerful machine for transfer and loading. Mini-loaders could be used in batching plants producing less than 300 m^3 on a daily basis. In Figures 1 and 2, there are schematic sketches of a star system and linear system respectively.

To analyze each of the systems, a batching plant with a production rate 60 m^3/h was chosen for a case study. To analyze the operational production cost in an eight-hour working shift for the whole system, aggregate supply and feeding which cause the most cost in the production of concrete and setting up a concrete plant was studied. Then, for both systems, the costs including the loader and human resources were estimated.

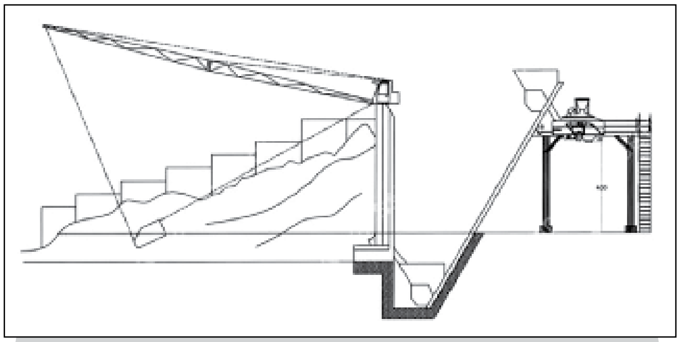

Figure 1. The star system of batching plant

Table 1. The summary of related investigations

NO.	Researchers	Case scenario	Important factors	Tools
1	Bellés et. al, 2012 [4]	Ready mixed Concrete Production and delivery scheduling	Number and volume of the stations, number of the production lines in each station, loading duration	A Multi-start algorithm
2	Srichandum and Rujirayanyong, 2010 [8]	Production scheduling for dispatching Ready Mixed Concrete trucks	Length of time and required volume of concrete	Bee Colony Optimization
3	Deligiannis and Manesis, 2008; Arýöz et. al, 2007 [12, 13]	concrete production, quality control of ready mixed concrete	Batching and mixing model, Quality control model, automation	Web-based technology, SCADA
4	Zayed and Nosair, 2006 [5]	Cost Management for concrete batching plant, and the influence of delay on the concrete unit cost	Efficiency, cost, delay, cost of equipment	Stochastic Mathematical Models
5	Lu and Lam, 2005 [3]	Optimized concrete delivery Scheduling and production	Optimal number of truck mixers, optimized concrete delivery scheduling	Using combined simulation and genetic algorithms
6	Cao et. al, 2004 [7]	Concrete plant operation optimization, scheduling required truck mixers	Critical resources and production planning, daily demand of the sites with the minimum cost and the maximum efficiency	Genetic Algorithm, Simulation of the operation
7	Feng et. al, 2004 [6]	Optimizing the schedule of dispatching RMC trucks, optimizing concrete distribution	Delivery and transfer duration, concrete placement duration, mixing duration, and the number of required mixers	Genetic Algorithm
8	Zayed and Minkarah, 2004 [9]	Resource allocation for concrete batching plant operation	Maximum benefit, optimal number of mixers, concrete volume, critical resources, estimation of the required space	Linear planning
9	Naso et. al, 2004 [10]	Optimal scheduling of Ready Mixed Concrete	Supply chain time	Genetic Algorithm
10	Zayed and Halpin, 2001 [11]	Management of planning operation and transfer	Distance of transportation, minimizing the production cost and decreasing the time of production	Simulation of concrete batching plant production

Considering the production capacity of the batching studied, 480 m^3/h of concrete was produced in a working shift. Each cubic meter weighed 2300 kilograms. When the weight of cement (350 kg) and water (250 kg) was deducted, the result was the weight of sand (1700 kg). Hence, the aggregate required for the whole production of a day was:

1700*480 = 816,000 kg = 816 Ton

The capacity of the aggregate trucks in ready concrete plants was 15 tons, therefore, the number of times a truck was used was:

816 ÷ 15 = 55 Runs

Supply of aggregate was done during a shift. Therefore, discharging of the trucks during a shift could be simulated with the following interval:

(8 h * 60 min) ÷ 55 = 8 min

4. TIME ANALYSIS OF BOTH SYSTEMS

4.1. Dragline system

Considering the estimation above, with the arrival of a truck about every 8 minutes, the aggregate was discharged at the depot which was usually out of the dragline's boom access radius. Hence, the dragline needed the loader to organize the depot, and help load aggregate. It could be stated that after discharge of 20 m^3 or 45 tons aggregate (three truck runs), the depot required organizing or its space would be blocked. Therefore, every 30 minutes, loaders started to organize the depot. To estimate the hours the loader works, the time cycle of the loader was estimated. It should be mentioned that the quality of keeping and transfer of aggregate in a star system was low, and it directly influenced the quality of the concrete.

A. The use of loader

Let's assume that a loader with 175 HP and bucket size of 2.5 m^3 was used. Since the length of the boom of the dragline studied was 14 meters, and the throw length of the rake was 26 meters, the space available for the loader to organize was eight meters. The time cycle of a loader to load, relocate, and return to the first place was about 19 minutes. Considering the capacity of the bucket of the loader and approximate weight of a cubic meter of aggregate, the capacity of the bucket in terms of aggregate was:

2.5*1.7 = 4.25 Ton

Therefore, the total time the loader was working for the whole aggregate was:

816 ÷ 4.25 = 192 → 192*19 = 3648 seconds = 1 hour

Therefore, the loader in a star model worked for one hour in a whole eight-hour shift, and rests for the other seven hours. This means that for a batching plant with the capacity

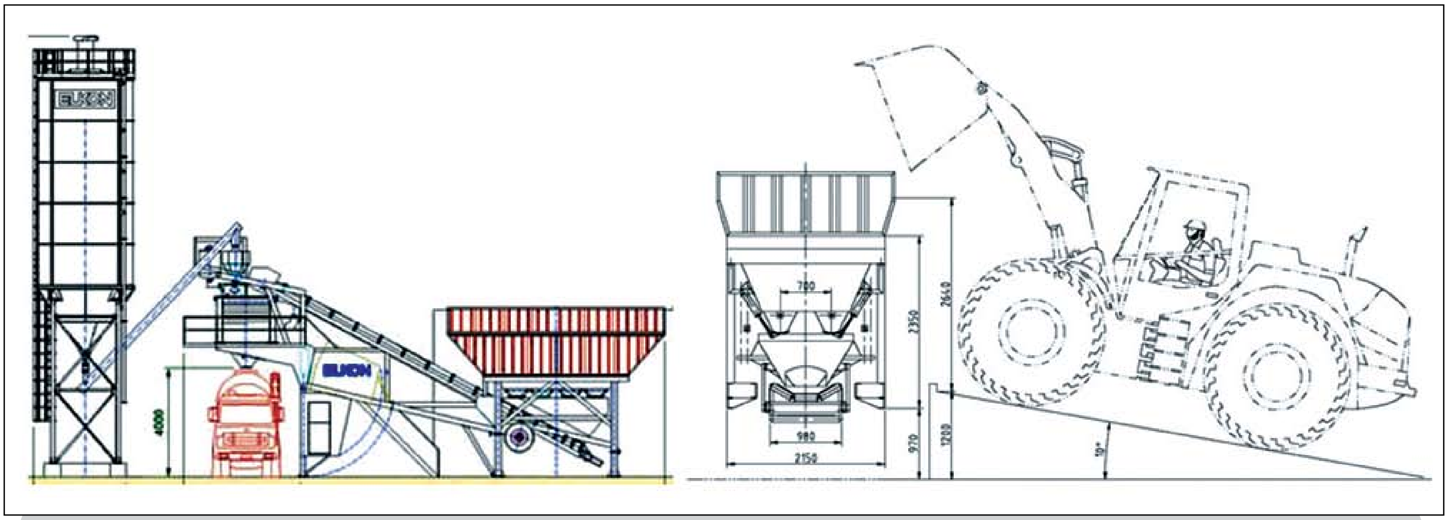

Figure 2. The linear system of batching plant

mentioned, 12.5 percent of the driver's time and the loader was used. This meant waste of the cost and non-optimal use of the equipment and human resources.

B. The use of mini-loader

Let's assume that the mini loader with the power of 87 HP and bucket capacity of 0.4 m^3 was used. With the specifications of the dragline mentioned above, loading, relocating, and returning took about 15 minutes. The capacity of the bucket in terms of aggregate was: 0.4.*1.7=0.68

Therefore, the amount of time the mini loader was working was:

816 ÷ 0.68 = 1200 → 1200*15 = 18,000 seconds = 5 hours

Therefore, the mini loader in a star model in an eight-hour shift had 5 hours' efficiency meaning that 62.5 % of the time of the driver and the mini-loader was used which meant a non-optimal system.

4.2. Linear system

In the study of this system for the batching, there was a need for a weighing feeder with the capacity of 30 m^3. The height of the feeder was four meters and its distance from the depot was usually 20 meters. In linear systems, as weighing feeders are used, supply, keeping, and transfer of aggregate was done more carefully and with better quality in comparison with star systems.

A. The use of loader

The cycle of the assumed loader for this distance was about 35 seconds. The time the loader was working was:

192*35 = 6720 seconds = 2 hours

Therefore, in this situation, the loader was working just for two hours which meant 25 percent efficiency of the loader and the driver during the shift.

B. The use of mini-loader

The assumed mini-loader had a cycle of 25 seconds feeding aggregate.

1200*22 = 26,400 seconds = 7.3 hours

In this situation, 91 percent of the time of the loader and the driver was used during an eight-hour shift. The results of the time analysis of the two systems are summarized in Table 2.

5. ECONOMIC ANALYSIS OF THE SYSTEM

In the analysis of both systems, to study the capital involved, one had to consider the costs of the machinery purchased or hourly rented. The cost of a new wheel loader was US$ 150000, and its hourly rent with the driver was US$ 110. However, the price of a dragline system batching plant (of a reputed company) with the capacity 60 m^3/h was US$ 35,000, and its hourly rent with the operator was about US$ 50. A 60 m^3/h batching plant with a linear system was US$ 50,000 and its hourly rent with the operator was US$ 60. The cost of the mini-loader was US$ 50,000 and its hourly rent with the driver was US$ 60.

The linear system required a person as a loader driver to feed aggregate. This driver with the loader worked for two hours in an eight-hour shift. The star system required two persons in the aggregate department. One was the operator of the dragline and the other was the loader driver. Therefore, the cost of the operation and the equipment for the two systems was estimated as below.

5.1 star system

A. The cost of renting the equipment for an eight-hour shift:

The use of loader: (batching plant 50*8) + (loader 110*8) = US$ 1280

The use of mini-loader: (batching plant 50*8) + (mini-loader 60*8) = US$ 880

Therefore, the ratio of the rent of the loader or the mini-loader to the total cost was:

For loader: 880 ÷ 1280 = 68.7%

For mini-loader: 480 ÷ 880 = 54.5%

Table 2. The results of time analysis of both systems

Supply aggregate system		Hours of Machine working in a shift	Efficiency of Machine (%)
Star	Loader	1	12.5
	Mini-loader	5	62.5
Linear	Loader	2	25
	Mini-loader	7.3	91

B. The operational cost of purchasing the equipment for the shift

The use of loader: (batching plant 35,000) + (mini-loader 150,000) = US$ 185,000

The ratio of the purchasing cost of the loader to the total cost: 81%.

The use of mini-loader: (batching plant 35,000) + (mini-loader 50,000) = US$ 85,000

And, the ratio of the purchasing cost of the mini-loader to the total cost: 58.8%

5.2. Linear system

A. The operational cost of renting for a shift:

The use of loader: (batching plant 60*8) + (loader 110*8) = US$ 1360

The use of mini-loader: (batching plant 60*8) + (mini-loader 60*8) = US$ 960

Therefore, the ratio of the cost of renting a loader or mini-loader to the total was:

For loader: 880÷1360 = 64.7%

For mini-loader: 480÷960 = 50%

B. The operational cost of purchasing equipment for a shift was:

The use of loader: (batching plant 50,000) + (loader 1,50,000) = US$ 200,000

The use of mini-loader: (batching plant 50,000) + (mini-loader 50,000) = US$ 100,000

Therefore, the ratio of the cost of purchasing a loader and mini-loader to the total was 75% and 50% respectively. To ease the analysis of the two systems, the results of the economic analysis is provided in Table 3.

6. ANALYSIS, SELECTION, AND IMPROVEMENT OF THE AVAILABLE METHODS

Tables 2 and 3 reveal that the use of the loader in the studied batching plants is non-optimal. In these sites, a moving unit called loader and a fixed unit called batching equipment were used. In a star system, the cost of the moving unit was four times as big as the fixed unit. This is against the principles of designing machinery lines. The use of a mini-loader in a linear system gave a higher efficiency. However, the amount of the capital involved in the production of concrete was still high in comparison with the total cost. Hence, to optimize the process of production in the aggregate supply, we had to adopt a way which optimized, minimized, or removed the loader.

Table 3. The results of economic analysis of both systems

Supply aggregate system		Operational cost of the equipment ($)		Ratio of the cost of the machine to the total (%)	
		Renting	Purchasing	Renting	Purchasing
Star	Loader	1280	185000	68.7	81
	Mini-loader	880	85000	54.5	58.8
Linear	Loader	1360	200000	64.7	75
	Mini-loader	960	100000	50	50

As in the concrete production stations, urban and non-urban RMC plants, and even in big projects such dam constructions, factors such as production rate, production duration, low depreciation, low cost of maintenance, and low cost of setting up the equipment are significant, the mere use of a dragline is non-optimal. In a linear system, feeding aggregate, production speed and efficiency are high. However, the study of this system demonstrated that the use of the loader is non-optimal which could be removed to double the efficiency and minimize the cost.

In order to remove loaders, conveyors along with funnel feeders was used as they had lower supply, energy, maintenance, and depreciation cost in comparison to the two systems mentioned here. To optimize the aggregate feeding line, conveyors could be used whose high continuous efficiency is noticed in production industry. A conveyor with a simple funnel at the beginning end of the line could be used to feed aggregate; the conveyor transfers aggregate from the funnel to the dispatching feeder which has a large capacity to depot the aggregate.

Funnel could be designed so that it could hold the load of three trucks. If it is designed as big as 3×3×3 meters, it will hold 27 m^3 or 46 tons of aggregate. After a truck discharges, the aggregate, depending whether it is sand or gravel, is transferred immediately to its specific hopper in the feeder. This system doesn't need a loader, and it consumes lower energy and enjoys higher and continuous efficiency. Two separate conveyors are used to feed sand and gravel.

The cost of the equipment for such a system including conveyors, funnels, electrical structure and facilities amounts

Table 4. The results of funnel-conveyor linear system

Supply aggregate system		Hours working in a shift	Efficiency (%)	operational cost of the equipment ($)	Ratio of the cost of the Supply aggregate equipment to the total (%)
Linear	funnel-conveyor	8 continuous	100	65000	23

to US$ 15,000. The schematic sketch of the suggested linear batching is shown in Figure 3. It should be mentioned that in this system, the inventory of the feeder needs to be checked regularly and on time. The planning of supply of aggregate by trucks needs to be done carefully. To implement inventory control systems, you could take advantage of the model of Economic Order Quantity (EOQ) (Waters; Mercado) [14, 15].

The operational cost of providing equipment for a shift in this system was:

(linear batching plant US$ 50,000) + (funnel-conveyor US$ 15,000) = US$ 65,000

The ratio of the cost of funnel-conveyor to the total was 23%. The results of the use of a funnel-conveyor linear system are demonstrated in Table 4.

7. CONCLUSION

As aggregate supply in ready-mixed concrete (RMC) plants is either a star or a linear system, loaders are used to load aggregate in both systems, therefore, the cost of supplying equipment, repair and maintenance, depreciation, and human resources increases. This means that using the loader is non-optimal. The purpose of this paper was to study aggregate feeding in batching plants techno-economically. The results revealed that the use of the loader in a star system produced 12.5% efficiency, and its cost was 81% of the total capital of setting up the production line. These figures in a linear system were 25% and 75% respectively. Moreover, the

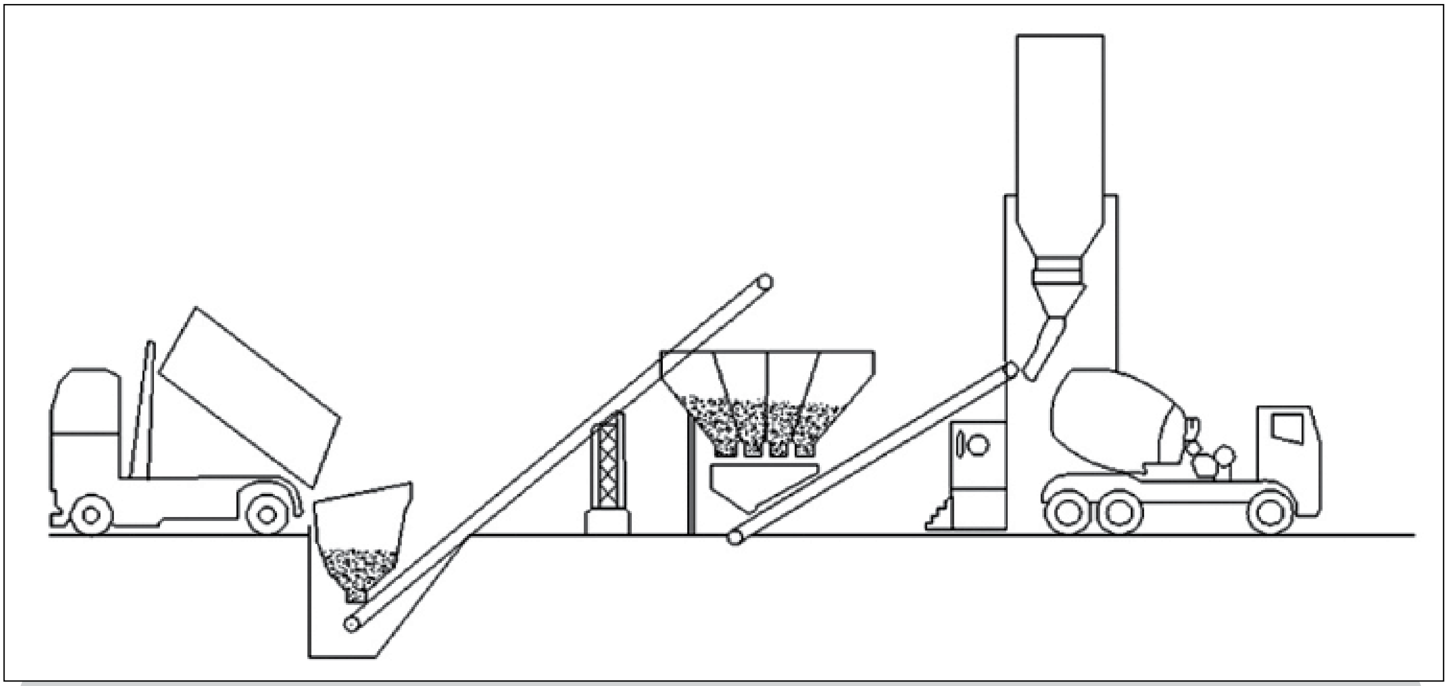

Figure 3. The batching plant with funnel-conveyor system

cost of supplying loaders in a star system was four times as big as the cost of supplying a batching plant.

To improve the continuous efficiency in production and to decrease the required capital, the correction of the aggregate feeding line was considered. Therefore, the funnel-conveyor system was introduced. The ratio of the cost of the equipment for such a system (funnel-conveyor) to the cost of a loader and a mini-loader was 10 and 30 percent respectively. This means that 70 to 90 percent of the initial capital required for a batching is economized. It should be mentioned that in this system, supplying aggregate by trucks needs to be checked carefully so that in critical times, the lines are not stopped due to lack of resources.

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Milad Ghanbari holds an M.S.c. in Construction Engineering and Management from Science and Research Branch from I.A. University, Tehran, Iran; pursuing his PhD in Construction Engineering and Management at the same University. For the last five years, he has been working in construction projects in Tehran. His research interests include construction project management, innovation in concrete production technology, sustainable development, recycling construction materials, soft computing and optimization methods. He has published several papers on the above topics.

Dr. Armin Monir Abbasi holds a degree in civil engineering (construction engineering and management) from Iran University of Science and Technology; PhD from Iran University of Science and Technology (PhD topic was plastic and drying shrinkage in self compacting concrete). He is an Assistant Professor at Payame Noor University. His research interests are concrete technology, system analysis and project management.

Dr. Mehdi Ravanshadnia is a Professor in Islamic Azad University, Science and Research Branch, Tehran, Iran. He is the manager of construction engineering and management group. He is an author of more than a dozen books and more than 50 papers in the field of construction project management. Also, he is a member of board of Tehran Construction Engineering Organization.