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Facility Layout Design and Simulation for Lean Gains

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Abstract: This study deals with the development of an alternative loading and shipping layout for a major chlorine and soda caustic producer in the U.S. Two simulation models, one of the current system and the other of the proposed layout were then constructed to estimate the potential manufacturing gains from the new layout. Finally, a statistical analysis of the simulation outputs justified the implementation of the proposed layout.

Key words: Facilities layout, simulation, chlorine and caustic soda industry, F-test

INTRODUCTION

Facility layout and design is an important component of a business's overall operations, both in terms of maximizing the effectiveness of production processes and meeting employee needs and/or desires. There are relevant criteria that need to be considered when building or renovating a facility for maximum layout effectiveness. These include ease of future expansion or change, flow of movement, materials handling, output needs, space utilization, shipping and receiving, ease of communication and employee morale and safety (Muther, 1955; Heragu, 1997; Heragu and Kochhar, 1999).

A major manufacturer of caustic soda and chlorine located in the southeast of the United States of America was in the need to create a more efficient rail freight system for movement of their chlorine railcars. Railcars are the means for transporting the chlorine throughout, this facility, since chlorine is not stored at the factory but constantly shipped as it is produced. The company employs twenty blowdown stations and 4 washout stations. All chlorine railcars have to go through the blowdown process, which takes approximately 4 h. Every once in a while, chlorine cars must go through an additional washout process, which takes approximately 24 h. The 4 washout stations also have the capability to blowdown cars. There are 3 tracks that contained the blowdown and washout stations. Figure 1 shows the current layout for the shipping and loading area of the facility. Track 00 contains 4 blowdown stations. Track 0 contains 8 blowdown stations and two washout stations. The two washout stations are located behind the blowdown stations so the washout cars cannot exit until the blowdown cars have exited. They are essentially "blocked in" by the blowdown cars. Track 1 is set up exactly the same way as Track 0. After the chlorine cars go through these processes, they have to reverse and switch on to Track 2 or 3. Tracks 2 and 3 each contain 3 loading stations. The chlorine cars take about 6 h to load each. After loading, the cars are pulled up to Track 7 to wait until Norfolk Southern pulls them onto their tracks to ship out to the customers. Norfolk Southern is the company that controls the movement on the railroad tracks outside of the facility. If Track 7 is full, then the cars wait for Norfolk Southern on the North end of Tracks 2 and 3.

The caustic cars have a much simpler process than that of the chlorine cars. They receive their inspection and cleaning before the cars are loaded at the loading stations. Caustic loading stations are located on Tracks 5 and 6. There are 6 caustic loading stations on each track. The cars take about 6 h each to clean, wash and load with caustic soda. After the cars are loaded, they follow the same exiting process as the chlorine cars.

The main purpose of the research was to develop an alternative loading and shipping layout that better suits the manufacturing facility. A 2nd goal of the research was to develop two simulation models: one of the current system and the other of the proposed layout. The collected simulation model statistics justified whether the company should keep their current layout or implement the proposed layout.

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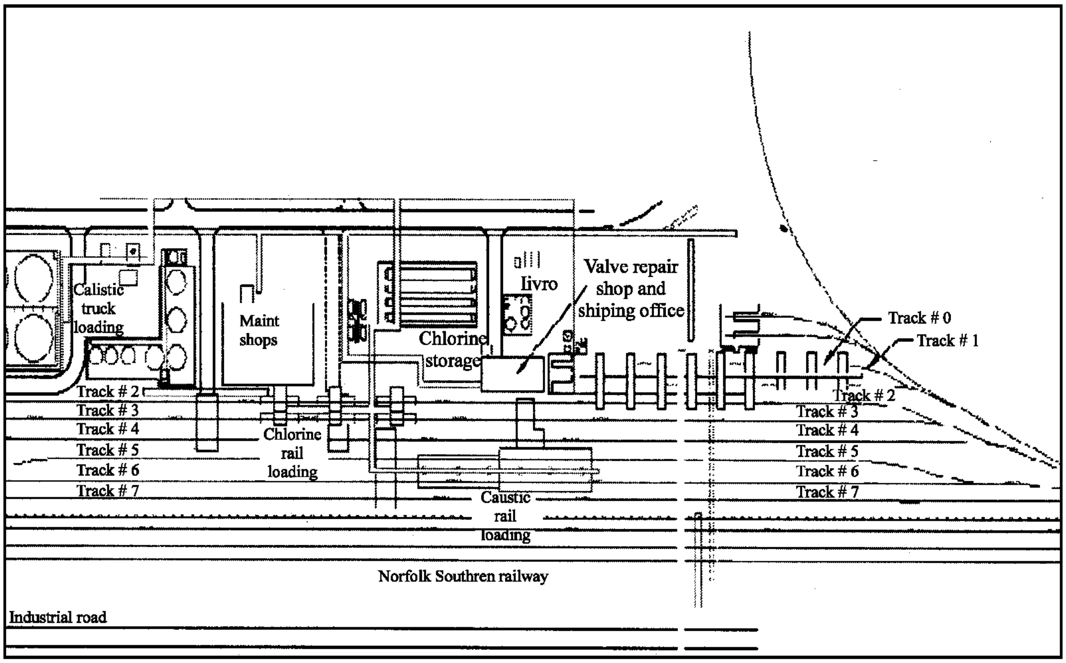

Fig. 1: Current shipping and loading area

RESEARCH APPROACH

The primary objective of the new shipping and loading area was to provide a more efficient facility arrangement so that the company could ship and load railcars in a more consistent manner. The new layout had to increase the capacity to load and ship railcars, which is important because production was planned to grow in the next two years. The company was also looking to build their own overhaul facility to refurbish railcars instead of outsourcing this task. The new layout had to leave sufficient space for an overhaul facility. The bottlenecks in the current layout were eliminated or improved in the new layout.

The first step in correcting the problem was to collect data on the current situation. A good understanding of the current process was needed in order to know what had to be corrected. Next, a few layout alternatives were to be generated and one of these pre-established proposed alternatives selected. This alternative was selected based on pre-established evaluation criteria and the company's own feedback on feasibility. Then, the current layout and the proposed layout were modeled via discrete simulation. The two simulation models were then compared based on their statistics. These performance statistics justified the effectiveness of the proposed layout versus the current one.

Generation of layout alternatives: Four alternatives were constructed for the shipping and loading area. These alternatives addressed the main problems associated with the current layout. These associated problems included reverse movement of railcars, blockage in the washout stations, high travel time, inadequate storage space and insufficient space for additional washout or blowdown stations. Auto CAD was used in order to generate these 4 alternatives:

- In Alternative I, the blowdown and washout stations had been moved to a location southeast of the current blowdown and washout stations. Figure 2 for a full view of Alternative Layout I. The chlorine cars would enter by using the first track available for cars to enter, which is called the salt loop. The cars would travel east on the salt loop and then turn west to go through the blowdown or washout process. Next, they would travel west and switch onto either Track 2 or 3 for loading.
- Alternative II (Fig. 3) suggested leaving the blowdown stations where they were except taking two off the North end and moving them to the South end. Therefore, the blowdown cars could travel forward, after they went through the blowdown stations, onto Tracks 2 and 3 for loading. The washout stations would not remain in the same location. They would be moved to the South end of the plant where the cars first entered. The cars requiring washout would travel in a loop in order to be washed out and then travel forward to Tracks 2 and 3 for loading.

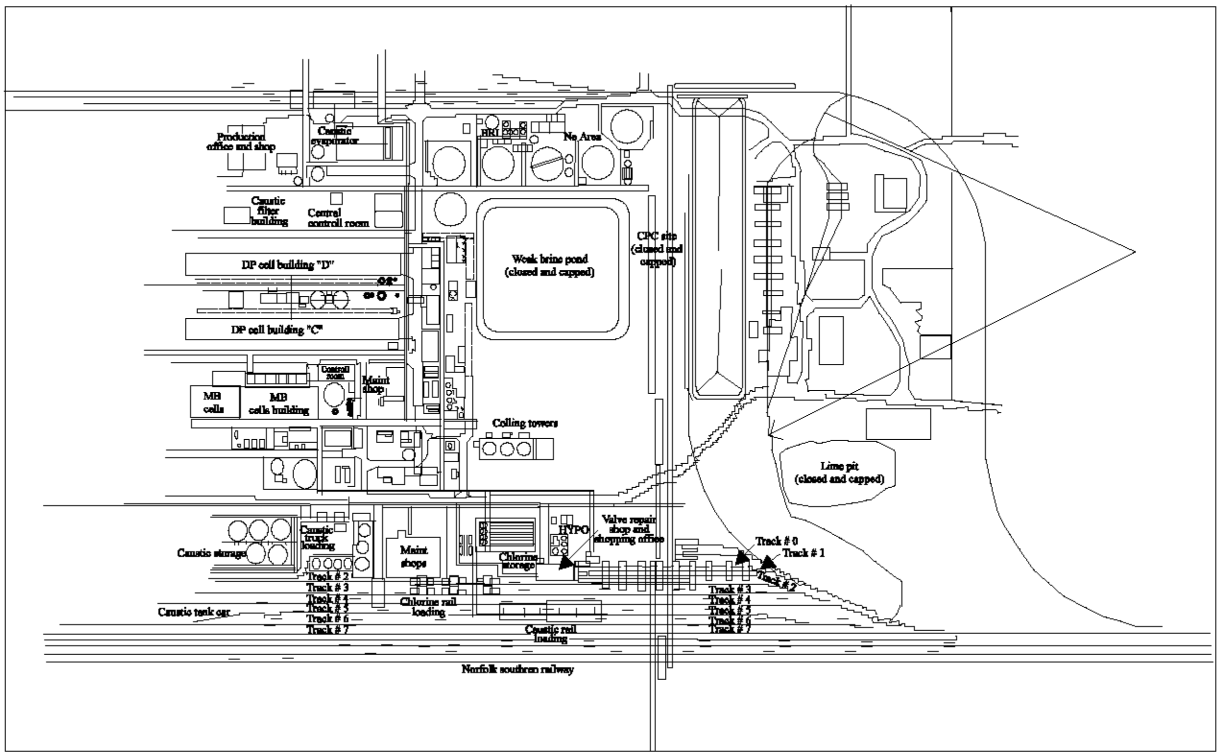

Fig. 2: Alternative layout I

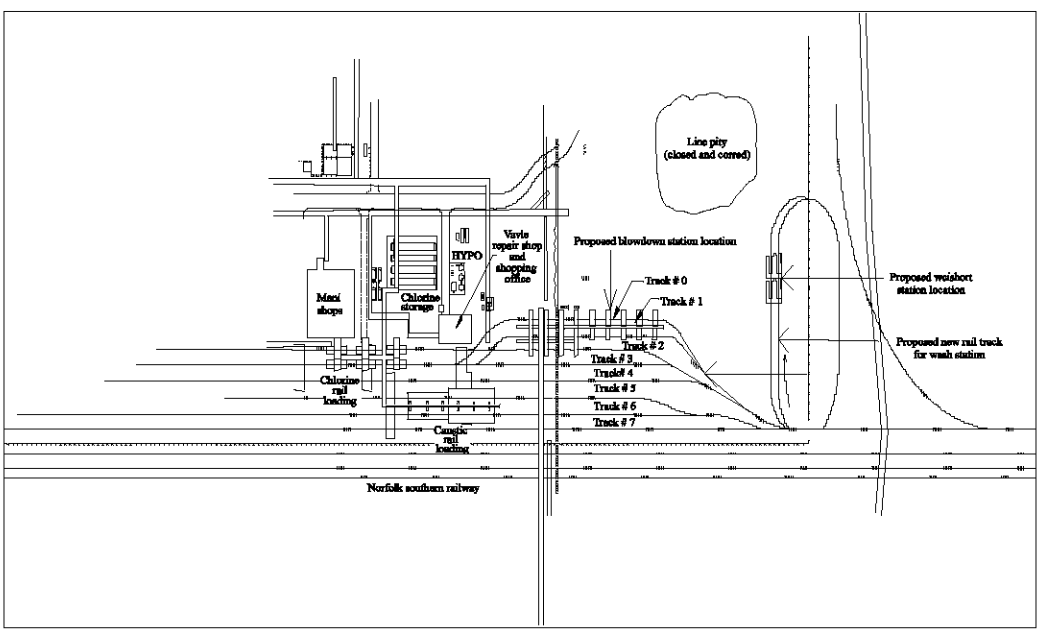

Fig. 3: Alternative layout II

- In Alternative III (Fig. 4), the washout stations had been relocated onto Track 00 and the blowdown stations had been relocated to the organics track. The railcars requiring blowdown would travel Northeast onto the organics track and go through the blowdown process. Then, they would travel in a circular motion and end up back where railcars enter in the south end of the plant. Last, they would travel onto Tracks 2 and 3 for loading.

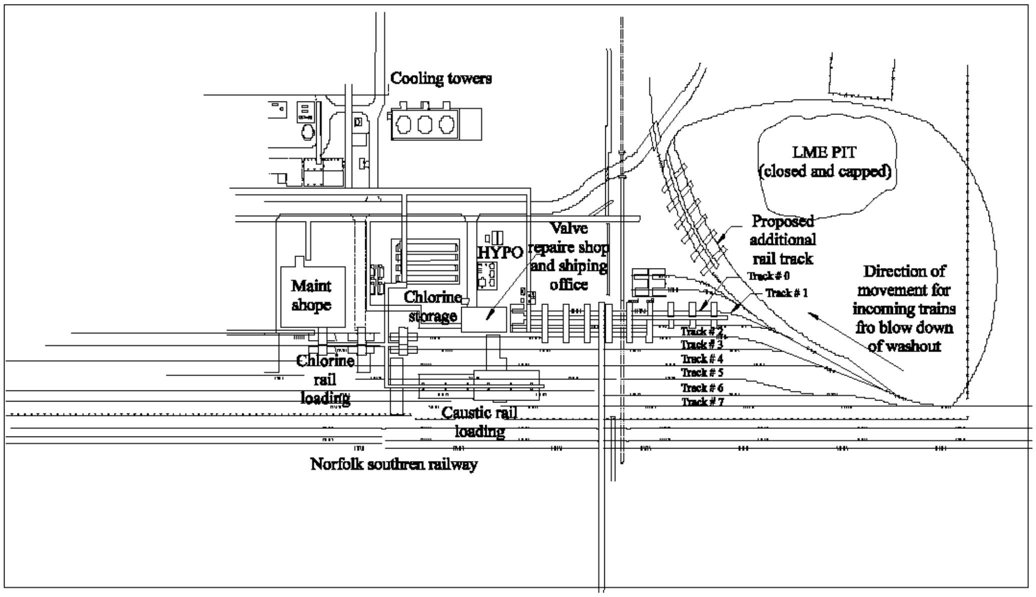

Fig. 4: Alternative layout III

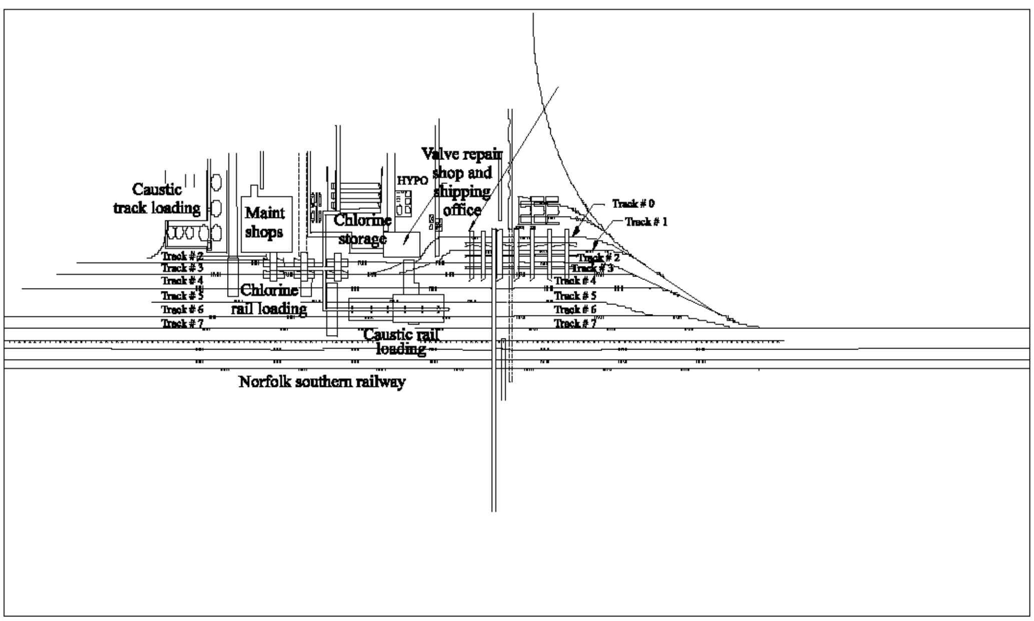

Fig. 5: Alternative layout IV

- Alternative IV was a good mix of the first 3 alternatives. Refer to Fig. 5 for a full view of Alternative Layout IV. This alternative would leave 6 blowdown stations on Track 0 and 6 blowdown stations on Track 1. It also would add 6 blowdown stations to Track 2 and 6-3. After cars went through the blowdown stations, they would move forward from Tracks 2 and 3 for loading. From Tracks 0 and 1, they would move forward via switches onto Tracks 2 and 3 for loading. There would now be three washout stations relocated to Track 00. An additional track spur, Track 000, would also be added east of Track 00 that would contain three more additional washout stations for a total of six washout stations.

Once the layout alternatives were generated, they needed to be evaluated and one selected as the final proposed alternative. The developed alternatives were compared through evaluation criteria and feasibility constraints. The company's personnel were consulted during the development of such evaluation criteria. Another factor that was considered in this selection process is the technical feasibility of the layout. After a meeting with the fleet maintenance manager and the shipping area supervisor, Alternative IV was chosen as the proposed layout alternative. The decision was based on two main aspects: feasibility and evaluation criteria. The employees did believe that Alternative IV was the most feasible layout out of the 4 alternatives. Also, the alternatives were analyzed based on evaluation criteria and Alternative IV met the criteria best.

Simulation models: Following common practice (Bekker and Saayman, 1999; Ondrey, 2005), two simulation models were developed: one of the current layout and one of the proposed layout. Both simulation models were constructed using ProModel. The methodology behind each simulation is similar for both models. Once the current layout was modeled, the proposed layout was simulated. The simulations output statistics shed light on the number of chlorine railcars that can be shipped and loaded daily.

There are several parameters that must be modeled within each simulation: locations, entities, processing, arrivals, attributes, variables, arrays and user distributions. The location section defines all of the points in the simulation model used for routing entities including their capacities. The entity section defines the different types of railcars included in the model. The processing section is where the travel logic is programmed; it is the most involved and complex section of the model. The arrivals section states, how often and in what quantities each type of car arrives. The attributes are variables associated with individual locations or entities. These can be either integer or real values. The variables are placeholders for real or integer numbers that may change during the simulation. An array functions as a table of variables of the same type. Lastly, user distributions specify the parameters of user-defined discrete or continuous probability distributions.

The main differences between the models are the capacity at the blowdown and washout stations, their locations, their processing logic and the user distributions for blowdown and washout cars. Due to these differences, the allocated space for the chlorine cars waiting to be loaded is also different. The caustic process is the exact same in both models. The loading process does not change either. These two processes were left unaltered since the bottleneck was specified as the blowdown and washout processes for the chlorine cars. The simulation models run for 24 h a day, 7 days a week in order to map the actual manufacturing process.

RESULTS

After the models were developed, output statistics were compared from the two simulations. Table 1 summarizes the statistics obtained from the two models.

All of the above statistics are based on a 20 day time period. As shown above, the number of chlorine cars loaded increased by 84 cars in 20 days, that is an average of 4.2 more cars per day, a 21.4% increase. The number of blowdown stations increased by 4 and the number of washout stations by two. This gives the company more resources in order to blowdown and washout cars. The washout utilization percentages show a substantial increase in the proposed layout. Both washout stations are now being utilized from 90-100% of the time versus before, when the utilization ranged from 61.86- 99.67% of the time. This shows a better allocation of the washout stations. The Track 2 Load Queue and Track 3 Load Queue are now 93.21 and 84.31% occupied, versus before, when they were 0 and 2.3% occupied, respectively. This means cars are almost always finished in the blowdown stations and waiting to be loaded, whereas before, this was rarely done. It also shows that there was valuable track space unused in the two queues. The proposed model utilizes this space for the blowdown stations. Another positive aspect of the proposed layout is the increase in chlorine storage facilities. Potentially, there is room for 108 chlorine cars versus the 95 chlorine cars that can currently be stored. The new layout includes a Track 0000 for chlorine car storage, which is a part of the reason for the storage increase.

Statistical analysis of key gain: The main objective of the study was to increase the number of chlorine cars that can be loaded per day. Therefore, a statistical analysis was conducted for this performance measurement. Each simulation was run 20 times. Table 2 for a list of the data points from each simulation run.

These numbers were used for the statistical comparison of the two models. First, an F-test two sample for variance was carried out using Microsoft Excel. This was conducted to ensure the variances are equal in the current and proposed simulation output (Table 2). Table 3 summarizes the results of such a F-test.

Table 1: Output statistics comparing simulations

Statistic	Current layout	Proposed layout	Difference
Number of chlorine cars loaded	393	477	84
Number of blowdown stations	20	24	4
Number of washout stations	4	6	2
Washout 1 utilization percentage	92.00%	98.47%	6.47%
Washout 0 utilization percentage	61.86%	91.99%	30.13%
Track 2 load queue % fully occupied	0%	93.21%	93.21%
Track 3 load queue %fully occupied	2.30%	84.31%	82.01%
Chlorine storage cars	95	108	13

Table 2: Simulation throughput results

Current layout	Proposed layout
19.65	24.00
19.8	23.85
19.65	24.00
19.5	24.15
19.8	23.85
19.5	24.00
19.65	24.15
19.65	23.85
19.8	23.85
19.5	24.00
19.5	23.85
19.8	24.15
19.8	24.00
19.5	24.00
19.65	23.85
19.5	24.15
19.65	24.00
19.65	23.85
19.8	23.85
19.65	24.00

Table 3: F-Test 2 sample for variances

	Variable 1	Variable 2
Mean	19.65	23.97
Variance	0.014210526	0.013263158
Observations	20	20
d.f.	19	19
F	1.071428571	
P(F<=f) one-tail	0.441018557	
F Critical one-tail	2.168251601	

Table 4: T-test 2-sample assuming equal variances

	Variable 1	Variable 2
Mean	19.65	23.97
Variance	0.014210526	0.013263158
Observations	20	20
Pooled variance	0.013736842	
Hypothesized mean difference	0	
d.f.	38	
t Stat	-116.5575187	
P(T<=t) one-tail	1.8752E-50	
t Critical one-tail	1.685954461	
P(T<=t) two-tail	3.75039E-50	
t Critical two-tail	2.024394147	

The F-value of 1.07 is less than the f-critical value of 2.17. Therefore, it can be stated with a 95% confidence that the variances are equal. Since the variances are equal, a t-test 2-sample, assuming equal variance, was conducted using Microsoft Excel. Table 4 depicts the results of such a test.

The null hypothesis is that the two means are equal. With a p-value below 0 it can be stated that the null hypothesis is rejected. With a 95% level of confidence, it can be stated that there is a difference in the two means.

This statistical analysis shows that the proposed layout chlorine car throughput is significantly greater than that of the current layout chlorine car throughput.

CONCLUSION

There are many benefits associated with implementing the proposed layout versus the current layout. Currently, the cars in the blowdown stations are traveling in a reverse movement when they exit to go to the queue for the loading stations. This creates a higher travel time from the blowdown stations to the loading station queue. Any transportation time is non-value added time. Therefore, transportation times should always be reduced if feasible. In addition, in the current layout, there are 20 blowdown stations. The proposed layout has 24 stations. This results in four additional railcars being blowdown at any particular time. If one or multiple stations break down, then the additional stations will also prove valuable. The proposed layout has 6 stations. This results in two additional railcars being washed out at a specific time. If a washout station breaks down, then, additional stations will prove valuable exactly like the blowdown stations. Chlorine car throughput went from a daily average of 19.65-23.85 cars, which is an average of 4.2 additional cars per day. Annually, the company will increase their chlorine car throughput from 7,172.25 cars per day to 8,705.25 cars. The company is currently turning away business because they cannot meet the demand. An increase in 1533 loaded and shipped chlorine cars would enable it to undertake some of the business they are currently turning away. This results in a higher customer satisfaction and ultimately, an increase in profits.

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