# Security Check: A Battle of Queuing

Guorong Wang

Institute of electric power engineering, North China Electric Power University, Baoding, China

973938536@qq.com

## Abstract

**As plane has become an indispensable transportation, any trouble that happens in airport may result in economic loss and citizen's complaint. In order to guarantee the optimization of airports' throughput, security of airlines and the optimization of airport service, we optimize security check process and arrangement. Based on our models, we provide several feasible recommendations.**

## Keywords

**Queuing theory,model,modification,suggestionn.**

## 1. Introduction

Screening passengers and their baggage at security checkpoint in airports is an indispensable process to guarantee the safety of all the passengers in a flight. However, extremely lone lines to checkpoints have been suffering huge criticism for its tediously long waiting time and great chances of resulting in passengers' missing flights.

Mr. Johnson, the minister of Transportation Security Administration, claim in a press conference that during summer in 2016, 98% of passengers wait for security check less than 30 minutes, 92% passengers wait for less than 15 minutes, and 7 busiest airports in the US have an average waiting time for less than 10 minutes. However, rigor of security check, increasing number of passengers and limited number of staff serve as main factors that constraint the speed of entering the inner-airport.

In order to make this poor situation better, we should find the bottleneck in current process and establish a model with the aim of increasing checkpoint throughput and reduce variance in wait time.

In the present situation, one is required to get through the security check by following these steps:

Arrive at checkpoint and wait in queue---Get his identification and boarding documents checked---Put belongings on X-Ray machines to get checked---Himself go through either a millimeter scanner or a metal detector---Finish his trip to checkpoint.

We decompose the problem into several steps:

Make use of the given data to set up the fundamental model

Use the model to explore and simulate passengers' flow and identify where the bottleneck is in the current process.

After finding out where the problem place is, set up the second model to give suggestion on modification.

Modify the current process to get a larger checkpoint throughput and a smaller wait time variance. After modifying, we model it to examine if the modification has impacted the passengers' flow and waiting time variance in a positive way

Take cultural difference into consideration and quantize it into computable statistics. Model the norm and its impact on waiting time.

## 2. Terminology and Definition

Table 1. Terms and symbols

| Symbols | Definition |
|---|---|
| $L_s$ | Numbers of passengers queuing for security check |
| $L_q$ | Numbers of passengers waiting for the service |
| $\lambda$ | Average numbers of arrived passengers in unit time |
| $\mu$ | Numbers of passengers who can be fully served in unit time |
| $W_s$ | The expectation of time of passengers staying in queuing system |
| $W_q$ | The expectation of time waiting in lines |
| $\rho$ | Service intensity of the checkpoint |
| $P_0$ | Odds that nobody is waiting in the line |
| $p_{ni}$ | The absolute probability when there are n passengers in the system and the passenger being served is at phase i |

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Among these terms, the units of time items are all second.

## 3. Basic Assumptions

All the passengers have already checked in, waiting for security check.

Passengers carry small-sized baggage which aren’t required to be checked.

Airline-prohibited items are placed in small-sized baggage.

There are some suspicious items with the passengers.

Each security checking staff has the same working efficiency.

Security checking machines are working in normal condition and won't break down.

Passengers arrive at the terminal on time and would board directly after the security check.

## 4. Models

### 4.1 Analysis of Task 1

In order to explore the passengers' flow using the statistics of security checkpoint, we include queuing theory to estimate the passengers flow.[1]

With the target of identifying bottleneck and problems in the process, we model the queuing in security checkpoints referring the queuing theory. And based on the data given, we find out the point where passengers' stranding is severe (the bottleneck), which leads to the breakthrough point of optimizing security check system.

Basically, queuing is comprised of people's entry, rules of queuing and serving.

4.1.1 People's Entry

Assuming passengers arrive at the checkpoint at every period with the same odds, and analyzing from the given data, we can get these conclusion:

i. The arrival numbers of passengers in non-overlapping intervals are independent.

ii. For $\Delta t$ which is sufficiently small, the odds of the arrival of one passengers in interval $[t, t+\Delta t]$ is irrelevant to t, but proportional to $\Delta t$, the length of intervals.

iii. For $\Delta t$ which is sufficiently small, the odds of two or more passengers arrive during time period $[t, t+\Delta t]$ are small enough to be neglected.

We assume the arrivals to checkpoint of passengers obey the Poisson distribution and the intervals of arrivals obey the Negative Exponent Distribution. The intervals of arrival correspond with Figure1.

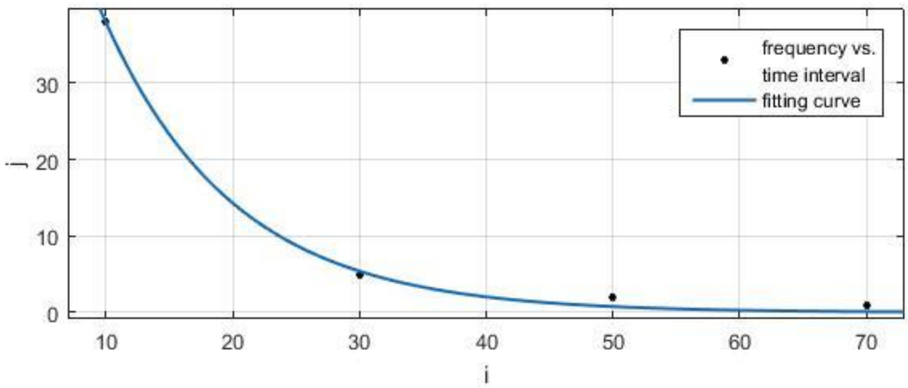


Figure 1. The negative exponential distribution figure of the intervals of arrival

Rules of Queuing

Passengers would keep queuing for security check and follow the rules of waiting, as there is no reduction of passengers in waiting for security check.

4.1.2 Serving

With limited facilities and staff, some checking projects like millimeter wave scan are single server system (M/M/1), other checking projects like ID check and X-Ray screening are multiple server system (M/M/s).[2]

Single Server System (M/M/1)

According to the M/M/1 model, we have the following formulas:

$$L_s = \frac{\lambda}{(\mu - \lambda)}$$

$$L_q = \frac{\lambda^2}{\mu(\mu-\lambda)}$$

$$W_s = \frac{1}{(\mu-\lambda)}$$

$$W_q = \frac{\lambda}{\mu(\mu-\lambda)}$$

Average serving time of one customer $t = \frac{\sum n \times t_n}{n}$

Average serving rate $\mu = \frac{1}{t}$

Average number of arrived passengers in unit time $\lambda = \frac{N}{t}$

Multiple Server System (M/M/s)

$$\rho = \frac{\lambda}{\mu}$$

$$\rho_s = \frac{\rho}{s} = \frac{\lambda}{s\mu}$$

$$p_0 = \left[\sum_{n=0}^{s-1} \frac{\rho^n}{n!} + \frac{\rho^s}{s!\quad(1-\rho_s)}\right]^{-1}$$

$$L_q = \frac{p_0 \rho^s}{s!} \sum_{n=s}^{\infty} (n-s) \rho_s^{n-s}$$

$$L_s = L_q + \rho$$

$$W_s = \frac{L_s}{\lambda}$$

$$W_q = \frac{Lq}{\lambda}$$

In our problem, we discuss the situation when **s**=2. Because one may enter 1of 2 ID check desk.

### 4.2 Analysis of Task 2

In our process of exploring bottleneck, we partition the process in checkpoint and analyze it by sector. The way we analyze the security check in the way of seeing it as a combination of different small check points is called the Analysis of Erlang Queuing Model.

4.2.1 Detailed method

On the basis that **k**-order Erlang Distribution is the sum up of **k** same negative exponential distributions, we can assume the serving time and arrival of passengers to be **k** independent identically distributed phases and process. Including the property of negative exponential distribution into analysis, we divide the interval of passengers arriving at the system into **r** mutually independent phase $t_i$ with the same negative exponential distribution .Let E ($t_i$) =1/r $\lambda$ , 1≤**i**≤**r**. In this way, every passenger has to go through **r** phases to enter the system.

Assuming that **n** passengers are already in the terminal (in other words, passengers have already passed nr phases), if **n+1** passengers has passed **j**=**nr**+**i-1** phases, we may apply it in describing the condition of a system. Such a system forms a homogeneous Markov Chain ({Xn, **n**≥0}).

Let its absolute probability $p_j$ = P (Xn=j) = P (phases that already be passed in the system).

We assume that there are n passengers in the system.

Possible phases before the **(n+1)**th passenger enter the system is $t_1, t_2, \dots, t_r$ .Thusly, the stationary distribution of passengers' should be the underneath figure 2.

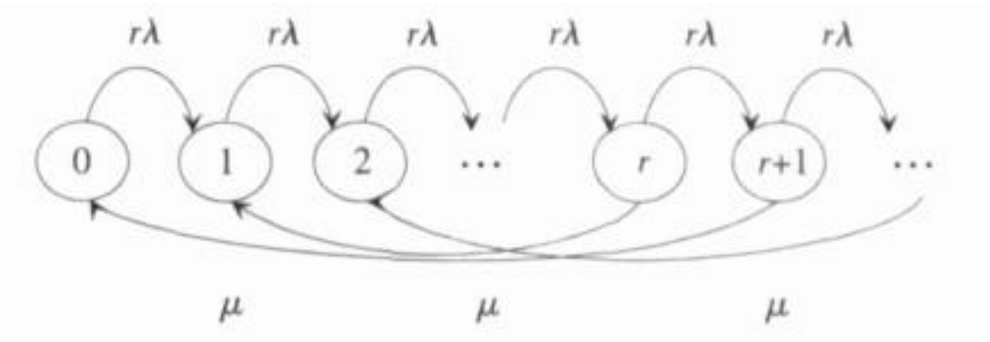


Figure 2. Stationary distribution of passengers

4.2.2 Models in Task

For the reason that passengers may be in different phases, we use (**n**, **i**) to state the condition of current condition of the system. In it, **i** stands for that passenger is being served in the **i**th phases. From the analysis we know that $p_{ni} = P\{N = (n,i)\}$, so these differential equations of the following states can be written:

0 $\mu_1 p_1 = \lambda_0 p_0$

1 $\lambda_0 p_0 + \mu_2 p_2 = (\lambda_1 + \mu_1) p_1$

2 $\lambda_1 p_1 + \mu_3 p_3 = (\lambda_2 + \mu_2) p_2$

… …

n $\lambda_{n-1} p_{n-1} + \mu_{n+1} p_{n+1} = (\lambda_n + \mu_n) p_n$

… …

Computing using the above-mentioned equations, we get the various indexes in the stationary distribution.

Finally, we come up with the distribution function $\mathrm{p}(t)=\frac{\mu k(\mu kt)^{k-1}}{(k-1)!}e^{-\mu kt},t\geq 0$

Thus, the mean value of serving time is $E(\mathrm{x})=\frac{1}{\mu}$, and the variance $D(\mathrm{x})=\frac{1}{\mathrm{k}\mu^2}$.

We can see from the result that when $\mu$ increase, the mean of serving time decrease, meaning that passengers' throughput increase when passengers' flow stay the same.

Meanwhile, when $\mu$ increase, with **k**'s value fixed, the variance of serving time would decline, which meets our target of reducing time difference in serving.

In summary, such modification achieve the aim of increasing passengers' throughput and reduce variance of waiting time. Our model have made positive impact to the current process and meet the demand of optimizing the current time-costing security check procedures.

However, there's still problems to be discussed:

1. How exactly to increase $\mu$'s value?

2. Would the modification unexpectedly influence the current cooperation of every sectors?

Here we offer some feasible options to meet the demand:

Examine passengers in groups

From the first model, we learn that lots of time is wasted in waiting to be served. We can easily conclude that low efficiency work happens in the intervals of serving for different individuals. [3]In another words, when an officer of TSA switch his checking target from the nth person to the n+1th person, there exists time loss.

From our computation in model 1, 9 out of 10 passengers are waiting to be checked and 121.05 seconds out of 132.63 seconds are spent in waiting for checking.

When it comes to solution, we let every 10 people be a group to be checked. In this way, we can save 10 seconds for each group of 10 passengers.

Set a 'Pre-bag and person-check' figure sign

We can include signs to improve the efficiency of putting bags onto X-Ray scanner. The signs should contain information of what needs to be taken out and reminder that they should take out items in advance to save time for himself and others

When the new influence is under discussion, the negative influence gathering groups brings us is hard to measure and quantize. But on the contrary, setting up signs would only bring positive impact on increasing $\mu$ and reducing waiting time variance. In addition, it is much more time-saving than setting up literal signs or giving reminder by officers, as figure sign is more direct than literal version and do not require labor doing this kind of tedious, trivial intervals.

4.3.1 Cultural Norms

Obviously, cultural norms of various countries have various way to impact security check's process. For instance, Americans lay great emphasis on individual's privacy and personal space, which may be likely to result in the slowness in baggage checking. Chinese are known for prioritizing individual efficiency and taking great care of the vulnerable group. In our model, we would take Chinese's tendency to give way to vulnerable groups into account and compare it to American ones.

Vulnerable groups consist of the old, the weak, the sick, the disadvantaged and the pregnant. People who are defined as the label above may go through security checkpoint at a relatively low pace. Consequently, setting up green access particularly for the vulnerable group in China would be great ideas to speed up and obey moral principle of Chinese.

4.3.1.1 Green Access

According to data on Wikipedia [4], throughput of Chicago O'Hare International Airport per year is 89,938,628 people in 2015. So passengers' flow per day is approximately 200,000. To simplify the model, we assume there's 100 passengers per minute (200,000 passengers equally allocated in 1,440 minutes). Assuming the vulnerable group take up 20% of the whole passengers, and 2 green access is opened for every 3 ordinary access, here's the analysis:

Assume serving time obey negative exponential distribution and parameter $\mu$ =1. We use Matlab to generate 100 random digits

Among them, we need to pick out $X_i$ , the time it takes for the one person of the vulnerable group.

After the expectation for $X_i$ ,E(X), be figured out, we can make conclusion based on the result and evaluate the benefits of adopting green access.

4.3.2 Travelers Styles

In the whole process of security check, the behavior of checking require passengers' enrollment in the entire checking. Passengers who travel in a particular style may have distinctive features passing checkpoint, causing notable fluctuation in waiting time. What's more, passengers' experience of taking flights would indispensably impact the time it costs to get through checkpoint.

4.3.2.1 Different Travelling styles

During the time we gathering airport throughput data, we found a significant difference between different types of travelers. [5] These styles fall into 3 sorts:

1. Experienced passengers. Such sort of passengers take up 60% of all passengers. They are familiar with what they are supposed to do on entering a flight. They don't need to consult officers for information. They would not carry forbidden items with them. They spend least time in these 3 types but have stringent requirement for checking time.

2. Normal passengers. This sort of passengers take planes sometimes. They know some of the rules of airlines but sometimes need reminders from checkpoint staff. They would take a lot of belongings with them. Most of them are students and visitors. Usually there's no forbidden items in their baggage.

3. First-time passengers. This sort of passengers have never taken a flight. They know little about airlines' rules. They frequently turn to staff and other passengers for help. Their consult take up most of staff's answering time. They would take food and daily necessities with them. There are lots of forbidden items in their baggage including liquid and controlled knives.

4.3.2.2 Classify by Size of Belongings

After evaluating behaviors of passengers, we conclude that the fluctuation of passengers' waiting time is mainly arisen by process to check belongings (aka F4, F7 and F9) (see **figure 3**). In the meantime, that passengers are carrying different amount of belongings would influence others. We plan to modify the steps of baggage checking to increase throughput and reduce variance. Considering the otherness of 3 types of traveler, our group adopt the method of classification inspection to reach optimization.

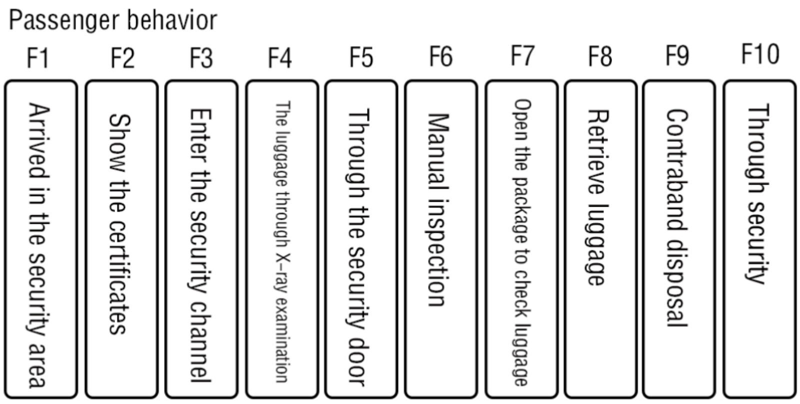


Figure 3. Passengers' behavior through getting security check

We set up baggage checkpoint in different size. So that in the process of baggage checking, passengers carrying different amount of baggage should go to the corresponding baggage entry.

People carrying lots of baggage should enter entry O1. These people are mostly first-time passengers and normal passengers. People carrying relatively less items should enter entry O2. These people are mostly experienced passengers.

Considering that most of the passengers have insufficient knowledge about security check's requirement, there should be a couple of access in O1 entry. Meanwhile, to reduce staying time in queues, arrange guidance officers in O1 entry to give reminder to passengers. Otherwise they might congest and waste time because of their lack of knowledge of requirements.

In O2 entry, knowing that they are carrying less luggage, we can reduce the amount of entries and allocate some entries to O1, relieving the pressure of entry 1. At the same time, we can arrange less officers in entry one.

Distributing limited resources to optimize entries with low speed of checking, we successfully increase passengers' flow and reduce waiting variance. Achieving these targets, we improve the customers' satisfaction index.

## 5. Simulations

Task 1: Exploring passengers flow and determine the bottleneck of current process

Passengers spend time in queuing in lines, getting through fundamental security process, and spend time on unexpected waiting time during check. In our model for passengers flow, we came out with the following statistics:

During ID check

$\mu$=0.174, $\lambda$=0.07886, $\rho$=0.453, $\rho_s$=0.2266, $P_0$=0.6306, $L_q$=0.0245, $L_s$=0.4775,

$W_s$=6.06, $W_q$=0.31

During individual and belonging check

$\mu$=0.0864, $\lambda$=0.07886, $L_s$=10.46, $L_q$=9.55, $W_s$=132.63, $W_q$=121.05

From the computed statistic, we can see that during ID check, approximately no one is waiting in queue or waiting to be served. Expectations for staying time and waiting time are 6.06 seconds and 0.31 seconds.

During individual check and belonging check, there are 10.45 people waiting in queue, 9.55 people waiting to be served. Expectations for staying time and waiting time are 132.63 seconds and 121.05 seconds.

Thusly, we can easily see the fact after checking ID, things start to go slow and more people have to wait for checking procedure, very different from what happens during ID check. This leads to the bottleneck of current process: excessively lone time it takes in process of checking individuals and belongings.

Task 2: Modify current process to improve throughput and reduce variance

In the model we build in the above of our paper, we conclude that through increasing $\mu$ (the numbers of passengers who can be fully served in unit time), airport can make passengers flow quicker and reduce the variance of waiting time.

Thusly, all we have to do is to improve the service efficiency of the staff working at the X-ray scanner and millimeter scan machine.

From the model analysis part, we have already advised two possible solutions. And both of the two solutions can serve as feasible modification to reduce variance and increase throughput.

Task 3: Security check considering cultural norms and travelling styles

1.

Assume serving time obey negative exponential distribution and parameter $\mu$=1. We use Matlab to generate 100 random digits as follows:

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2.6388 | 0.4323 | 0.2189 | 0.0161 | 0.3040 | 0.6178 | 0.4017 | 0.8480 | 1.3270 | 1.3443 |
| 0.6508 | 0.2227 | 2.8056 | 1.7888 | 1.3126 | 0.3594 | 1.6585 | 0.7298 | 0.1931 | 0.5203 |
| 2.3358 | 0.7901 | 0.9181 | 2.2423 | 0.8608 | 0.4057 | 0.9972 | 2.1152 | 0.0175 | 3.7937 |
| 0.2007 | 0.8384 | 0.6408 | 0.9878 | 0.6017 | 1.7252 | 0.7750 | 0.5285 | 0.3144 | 0.8551 |
| 0.2014 | 0.1920 | 0.8752 | 1.6189 | 0.0590 | 2.0556 | 0.0185 | 1.4864 | 1.0675 | 1.1625 |
| 0.3251 | 2.4833 | 0.4203 | 0.7140 | 0.8729 | 0.0009 | 1.8553 | 0.9555 | 0.5377 | 1.8233 |
| 1.8980 | 2.0161 | 0.4653 | 1.0803 | 0.0171 | 1.7654 | 0.1560 | 0.5396 | 2.2278 | 1.7217 |
| 0.4161 | 1.7522 | 1.2311 | 0.0496 | 1.1991 | 3.4234 | 0.4389 | 1.3791 | 0.0984 | 0.8607 |
| 0.6566 | 0.9392 | 0.8401 | 0.0830 | 0.3551 | 0.5777 | 0.9774 | 1.2364 | 0.1282 | 2.3620 |
| 0.0274 | 0.1847 | 4.1677 | 2.9436 | 0.4059 | 0.1257 | 1.6559 | 0.4827 | 0.2012 | 0.5133 |

Among them, $X_i$ ,the time it takes for the vulnerable group to go through checkpoint is listed:

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 2.6388 | 2.8056 | 1.7888 | 1.6585 | 2.3358 | 2.2423 | 3.7937 | 2.0556 | 1.4864 | 2.4833 |
| 1.8553 | 1.8980 | 1.7654 | 1.7522 | 3.4234 | 1.3791 | 1.2364 | 2.3620 | 4.1677 | 2.9436 |

The result of numeral computation: expectation for $X_i$ is E(X)=2.3

For the green access, passing time for an individual is 22 minutes. For the normal access, passing time for individual is 17 minutes.

If there're only normal entries and one would randomly enter one of the entries, the time it takes for one to go through the checkpoint is 20 minutes. We can learn that queuing time for normal passengers is reduced by setting up green entries. It is beneficial for reducing serving time and accelerate the flow of normal passengers in a way. However it enlarge the gap between the two of them. Viewing from the general serving time, setting up green access save 6 minutes.

2.

In our demonstration in the Model section, we provide with the solution of classifying entries by the size of passengers' belongings. By arranging passengers by their property, we successfully increase passengers' throughput and reduce variance of waiting time. The delightful result attribute to the distribution of limited resources.

Task 4: Policy and procedural recommendations proposal

After computing on our model and doing analysis by gathering data, we discover that the main problem of security check in airports shows up in the checking steps. Under the premise of safety, the major problem to be solved is how to reduce the time and variance of queuing. Confronted with this, our group provide some general suggestion:

1. Arrange luggage and human check properly. Deal with people carrying forbidden items in appropriate way. Avoid slowing down the whole passengers' flow because of the stagnation caused by the problem of a specific person.

2. Open special entries when facing different people. You should not neglect the needs of individuals.

3. Reasonably adopt new technology, e.g. face recognition and the use of explosion-proof dogs. Try your best to strengthen security check efforts as well as increase security check efficiency.

These suggestions make great difference in a culture where people care about themselves and respect others, as well as saving time for both individual and collective efficiency.

## 6. Strengths and Weaknesses

Strengths

The model simulate the current situation using several simple formulas and can function as a computing model which can provide time the security check needs when given different data. Meanwhile, using exact numbers and error-less formulas, the outcome is precise and persuasive.

In our first and second model, we adopt classical theories from the Queuing Theory, Erlang Queuing Model and Homogeneous Markov Chain. They can all be easily understood and at the same time, provide rigorous and feasible functions for this problem.

Weaknesses

Although our model has nice statistical properties, it is highly related to statistics. Once the statistics become unclear or uneasy to access, our model would fail in producing help.

Besides, some of our measures are based on unrealistic foundations. For example, our assumption that each security checkpoint officers have the same working efficiency is not practical. In reality life, there would be larger variance in the airport.

Some of our solutions are lack of statistics support, so that they are persuasive enough anyway.

## 7. Conclusion and Future Works

From the above models we constructed, we learn clearly about how passengers' flow is affected by various sectors at the checkpoint. We find, as expected, the bottleneck of current process and provide several plausible modifications to increase throughput.

Moreover, we not only advice on modifying current security check system, but also offer possible plan of improving security check process based on cultural difference.

Although our work simulate the process of passengers getting through security check, it didn't grasp in the real manner of getting through TSA checkpoint. A lot of further researches must be taken into consideration. These researches need to take social and detailed cultural impacts into account. What's more, works on improving functions of machines are of vital significance. There would be inevitable influence from the inconsistent working efficiency between different officers and machines and from chances of accidents. Last but not least, the quantization of cultural impact require more professional research and conclusion.

Consequently, a great improvement has been achieved in understanding the behavior of such a simple structure as a checkpoint system. Most of the initial objectives were met and developed into more complex objectives that require a detail analysis regarding this structure.

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