

EVALUATING THE ECONOMIC IMPACT OF DEMAND, SUPPLY AND PROCESS UNCERTAINTY IN A RETAIL SUPPLY CHAIN

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Received: May 31, 2010; Revised: Aug 20, 2010; Accepted: Aug 26, 2010

Abstract

The aim of this paper is to examine the relationship between the uncertainty in both demand and supply sides, and economic impact, in a retail supply chain. These uncertainties increase the risk within the chains, and risk is a consequence of the external and internal uncertainties that affect a supply chain. A case of a retailer that is not aware of information inaccuracy as well as inventory error, or chooses to ignore them in order to evaluate the efficiency loss due to errors compared with an error free situation was analyzed. This inaccuracy is caused by the uncertainty of customer demand, supplier delivery lead time and shipment quantity. The results indicate that the elimination of uncertainty can reduce supply chain costs and hence, increase profit.

Keywords: Uncertainty, economic impact, retail supply chain, information inaccuracy

Introduction

The competition to achieve high customer service levels at minimal cost has placed a strong emphasis on control of information and material flows in today's manufacturing and retail environments. Most companies have made substantial investments in innovation systems enabling them to improve the level of accuracy of their supply chain records and inventory data. Although introduction of these systems replaces the manual inventory data keypunching processes, which significantly reduce inventory inaccuracies, the existence of errors polluting inventory data records is still a quite commonly observed issue in

practice (Sahin and Dallery, 2009). DeHoratious and Raman (2004) reported inaccuracies of 65% in the nearly 370,000 inventory records observed across 37 retail stores of two leading retailers in France. They identified several reasons for the inaccuracies and uncertainties in their operations, including replenishment errors, employee theft, customer shoplifting, improper handling of damaged merchandise, imperfect inventory audits, and incorrect recording of sales. Gentry (2005) also reported a discrepancy between recorded and actual inventory, amounting to \$142 million at "the Limited", a well-known apparel retailer.

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Uncertainties in parameters in supply chain management and control problems have been treated as stochastic processes and described by probability distributions. These uncertainties created by inventory inaccuracy have become topical issues of interest amongst academics and practitioners in the last few years. The adoption of supply chain management principles by many organizations has resulted in more networked, highly dependent organizations. While this has obvious operational benefits that have been recognized in the literature, it has, at the same time, resulted in increased vulnerabilities of supply chains. Supply chains are vulnerable to risks that arise from problems in coordinating supply and demand (Klenindorfer and Saad, 2005).

Treating uncertainty is an important issue in supply chain modeling and analysis of supply chain behaviour and performance (Petrovic, 2001). Different sources of uncertainty in a supply chain can exist, encompassing suppliers, production processes and customers. Davis (1993) also identified three distinct sources of uncertainty in supply chains—supply uncertainty, process uncertainty, and demand uncertainty. Supply uncertainty is caused by the variability of supplier performance due to late or defective deliveries. Process uncertainty results from the unreliability of the production process due to machine breakdowns. Finally, demand uncertainty, which according to Davis (1993) is the most serious of the three, arises from volatile demand or inaccurate forecasts. In fact, these uncertainties may be different in nature, caused by random events, imprecision in judgment, lack of evidence available, or lack of certainty in evidence.

Yucesan and De Groote (2000) performed a survey in supply planning under uncertainties, but they focus on the impact of the production management under uncertainty on the lead times by observing the service level. Process uncertainties are also considered by Koh *et al.* (2002) and Koh and Saad (2003). To avoid these uncertainties, the companies use safety stocks which are rather expensive.

When there is uncertainty, the companies may be more willing to reserve future supplier capacity in advance and thus guarantee the availability of the input. Disruptions in supply inflows may adversely affect profitability through an increase in lost sales of the goods. So, the problem is to control inventories and to avoid stockout while maintaining a high level of service. Thus, efficient supply planning methods to order the correct quantity of goods at the right amount and time should be developed.

In this paper, a case of having uncertainty on inventory in a retail supply chain is studied. This is to gain a better understanding of the retail supply chain dynamic behaviour and performance in the presence of various sources and types of uncertainty. The paper is organized in the following way. The next section describes the simulation optimization. Description of the retailer modeling and simulation is then given in Section 3, including basic assumptions, shop configuration, simulation model experiment, retail supply chain performance measures, and experimental conditions. Section 4 presents the results under the base case and other cases under each type of uncertainty, and finally the conclusion is made.

Simulation Optimization

Simulation optimization is defined as the process of finding the values for the input variables such that an expected system performance from stochastic simulation is optimized (Fu, 2002; Swisher *et al.*, 2000). In simulation based optimization, one or more discrete-event simulation models replace the analytical objective functions and constraints in traditional optimization problems. The decision variables are the input variables used to run the simulation model, and the performance measures are the responses generated from the simulation model. Some popular approaches for solving the single objective problems (Azadivar and Tompkins, 1999) include:

- gradient-based search methods

- stochastic approximation methods
- sample path optimization
- response surface methods
- meta-heuristic search methods.

In this study, the simulation and optimization procedure are completed using ARENA commercial software and OptQuest tool, respectively. For analyzing complex systems such as this case, the objective functions are not expressed as explicit functions of the input parameters; rather they normally involve some performance measures of the system whose accurate values can be found only by running the simulation model. OptQuest tool incorporates a combination of three meta-heuristics (Glover *et al.*, 1999): scatter search (SS), tabu search (TS), and neural networks (NN). It is provided with ARENA. Like all practical simulation optimization methods, OptQuest is also an iterative heuristic. It requires the specification of lower, suggested and upper values for the variables that are to be optimized. Moreover, it requires the selection of the (random) simulation output that is the goal or objective variable to be maximized. In this problem, the maximization of the shop's profit as objective by OptQuest has been selected. OptQuest allows the user to explicitly define integer and linear constraints on the deterministic simulation inputs. Here, any constraints on the decision variables are not specified.

Retailer Modeling and Simulation

Basic Assumption

The attention is focused on a retail supply chain, including suppliers, a retail shop and end customers. Assumptions concerning shop operations and control are the following:

- The inventory of each product in the shop is controlled based on a periodic review policy. The inventory stock is set up periodically to a certain level as optimized by OptQuest.
- End customer demand is fulfilled from the shop's inventory. When demand exceeds the end product stock, unmet demand

is considered to be shortages.

- The raw material inventory is supplied from external suppliers.

- Replenishment quantities for each inventory are received with a given, planned lead time. The lead time includes the time necessary for order processing, the production time and/or transportation time.

- The base case is the case that there is no uncertainty in the demand, supply and processes.

Shop Configuration

In the base case, a customer randomly comes in the shop with a mean inter-arrival time of 25 minutes under exponential distribution. Each customer has a chance to buy more than one product (maximum 3 products) with different probabilities. The probabilities to buy products are different as they are classified to have low, medium and high potential demand products. If these customers cannot find their desired products, it will be recorded as lost sales and hence the penalty cost incurs. The shop uses the periodic review, with order up to the target stock level (T, OptS) policy. OptQuest is used to find the optimal OptS of each product in the shop. The retailer makes orders to its suppliers every week and the ordered products will arrive in 2 days. The suppliers are considered as external members who have unlimited production capacity. However, because of the uncertain factors within their delivery lead times and product supply, suppliers may not be able to supply products to the shop correctly and punctually. In addition, the customer demand is also uncertain so the shop could experience some shortages of desired products from its customers. As a pilot case, it is assumed that there are twenty products in the shop. These products are varied in price ranging from 20-120 Baht. The shop's policy is to mark-up the profit 30% from the unit cost, and the lost sales cost is marked up to 120% from its price.

Simulation Model Experiment

The length of each simulation run is set

to be 1 month, which consists of 4 weeks/month, 7 days/week, 24 hours/day, for a total of 40,320 minutes. For each run, 12 independent replications are completed. Based on 12 replications, a 95% confidence interval for the interested observation (customer flow time) has a width of less than 5% of the point estimate for this value. In the simulation model, since it is a popular and useful variance reduction technique to compare two or more alternative configurations, the common random number (CRN) variance reduction technique is used. And because a steady state analysis is needed to analyze a long time period, the warm-up period is decided to be 10,880 minutes or one week (Kleijnen, 1987).

Retail Supply Chain Performance Measures

Performance measures are used in supply chain management to determine the efficiency or effectiveness of a given supply chain. To determine supply chain performance, a number of performance measures are used, such as customer lead time, service level, or other financial measures. In this study, a financial measure, which is the retail shop profit, is used. This profit can be formulated as follows:

Let

i = product index, $i = 1, 2, 3, \dots, 20$

therefore, the objective function can be determined as:

Maximize Profit = Revenue – Total Relevant Costs (1)

$$\text{Revenue} = \sum_i^{20} n_i p_i \quad (2)$$

$$\text{Total relevant costs} = \sum_i^{20} (H_i + L_i + O_i + M_i) \quad (3)$$

where:

n_i = Number of units sold (Baht)
 p_i = Selling price per unit of product i (Baht)

H_i = Holding cost of product i (Baht)
 L_i = Lost sales cost of product i (Baht)
 O_i = Ordering cost of product i (Baht)
 M_i = Material cost of product i (Baht)

Holding Cost

The quantity of products that is delivered to the shop will be kept in the shop until it is sold. Thus, the holding cost charged to each item is based on the quantity and duration.

$$H_i = \frac{QT_i}{T} \times UC_i \times C_{th} \quad (4)$$

where:

QT_i = Holding time of product i in the shop (minutes)
 T = Replication length (minutes)
 UC_i = Unit cost of product i (Baht)
 C_{th} = Cost of capital due to part holding (percentage of unit cost per unit time (i.e., per replicating length))

Lost Sales Cost

There will be a lost sales cost for any lost sales item.

$$L_i = LS_i \times S_i \quad (5)$$

where:

LS_i = Lost sales cost per unit of product i (Baht)
 S_i = Number of lost sales units of product i (units)

Ordering cost

The ordering cost is calculated based on the truck load (30 units per each stock keeping unit (SKU). If ordering size is greater than 30 units, the ordering cost will increase in a multiple batch of 30 units (truck load).

$$O_i = RB_i \times OS_i \quad (6)$$

where:

BR_i = Number of ordering batches of product i (units)
 OS_i = Ordering cost per batch of product i (Baht)

Raw Material Cost

This raw material cost is the cost of goods sold, which is calculated from the number of units sold multiplied by their unit costs.

$$M_i = N_i \times UC_i \quad (7)$$

where:

N_i = Number of units sold of product i (units)

UC_i = Unit cost of product i (Baht)

The following cost structure is used throughout the study.

Unit cost (UC_i)	15-90 Baht/unit
Unit selling price (p_i)	20-120 Baht/unit
Cost of capital due to part holding (C_{ih})	50% of unit cost/month
Lost sales cost (LS_i)	120% of unit cost/unit
Ordering cost (OS_i)	35 Baht/batch

demand uncertainty is represented by the uncertainty of customer demand (customer inter-arrival time). When this inter-arrival time is reduced, more customers will come to the shop and vice versa. Finally, the process uncertainty is represented by the uncertainty in number of delivery units to the shop (missed quantity). The missed quantity is inherent to the current process of physically handling the product (i.e., receiving, storing, picking, and shipping). In all three types of uncertainty, six levels of variation from $\pm 10\%$, $\pm 20\%$ and $\pm 30\%$, varied from their pre-determined values from the base case, were tested. For example, if the lead time is studied with the uncertainty of $+10\%$ from the base case, there is a chance that the delivery lead time could be longer, uniformly varying from 2 days (2880 min) to 2.2 days (3168 min) if the uncertainty is set to -10% , the delivery lead time could be shorter, uniformly varying from 1.8 days (2592 min) to 2 days (2880 min).

Experimental Conditions

In this study, the supply uncertainty is represented by the uncertainty of delivery lead time. The uncertain lead time implies that the materials being ordered are meant to arrive, not on time. They could arrive earlier or later than their promised date. Future shop demands will also have their own uncertainties. This

Results

Table 1 shows the average revenue, costs and profit per month from the base case where there is no uncertainty in the model in which the retail shop makes a profit of around 37405 Baht per month. Table 2 presents the optimized target stock levels (OptS) from all twenty products as generated by OptQuest.

Table 1. Monthly revenue, costs and profit

Average monthly results	Base case
Revenue (Baht)	275,459.12
Related cost	
- Holding cost (Baht)	19,320.44
- Lost sales cost (Baht)	6,049.00
- Ordering cost (Baht)	6,090.00
- Material cost (Baht)	206,594.34
Total costs (Baht)	238,053.78
Profit = Revenue – Costs (Baht)	37,405.34

Considering the supply, demand and process uncertainty, Tables 3-5 and Figures 1-3 represent the effect of this variation on the shop's revenue, related costs and profit from the supply, demand and process uncertainties. According to Table 3 and Figure 1, it was found that the supply uncertainty (lead time variation) shows the least significance to the retail supply chain, as compared to the other two uncertainties. When the lead time is shorter, it would benefit the shop by

significantly reducing the lost sales cost, but marginally increasing the holding cost. This variation in lead time, at the end, could affect the shop's profit by increasing its profit up around 7%. In addition, it was also found that the reduction in the lead time would have a higher impact on the shop than an increase in the lead time, at the same level of lead time variation. And if the lead time increases to 30%, it still shows a marginal effect on the shop's profit (less than 1.5% of its profit's

Table 2. Optimized target stock level as recommended by OptQuest

Product #	OptS (rounding to a multiple batch of five units)
1	95
2	95
3	95
4	95
5	60
6	60
7	155
8	60
9	60
10	155
11	60
12	155
13	95
14	60
15	60
16	155
17	155
18	60
19	60
20	60

reduction).

Demand uncertainty shows the most significant impact, as compared to the other two uncertainties (Table 4 and Figure 2). The result shows that either increase or decrease of the demand results in reduced profit of the shop. Again, an increase in the customers' demand (reduction of the inter-arrival time of customers) causes a more severe effect than the reduction of the demand. The profit could be reduced up to 125% when the rate of customers' arrival increases by 30%. This eventually results in profit loss for the retail shop. Basically when the demand increases without prior notice to the shop, the lost sales will sharply increase, and this significantly jeopardizes the financial status of the shop. Other costs seem to have less significance, as compared to the large increase of the lost sales cost.

Process uncertainty also shows some effects on the retail shop. This uncertainty is caused by an error in the shop's inventory and tracking system. The inventory inaccuracy could stem from defective delivery, loss during the delivery, theft or a missed shelf in the shop, etc. According to Table 5 and Figure 3, the result shows that the reduction of the number of delivery units to the shop causes a more significant effect than an increase in the number. When the number of delivery units is higher than expected, it causes only a marginal increase in the profit (only up to 2%) as the lost sales slightly reduce, while the holding cost slightly increases. However, if the number of delivery units to the shop is lower than expected, the lost sales would quickly jump up, and result in a huge reduction of the retail shop's profit.

Analysis of Variance (ANOVA) under the variance component model is also used to analyze an individual effect of the variance of uncertainties on interested costs and profit variation. Table 6 shows ANOVA results of these percentage variations. The percentage variation is calculated as follows:

$$\% \text{ variation} = \frac{\sigma_{\text{factor}}}{\sigma_{\text{Total}}} \times 100\% = \frac{\sigma_{\text{factor}}}{(\sigma_{\text{factor}} + \sigma_{\text{error}})} \times 100\% \quad (8)$$

Table 3. Monthly performance of supply uncertainty (delivery lead time) and the percentage difference, as compared to the base case

Uncertainty	% Variation	Revenue	Material Cost	Holding Cost (HC)	Lost Sales Cost	Ordering Cost	Monthly Profit	% HC Change	% Lost Sales Change	% Ordering Cost Change	% Profit Change
Supply (lead time)	-30 %	280,326.87	210,245.15	20,142.42	3,704.01	6,195	40,040.29	4.25	-38.77	1.72	7.04
	-20 %	279,264.00	209,448.00	19,812.89	4,743.20	6,195	39,064.91	2.55	-21.59	1.72	4.44
	-10 %	278,798.15	209,098.61	19,466.98	6,283.39	6,195	37,754.17	0.76	3.87	1.72	0.93
	0 %	275,459.12	206,594.34	19,320.44	6,049.00	6,090	37,405.33	0.00	0.00	0.00	0.00
	10 %	277,333.83	208,000.37	18,888.62	7,447.78	6,125	36,872.05	-2.24	23.12	0.57	-1.43
	20 %	277,078.55	207,808.91	18,565.78	7,409.19	6,160	37,134.66	-3.91	22.49	1.15	-0.72
	30 %	276,695.20	207,521.40	18,197.90	7,802.38	6,125	37,048.52	-5.81	28.99	0.57	-0.95

Table 4. Monthly performance of demand uncertainty and the percentage difference, as compared to the base case

Uncertainty	% Variation	Revenue	Material Cost	Holding Cost (HC)	Lost Sales Cost	Ordering Cost	Monthly Profit	% HC Change	% Lost Sales Change	% Ordering Cost Change	% Profit Change
Demand (inter-arrival time)	-30 %	341,748.13	256,311.10	15,391.72	72,087.23	7,490	-9,531.92	-20.33	1,091.72	22.99	-125.48
	-20 %	319,990.95	239,993.21	16,643.08	38,321.20	6,825	18,208.46	-13.86	533.51	12.07	-51.32
	-10 %	295,925.93	221,944.45	17,879.11	18,239.70	6,510	31,352.67	-7.46	201.53	6.90	-16.18
	0 %	275,459.12	206,594.34	19,320.44	6,049.00	6,090	37,405.33	0.00	0.00	0.00	0.00
	10 %	252,008.15	189,006.11	20,984.75	2,454.90	5,565	33,997.39	8.61	-59.42	-8.62	-9.11
	20 %	231,729.85	173,797.39	22,434.52	673.10	5,250	29,574.84	16.12	-88.87	-13.79	-20.93
	30 %	214,978.02	161,233.52	23,740.33	245.49	4,795	24,963.68	22.88	-95.94	-21.26	-33.26

Table 5. Monthly performance of process uncertainty (missed quantity) and the percentage difference, as compared to the base case

Uncertainty	% Variation	Revenue	Material Cost	Holding Cost (HC)	Lost Sales Cost	Ordering Cost	Monthly Profit	% HC Change	% Lost Sales Change	% Ordering Cost Change	% Profit Change
Process (missed quantity)	-30 %	264,925.33	198,694.00	16,120.33	18,054.74	5,740	26,316.26	-16.56	198.47	-5.75	-29.65
	-20 %	269,398.20	202,048.65	17,168.39	12,668.00	5,915	31,598.17	-11.14	109.42	-2.87	-15.52
	-10 %	272,573.35	204,430.01	18,260.91	8,858.21	6,055	34,969.22	-5.48	46.44	-0.57	-6.51
	0 %	275,459.12	206,594.34	19,320.44	6,049.00	6,090	37,405.33	0.00	0.00	0.00	0.00
	10 %	276,206.38	207,154.79	20,452.71	4,498.00	6,125	37,975.89	5.86	-25.64	0.57	1.53
	20 %	277,042.35	207,781.76	21,507.79	3,494.41	6,125	38,133.39	11.32	-42.23	0.57	1.95
	30 %	277,588.67	208,191.50	22,509.24	2,839.60	6,125	37,923.33	16.50	-53.06	0.57	1.38

According to the result of the ANOVA shown in Table 6, the process uncertainty in which the number of delivered units fluctuated has the highest significant effect on the variation of the holding cost. The variance of the demand uncertainty from customers has the most impact on the variation of the lost sales and ordering cost. And finally, the variance of the demand uncertainty also has the highest impact on the variation of the profit. In addition, the variance of the supply uncertainty (lead time) has no effect on the variation of the ordering cost at all. This is since the shop operates with a reorder cycle policy where it has to order once a week no matter what the variability of the lead time is.

All of these results are in line with the conclusion made earlier.

Conclusions

There are three main causes of uncertainty in the retail supply chain under study-supply, demand and process uncertainties. The impact of the uncertainty on supply chain performance varies by the factor that causes it. Similar to the results presented by Davis (1993), the findings suggest that inaccuracy caused by the demand uncertainty, such as demand forecast error, appears to have the biggest impact on the retail shop, as compared to inaccuracy caused by inaccuracies in supply and process.

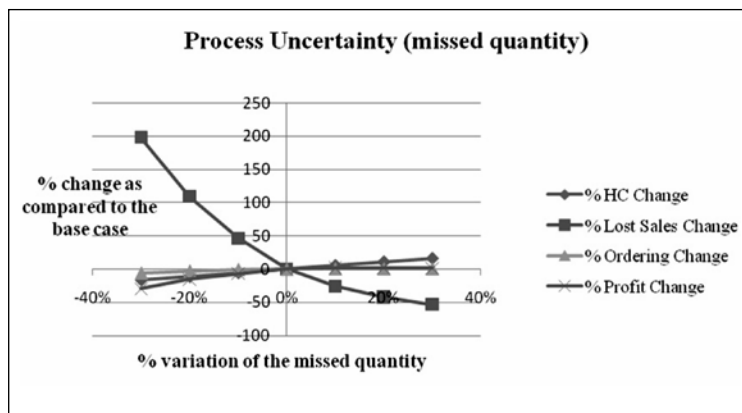


Figure 1. Supply uncertainty

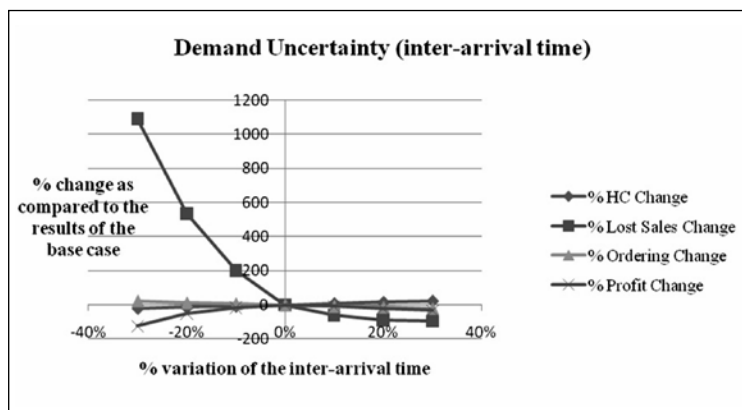


Figure 2. Demand uncertainty

In this model, inventory inaccuracy caused by the supply uncertainty (lead time uncertainty) shows little impact to the shop's profit while the process uncertainty gives a moderate effect. In addition, the variation on the lower side (i.e., shorter lead time, quicker customers' inter-arrival time, and less sales units in the shop) results in a higher impact on the shop's profit. As a result, underestimating these figures can cause a more severe effect on the shop's profit than overestimating them.

This study is limited to a single retail chain configuration with specific parameter estimates (e.g., for demand, lead time and incorrect delivery variability) and default values for the factors that cause inventory inaccuracy. The results suggest that it can be useful for companies that face a high level of

inventory inaccuracy to examine procedures or technologies to eliminate them. To give some guidelines, the results of the model indicate that variability of the parameters of interest can reduce the shop's profit up to 125%.

Further studies of other supply chains are needed in order to understand under which circumstances it is worthwhile to attack the problem of inventory inaccuracy. Case studies based on real data should be conducted to study the impact of the uncertainty in relation to total supply chain cost. In these case studies, one may also compare the benefits of eliminating the uncertainty with associated cost of process changes or the introduction of new technologies.

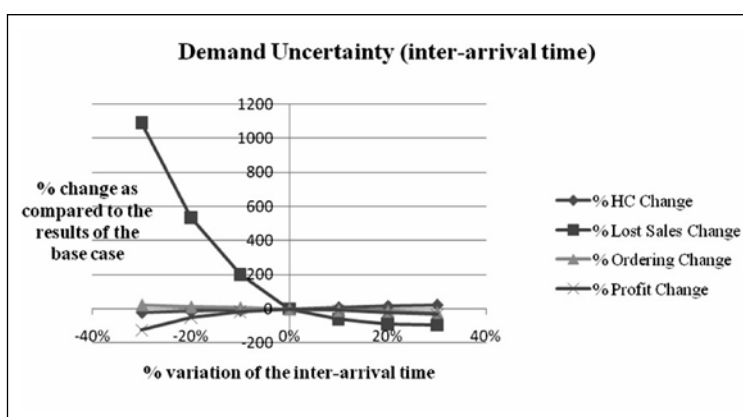


Figure 3. Process uncertainty

Table 6. ANOVA result of percentage variation on costs and profit

Uncertainty factor	Holding cost	Lost sales cost	Ordering cost	Monthly profit
Supply (lead time)	44.28%	32.11%	0%	15.61%
Demand (inter-arrival time)	64.55%	97.8%	98.69%	93.67%
Process (missed quantity)	92.9%	76.9%	25.28%	68.9%

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