Traffic Flow Analysis Based on Queuing Models

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Abstract

One of the most important issues in the plant layout design especially in mass production organizations with high inter-plant logistics is 'material flow and inter-plant traffic analysis and its effects on the production capabilities or pauses in production lines. In this paper the inter-plant traffic analysis issue on the basis of single channel queue model (M/M/1) is analyzed in a carmaker company (IKCO). Through the analysis, the production stop rate and relevant costs are estimated.

Key words: Material flow, Traffic, Queue;

1. Introduction

Heavy internal traffic in the routes of plants is one of the major difficulties involved in production factories that make it very vague the possibility of obtaining the production goals. It seems to be very complicated to do analysis of this factor and its effects on the production stops in design and project phase, particularly production line is not yet approached to the production nominal targets to attentively consider the consequences of growing traffic on the plant's internal logistics. Hereby this problem is one of the logistics challenges from the project beginning. This undergoing engagement remains still vague because there is no standard procedure or criteria having power of deterministic responding to the respected area's questions.

It is obvious that the traffic volume in the plant has a relation with the plant arrangement or plant layout and its existing capacity of inter – sectional routes. Assuming a good plant layout has been designed and implemented, the next major factor for optimising inter-plant traffic would be material flow routing and determination of paths nodes among diverse aspects of material flow.

There have been used various meta-heuristic algorithms, having shown good results, such as material handling routing heuristics and application of Ant Colony Optimisation (ACO) for these issues. This method, as its name shows, uses the ant colony optimisation algorithm in vehicle routing problem (VRP).

Looking like other heuristics such as tabu search, simulated annealing, and genetic algorithms, modified ACO heuristic has been used for solving well-known TSP and VRP problems. ACO algorithm is altered in case of the former TSP problem solving and VRP multi – dimensional routes. Examinations indicate that this algorithm gives optimised solutions. Indeed, this way is rivalry and acceptable in VRP respected problems especially in big problem   areas [1]. Hani et al (2007) used ACO heuristic to prepare layout alternatives and optimise existing layout at industrial cases [4].

Furthermore, the size of nominated optimisation list will be an essential factor for finding optimised series of solutions, and solution time of this algorithm is comparably better than other algorithms.

One of the most important logistics problems has been the trend of reaching the most efficient vehicle routings in material flow analysis and logistics efficiency. If an organization can shorten the length of to-be-delivered material handling movements on mean time or reduce the number of logistics vehicles, it would be more efficient to offer better customer services and even increase its market share considerably. General type of vehicle routing problem is to efficient determination of logistics equipments routes from a central warehouse toward customers and returning to origin point regarding to equipment capacities and logistics system conditions.

In all kinds of these problems, fitness function, for example would be to deviate the routes combination expenses for certain logistic equipment in case of facilitating goods delivery from the origin to the destination. Regarding to close correlation between the expenses and the pending distances, trying to decrease the total amount of pending routes will be undertaken through equipment. In this situation, considering fitness function of the problem, designer tries to optimise solution meanwhile increasing or at least keeping offered service levels. Process of selecting vehicles route will give the possibility of choosing each desired customer to be serviced by any of the vehicles or at any routing.

Nevertheless, VRP is a combinatorial optimisation problem in which the number of feasible solutions increases exponentially by the number of customers. Besides, equipment VRP has a close relation with travelling salesman problem, because in VRP, we should determine specific route for each vehicle in go and back cycle. Algorithms deficiency for solving vehicle routing problem in polynominal time for diverse types of the problem results in assuming VRP as NP-Hard difficult optimisation. In these problems, implementation of heuristics is a rational method to find the optimal solution.

Decision support systems of VRP problems have been studied by researchers in different fields. Jimenez et al (2005) studied material handling system modelling and used it in integration of decision making [5]

2. Literature review

Equipment waiting (delay) time and the length of the equipment queue in different conditions at planning phase are important factors in logistics system design. Many approaches such as simulation, queuing theory, diverse meta-heuristic algorithms etc are studied in literature for this type of problems. Le-duk & Dekoster [6] studied the travel time estimation problem using statistics and probability theory. Although there are many different targets considered in these problems, the most popular one that is attended in must of issues is the time of preparing a random order.

The current trends in logistics, supply chain and production networks have highlighted the importance of these issues on productive and cost efficient operations. In logistics of distribution, small and high frequent orders have been replaced by large sized and low frequent orders that need quicker processing and preparations. In case of production and supply, the general approaching has been smaller batch sizes, reducing of production cycle time and delivering at point of use.

With these challenges in business at current decades, flexibility and quick responses to customer needs have been more essential factors in warehouse oriented

production companies to survive and keep their competency capability in the current competitive market.

Four essential factors of efficient and productive order batching and preparation operations are as follows:

> Warehouse layout design
> Order batching and routing policies
> Warehousing and storage strategies
> Orders categorizing methods

Routing and layout issues have been more attentive and widely studied in literature. Rod Bergen and De-koster have shown that in a warehouse with multiple crossing aisles dynamic programming can optimize the routing policy.

Rod Bergen developed a model for designing optimal layout (determining optimal number of crossing aisles) in a warehouse that inventories are positioned randomly inside it. In his study, the goal was to minimize order preparation time. Caron et al. (1998) and Petersen and Schmener (1999) studied the effects of warehousing policies on average travelling distances. They considered two groups of algorithms: seedy algorithms and time saving algorithms that are more complicated algorithms. They compared results of two different routing strategies: S-shape strategy and largest-gap strategy. Algorithms comparison criteria were travel time, number of created batches and their execution simplicity.

Some important goals of warehouses layout design and activity optimisation criteria are to minimize travel distance and route time. Different quantitative and qualitative indices and criteria have been studied in the literature. L.Chien lin and G.P.Sharp studied wide variety of these indices and categorized them into seven major groups [2]. McKinnon (1999) studied traffic effects on logistics efficiency and developed indices to combine VRP problems with material flow logistics issues [7]. Wilson (2007) considered the impacts of traffic and transportation system on supply chain performance [9] and Winston et al (2004) developed a model to study inventory costs on shipping problems [10].

Wide application of evolutionary optimisation and their good results in solving different problems were due to stimulate the public interests. Filippo Queirolo et al. [8] developed a genetic heuristic algorithm for warehouse layout design and decreasing travel time. They proposed a system for efficient allocating of diverse groups of inventories inside the warehouse. The Proposed system is based on genetic algorithm and simulation model. Comparison experiments implemented to study the system efficiency and through these studies, researchers were to establish guidelines for warehouse activities and layout optimisation to be applicable by executives and managers. Some of these guidelines can be found in freight best practices [3].

The main Storage activities are divided into the following categories:

Receiving inventories from the sources
Holding inventories until requested time
Retrieving inventories when needed

Material storage for an inter-organizational customer indicates the need for work-in-process inventory holding whereas inventory storage for external customers may indicate the need for final product warehousing. In both cases storage duties are the same and apart from type of inventories held in the warehouse, successful layouts of the warehouse should ensure the following issues:

- Productive utilization of human forces
- Maximizing inventories accessibility
- Secure inventory holding

Nevertheless layout objectives and warehouse activities are clearly known; but on contrary, warehouse layout problems are often considered as difficult optimisations because of huge variety of inventories inside a warehouse, large fluctuations in demands and dynamism in warehouse design factors such as required area, type of inventories etc.

Usually optimisation objectives in these problems are one-criterion objectives such as maximizing warehouse floor utilization or minimizing order batching time and so on which give up static solutions for the problem whereas including equipment alternatives or storage methods to the problem, makes them more difficult. Inventory management will deeply influence organizations with high volume material consumption rates. Even though, connecting material management to demand exact forecasts or effective scheduling plans, material handling and transportation which are often not considered as value adding operations, will be next dilemma of such systems. The major objective of Queirolo study was to minimize warehouse general costs by reducing total route time that resulted in proposing Z-SIM systems.

3. Modelling of travel time

Equipments serving material handling tasks and internal logistics flows are to handle materials from warehouses or subassembly shops to next points of production processes. The major essential factor affecting efficiency of inter-plant logistics is implemented layout and vehicles routing. After implementation of a layout, many conditions such as processes modifications, intruding new products, phasing out of old products, shift in production rates, development plans, and social or governmental policies etc would lead to deficiency of the layout. Since layout modifications are costly activities, organizations often avoid these expensive optimisations; instead they look for cheaper solutions.

One of the effective keys to overcome with market revolutions and working conditions would be vehicle routing and effective scheduling material flow and optimised stock levels at destination points.

This study tries to model physical flow of material inside the plant and determine optimum inventory levels at points of use.

In this study we will use single channel queue model and travel time estimation of transferring materials from one point to another one for inter plant traffic analysis and then we will study its effects on approaching production targets. This investigation can also be used as an indicator of the fewest stock policies to be kept inside shops to achieve desired service levels. Also, in the case of defined stock policies at the shops, it can be used in evaluation of diverse policies efficiency and to estimate average production interrupts and its related costs at interested time periods or to evaluate various layout alternatives and inventory strategies

Considering vehicle cycle, total travel time is combined of four segments, $T_i = T_{load} + T_{travel} + T_{queue} + T_{unload}$. The first and last segments are T_{load} and T_{unload}. T_{load} Is the time of order preparation and loading of the materials on the equipment and the fourth part, T_{unload} is the time of unloading materials and delivering them to the workstation. Based on observations of real system operation and testing data gathered on loading and unloading time, using SPSS software to find the best fitness, each of the loading and unloading times are normally distributed with parameters μ_{load} and μ_{unload} as averages and σ_{load} & σ_{unload} as standard deviations of the related distribution. This study confirms normal distributed loading and unloading times for different types of equipment so that the same values have been considered for distribution parameters.

The Second part, T_{travel}, is the standard time of vehicle movement from the origin to the destination in the case of absence of any other vehicles on the route. It is clear that, presence of other vehicles in the route increases travel time by increasing queue time. Travel time is just dependent on the length of the travel route and vehicle average speed. In inter-plant traffic flow, in which lengths and widths of paths are shorter and narrower than out-of-plant roads and streets, vehicles average speed is almost constant and independent from vehicle type. Also, it is noticeable that, vehicles variety used inside a factory is not high and they almost have similar specifications. This point, affirms the above-mentioned gist. Finally, factual observations on average speed of different types of equipments, vouches the assimilation of equipments average speed. At travelling from origin i to destination j, every vehicle passes a specific route P_{ij}, which is formed of certain segments. Denote L_{ij} to be summation of lengths for all segments forming route P_{ij}, $L_{ij} = \Sigma l_{k}$, $k \in \{i,j\}$ Denoting average speed of equipment with V_0 and total length of the route by L_{ij}, equipment travel time T^{ij}_{travel}

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can be calculated as $T^{ij}_{travel} = L_{ij} / V_0$. Regarding to Central Limit Theorem, and considering μ_0 and σ_0 as average and standard deviation of vehicle travel time through one meter of a route in standard conditions, so T_{travel} that is total time of equipment movement in the route with length L_{ij}, has a normal distribution with average of $\mu^{ij}_{travel} = \mu_0 . L_{ij}$ and standard deviation of $\sigma^{ij}_{travel} = \sigma_0 . \sqrt{L_{ij}}$. Because this case is the same as adding up L_{ij} different independent normally distributed variables. Bigger distance between origin and destination, closer T_{Travel} to normal distribution Finally, third part of travel time, T_{queue}, is the average delay time of the vehicle in relation with traffic volume on the routes. In other words, it is average waiting time that a vehicle needs to pass a crowded route. Equipment arrives to the segments of the routes and if there were any other equipment on the line, it takes waiting time before passing each segment of the route. Route segment acts like a server in queue model. Since inter-plant routes usually would not allow simultaneous crossing with other equipments, when a vehicle is passing from a section on the path, other equipments would not pass this section and they should wait for crossing of in advanced vehicles. This is similar to serving a customer in queue models by a server. So, in this case the server in considered unique. Despite average speed of vehicles on the routes, observations show exponential distribution for crossing time - the time needed for a vehicle to pass a section forming a route. These observations also confirm exponential distribution of vehicles inter-arrival times. So that, T_{queue} or traffic delay time can be estimated using queue M/M/1 models.

If vehicles entrance rate -number of equipment entering to a specific segment is indicated by λ_k and service rate or the number of equipments per hour that may pass by this segment considering equipment length and movement average speed indicated by μ, thereby average waiting time at this segment would be $\lambda_k / (\mu(\mu-\lambda_k))$ from M/M/1 queuing model. Because of stochastic characteristics of queue models, the average waiting time at each of the partial routes will be a positive value that can be estimated by $\lambda_k / (\mu(\mu-\lambda_k))$. Consequently, traffic parameter of waiting time-T_{queue} and equipments delay through route is equal to summation of all waiting times in all segments of the route, in other words $T_{queue} = \sum_k (\lambda_k/(\mu(\mu-\lambda_k)))$ and we will have below formulation $T_i = T_{load} + T_{Travel} + T_{queue} + T_{Unload}$.

Denoting the least stock level for components in destination shop by S_{min} and considering P_r as production rate, maximum available time for equipment i to replenish inventories at the shops would be $T_{min}=S_{min} / P_r$. By the way, the probability of production interrupt due to equipments delay can be calculated by:
P^i_{stop}=Pr {Production interrupt due to equipment delay} = Pr {replenishment time > T_{min}} =
=Pr {$T_i=T_{load}+T_{travel}+T_{queue}+T_{unload} >T_{min}$}
Expected duration of production interrupt in this case is $T^i_{stop}=T_i-T_{min}$. According to k routes per day to handle

material flows inside the plant, average daily production interrupt is equal to $E[T_{stop}] =\sum_k \{P_{stop} . T_{stop}\}$. So, denoting lost profit per product unit by Z, average of daily profit lost from missed products and production stop is equal to:
Average lost products per day: $E[T_{stop}]$ *P_r*(Daily working hours)
Daily profit loss, average lost products per day * product unit profit would be: $E[T_{stop}] . P_r$ *22*Z
Average lost products per year can be calculated by: $E[T_{stop}] . P_r$ *(working hours per year)
Annual average lost in profit: Average lost products per year *unit profit loss
In case of given T_i distribution, the least stock policies for each destination shop can be calculated and by the way, minimizing production stop risk caused by material or component slack would be possible. Based on arrival time intervals and its stochastic distribution, average profit lost per day or year will be deployed for calculation of least stock policies at destination shops. Tacking account exponential distribution probability function $F(x)= \lambda_e^{-\lambda x}$, $X\geq0$ or its CDF $F(x)= 1- e^{-\lambda x}$, $X\geq0$, the parameter value -lambda would be available permitted time to deliver an order and variable x would be stock level of the component.

4. Case Study-Determining optimum in-shop stock levels for L90 production site

This model can be handled in determination of minimum stock levels of materials at destination shops. Stock level of materials affects inventory supply and absence of inventory suspends production, which imposes heavy costs to the organization. Here we analyse an internal route of Tondar90 production site in Iran Khodro Co. The highest traffic rate in Tondar90 site belongs to a specific part of the routing network that connects trim warehouse no. 2 to trim shop. In the case of producing 31 cars per hour, highest rate of equipment per hour should pass through the route. It is combined of 3 partial segments 1,2,3. Entrance rate to the segment number 1 is 77 equipments per hour and for segments 2 & 3 are regularly 32 & 28 vehicles per hour. Regarding to the model conditions in which the lengths and average velocity of the vehicles are approximately the same, it will be possible to calculate service rate of any segment in the route. In this case, average length of vehicles is 20 meters (with front and rear safety distances) and the average speed of the vehicles is measured 1.4 m/s (5 Km/h). It is clear that in this case having above-mentioned conditions, all routes and segments will have equal service rates. So, the service rate μ for all routes will be μ = 3600 / (20/1.4) = 252 vehicle per hour. Therefore the maximum number of vehicles can pass through each route in one hour at the best situation is about 252 vehicle. Because of stochastic nature of the problem, even though the service rate is big, traffic time –the time of waiting in queue before passing through a route, of the vehicles will be positive and non-

zero values. Average loading and unloading times are about 10 minutes.

Here bye we have:

- Service rate, μ=250
- Entrance rates to the segments, λ_1=77, λ_2=32 and λ_3=28.
- Average waiting time or traffic time,

$$T_{Queue}^1 = \frac{\lambda_k}{\mu(\mu - \lambda_k)} = \frac{77}{250*(250-77)} = 0.00178 \; Hour = 6.41 \; Sec$$

$$T_{Queue}^2 = \frac{32}{250*(250-32)} = 0.000587 \; Hour = 2.11 \; Sec$$

$$T_{queue}^3 = \frac{28}{250*(250-28)} = .0005 \; Hour = 1.82 \; Sec$$

$$\sum T_{queue}^k = 10.34 \; Sec$$

- Total loading and unloading time,

$$T_{load} = 10 \min = 600 \, Sec,$$

$$T_{Unload} = 10 \min = 600 \, Sec$$

So, total travel time between trim warehouse and trim shop in average is

$$T_i = T_{load} + T_{travel} + T_{queue} + T_{Unload} = 1287.38$$

Therefore the average travel time of the route would be 1287 seconds or 0.3575 hours that can be used in calculating exponential distribution parameter. At present, the least stock policy is 10 parts in one box pallet (except of the pallet located at line side for consumption), so we would have:

$$T_{min} = \frac{S_{min}}{P_r} = \frac{10}{25} = 0.4 \; hour, \lambda = \frac{1}{0.3575} = 2.8$$

And

$$P_{stop} = \Pr\{T_i > T_{min}\} = 1 - \Pr\{T_i \le 0.4\} =$$

$$1 - (1 - e^{-2.8*0.4}) = e^{-1.12} = 0.3263 \cong 33\%$$

Calculated risk of production stop is relatively high and this calculation shows that by increasing of production rate and approaching to nominal production targets of 25 car per hour, total lost cars per year will be considerably high and noticeable which leads to immense losses in expected profit and demonstrates logistics deficiency.

Considering a predefined production interrupt rate - for instance 0.01% for destination shops such as trim shop, the least stock level at destination should increase to another value. For calculation of new stock levels we have:

$$P_{stop} = 0.0001 \Rightarrow \Pr\{T_i > T_{min}\} = 0.0001 \Rightarrow$$

$$\Pr\{T_i \le T_{min}\} = 1 - 0.0001 = 0.9999$$

Using exponential distribution with calculated parameter we would have:

$$1 - e^{-2.8x} = 0.9999 \Rightarrow e^{-2.8x} = 0.0001 \Rightarrow -2.8x = -9.21034 \Rightarrow$$

$$x = 3.29 = T_{min}$$

By calculation of the least time to stock materials inside the shop, we can determine minimum stock levels for each part to be kept inside the shop.

$$S_{min} = T_{min} \cdot P_r = 3.29 * 25 = 82.25 \approx 83 \; part,$$

$$\frac{83}{12(Pallet \; Capacity)} = 6.9 \cong 7 \; Pallet$$

This calculation shows that in order to decrease production interrupt probability to a predefined value (such as 0.01%), stock level of the materials supplying from warehouse no 2 should increase to 83 parts. Considering 12 parts in a pallet, stocking 7 pallets of the part inside trim shop would be needed.

5. Conclusion

In the present study, we studied material flow from traffic viewpoint and proposed single channel queue model for in-site traffic analysis and then applied it in determination of optimum stock levels of materials at destination shops. We used the results of the study on a typical case. By application of the method, we calculated the least stock levels at destination shops for a predetermined production interrupt rate. As discussed in the text, an order triggered by inventory consumption, replenishes inventories to the reordering point, which is considered as the material stock level and here we proposed a queue model to optimise it. In the case of using pull systems or routine scheduled replenishment plans instead of push systems, in-shop stock levels would decrease rather than calculated values.

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