UDYOG PRAGATI

The Journal for Practising Managers

Vol. 42, No. 1

January - March 2021

ISSN 0970-3365

NITIE
उद्योग प्रगति

NATIONAL INSTITUTE OF INDUSTRIAL ENGINEERING
Mumbai-400 087 INDIA

UDYOG PRAGATI

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Vol. 42, No. 1, January - March 2021

Udyog Pragati is published as a Quarterly Journal by the National Institute of Industrial Engineering.
The Views expressed in this Journal do not necessarily represent the official views of NITIE.

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Printer & Publisher : Shri Basavraj Swamy, Registrar

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IN THIS ISSUE...

Editorial

We are happy to hand over Udyog Pragati's issue – *The Journal for Practising Managers* focusing on various pros and cons evolving in the manufacturing. The efforts are made to draw your kind attention towards India's manufacturing sector, which faces many issues and could contribute only 12% in total employments where the expectations from this sector were very high. The manufacturing industry consists of various activities like the mechanical, physical, or chemical transformation of material, substances, or components to finished products. Despite being an agricultural economy manufacturing sector, it is considered a core contributed 16 to 17%, reaching 25% until 2025.

The first article, entitled, "Implementation of Theory of Constraints using Drum-Buffer-Rope method in the fly-wheel housing manufacturing industry," talks about improving productivity with TOC application. In contrast, the second article articulates the adoption of IoT in Indian manufacturing firms using AHP.

Customer satisfaction is prime in the success of any industry. Further research article focuses on cost optimization using Gurobi Solver Engine to view risk-pooling in the allocation of customer orders in a technology-driven online retailing marketplace. Mumbai *Dabbawala's* case is thoroughly discussed here with a well-proven supply chain approach.

At the end of this journal, mathematical modeling is applied to solve the case study of a two-sided mixed-model assembly line balancing problem. This study observes that the cost-oriented approach provides a better solution than the station-oriented system to reduce total worker cost and overall cost in terms of efficiency.

Prof. Rakesh Raut

Editor in Chief

Implementation of Theory of Constraints Using Drum-Buffer-Rope Method in Flywheel Housing Manufacturing Industry

Kuldeep S Pawar[1], Reena Pant[2], Sachin Chavan[3]

The advances in technology has led to tremendous improvements in manufacturing systems. Synchronous Manufacturing System (SMS) is one such example. It is a manufacturing management methodology that consists of particular techniques and principles where every action is evaluated in terms of common goals of optimization of resources. SMS introduces the concept of Drum-Buffer- Rope (DBR) approach. DBR is a generalized system and solves most of the problem of bottlenecks of inventory in a production line. Reducing Work In Process (WIP), Raw Material (RM) inventory to improve cycle time, improving upon time delivery and hence profit are improved by it. The DBR is a methodology of Theory of Constraint (TOC), introduced by Dr. Eliyahu Goldratt. It works as a special technique for SMS.

This paper is based on the application of TOC to improve the productivity of flywheel housings in an organization. The organization is facing the problem for timely delivery of the flywheel housings. The bottlenecks in the production line are identified by DBR methodology and TOC is applied. For this data of flywheel housing manufacturing process, resources required, WIP inventory and RM inventory is collected. The critical analysis of data has helped in recognizing the constraints in two machines of the production line. The challenges are taken to overcome these constraints by utilisation of available resources. The Successful implementation of TOC is resulted into reduction of WIP, RM inventory and on time delivery. Due to which productivity has improved leading to increase in the profit.

Keywords: *DBR, TOC, SMS, Flywheel Housing, Product Costing.*

Introduction

The objective of any manufacturing system is to convert the raw materials into finished products. Synchronous Manufacturing System (SMS) is a manufacturing management methodology that consists of certain techniques and principles where every action is evaluated in terms of common goal of the organization. SMS helps to achieve better performance and efficiency in a manufacturing organization. There are various techniques of SMS like Material Requirement Planning (MRP), Just in Time (JIT) and Line Balancing. These techniques are used for performance improvement and eliminate wastage but their installation period is high, while in line balancing cost of adding capacity is high. A relatively new approach called Theory of Constraint (TOC), introduced by Dr. Eliyahu Goldratt, overcomes these problems. TOC also known as Constraint Management (CM) or Synchronous Manufacturing (SM) is global managerial methodology, which tries to concentrate on the most critical issues of the system. These constraints should be identified and logically solved to improve the performance of system.

SMS introduces the concept of Drum Buffer Rope (DBR) approach, which is generalized system and states how it satisfies and solves most of the problems of inventory levels in manufacturing environment. Reducing Work in Process (WIP) inventory to improve cycle time, delivery and product quality has become the key for maintaining the profitability.

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In this work carried out in an industry initially problems like accumulation of WIP inventory, raw material inventory and failure of in time delivery of flywheel housings are prominent. So, to overcome these problems and improve productivity, application of TOC in which line balancing approach has been applied. The details are given herewith.

Study of Current Practices of the Company

The company manufactures different types of housings on the housing production line according to the customer demands. On the housing production line housing number 39.468, housing number 3528, housing number 3.974, housing number 4H682 and housing number X1815822 are manufactured.

Once the customers place an order for any housing component, the production planning and control department schedule for monthly production. They divide monthly production requirements into weekly production requirement and weekly into daily production requirement.

Company is facing problem for delivering the flywheel housing product number (39.468) after an increased demand from the customer. After studying the past data of housing component such as, manufacturing process, resources required, WIP inventory and raw material inventory, the problems regarding dispatch and inventory control for the components are found. They are listed below:

1. Problems associated with dispatch.
2. Problems associated with WIP inventory.
3. Problems associated with Raw material inventory.

Literature review

After referring round about twenty-five international and national journal papers it is found that applying the TOC-DBR concept has helped in removing the bottle necks and improving the productivity. Hence application of these concepts will be used for achieving the objectives of the project

Some authors analyzed the effect of Theory of Constraints (TOC) and its mechanism in improving the lead-time performance and workload control provides effective tools that can be used in combination with the Drum–Buffer–Rope mechanism in order to balance the flow of work to the production floor. In the following section TOC concepts are discussed

Linhares et al. [2009] studied on theory of constraints and the combinatorial complexity of the product-mix decision. Here, (TOC) propose that, when production is bounded by a single bottleneck, the best product mix heuristic is to select products based on their ratio of throughput per constraint use.

Lee et al. [2010] researched on enhancement of TOC Simplified Drum-Buffer-Rope system using novel generic procedures. Author shown that Theory of Constraints (TOC) Simplified Drum-Buffer- Rope (SDBR) system works effectively in typical job shop environments.

Sivasubramaniam et al. [2000] studied the effect of Drum-Buffer-Rope approach principal on the performance of synchronous manufacturing by conducting a case study in a small scale industry. The optimum production rate at each work centre is computed.

Zhai et al. [2011] investigated the job shop bottleneck detection based on orthogonal experiment. Author has shown that, according to a new bottleneck definition which is proposed based on the principle of ''Bottlenecks determine the performance of manufacturing systems'' in TOC.

Methodology

1. Identification of the constraint resources in the selected production line.

To identify the constraint is the most important step in Theory of Constraints. According to constraint identification process there are two important criterions to determine them. They are

i. Analysis of capacity

Comparison of total available capacity of each resource and total required capacity of the resources. The resource whose capacity is less than demand is identified as constraint resource (CR), the resource whose capacity is more than demand is identified as non-constraint resource (NCR) and the resource whose capacity is close to demand or nearly equal to demand is identified as capacity constraint resource (CCR).

ii. Analysis of WIP

Accumulated at each resource in the selected production line. The resources having maximum accumulation of work in process inventory are identified as constraint resources.

2. Analysis regarding the total available capacity of each resource in selected line.

To identify the constraint, the comparison of the total available capacity of each resource with the demand placed on each resource. The capacity analysis includes both labour capacity as well as the machine capacity. The labour is not a critical issue, because of the availability of skilled labours in the surroundings. Hence, the capacity analysis for machine capacity only has to be performed. The time study data analysis of each resource in the selected housing production line has carried out for the same.

Time Study Sheet

To find the capacity of each resource the time study is conducted. The durations for; machining cycles, loading, unloading and transfer time for each job is measured four times a shift. The summary of time study is shown in the following table-1

Table 1: Total Available Capacity of the Resources

Machine Resources	Cycle Time (min.)	Loading and Unloading Time (min.)	Total time per unit (min.)	Transfer Time (sec.)
Turret Lathe 1	6.00	3.00	9.00	25
Turret Lathe 2	6.00	3.00	9.00	20
VMC 4	7.00	3.00	10.00	25
VTL2	8.50	3.00	11.50	20
HMC2	12.50	----	12.50	20
VMC1	5.00	3.00	8.00	28
Deburing and Chamfering	4.50	----	4.50	21

3. Analysis of available machine capacity per day for each resource in the line.

There are three types of allowances followed in industries. Which are setup allowance and maintenance allowance for machine and fatigue allowance of the operators.

Machine Setup Allowance

Machine setup allowance is considered on the basis of process trails, tooling trouble, inspection problems, inert, jigs and fixture factors. The setting time required for selected housing product (39.468) on each resource in the housing production line is shown in table-2.

Table 2: Average Setting Time required on the Resources

Machine Resources	Setup Time (min.)
Turret Lathe 1	9.00
Turret Lathe 1	9.00
VMC 4	35.00
VTL 2	20.00
HMC 2	40.00
VMC 1	22.00
Deburing & Chamfering	----

Maintenance allowance

Maintenance allowance is considered on the basis of both preventive maintenance and breakdown maintenance. Different types of preventive maintenance and the time required for these preventive maintenance is shown in table-3.

The breakdown problems of the resources and average time required to recover the breakdown problems is shown in table-4.

According to previous data of the company and time study literature, machine setup

allowance is considered about 4%, machine maintenance allowance is considered about 3.6% and fatigue allowance of operator is considered about 7.4%. By applying these allowances, the total available machine capacity is calculated as below-

Total available time per shift = 8 × 60 = 480 minutes.

The total allowance including setup allowance, maintenance allowance and fatigue allowance of operator has considered 15% for each shift. Therefore, machines are utilizes 410 minutes per shift including allowances. Thus, the total available capacity per day for all the resources in line is 1230 minutes approximately.

4. Analysis of demand placed on the resources by time study.

The analysis of the total required capacity of the resources carried out separately for each shift in a day.

Table 3: Average Time Required for Preventive Maintenance on the Resources

Preventive Maintenance	Average Maintenance Time (min.)	Frequency per day/shift
Lubrication oil level	5.00	Ones / day
Spindle oil level	5.00	Ones / day
Coolant contraction level	6.00	Ones / shift
Machine all axis oiling	6.00	Ones / shift
Hydraulic oil level	5.00	Ones / shift
Cleaning of machine	10.00	Ones / shift

Table 4: Average of Time Required for Breakdown Maintenance on the Resources

Machine Resource	Type of Brake down problem	Maintenance time (min.)
VMC 4	Tool holding problem	18.00
VTL 2	Spindle stop to running (Belt slip problem)	20.00
HMC 2	1) ATC Problem	25.00
	2) Pallet sensing problem	18.00
Turret Lathe	Electrical motor problem	25.00

The time study conducted for selected production line. The result obtained from time study are given in the following table-5

After determining the cycle time required for machining operation on selected housing product,

the demand for each product per day has been determined. The table-5 shows total time required per day for manufacturing on the respective machines on the housing production line.

5. Comparison of total available capacity of the resources and total demand placed on the resources.

Once the CR and NCR are identified the constraints resources of the selected production line are identified. Table 6 shows the details of comparison.

Table 6 show that available capacity of resources; Turret Lathe 1, Turret Lathe 2, VMC 4, VMC

Table 5: Demand per Day on Resources

Sr. No	Machine Name.	Total Time Required per Unit (min.)	Demand / Day (housings)	Total time / Day (min.)
1	Turret Lathe 1	9.00	120	1080
2	Turret Lathe 2	9.00	120	1080
3	VMC 4	10.00	120	1200
4	VTL 2	11.50	120	1380
5	HMC 2	12.50	120	1500
6	VMC 1	8.00	120	960
7	Deburing and Chamfering	4.50	120	540

Table 6: Comparison between Available Capacity and Demand Placed on Resources

Sr no.	Machine resource	Available Capacity (min.)	Demand per Day (Required Capacity) (min.)	Remark
1	Turret Lathe 1	1230	1080	Non Constraint Resource
2	Turret Lathe 2	1230	1080	Non Constraint Resource
3	VMC 4	1230	1200	Non Constraint Resource
4	**VTL 2**	**1230**	**1380**	**Constraint Resource**
5	**HMC 2**	**1230**	**1500**	**Constraint Resource**
6	VMC 1	1230	960	Non Constraint Resource
7	Deburing and Chamfering	1230	540	Non Constraint Resource

1, Chamfering and Deburing are more than demand; hence these resources are identified as NCR. But available capacity of resources VTL 2 and HMC 2 are less than the demand, hence VTL 2 and HMC 2 are identified as CR.

6. Analysis of the Number of WIP Inventory Accumulated at Each Resource.

Analysis shows that WIP inventory accumulated at HMC 2 and VTL 2 machine. From the data available average WIP inventory registered 207 housings before implementation of TOC in the industry where this work is carried out.

7. Exploitation of the constraint resources by preparation of master production schedule for the constraint resources.

Once the constraint resources are identified they should be exploited to utilize them for maximum. The exploitation includes preparation of the master production schedule for the constraints. This schedule is called as "Drum". Once the drum schedule is decided, the schedules for other non-constraint resources are adjusted to support the drum schedule. The next step of exploitation is decision regarding the location and sizes of "Buffer" stock. The buffer stock should be maintained in front of the constraint resource so as to avoid any disruption in the flow. "Rope" is decided to channelize the operations.

Preparation of 'Drum'

The Theory of Constraints argues that, the best place for control point is at the bottlenecks. These control points are the drums, as it strikes the performance of manufacturing function.

Drum includes single machine scheduling of the CR. Once the monthly demand of housing received from the production planning department, this demand is converted into the number of days for production on the CR. As the company manufactures different types of housings, the loading of the constraint resources VTL 2 and HMC 2 machine has been done on the basis of the due dates for different housings. At the same time the company has to carry out at least five housing products settings per month. This has to be done for the housing production line. Therefore there is considerable impact of setting time on the availability of the CR. Hence, the schedule is prepared in such a manner that non-productive time of the CR be as less as possible.

Decision regarding Buffer

Initially utilization of the constraint resources HMC 2 and VTL 2 machine has carried out in idle period by providing buffer for them. During idle period 35 minutes are available. This period is utilized for two shifts and resulted in improvement in production volume. But production volume of selected housing product could not went up to the required demand. The suggestion of utilization constraint resources in the idle period found unsuitable on practical grounds because of unavailability of skilled workers on these resources and also reluctance from workers. Hence, utilization of CR in idle period is not possible to achieve required demands.

Decision regarding buffer stock (capacity buffer)

To get better solution capacity buffer is tried in place of time Buffer. The resources identified as CR the HMC 2 has capacity of 1230 minutes per day (3 shifts) and the demand is 1500 minutes per day prior TOC. For achieving the production target 40 parts are required from each resource in housing production line per shift, but because of limited capacity HMC 2 machine it produce only about 32 parts per shift. Hence there is shortage of about 8 parts per shift.

HMC 2 machine is utilized for side milling, side drilling, tapping and countering operations on selected housing product. For these operations, cycle time required on HMC 2 machine is 12.5 minutes. To overcome this problem Tap Fast 1 (TM L1) machine is introduced. The tapping and chamfering operations of HMC 2 machine are shifted to Tap Fast 1 machine. Therefore, HMC 2 machine now utilizes only for side milling and side drilling operations.

Now side milling and side drilling operations require only 10 minute cycle time on HMC 2 machine. The Tap Fast 1 machine utilizes this for tapping and chamfering operations with Cycle time on (TM L1) is 5 minutes per job for tapping and chamfering operations. Therefore, HMC 2 machine has converted CR into CCR. If it is not properly scheduled it will again be convert into CR. Layout

Table 7: Time Study of the HMC 2 and Tap Fast 1 Machine Resources

Part No: 39.468				Part Name- Flywheel Housing.
Resource	Date	Remark		Total Cycle Time (min)
		Cycle Time (min)	Loading/Unloading (min)	
HMC 2	04/11/2015	10.00	----	10.00
		10.00	----	10.00
		10.00	----	10.00
		10.00	----	10.00
		10.00	----	10.00
Tap Fast 1	05/11/2015	2.48	2.53	5.01
		2.51	2.50	5.01
		2.49	2.51	5.00
		2.5	2.49	4.99
		2.5	2.50	5.00

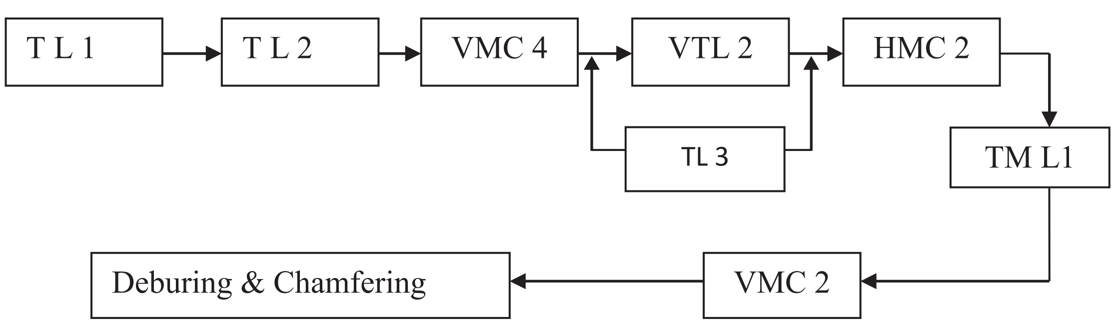
of Housing production line after involving Tap Fast machine is shown in figure - 1.

a) Solved VTL 2 constraint resource

Ones HMC 2 machine is converted from CR to CCR, the performance of housing production line is measured. It is found that, VTL 2 machine is a constraint resource because its capacity is less than demand. Also large WIP inventory is accumulated at VTL 2 machine.

The capacity of the each resource in housing production line is 1230 minutes per day. The demand of VTL 2 machine is 1380 minutes per day. This means that, capacity of VTL 2 machine less than demand placed on it. At VTL 2 machine it observed that 5 parts WIP inventory is accumulated per shift;

Fig 1: Layout of Housing Production Line after Involving (TM L1) Machine



hence VTL 2 machine is identified as CR. Because of limited capacity of VTL 2 machine there is disruption of the product flow in the housing production line. For achieving the production target, 40 parts are required from each resource in housing production line per shift. But, because of limited capacity VTL 2 machine it produces 34 to 35 parts. Hence there is shortage of 5 parts per shift.

To overcome this problem, Turret Lathe 3 (TL 3) machine is introduced. Turret lathe 3 machine take load of 5 housing parts (capacity buffer stock) along with VTL 2 machine and balances the production line. Total cycle time of (TL 3) machine is 16 minutes per job. After introducing (TL

3) machine, it provides 5 parts per shift and line is balanced. Each shift TL3 is utilized for 80 to 90 minutes. Remaining 320 minutes TL3 utilized for machining of other housing products and development work. Time study data of Turret Lathe 3 machine is shown in table 8.

Table 8: Time Study of Turret Lathe 3 Machine

Part no-39.468		Part name - Flywheel housing.		
Resource	**Date**	**Remark**		**Total Cycle Time (min)**
		Cycle Time (min)	**Loading/Unloading (min)**	
Turret Lathe 3	11/12/2015	13.01	3.03	16.04
		13.02	3.00	16.02
		13.02	3.03	16.05
		13.04	3.00	16.04
		13.00	3.02	16.02

Now, the VTL 2 machine resource has converted CR into CCR. Layout of Housing production Line after involving Turret Lathe 3 and Tap Fast 1 machines is shown in fig 1.

8. Determine performance measurement parameters in selected line after application of Theory of Constraint.

Identification of constraints resources which are generating bottle necks is balanced by utilizing the available extra resources of the organization to fulfil the customer demand.

Results

To examine the impact of TOC following are the performance measurements.

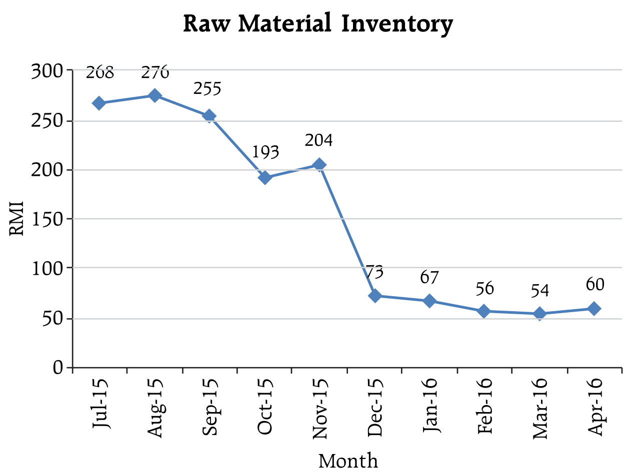
1. Results obtained by TOC Implementation, on Raw Material Inventory (RMI)

The average number of raw material inventory prior implementation is 239 housings, which is reduced to 62 after successful implementation of TOC.

Table 9: Analysis of Number of Raw Material Inventory (RMI) before and after Implementation of TOC

Part Name - Flywheel Housing (39.468)					
Months	**Week**				**Total RMI**
	Week 1st	**Week 2nd**	**Week 3rd**	**Week 4th**	
Before TOC					
July 2015	68 Housings	70 Housings	64 Housings	66 Housings	268 Housings
Aug 2015	69	74	70	63	276
Sept 2015	68	65	58	64	255
Oct 2015	47	51	46	49	193
Nov 2015	39	67	51	47	204
After TOC					
Dec 2015	19	17	16	21	73
Jan 2016	16	19	15	17	67
Feb 2016	14	13	12	17	56
Mar 2016	14	15	12	13	54
Apr 2016	15	16	16	13	60

Fig 2: Average Number of Raw Material Inventory before and after of TOC



2. Result obtained by TOC Methodology on Average WIP Inventory

Table 10 shows average number of WIP inventory prior and after implementation of TOC. The implementation of TOC for raw material has also resulted in considerable amount of reduction in WIP inventory of selected housing product.

The average number of WIP inventory before implementation is 207 housings. This reduced to 35 housings per month after implementation of TOC.

3. Effect of TOC for on Time Deliveries

The average percentage of on time deliveries for selected housing product, before and after implementation of TOC is shown in table 11 & 12.

Table 10: Average Number of WIP before and after TOC

Month		July 2015	Aug 2015	Sept 2015	Oct 2015	Nov 2015		Dec 2015	Jan 2016	Feb 2016	Mar 2016	April 2016
Average WIP (Housing)	Before	235	246	219	161	172	After	46	38	30	27	32

Table 11: Analysis of Number of On Time Deliver before and after TOC

Part Name – Flywheel Housing (39.468)										
Month	Housing Schedule	Week 1st		Week 2nd		Week 3rd		Week 4th		Total Prod.
		Plan	Act. qty	Plan	Act. qty	Plan	Act. qty	Plan	Act. qty	
Before TOC										
July 2015	1200	300	241	300	235	300	246	300	242	964
August 2015	1200	300	237	325	251	300	238	275	226	952
September 2015	1200	325	258	300	243	275	231	300	247	979
October 2015	1200	300	261	300	257	300	262	300	257	1037
November 2015	1200	275	249	300	241	325	276	300	259	1025
After TOC										
December 2015	1200	300	288	300	291	300	290	300	284	1153
January 2016	1200	300	291	300	287	300	293	300	290	1161
February 2016	1200	300	293	300	292	300	294	300	289	1168
March 2016	1200	300	293	300	291	300	295	300	292	1171
April 2016	1200	300	292	300	290	300	291	300	293	1166

Table 12: Average Percentage of On Time Deliveries before and after TOC

Month		July 2015	Aug 2015	Sept 2015	Oct 2015	Nov 2015		Dec 2015	Jan 2016	Feb 2016	Mar 2016	Apr 2016
% of OTD (Housings)	Before	80%	79%	81%	86%	85%	After	96%	97%	97%	98%	97%

Fig 3: Average Number of WIP inventory before and after of TOC

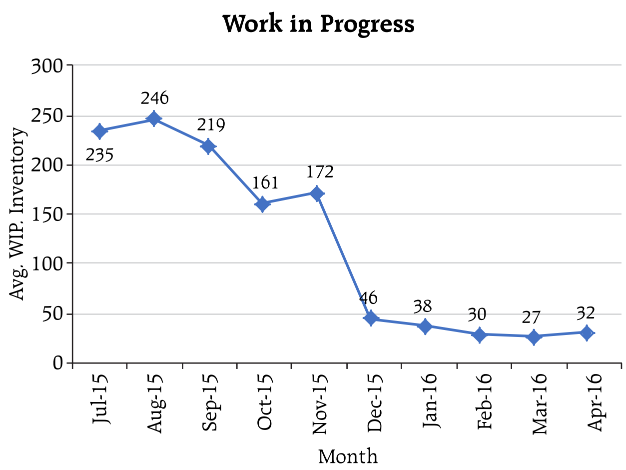
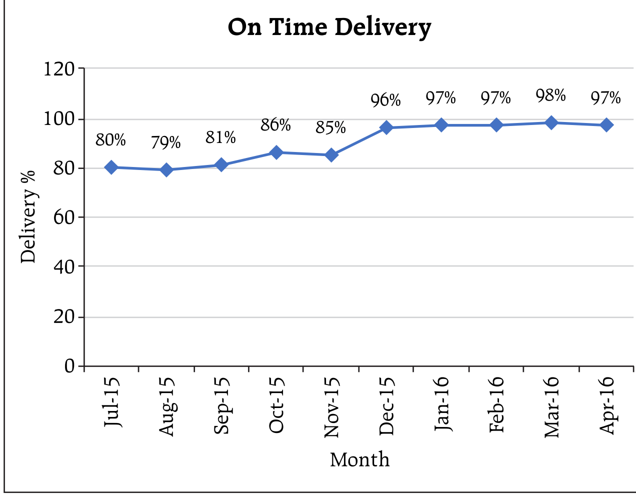


Fig 4: Percentage of On Time Deliveries before and after of TOC



After implementation of TOC, continues flow of product line is observed. Due to this, reduction in raw material inventory and WIP inventory is observed which leads to reduction in production lead time. This has helped in archiving the target without any constraints. TOC implementation has helped in eliminating any production loss on the constraint resource. The average amount of on time delivers before implementation is 82%. This improves up to 97% after implementation. There is 15% increment in on time deliveries by implementation of TOC. This consequently resulted in improved throughput. The table 12 shows analysis of on time delivery.

The on time delivers graphically represented by figure 4.

4. Effect of TOC Implementation on Profit

After implementation of TOC it is observed that, there is little additional investment in the machining cost of the selected housing product. The analysis of profit each month before and after implementation of TOC is shown in table 13.

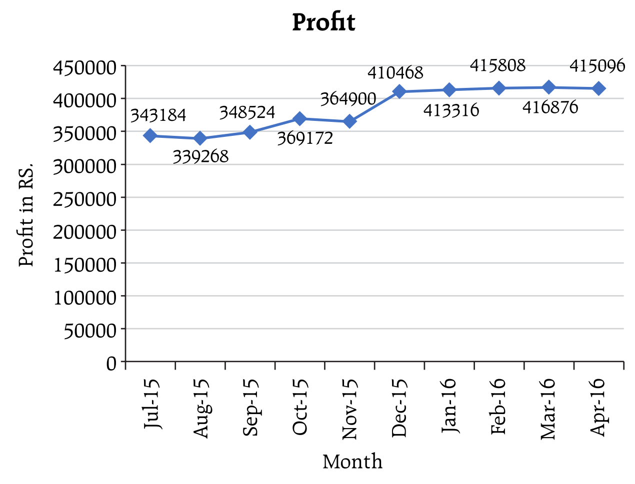
Total manufacturing cost = Foundry cost + Machining cost
= Rs. 2,128/- + Rs.522/-
= Rs. 2,650/-

From table 13, average profit after implementation of TOC is, Rs. 4,14,313/-, which is a considerable amount and shows 17% of improvement.

Table 13: Analysis of Profit before and after Implementation of TOC

Month	Production of Housings	Profit per Month (Rs.) (Production × Profit)	AVG Profit
July 2015	964 housings	964×₹356 = ₹3,43,184/-	353010/-
August 2015	953	953×₹356 = ₹3,39,268/-	
September 2015	979	979×₹356 = ₹3,48,524/-	
October 2015	1037	1037×₹356 = ₹3,69,172/-	
November 2015	1025	1025×₹356 = ₹3,64,900/-	
December 2015	1153	1153×₹356 = ₹4,10,468/-	4,14,313/-
January 2016	1161	1161×₹356= ₹4,13,316/-	
February 2016	1168	1168×₹356 = ₹4,15,808/-	
March 2016	1171	1171×₹356 = ₹4,16,876/-	
April 2016	1166	1166×₹356 = ₹4,15,096/-	

Fig 5: Average Profit before and after TOC



5. Measurement of Productivity

After the analysis of performance parameters such as on time deliveries, WIP inventory, Raw material inventory and Profit, the productivity measurement has been carried out for selected housing component. The analysis of Labour productivity, Machine productivity and Material productivity are calculated and shown below.

6.1 Labour Productivity

Labour productivity	=	Production in terms of standard hours / Actual man hours
Labour productivity before TOC	=	992 / (7*8)
	=	17.71 labour hour / shift
Labour productivity after TOC	=	1163 / (8*8)
	=	18.17 labour hour / shift
Difference of labour productivity before and after TOC	=	18.17 - 17.71
	=	0.46 labour hour/shift

Labour productivity is improved by =2.59 %.

6.2 Machines Productivity

Machine productivity	=	Output in standard hours / Actual machine hours
Machines productivity before TOC	=	992 / 410 min
	=	2.4195 machine hour/shift
Machines productivity after TOC	=	1163 / 410 min
	=	2.8356 machine hour/shift
Difference of machines productivity before and after TOC	=	2.8356 - 2.4195
	=	0.4161 machine hour/shift

Machine productivity is improved by = 17.19%.

6.3 Material Productivity

Material productivity	=	Number of units produced / Material cost
Material productivity before TOC	=	992 / ₹2619/-
	=	0.3787 material cost / shift
Material productivity after TOC	=	1163 / ₹2650/-
	=	0.4388 material cost / shift
Difference ofmaterial productivity before and after TOC	=	0.060 material cost / shift

Material productivity is improved by = 15.87%.

Measurement of productivity indicates that, labour productivity is improved by 2.59%, machine productivity is improved by 17.19% and the material productivity improved by 15.87%.

From the above analysis it is observed that machine and material productivity are satisfactory increased as compare to labour productivity. The labour

Table 14: after implementation of Theory of constraints, the analysis gives following results

Performance Parameter	Before TOC	After TOC	Percentage of Improvement
On Time Deliveries	82%	97%	15%
Production Volume	992%	1162%	17%
Profit	₹3,53,010/-	₹4,14,313/-	17%
Labor Productivity	17.71	18.17	2.59%
Machine Productivity	2.4195	2.8356	17.19%
Material Productivity	0.3787	0.4388	15.87%
Work in process inventory	207	35	83%
Raw material inventory	239	62	74%

productivity increased only by 2.59% because of additional resources.

The overall results are summarised in the following table-14

Conclusions

The bottleneck in production line is the accumulation of WIP inventory at machine VTL-2 and HMC-2. This problem has been analysed for the current production line by DBR methodology of TOC. For implementing DBR to balance the line addition of Turret Lathe (TL 3) parallel to Vertical Turret Lathe (VTL-2) and Tap Fast machine in series with Horizontal Milling Centre (HMC-2) is done.

By proving this solution remarkable increase in production and therefore profit is realised.

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Analyzing the barriers to Internet of Things (IoT) adoption in Indian manufacturing firms Using Analytical Hierarchy Process

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Manufacturing industries in India are facing intense competition from worldwide, and it is high time that they need to be smarter by embracing upcoming technologies like Internet of things to have a cutting edge in today's competitive world. The purpose of this paper is to identify barriers for IoT adoption in manufacturing sector in Indian context. Authors have identified eleven barriers to IoT adoption and implementation from selected existing literature and expert's inputs. They have adopted Analytical Hierarchy Process (AHP) methodology to rank the identified barriers as per relative significance. The most significant barriers identified through research analysis are - lack of top management vision for adopting new technology (B1), high initial investment cost for implementation (B6) and Risk involved in transitioning to new business model (B4). The findings will help to practise managers to frame the strategies and prioritize their efforts for IoT adoption in Indian manufacturing sector.

Keywords: *Internet of things (IoT); Barriers; Manufacturing sector; India; Analytical Hierarchy Process (AHP)*

Introduction

In today's era, the internet has become one of the basic needs of human being with food, water, clothing and shelter. Internet is just few decades old, and we can already see the significant applications of internet in various fields. One of them is Internet of Things (IoT). This term was first coined by Kevin Ashton in 1999 (Ashton, 2009). However the definition of IoT has evolved in past few years. One of the definition for IoT is "Interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications. This is achieved by seamless ubiquitous sensing, data analytics and information representation with cloud computing as the unifying framework" (Gubbi et al., 2013). In simple words, IoT means ability of things or objects to communicate via internet. By enabling these objects to 'communicate', they can acquire valuable data through sensors, which can then be passed onto backend systems for analysis, and further execution. IoT technology comprises of five Key enablers namely, RFID, WSN, Middleware, cloud computing and IoT application software. RFID and WSN consist of number of sensors which can track and record status of various objects. Middleware establishes connection between all these sensors or RFID tags and makes communication smoother. Cloud computing is the on-demand access to a shared pool of database storage and computing services via internet with a pay-as-you-go model. Lastly, IoT application software enables device to devise interactions in which they intuitively analyse data, identify patterns and recommend solutions (Lee and Lee, 2015). This technology has many applications across various sectors namely Transportation and Logistics,

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Healthcare, Smart Homes, Smart Cities, Security and Surveillance and so on (Atzori et al., 2010).

Even though Internet of Things impacts every business, it can drastically transform industrial businesses such as manufacturing sector. IoT has many applications in the manufacturing sector. It helps in real-time tracking and tracing of the product throughout supply chain. This real-time product flow monitoring helps in optimised scheduling and better utilisation of machinery. IoT also helps in better inventory management by keeping track of real-time work in process inventory across various geographical locations (Bandopadhyay et al., 2011). IoT can enhance productivity by predictive maintenance which involves monitoring real-time health of equipment. IoT system also helps in monitoring energy consumption of all the objects on shop floor and using data analytics it helps to find hidden patterns which can lead to minimising energy consumption (Lee and Lee, 2015).

When we talk about the manufacturing sector specifically in Indian context, it is to be noted that it is becoming one of the fastest-growing sectors in India. As per report by Indian Brand Equity Foundation (www.ibef.org), India aspires to become fifth largest Manufacturing industry in the world by end of year 2020. Currently, manufacturing sector contributes approximately 16% of national Gross Domestic Product (GDP) which is estimated to increase to 25 per cent by the year 2022. Government of India has also launched "Make in India" initiative to create footprints of Indian manufacturing industry on world map. In this globalisation era, manufacturing industries are facing intense competition in the form of the product pricing, quality, functionality, uniqueness and lead time from global counterparts.

Meanwhile, consumers are also becoming more aware and have more diversified demand like customised products (Yang et al., 2018). To face these challenges, it is high time that the manufacturing industries in India need to be smarter by embracing upcoming technologies like Internet of things to have a cutting edge in today's competitive world. But, it is seen that despite many advantages of IoT technology, its adoption is still in infancy stage in India. It has been observed that many Indian enterprises are showing interest in IoT adoption but, high initial investments, lack of high-speed internet, lack of competent infrastructure and lack of clarity on cost benefits are some of the major hindrances in IoT adoption in India (Asir et al., 2015). In order to have cutting edge in today's competitive scenario, Indian manufacturing industries must adopt upcoming IoT technology. For that they should first identify and prioritise the barriers for the same. To the best of author's knowledge, no work is done on determining barriers to IoT adoption specifically in Indian manufacturing industry.

In present literature, descriptive type of research and TOE framework are widely used methods to enlist the factors influencing IoT adoption. Also, few researchers have used a multiple case study approach to determine barriers to IoT adoption. To rank and prioritise the identified factors influencing IoT adoption, many researchers have used statistical tools such as Hierarchical logistic regression analysis, Structural Equation Modelling, Exploratory Factor Analysis or Confirmatory Factor Analysis. However, these statistical methods work with certain assumptions such as linearity and independence among variables which may result in incorrect conclusions. To identify and prioritise barriers for IoT adoption is a multiple criteria decision making (MCDM) problem. Few researchers have used MCDM techniques in their study. Lin L.C. (2009) have adopted Fuzzy Delphi and Fuzzy Analytic Hierarchy Process methods to find out key factors to adopt RFID technology in Taiwan logistics industries. A similar study was conducted by Hsu et al. (2016) for Taiwan logistics industries using DEMATEL technique to evaluate factors influencing

IoT adoption. However, to the best of author's knowledge, no work has been done to identify and rank barriers for adoption of Internet of Things specifically in Indian manufacturing sector.

Research Objectives

In this paper, authors attempt to identify and rank barriers for adoption and implementation of the Internet of Things in manufacturing sector in India using Analytical Hierarchy Process (AHP) as a research methodology. The first objective of the study is to identify barriers for adoption of Internet of Things in manufacturing sector. Though sector-specific barriers can be identified through existing literature, same barriers may have different impact in different country, and hence it might have different significance for that country. Therefore, second objective of the study is to evaluate and prioritise IoT adoption barriers. Hence, Analytical Hierarchy Process is used to determine relative importance of identified barriers for IoT adoption specific to Indian manufacturing sector. Hence, following research questions were formulated for the study.

RQ1: What are the possible barriers hindering IoT adoption in the manufacturing sector in Indian context?

RQ2: What are the raking of the identified barriers as per significance, which will help practitioners to tackle them and adopt IoT technology?

To answer these research questions, a review of related literature with a brief description of identified barriers related to IoT adoption in Indian manufacturing sector are presented in Section 2.A research methodology is described in section 3 whereas case study and detailed results are discussed in Section 4. Managerial implications and direction for future studies are given in Section 5. Finally, Section 6 comprises of conclusion and limitations of the study.

Review of literature

IoT in the Manufacturing Sector

Internet of things (IoT) is considered as a paradigm shift in the field of IT infrastructure which promotes economic development. Many researchers have conducted a study to determine critical factors affecting IoT adoption in various industries. In this study, authors will be focusing on the studies conducted specifically to manufacturing sector. In earlier studies, researchers have only focused on barriers to RFID adoption. Chang et al. (2008) and Lin L.C. (2009) surveyed to assess the critical factors influencing RFID adoption in Taiwan logistics industry. Reyes et al. (2016) also conducted similar research in logistics industry across the world. Wang et al. (2010) conducted a survey to discuss potential challenges to adopt RFID in Taiwan manufacturing firms. Lim et al. (2013) have conducted literature review of articles published between year1995 to 2010 related to RFID and its impact on warehousing operations and presented the obstacles to RFID adoption in warehousing. Chen and Papazafeiropoulou (2012) conducted an empirical study to identify factors affecting RFID adoption in Taiwanese IT manufacturing SMEs. Similar studies were conducted by Pool et al. (2015) for Iranian manufacturing SMEs and Fossowamba et al. (2016) for SMEs in USA, UK, Australia and India.

Bi et al. (2014) conducted a literature review and discussed challenges manufacturing enterprises would face while adopting IoT infrastructure. Contreras et al. (2017) have focused on security and data privacy issues in his literature review conducted on articles discussing productivity improvement using IoT in manufacturing industry. Hsu et al. (2016) and Tu et al. (2018) conducted a survey in Taiwanese logistics industry to determine critical factors influencing IoT adoption. Chan et al. (2013) performed an empirircal study specific to Malaysian manufacturing firms to identify the factors which affects the adoption and deployment of mobile supply chain management. Haddud et al. (2017) assessed the potential benefits and challenges of IoT adoption for individual organisations and complete supply chains, by taking online survey of academicians across six continents. Arnold et al. (2016) and Kiel et al. (2017) have examined the influence of IoT on business model through multiple case study approach by taking interviews of experts from German manufacturing companies. Asir et al. (2015) assesed India's readiness for adoption of new technology namely Internet of Things (IoT) by enlisting challenges to it's adoption and immediate opportunities. Silva et al. (2019) conducted an empirical syudy to enlist key factors which should be considered while adopting and implementing Digital Manufacturing.

Analytical Techniques used in IoT adoption

In the existing research, it is seen that literature review is the most commonly used tool to enlist the challenges in IoT adoption across various sectors. Authors namely Lim et al. (2013); Bi et al. (2014) and Contreras et al. (2017) have talked about various challenges in IoT adoption related to the manufacturing sector by reviewing existing literature. Also, Arnold et al. (2016) and Kiel et al. (2017) used a multiple case study approach to find the factors influencing business models due to IoT adoption. Empirical investigations have also been done by some authors. Chen and Papazafeiropoulou (2012) have identified most significant factors influencing RFID adoption decisions by Exploratory factor analysis. Pool et al. (2015) proposed a conceptual model using TOE framework for factors influencing RFID adoption and conducted Structural Equation modelling to test the model. Similarly, Wang et al. (2010); Reyes et al. (2016) and Fossowamba et al. (2016) proposed a conceptual model using TOE framework for fac tors influencing IoT adoption and conducted regression analysis to test the model. Chang et al. (2008) have proposed a conceptual model for RFID adoption and discriminant analysis was performed to test the model. Similarly, Haddud et al. (2017) have proposed a conceptual framework for IoT adoption and statistical analysis was performed to test the model. Tu et al. (2018) analyzed the factors affecting IoT adoption and their interrelationships using Partial least square structural equation modelling. Few researchers have used MCDM techniques in their study. Lin L.C. (2009) have adopted Fuzzy Delphi and Fuzzy Analytic Hierarchy Process methods to find out key factors to adopt RFID technology. Hsu et al. (2016) have proposed a conceptual model using TOE framework and used DEMATEL technique to evaluate factors influencing IoT adoption.

Research Gaps

It is evident from the literature study that researchers are aware of Internet of things as an upcoming technology and have analysed barriers for its adoption in various industries. Specific to manufacturing industries, many researchers have focused on barriers to RFID adoption, and only in recent studies we could find the research work is done on analyzing barriers to IoT adoption. Also, most of the researchers have assessed barriers which are country-specific. Studies on identifying barriers to IoT adoption related to manufacturing industries were conducted in developed countries such as Taiwan and Germany (Hsu et al., 2016; Tu et al., 2018; Arnold et al., 2016). However, there is no work done on identifying barriers to IoT adoption specific to Indian manufacturing industries. Also, in present literature, descriptive type of research and TOE framework are widely used methods to list the factors influencing IoT adoption. Many researchers have used statistical analysis technique to find out most critical factors influencing IoT adoption. Few researchers have used MCDM techniques to evaluate most critical factors influencing IoT adoption, but studies were specific to Taiwan logistics industries (Lin L.C. 2009; Hsu et al., 2016).

These research gaps have helped us to decide the research problem. There is an urgent need for analysis and identification of barriers to IoT adoption in Indian manufacturing sector. This paper tries to address this research gap by identifying barriers to IoT adoption for manufacturing sector through existing literature and by ranking identified barriers using Analytical Hierarchy Process (AHP) approach.

Barriers for IoT adoption in the manufacturing sector

In this study, authors would be focusing on identifying barriers for IoT adoption in Indian manufacturing industry based on literature review. Eleven barriers were identified in this study based on selected research articles. The search was conducted using the combination of key terms: 'Internet of Things/IoT' AND 'Adoption' AND 'Manufacturing Industry/Sector'. The systematic search was done using open source database to collect the research articles. We excluded white papers, theses, book chapters, conference proceedings and websites and only articles published in peer-reviewed journal were included in this review. Also, articles published in languages other than English were excluded from this study. Further, based on the Title and abstract review, we have excluded those articles which were not directly relevant to our study. In addition to the above-selected papers, few more papers were selected by reviewing the reference lists of the selected papers.

The list of barriers with a brief description is given in Table 1.

Table 1: Barriers for IoT adoption in Indian Manufacturing Sector

Sr No	Barriers for IoT adoption	Description	Authors
1	Lack of top management vision for adopting new technology	Top management support has high influence on organization's acceptance of new technologies. Acceptance and implementation of new technology like IoT requires investment of time, money and support from top management.	Chang et al. (2008); Lin et al. (2009); Wang et al. (2010); Chan et al. (2013); Pool et al. (2015); Reyes et al. (2016); Hsu et al. (2016); Silva et al. (2019)
2	Privacy and Security issue	As enormous data is continuously being shared through internet of things, data security is major concern. Authentication, authorization and access control mechanisms are required to avoid the threats related to data security. Also as these connected devices are sharing lot of personal or industry specific information, data privacy is another major concern.	Lin et al. (2009); Lim et al. (2013); Chan et al. (2013); Asir et al. (2015); Hsu et al. (2016); Reyes et al. (2016); Kiel et al. (2017); Contreras et al. (2017); Haddud et al. (2017); Silva et al. (2019)
3	Unawareness about IoT benefits	Although there are many research papers talking about advantages of implementing IoT technology, many applications of IoT technology are in nascent stage and there is lack of clear understanding about business benefits of the same.	Chan et al. (2013); Fossowamba et al. (2016); Haddud et al. (2017); Tu et al. (2018)
4	Risk involved in transitioning to new business model	Any paradigm shift in technology requires change in business model. New framework of business model is required for IoT technology implementation. As there is unawareness about ROI for IoT technology, organizations are not willing to take risk involved in adopting new business model for IoT technology.	Arnold et al. (2016); Haddud et al. (2017); Kiel et al. (2017)
5	Unawareness about return on investment (ROI)	Main barrier for IoT technology adoption is there is no standard procedure to calculate ROI especially when it requires high initial investment. High risk is involved in evaluating and generating financial returns. Unknown payback period is the biggest barrier in adoption of IoT.	Chang et al. (2008); Lim et al. (2013); Chan et al. (2013)

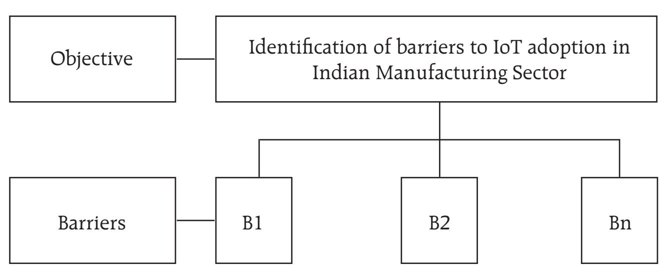
Sr No	Barriers for IoT adoption	Description	Authors
6	High initial investment cost for implementation	Implementation of IoT involves high initial investment including purchase of sensors and networks cost, Software cost, maintenance cost, training cost etc. Indian organizations lack in the financial resources for the same. Also, as the costs of sensors are reducing day by day, Indian firms prefer waiting for reduced cost.	Chang et al. (2008); Lin et al. (2009); Chen and Papazafeiropoulou (2012); Radziwon et al. (2013); Chan et al. (2013); Asir et al. (2015); Reyes et al. (2016); Haddud et al. (2017); Tu et al. (2018); Silva et al. (2019)
7	Employee's lack of acceptance to adapt new technologies	Employees resist to accept IoT technology due to fear of losing a job.	Haddud et al. (2017); Silva et al. (2019)
8	Lack of training programs	After adopting IoT, employees no longer will be just operators, they will be actual problem solvers doing the analysis of data captured by IoT. So training program will be needed to understand IoT technologies.	Chen and Papazafeiropoulou (2012); Kiel et al. (2017); Silva et al. (2019)
9	Lack of skilled / expertise Manpower	Expertise manpower is required to handle IoT technologies. With enormous data coming in, technical knowledge and IT competencies are required for effective implementation of IoT technology.	Haddud et al. (2017); Silva et al. (2019)
10	Lack of competent Technology	IoT application needs IT hardware to implement, support and manage IoT devices and software systems with high speed internet are needed for real time analysis of data generated by IoT devices.	Lin et al. (2009); Wang et al. (2010); Bi et al. (2014); Pool et al. (2015); Asir et al. (2015); Reyes et al. (2016); Silva et al. (2019)
11	Lack of Standardization	Implementation of new technology like IoT is a challenge, but main barrier for this technology adoption is lack of standardization of interoperability interfaces between different IoT devices belonging to different vendors. There are different companies who have prepared different versions of standards which are not compatible with each other.	Chang et al. (2008); Chen and Papazafeiropoulou (2012); Lim et al. (2013); Bi et al. (2014); Asir et al. (2015); Haddud et al. (2017)

Methodology

Multi-criteria decision making (MCDM) techniques is a widely used approach for modelling complex issues. The analytical hierarchy process (AHP) is one of the MCDM techniques widely used as a ranking tool from past three decades. This methodology was developed by Thomas L. Saaty in 1970s and has been applied in different fields of research. The purpose of this study is intended to propose critical barriers to IoT adoption in manufacturing sector in the Indian context. Hence, AHP methodology was chosen for this study as its applicability is widely proven in literature and it is easy to use. In this methodology, each criterion is compared with other criteria in pairwise mode. This methodology ranks the identified factors as per relative importance and helps practicing managers in taking decisions by converting a complex problem into simple hierarchical level (Mishra et al., 2018; Raut et al., 2018). This tool is based upon a mathematical structure of consistent matrices and their associated right Eigen vector's ability to generate true or approximate weights (Saaty, 1980). It may be noted that group decision making using AHP yields better results (Saaty, 2008; Saaty, 1986, 2000; Mishra et al., 2018; Raut et al., 2018). Hierarchy of AHP for selected research problem is shown in Fig. 1.

As stated by Saaty (2003), even though AHP methodology can accommodate any number of criteria for analysis, it can give precise results if criteria

Fig. 1: Hierarchy of AHP



considered for analysis are nine or less. If more than nine criteria are considered in the study, there may be problem of inconsistency in the results. Also, more time will be required for analysis. Despite these shortcomings, we can find in existing literature that many authors have conducted analysis for more than nine criteria (Raut et al., 2018; Govindan and Shankar, 2016; Raut et al., 2019). In the present study, eleven criteria were identified through literature review and validated using expert's opinion. Considering the significance of criteria in manufacturing sector-specific to Indian context, the experts could not omit any criteria from the list. The expert team consisted of diversified blend of Industry and academia experts. Team of ten experts was considered for the present study which comprises of three manufacturing plant heads, two IT managers, three professors from operations and supply chain management department and two research scholars working in same domain. The average experience of an expert was 15 years except research scholars. After finalizing the selection of barriers to IoT adoption through expert's opinion, AHP analysis was performed in MS- Excel.

The procedure followed in AHP methodology is presented through a flowchart which is shown in Fig. 2 and is explained as follow-

1. Identify and finalize the barriers to IoT adoption in the Indian manufacturing sector from literature and expert's opinion.
2. Make a comparison of selected barriers in pairwise mode by inputs collected from experts using Saaty's scale as shown in Table 2 and the final matrix of pairwise comparison of barriers is shown in Table 4.
3. Calculate the largest Eigenvalue of the matrix λ_{max} for weighing the barriers considered in the matrix.

Fig. 2: Flow chart of ranking the barriers using AHP methodology Source: Ho et al. (2006), Raut et al (2018) and Xu et al. (2013)

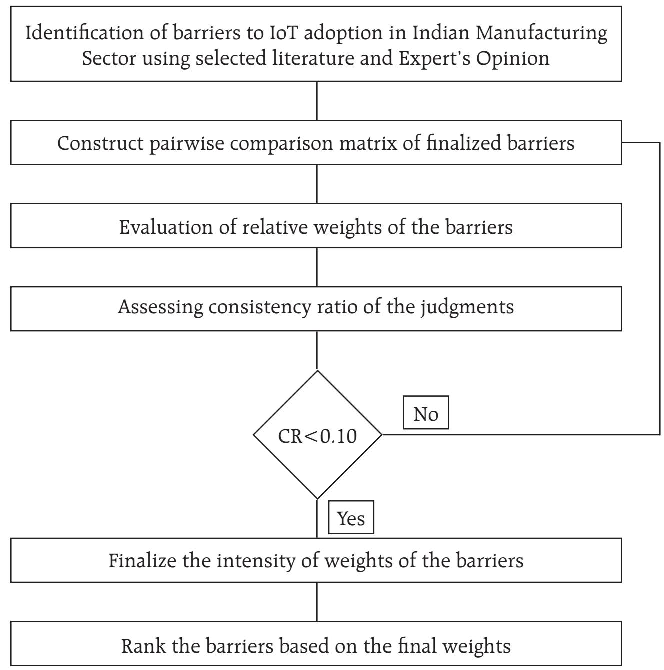


Table 2: Saaty's scale

Intensity of importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values between above stated scale values

Source: Saaty, 2008

Table 3: Random consistency indices

n	3	4	5	6	7	8	9
RI	0.524	0.881	1.108	1.247	1.341	1.405	1.449
n	10	11	12	13	14	15	
RI	1.485	1.514	1.536	1.555	1.571	1.583	

Source: Alonso and Lamata, 2006.

Table 4: Pairwise comparison matrix of the barriers to IoT adoption in Indian manufacturing sector

Barriers	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11
B1	1.00	9.00	9.00	9.00	9.00	9.00	7.00	7.00	7.00	9.00	5.00
B2	0.11	1.00	1.00	1.00	3.00	1.00	1.00	3.00	2.00	1.00	5.00
B3	0.11	1.00	1.00	1.00	1.00	3.00	1.00	1.00	4.00	1.00	5.00
B4	0.11	1.00	1.00	1.00	1.00	1.00	2.00	2.00	3.00	3.00	5.00
B5	0.11	0.33	1.00	1.00	1.00	2.00	1.00	3.00	1.00	2.00	5.00
B6	0.11	1.00	0.33	1.00	0.50	1.00	4.00	3.00	4.00	5.00	5.00
B7	0.14	1.00	1.00	0.50	1.00	0.25	1.00	2.00	5.00	4.00	2.00
B8	0.14	0.33	1.00	0.50	0.33	0.33	0.50	1.00	2.00	1.00	1.00
B9	0.14	0.50	0.25	0.33	1.00	0.25	0.20	0.50	1.00	1.00	3.00
B10	0.11	1.00	1.00	0.33	0.50	0.20	0.25	1.00	1.00	1.00	3.00
B11	0.20	0.20	0.20	0.20	0.20	0.20	0.50	1.00	0.33	0.33	1.00

4. Compute Consistency Index(CI) to assess consistency in the judgments given by experts using the following relation, CI = $(\lambda_{max} - n) / (n - 1)$
5. Choose the value of the random index (RI) for number of barriers (n) by referring to Table 3. In the present analysis, the number of barriers is 11; Therefore, n=11 and the corresponding value of RI=1.5141.
6. Find consistency ratio (CR) to evaluate the soundness of the judgments using relation, CR=CI/RI For n> 5, the value of CR should be less than 10% to accept the final results; otherwise the steps should be repeated by changing values in pairwise comparison matrix till consistency is achieved (Raut et al., 2018).

Results and Discussion

The priority weights of the barriers to IoT adoption Indian manufacturing sector calculated using AHP methodology are presented in Table 5. The most significant barriers identified through our research analysis in descending order of their ranking are - lack of top management vision for adopting new technology (B1) with a weight of 0.416, high initial investment cost for implementation(B6) with a weight of 0.085 and Risk involved in transitioning to new business model(B4) with a weight of 0.084. These three factors need immediate attention of policymakers to improve

Table 5: Relative weights and ranking of barriers to IoT adoption in Indian manufacturing sector

Barrier No	Barriers to IoT adoption	Weights	Ranking
B1	Lack of top management vision for adopting new technology	0.416	1
B2	Privacy and Security issue	0.079	4
B3	Unawareness about IoT benefits	0.076	5
B4	Risk involved in transitioning to new business model	0.084	3
B5	Unawareness about return on investment (ROI)	0.069	6
B6	High initial investment cost for implementation	0.085	2
B7	Employee's lack of acceptance to adopt new technologies	0.066	7
B8	Lack of training programs	0.037	8
B9	Lack of skilled / expertise Manpower	0.032	10
B10	Lack of competent Technology	0.037	9
B11	Lack of Standardization	0.020	11

IoT adoption Indian manufacturing sector. Top management of manufacturing industries should have vision for adoption of new technologies. However, high initial investment cost is major hindrance in IoT adoption. Also, adoption of any new technology requires changes in business model with proper action plan. However, organisations are reluctant to accommodate changes in business model due to risk of failure and huge monetary losses associated with it.

The intermediate level barriers have moderate significance and holding rank from fourth to seventh are - privacy and Security issues (B2) with intensity of 0.079 holding the fourth position, unawareness about IoT benefits (B3) with weight of 0.076 secured fifth position, unawareness about return on investment (ROI) (B5) with magnitude of 0.069 is at sixth position and employee's lack of acceptance to adopt new technologies (B7) with weight of 0.066 stood at seventh position. These barriers are less significant as compared to barriers holding ranks in first tier. Privacy and security issues are widely discussed in the existing literature. However, there is need for clear understanding about IoT benefits and standard payback model for return on investments done in adoption of IoT technology. Also, organisations should help their employees to understand the role changes due to adaption of new technologies which will reduce employee's resistance.

The remaining barriers have low raking compared to top seven factors mentioned above. These factors have a lesser influence on decision of IoT adoption in Indian manufacturing sector. Less influencing factors in descending order from eighths to eleventh position as per their relative weights are - Lack of training programs (B8) with intensity of 0.037, Lack of competent Technology (B10) with same intensity of 0.037, Lack of skilled / expertise Manpower (B9) with weight of 0.032 and Lack of Standardization (B11) with magnitude of 0.020.India lacks the incompetent technology required for IoT adoption. Government bodies and policymakers should focus on developing such required technology. As IoT is new technology, India also lacks in skilled employees. We need to design special training programs for skill development of employees which in turn will help in smooth deployment of IoT technology.

Managerial Implications

The purpose of the present study is to identify and rank barriers for adoption and implementation of the Internet of Things in manufacturing sector in India. Eleven barriers were identified using past literature and expert's input and evaluated using AHP methodology. The primary outcome of this research is to facilitate practising managers from manufacturing industry to be aware of barriers to adoption of IoT technology in Indian manufacturing sector. The results of this work will be beneficial for Indian industries which are early adopters of smart manufacturing approach. With basic understanding gained through results of present research, practitioners can work on eliminating these barriers. However, it is not possible to eradicate all the barriers simultaneously. Hence, with the help of ranking given using AHP methodology in the present research, they can frame the strategies and prioritise their efforts in most effective way.

Conclusions, limitations and future scope

Internet of things (IoT) is a paradigm shift in information technology which can offer several competitive advantages and it can drastically transform industrial businesses such as manufacturing sector. However, its adoption is still not significant in Indian manufacturing sector. It's high time that manufacturing industries in India need to be smarter by embracing upcoming technologies like the Internet of things to have a cutting edge in today's competitive world. Hence, there is urgent need to understand the barriers to IoT adoption specific to

Indian manufacturing sector. In the present study, an attempt has been made to identify barriers for IoT adoption in manufacturing sector in Indian context based on selected existing literature and expert's inputs. Then, ranking of the identified barriers based on their relative importance was performed using AHP methodology. The contribution of the study is many folds.

The findings of the study identify that top management contribution is the most significant factor in IoT adoption. This barrier has to be eradicated with first priority. Attitude and vision of top management leadership play critical role in new technology acceptance. The high initial investment cost is considered as the second most significant barrier to IoT adoption in Indian manufacturing sector. Indian organizations lack the financial resources for the same. Also, as the costs of sensors are reducing day by day, Indian firms prefer waiting for reduced cost. When this cost will go down, we can see increase in adoption rate in near future. Government of India can promote incentive schemes for manufacturing industries to adopt and implement new technologies. India is also lacking competent technologies required for IoT adoption. Government bodies and policymakers should focus on developing such required technology. Also, one of the significant barriers is no standard procedure to calculate ROI especially when it requires high initial investment. Academicians should work upon identifying standard payback model for IoT technology. Another significant barrier to IoT adoption lack of skilled employees. For handling any new technology, new skill set will be required. Organizations need to design special training programs for skill development of employees which in turn will help in smooth deployment of IoT technology. Government of India can provide such training programs at subsidized cost for technological upliftment. To sum up, we can conclude that, in a developing country like India, government plays very critical role in successful adoption of new technology.

While the number of articles on Internet of things is significantly growing in numbers, very few researchers have worked on identifying barriers to IoT adoption in manufacturing and supply chain management (Hsu et al., 2016; Haddud et al., 2017, Tu et al., 2018). However, to the best of author's knowledge, no work has been done to identify and rank barriers for adoption of Internet of Things specific to Indian manufacturing sector. The barriers enlisted in this study will act as guidance to practising managers for decision making and to frame the strategies and prioritize their efforts in most effective way for IoT adoption. However, there are certain limitations to this study. The present study identifies and ranks eleven barriers to IoT adoption in Indian manufacturing sector using AHP methodology. However, there may be few factors which will influence the adoption decision but are not considered in this study.

In future studies, more factors can be considered to yield better results. Also, only ranking of the identified barriers is performed in the present work. Finding causal relationships between identified barriers can be taken as a future study. (Xu et al., 2013) The present study is specific to manufacturing sector in India. Various sectors can be taken for exhaustive investigation by future researchers. The AHP methodology used in this study has few weaknesses. There is no way to validate relative weights decided based on expert's judgments. Also, experts selected for this study are not randomly selected and hence, the inputs for the analysis can be biased which will strongly influence result. (Saaty,2008) To avoid these uncertainties, other MCDM techniques such as decision making trial and evaluation laboratory (DEMATEL), interpretive structural modelling (ISM) or technique for order preference similarity to ideal solution (TOPSIS) can be used in future studies (Raut et al., 2018).

Similar studies can be performed in other developing countries by taking the findings of the present study as a guidelines. Also, a comparative study can be conducted between barriers identified to IoT adoption in manufacturing sector for developed and developing countries which will be useful for practicing managers.

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Effects of risk-pooling in the allocation of customer orders and returns in online retailing

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This paper deals with allocation of integrated customer orders and returns in an online retail environment employed with virtual pooling and transshipments. A four-echelon online retail supply chain is formulated as a mixed integer programming model which involves the allocation of customer orders and customer returns to the fulfillment or return distribution centres as applicable, with an option to have reactive transshipments between fulfillment distribution centres. The cost minimization problem is solved optimally for some numerical experiments using Gurobi Solver Engine. Findings identified from the study include the importance of risk pooling in online retailing and the benefits of considering return allocation integrated with order allocation. The results from experiments show significant reduction in initial inventory at DCs and overall cost savings when returns and risk pooling are considered during order allocation.

Keywords: *Online Retail, Risk Pooling, Virtual Pooling, Inventory Transshipment, Order allocation, Return allocation*

Introduction

The rapid growth of the online retail industry has made industry practitioners and academicians to focus on the key operational aspects in the area of e-tailing. One of the most important aspect in online retail is the allocation of orders and returns to the distribution centres (DCs) or the suppliers. Once the customer places an order or requests for a return, the online retailer has a lead-time of a couple of days to a week or two to honour the same. Making use of this lead-time efficiently for allocating orders and returns is very important (Tarobi *et al.*, 2015).

On a typical operational day for an online retailer, there will be many a number of orders and returns from customers. An online retailer can choose to make the allocation decision towards the end of the day for the orders and returns placed on that particular day. These orders and returns will have a stipulated period of lead-time, say *x* days. In this time window, the e-tailer has multiple options in allocating the orders and returns. Intuitively, the online retailer can choose the nearest DC to fulfill a particular order or a return, depending on the stock availability of the product in case of an order, or the availability of capacity to accept return in case of a return request. If the nearest DC does not fulfill the criteria, another DC which has either the stock for the order or the capacity for return, may honour the order or return in question. This idea of aggregating inventory or capacity across multiple facilities is termed as virtual pooling (Chopra and Meindl, 2013).

In a virtually pooled setup, online retailers can adopt multiple ways to honour an order. Most e-tailers make use of third party logistics (3PL) to ship products to the customers' doorstep. If an order has to be fulfilled from a far-away DC, either the items can be shipped directly to the customer using 3PL services or it can be shipped to the closest DC to the customer, from where a 3PL vendor can be used, which would reduce the cost of shipping through 3PL. The shipment amongst DCs can be combined across orders (unlike 3PL shipments), which can bring in economies of scale considering the use of full truck loads (FTL). Such shipment of items amongst DCs once the order is placed can be called as reactive transshipments (Oeser, 2015, Paterson et al., 2011).

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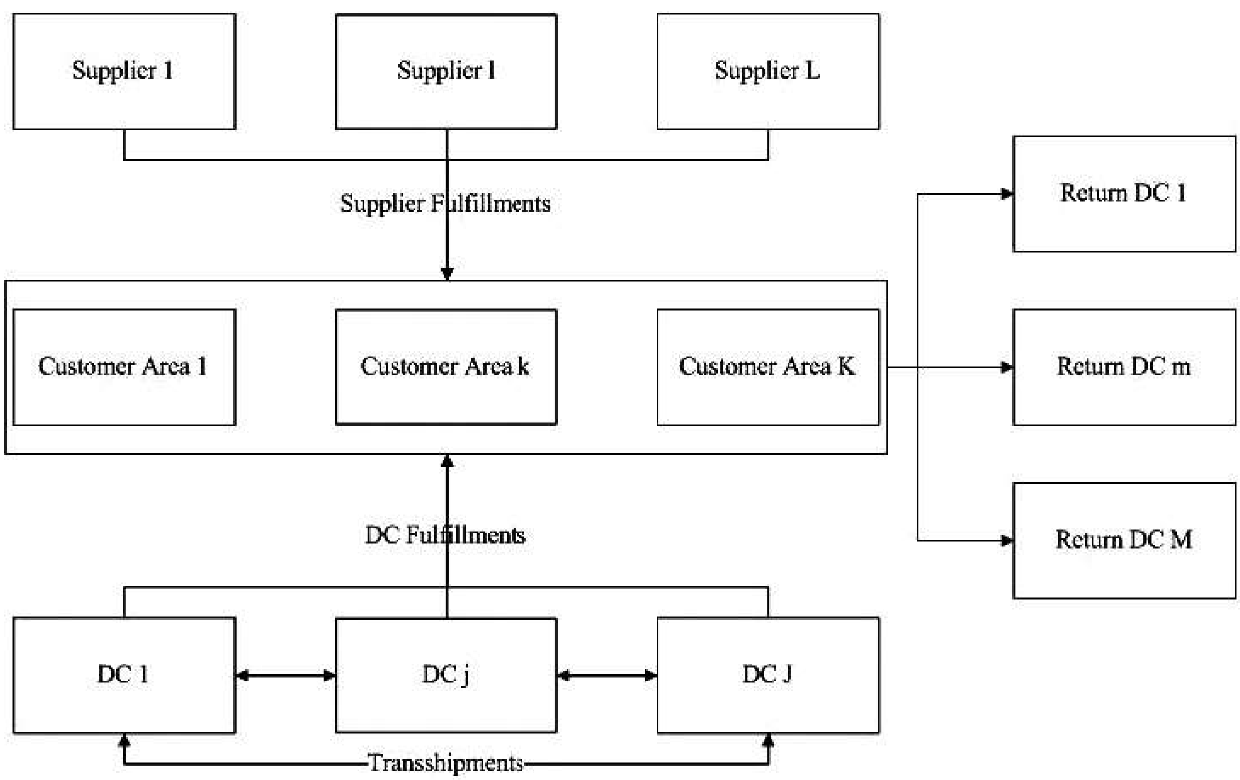
Online retailers also have an option to divert any order to the supplier of the product, who can directly deliver the product to the customer. The supplier can charge the online retailer for the shipment costs. This option requires prior knowledge of inventory levels with the suppliers. E-tailers only offer items that are available and hence keep their stock levels always updated and while using the option of direct delivery from suppliers, they keep the stock levels updated considering the inventory with the suppliers. Thus, suppliers' stock is also considered in the virtual aggregation of inventory.

In the event of a product return, the item has to be collected at the customer's door step and transported to a DC which can accept the item. Not all DCs accept returns, moreover, different DCs may accept return for different items, and not all items. Once a product is obtained from the customer, the product has to be put to quality check. If the item passes the check, it may need repackaging and it has to be transferred to the fulfillment DC, which may be the same facility itself or a different one. If the product does not comply with the quality specifications, it needs to be returned to the seller or salvaged, based on the tactical decision taken for the product.

The products that get transferred to the fulfillment DCs will get added to the inventory. Between two replenishments, the repackaged products will participate in the order allocation process discussed above. If a product is collected on Day 1 and reaches the fulfillment DC on Day 3 after all the processes, from Day 3, the inventory at that DC will have this product as well and can be allocated to an order. Until the next replenishment occurs, the stock levels are heavily dependent on the returns as well, which in turn drives the order allocation process.

Figure 1: shows the overall flow of items in e-tailing.



In the backdrop of the above discussed business model followed by most e-tailers, this paper intends to develop a model integrating order processing and returns processing. Solving such a model will provide insights on the everyday operational problems such as order allocation, return allocation and quantity of transshipments. Further, the model can be used to explore the impact of transshipments and having direct shipments from suppliers as options in different scenarios. These insights can be utilized for the tactical decisions in the future.

Section 2 reviews the existing literature on e-tailing and risk pooling broadly. Section 3 defines the problem addressed through this work and further details the problem formulation. Section 4 discusses the insights obtained from the experiments, and the final section concludes the work stating the future scope as well.

Literature Review

A lot of academic and industrial studies have taken place concerning e-tailing. Even though delivery shipping costs are considered as an addition to the expenses in an e-tailing framework especially when delivery charges are waived off, there are studies portraying how savings can be made to make-up for this. E-tailing involves lower property costs, inventory costs, and processing costs such as printing and postage expenses than brick and mortar retail outlet chains (Chen and Leteney, 2000). In the previous section, the importance of lead-time and the flexibility involved with it was discussed, which is a key advantage to meet customers' requirements efficiently. With all the advantages that are expected out of the e-business, more and more brick and mortar stores are entering the online market (Boston Consulting Group, 2000).

With the fast growth of e-tailing in terms of e-tailers and customers' usage, a lot of studies have focussed on evaluating online framework with the traditional retailing enlisting the pros and cons of e-tailing. A comparison of traditional retailing with e-tailing highlighting key factors to succeed in e-tailing and raising the important management issues that arises in the virtual framework was studied by Chen and Leteney (2000). Lin and Mahmassani (2002) studied various delivery policies for online groceries in the US and employed the vehicle routing problem solution. The impact of these policies in some experiments are analysed in the paper. De Koster (2003) examines some of the fulfillment strategies for store inventory, picking, and order delivery, and has identified the pros and cons of these strategies. Cao and Zhao (2004) proposed a conceptual structure integrating various aspects of e-tailing and has analysed the order fulfillment performance based on various e-tailer attributes such as multiple fulfillment channels, inventory management systems, order tracking, and product pricing, and identified significant impact on the order delivery performance through empirical results. Mokhtarian (2004) analysed some of the problems involved with the evaluation of transportation and spatial aspects of e-tailing. The study compares brick and mortar framework with e-tailing and concludes that none has a uniform domination over the other.

In 2008, Agatz et al. presented a comprehensive review of e-tailing, covering various aspects and corresponding works done till 2008, and identified the need for more work addressing the optimization of inventory and delivery operations in e-tailing. Campbell and Savelsbergh (2006) reported that most works in the field has dealt with the profits of difference service and not on the optimization of a single model's performance. Also, the allocation of orders and inventory transfers has not been optimized explicitly. In 2005, Xu's PhD work dealt with 3 problems in the e-tailing environment, one of which considered a network of fulfillment DCs and customers, and optimized the allocation of orders once it was placed. Another one allocated low demand SKUs amongst the DCs and the other one involved the optimization of inventory within a DC. Hsu and Li (2006) proposed an optimization of delivery shipment cycles by striking a balance between delivery costs and delivery lead times through a non-linear profit maximization model with lead-time dependent demand.

Aksen and Altinkemer (2008) formulated a mixed integer programming problem for facility location and routing decisions to switch from retailing to e-tailing and solved it using an augmented Lagrangian relaxation algorithm. Liu et al. (2010) proposed a location model assigning online demands to capacitated DCs that currently serve store orders in a multi-channel supply chain with risk pooling applied. The study looks at the trade-off between risk pooling effects and transportation costs. Evangelist et al. (2011) has a patent in the order fulfillment of online and physical store demands. Acimovic (2012) completed his doctoral work based on order fulfillment problems employed in various datasets proposing heuristic solutions, which are computationally tractable. The work was later published in 2015 (Acimovic and Graves, 2015). Tarobi et al. (2015) formulated a mixed integer linear programming problem optimizing the order allocation to fulfillment DCs taking multiple shipping options into consideration and having risk pooling employed.

The number of works in handling customer returns are relatively less, though returns is an integral part of e-tailing and in industries like fashion, return rate is as high as 45 percent (Tarn et al., 2003). Eradicating cost of returns is not feasible in an e-tailing model and hence an efficient returns allocation is essential (Min et al., 2006). There is a huge difference between returns in e-tailing and end-of-life returns (Dekker et al., 2013) and supply chain coordination models (Tsay et al., 1999). In 2009, Peterson and Kumar studied the product returns behaviour in an e-tailing framework stating the sparseness of works in returns. Works on returns are less in e-tailing and the ones that are present studies the behaviour patterns. There is no work for the returns allocation problem in the e-tailing framework.

This paper intends to address this gap of allocating customer returns. Further the customer returns and orders over a time period is known upfront and the work intends to minimize the overall costs involved using an integrated model with orders and returns allocated together. The problem will employ risk pooling as well.

Risk pooling has become a basic concept in operations management finding its way in the operations management books itself. Chopra and Meindl, 2013 explains the various inventory aggregation techniques and its advantages. Oeser (2015) has covered various aspects of risk pooling in his book. Paterson et al. (2011) has done an extensive review on lateral transshipments within an inventory system between facilities of the same echelon. There are many works that model lateral transshipments in different inventory models and are solved mostly using optimization techniques (Liao et al., 2014, Özdemir et al., 2013, Yang et al., 2013). Liu (2010) proposed a model for online demand pooling in a multi-channel scenario through virtual pooling. There has been a lot of research in the field of risk pooling and this paper will be an addition to the literature, which involves an integral problem with reactive transshipments and virtual pooling.

Problem Description

The problem considered in this study consists of 4 levels, with J Fulfillment DCs, K Customer Areas, L Suppliers, and M Return DCs. Customers can order one or more products out of the I different products offered. The problem is modelled for one period and all the orders and returns have to be honoured in the same time window. The knowledge of inventory levels at every DC and Supplier for each product is known upfront. The capacity of DCs to accept returns for each product is also known upfront. With this information, the following questions needs to be addressed through the model:

1. Which fulfillment DC or Supplier should be allocated to each item ordered by each customer?
2. Which DC should accept the return requested for each product by each customer?
3. How much transshipments should be done between every pair of DCs?

The objective of the model is to incur minimum combined transportation and transshipment costs while honouring the orders and returns. In order to reduce the complexity of the problem, customers from a particular area coming under similar cost caps are grouped under various customer areas, which reduces the number of variables and constraints considerably.

Model Formulation

Customer demand for each area *k* is known and can be served by either through shipment from one of the fulfillment DCs, preferably the nearest, or through shipment from one of the suppliers, or from DCs after transshipment or as a combination of all these options. The costs involved in these options include the cost to ship from DCs to the customer areas, cost of transshipments involved, and the cost of honouring through the supplier.

Customer return requests for each area *k* is also known and has to be accepted by the return DCs. The shipment of returns will occur to the nearest DC where capacity for the particular item is available. Returns from one customer area k can be shipped to different DCs based on capacity constraints.

The overall cost function will include (i) shipment costs from fulfillment DCs to customer areas (ii) shipment costs from suppliers to customer areas including the premium (iii) transshipment costs between DCs (iv) return shipment costs from customer areas to return DCs. The objective of the model is to minimize the summation of all costs. The formulation of the problem results in a mixed integer linear programming (MILP) problem.

First constraint is the demand constraint that ensures that the demand for each product from every customer area is honoured. Second constraint ensures that the number of items shipped from each fulfillment DC together with the overall transshipments of each product does not exceed the inventory levels at each fulfillment DC for every product. Third constraint ensures that the number of items shipped from each supplier is within their stock level. Fourth constraint ensures that all returns for every item from each customer area is honoured. Fifth constraint takes care of the capacity constraint for each product at every return DC while returning shipments are allocated. The formulation for the problem is given below.

Notations

Indices	
i	Products
j	Fulfillment DCs
k	Customer Areas
l	Suppliers
m	Return DCs

Parameters	
c^{d}_{ijk}	Cost of shipping Product i from DC j to Customer Area k
c^{s}_{ilk}	Cost of shipping Product i from Supplier l to Customer Area k
$c^{t}_{ijj'}$	Cost of transshipping Product i from DC j to DC j'

c^{r}_{ikm}	Cost of shipping Product i from Customer Area k to Return DC m
d_{ik}	Demand for product i from Customer Area k
r_{ik}	Number of returns for product i from Customer Area k
I^{d}_{ij}	Inventory level of product i at Fulfillment DC j
I^{s}_{il}	Inventory level of product i at Supplier l
C_{im}	Return capacity for product i at Return DC m

Decision Variables	
x_{ijk}	Quantity of Product i to be shipped from DC j to Customer Area k
y_{ilk}	Quantity of Product i to be shipped from Supplier l to Customer Area k
$q_{ijj'}$	Quantity of Product i to be transshipped from DC j to DC j'
z_{ikm}	Quantity of Product i to be returned from Customer Area k to Return DC m

Conditions

- Overall demand is less than the cumulative inventory at hand.

$$\sum_{k=1}^{K} d_{ik} \le \sum_{j=1}^{J} I_{ij}^{d} + \sum_{l=1}^{L} I_{il}^{s} \quad \forall\, i \tag{1}$$

- Overall return DC capacity is more than the returns.

$$\sum_{k=1}^{K} r_{ik} \le \sum_{m=1}^{M} C_{im} \quad \forall\, i \tag{2}$$

Model Formulation

The overall cost function will include (i) shipment costs from fulfillment DCs to customer areas (ii) shipment costs from suppliers to customer areas including the premium (iii) transshipment costs between DCs (iv) return shipment costs from customer areas to return DCs. The objective of the model is to minimize the summation of all costs. The formulation of the problem results in a mixed integer linear programming (MILP) problem which is illustrated below:

$$Min \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} c_{ijk}^{d} * x_{ijk} + \sum_{i=1}^{I}\sum_{l=1}^{L}\sum_{k=1}^{K} c_{ilk}^{s} * y_{ilk} + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{j'\neq j} c_{ijj'}^{t} * q_{ijj'} + \sum_{i=1}^{I}\sum_{k=1}^{K}\sum_{m=1}^{M} c_{ikm}^{r} * z_{ikm} \tag{3}$$

Subject to

$$\sum_{j=1}^{J} x_{ijk} + \sum_{l=1}^{L} y_{ilk} \ge d_{ik} \quad \forall\, i,k \tag{4}$$

$$\sum_{k=1}^{K} x_{ijk} + \sum_{j'\neq j}(q_{ijj'} - q_{ij'j}) \le I_{ij}^{d} \quad \forall\, i,j \tag{5}$$

$$\sum_{k=1}^{K} y_{ilk} \le I_{il}^{s} \quad \forall\, i,l \tag{6}$$

$$\sum_{m=1}^{M} z_{ikm} \ge r_{ik} \quad \forall\, i,k \tag{7}$$

$$\sum_{k=1}^{K} z_{ikm} \le C_{im} \quad \forall\, i,m \tag{8}$$

$$x_{ijk}, y_{ilk}, q_{ijj'}, z_{ikm} \ge 0 \text{ and } \in I \quad \forall\, i,j,j' \neq j,k,l,m$$

Equation (3) is the objective function which minimizes the summation of all costs discussed above. Equation (4) is the demand constraint which ensures that the demand for each product from every customer area is honoured. Equation (5) ensures that the number of items shipped from each fulfillment DC together with the overall transshipments of each product does not exceed the inventory levels at each fulfillment DC for every product. Equation (6) ensures that the number of items shipped from each supplier is within their stock level. Equation (7) ensures that all returns for every item from each customer area is honoured. Equation (8) takes care of the capacity constraint for each product at every return DC while returning shipments are allocated.

Numerical Experiments

As part of the study, a few experiments are conducted to obtain some managerial insights. All experiments are conducted using the Gurobi Solver Engine 6.5. All the experiments conducted as part of this study involves 1 product, 3 suppliers, 6 fulfillment DCs, 3 return DCs, and 30 customers. The problem results in 486 integer decision variables and 75 hard constraints. All iterations converged within 10 seconds on an average.

For the experiments, data is generated as follows.

- Shipment costs for orders and returns DCs between Customer Areas are calculated based on the distance between them.
- Transshipment costs are assumed to be 10 percent of the 3PL shipment costs.
- Supplier shipment costs are taken with an addition of a premium amount along with the shipment costs.
- Demand and Returns are generated for each customer area using uniform distribution as adopted in the paper by Tarobi *et. al.* (2015).

Computational Results

The base MILP problem is run multiple times with and without transshipments and supplier shipments for different demand and return levels. A sample of five iterations is illustrated in table 1. Transportation and transshipment cost savings based on the average is above 5 percent. Also, the inventory levels required to be maintained at the DCs with transshipments and supplier shipments are above 23 percent. The overall cost savings considering reduced inventory levels is very high, which rationalize the need to employ transshipments and supplier shipments.

The DC inventory level to be maintained depends on the supplier premium and transshipment multiplier values as well. Hence, the above experiment is put to an impact analysis with supplier premium values of ₹ 25, 50, and 75 and transshipment multiplier values of 10, 30, and 50 percent. The results of the analysis are captured in the figures 2, 3, and 4.

Fig. 2: Impact Analysis of Supplier Shipments

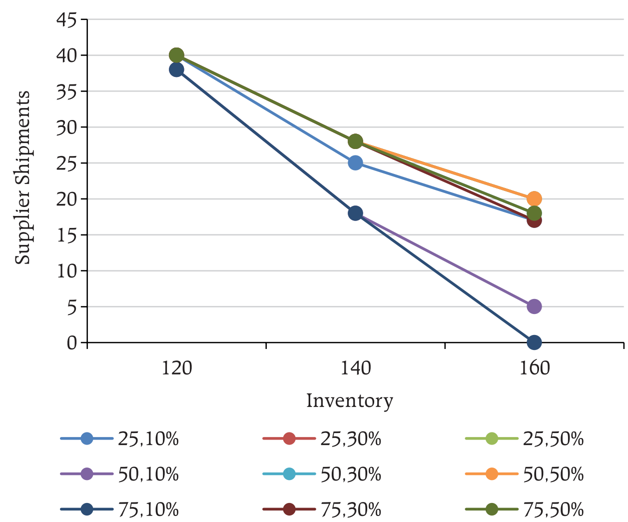


Table 1: Base Problem Experiment Results

With Transshipments and Supplier Shipments						Otherwise		
Runs	Demand	DC Inventory	# Transshipments	# Supplier Shipments	Overall Costs (₹)	Total Shipments	DC Inventory	Overall Costs (₹)
1	130	120	17	10	20975	130	130	21385
2	139	120	18	19	21830	139	140	22140
3	152	120	24	32	22900	152	152	24095
4	152	120	21	32	26385	152	152	31215
5	164	120	20	44	28295	164	165	28145
Avg	**148**	**120**	**20**	**28**	**24077**	**148**	**148**	**25396**

Fig. 3: Impact Analysis of Transshipments

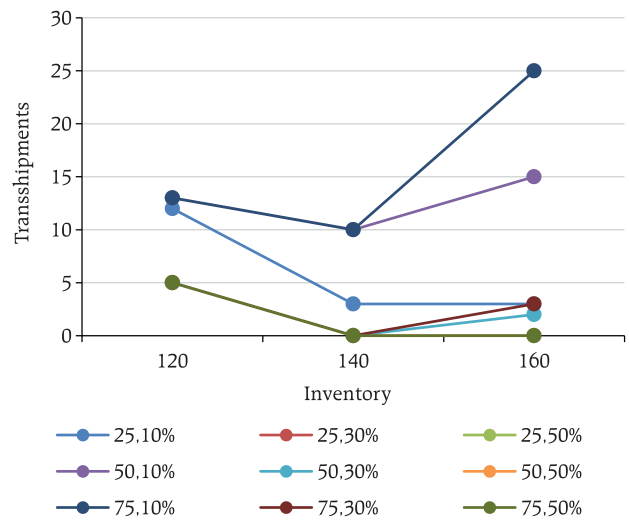
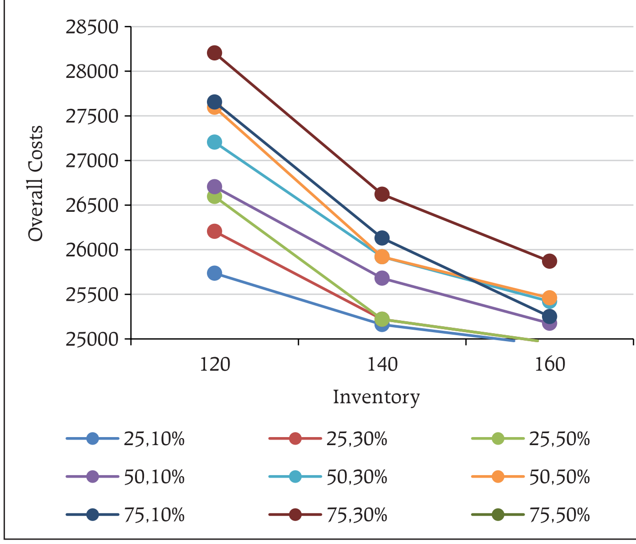


Fig. 4: Impact Analysis of Overall Costs



Following are the observations based on the impact analysis conducted:

- The number of transshipments reduces from 8 percent to about 1 percent of the total shipments when the multiplier is 30 percent and above.
- The shipments from supplier accounts for 13.6 percent of the total shipments when the premium is ₹ 25, and reduces slightly to 12.4 percent when the premium is increased to ₹ 50. When the premium is more than ₹ 50, supplier shipments takes place only when DC runs out of inventory.
- Overall costs vary primarily based on the premium and then based on the multiplier as shown in figure 11. With ₹ 50 and 10 percent, and with ₹ 25, overall costs are much lower and be considered acceptable at all the three inventory levels.

The model can be used to simulate the real life allocation of orders and returns placed every day. If this same experiment is conducted for 6 days, assuming replenishment occurs once in 7 days, and inventory is updated every day after the orders and returns are allocated, the real life allocation of orders can be monitored, based on number of orders, returns, and the amounts of returns that are pushed back to the inventory. This will help in understanding the apt level of inventory considering returns as well. The results for the 7 day simulation is tabulated in table 2.

Findings from the simulation are listed below:

- Without returns, the level of inventory to be maintained at the fulfillment DCs was ranging from 120 to 140 with transshipments and supplier shipments. With returns, experiments have proven that inventory of 60 to 70 will suffice the demand. This shows that considering returns helps in reducing the inventory by 50 percent on an average.
- The overall costs with and without risk pooling does not differ much, though risk pooling proves to be less costly.
- The average inventory handled over the 7 day period is less 50 percent when risk pooling is employed in this case. The integration of risk pooling and returns handling helps in high cost savings considering the overall logistics costs.

Table 2: Seven Day Simulation Results

Days	Demand	Returns	With Supplier Shipments and Transshipments				Otherwise	
			DC Inventory	# Supplier Shipments	# Transshipments	Overall Costs	DC Inventory	Overall Costs
1	150	65	420	0	0	21830	630	21830
2	182	74	270	0	0	23025	480	23025
3	168	66	141	27	31	23200	351	21150
4	182	83	54	128	42	38610	237	28825
5	109	80	68	41	46	28545	123	29400
6	74	74	65	9	36	20295	79	26580
7	63	91	60	3	29	18470	65	23370
Sum	**778**	**468**	**658**	**208**	**184**	**152145**	**1335**	**152350**
Avg	**112**	**67**	**94**	**30**	**27**	**21735**	**191**	**21765**

Managerial Insights

In e-tailing, risk pooling helps in making major cost savings through virtual aggregation and reactive transshipments. In order to consider virtual aggregation and transshipments, an optimization model has to be formulated for the allocation of orders considering risk pooling. Such a model was created as part of this paper to quantify the benefits of following risk pooling in e-tailing. This is established from the experiments conducted in this study through reduction in transportation costs and highly reduced inventory levels.

Further, customer returns being a very critical part of e-tailing, integrated allocation of returns along with orders will provide the overall impact. Hence, the model is extended to include customer returns as well and integrated allocation of orders and returns can be done for a time-period. The benefits of having returns integrated with risk pooling is proven through the simulation results. There is 50 percent reduction in initial inventory level with returns and 50 percent reduction in overall inventory handled when risk pooling is in place. The overall costs are also lesser with returns and risk pooling in place.

This work proves that risk pooling is essential and effective in an e-tailing framework and integrating it with returns further increases the cost effectiveness. E-tailers need to make the most out of such a model by employing it in everyday allocation of orders and returns as well as for tactical and operational analyses. The two-fold usefulness of the model is established through the various experiments conducted as part of the study. The high levels of inventory reduction helps in reducing fixed costs as well since storage spaces can be reduced, thus having influence even in strategic decisions of facility location and layout.

Conclusions

The e-tailing business in India has a tremendous growth opportunity, which will depend on the right systems in place and the right resources being utilized. One of the major decisions to be made in e-tailing at an operational level is the orders and returns allocation in the window of opportunity once the customer requests for the same having risk pooling in place. The paper analyses the problem and formulates a model, which can be employed for allocation on a daily basis and also can be employed for various analyses helping in short term and medium term decision making.

Current literature does not have studies integrating order and return allocation along with risk pooling. There are studies which integrates order allocation process with risk pooling and has been proven to be beneficial (Torabi et. al., 2015). This paper integrates order and return allocation along with risk pooling, and analyses the impact of risk pooling and returns in terms of cost and inventory levels maintained and has found major savings. The model formulated can be used on an everyday basis for allocation of orders and returns, and can be used for multiple analyses for decision making.

The study however can be improved in multiple ways. The data taken as part of the study is for a small area and hence, the problem is small. For generality, multiple iterations of the problem have to be performed with different datasets. The study does not consider the option of cancelling an order once it's placed, before it is delivered, which is a valid option in e-tailing. This is a required extension to have the actual e-tailing system exactly modelled. The analysis done as part of this paper is only for single product scenarios and does not take care of order consolidation in shipping, which is another helpful extension to this work.

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Mumbai Dabbawala's Case: An Excellence to Supply Chain Co-ordination

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The Mumbai Dabbawala Association is an organization based in India which is world famous for its Supply Chain network and expertise. Quite often we have seen businesses fail because of lack of technology mainly for sharing of information but the Dabbawala's are the exact opposite of such organizations. This paper highlights how the Mumbai's Dabbawala's have been able to achieve success by designing its supply chain without any investment in technologies. The Dabbawala's employees are actually partners and not employees of the organization. The Mumbai's Dabbawala's have been delivering home-cooked food from the customer's houses to the customer's offices since the past 129 years and have a track record of making less than 1 mistake in every 16 million deliveries to offices. The association has approximately 85% of its employees/partners who are illiterate and have been able to achieve a 100% customer satisfaction rate.

Keywords: *Mumbai Dabbawala, Supply Chain, Performance Excellence*

Introduction

A. About Mumbai - The commercial Capital of India

Just like Washington doesn't control New York, New Delhi doesn't control Mumbai, which is the financial/ commercial capital of India (Thomas, 2007). Mumbai accumulates to approximately 603 Km2 of land, in which a total population of 12.47 million people reside (as of 2011) (Indian Government, 2011). The Mumbai railway network has been operating for more than 150 years, originally designed by the British in India. Mumbai (formerly known as Bombay) is a city, which has been geographically designed according to the railway network. It has approximately 160 localities out of which most of the localities are segregated in two different categories of East and West of the railway line. For example as we can see that Station Number 11, Dadar is one railway station, but locality wise, its divided into two different localities of Dadar East and Dadar West. This is nothing but the classification of Dadar from the East and West side of the station.

This information is very important in terms of understanding the supply chain of the Mumbai's Dabbawala's.

B. About Dabbawala

"Dabbawala" is a Hindi word describing a man selling boxes. However, in Mumbai a "Dabbawala" is referred to a man whose job is to pick up home-made freshly cooked food from the home of the customer and deliver it to the customer's office (Patel & Vedula, 2006). Dabbawala is a business with approximately 5000 employees who are not actually employees but business partners of the Charitable Trust NMTBSA (mentioned below), with their main aim is to make sure that their customers get to eat healthy food made by someone who understands their taste and prepares the food as hygienically as possible. Like mentioned earlier, Mumbai is one of the most populated cities in the world. With approximately 20700 people living per square kilometer, it is nearly impossible for a person travelling in a local train to even flex a little bit. In such situations carrying large tiffins becomes very difficult. This gives rise for the needs of the Dabbawala's services. Dabbawala, as this paper would show has one of the most efficient supply chains in the world with no investment in technology, no negative effect to the environment and one of the most promising organizations with a six sigma certification awarded in recognition of 99.9997% accuracy rate of deliveries.

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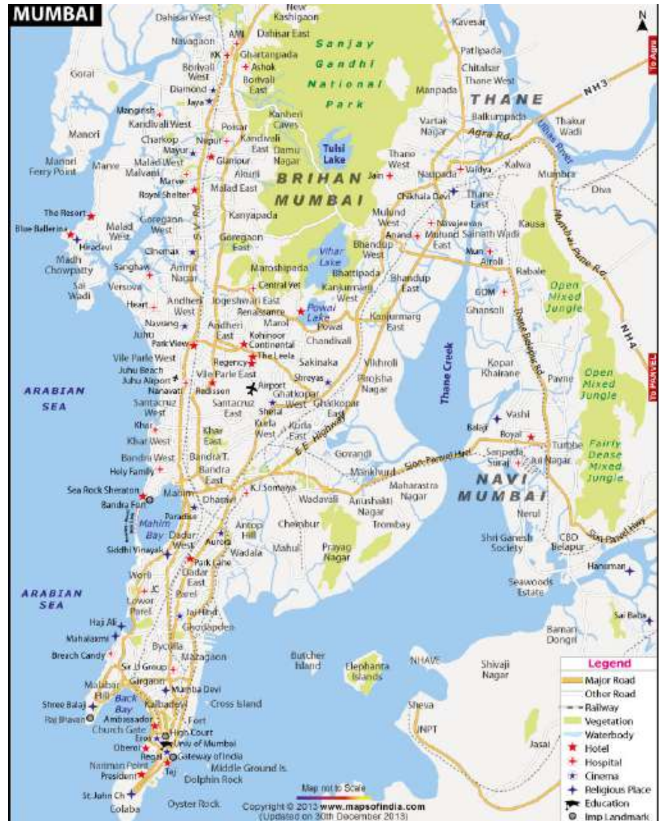
(Bhabha Atomic Research Centre, 2014)



(Travel India, 2014)

Evolution of the concept, historical background, current trends and context

According to Mumbai Dabbawala Association, "The Dabbawala was inaugurated due to the need of a Parsi banker who desired homemade food on a regular basis from home, and he hired the first Dabbawala ever". With this desire evolved a need of many other Indians who liked the idea and demanded the same service. In 1990, 'Mahadeo Havaji Bachche', perceived this need at the right time created what we today call the "Mumbai Dabbawala". The Mumbai Dabbawala is an organization, in which approximately 85% of the employees are illiterate. The concept of the Dabbawala evolved in 1890 was when the first time a coding system was designed to match the deliveries to the final destination. The coding system, is one of the only few coding systems in the world that did not need to evolve too much with the changing demand patterns of the business. The Dabbawala's not only deliver the homemade food in the morning from the customer's house to their office, but they also deliver empty tiffin's back from the customer's office to their homes.

The Dabbawala's transacts 200,000 customers on any average day for 6 days a week, 51 weeks i.e. 400,000 tiffin's a day (to and fro). The Dabbawala's have always delivered the tiffin's to the customer's office regardless of the floods that happened in Mumbai, the bomb blasts that happened in Mumbai. The overall organization structure makes it such a strong business that the Mumbai Dabbawala are famous in different parts of the world for their time management. The Dabbawala's have had guests such as Prince Charles visit their premises, the Dabbawala's are the first to get a six sigma certification from Forbes and they are positioned next to Motorola for their immense supply chain management recognizing that they do only 1 in 16 million errors. However, if any random Dabbawala is asked that, have you made an error such as exchanged tiffin's, reached after lunch hours, he would not agree to it.

Each Dabbawala, serves approximately 30 customers charging 300-400 rupees per customer (£3-4 or $6-8), totaling up to 9000 - 12000 rupees per month. For this reason they not only work as Dabbawala, they do a lot of additional odd jobs such as delivering newspapers, driving auto rickshaws etc. They are satisfied with these salaries, even though if you ask a middle class man, there is no way he can survive with such a low salary. It is the organization which ensures that the employees are satisfied which mainly contributes to such a passion of a Dabbawala to perform outstanding job that pays awfully less. The Mumbai Dabbawala has an attrition rate of 0% and a retention rate of 100%. Even though, like any other organization in the world the Mumbai Dabbawala's have had instances with disputes, however none of the Dabbawala's has ever been convicted or faced a police case.

The Mumbai Dabbawala's have solved the problem of thousands of people, by providing them a solution through which their customers can save a lot of money, eat healthy food prepared by their loved ones with their choice of taste and can eat at proper lunch hours. The Dabbawala's although an organization with the majority of illiterate employees is one of the only few organizations which has been researched by PhDs and MBAs from all around the world and has had famous celebrities and people from the Royal families from all around the world as guests on their premises. To study the overall organization from a Management perspective is beyond the scope of this paper, however this paper would elaborate mainly on the Supply Chain Processes of the Mumbai's Dabbawala's. Some of the important factors about the development of the processes and the actual processes are mentioned further in this paper. Also, the Supply Chain design and the efficiency of the organization have further been mentioned in the following sections.

Description of the supply chain practice including its key elements

According to Chopra and Meindl, "strategic fit can be achieved by a company only if its supply chain capabilities are sufficient to support its capability to meet the needs of its target clients" (2013). In our opinion, the Mumbai Dabbawala's have successfully been able to meet the strategic fit. Let us examine this using the methodology of Chopra and Meindl:

1. "Understanding the Customer and Supply Chain Uncertainty" (Chopra, Meindl, 2013): The response time bearable by the customers is very short, the different product variety needed by the customers is not too much, the service level required is fairly high, the Anticipated Innovation Rate required for the service is very limited or negligible and finally the implied demand uncertainty is not too high. Most of the characteristics imply that the Demand uncertainty is low and fairly predictable. The only exceptions to this are the days when there are natural disasters such as floods or terrorist attacks, these are the days when people would prefer having home food until its safe for them to travel back home. However, the Dabbawala's have certainly been able to meet these criteria and been able to anticipate supply chain uncertainties very successfully indicating "low implied demand uncertainty".
2. "Understanding the Supply Chain Capabilities" (Chopra, Meindl, 2013): Most of the factors under

this part to decide the strategic fit of the company don't apply to Mumbai Dabbawala's. To start with, they do not need to respond to extensive ranges of quantities i.e. the quantity demanded doesn't fluctuate a lot. However, they need to meet short lead times which pushes it to be a little responsive to its customers. They do not need to handle a huge variety of goods since it's a very different type of service and it doesn't need to build highly innovative products. Mumbai's Dabbawala's, however need to meet a high service level, but the Dabbawala's have mastered the art with experience and training from seniors to meet these service levels very efficiently. Lastly, they also don't need to handle the uncertainty of supply, because if the customer's home doesn't prepare the Dabba by the time the Dabbawala arrives, he doesn't wait too long and leaves because he can't disappoint other customers. So to sum up their Supply Chain Capabilities, they need to be "Somewhat efficient" and are "Highly Efficient".

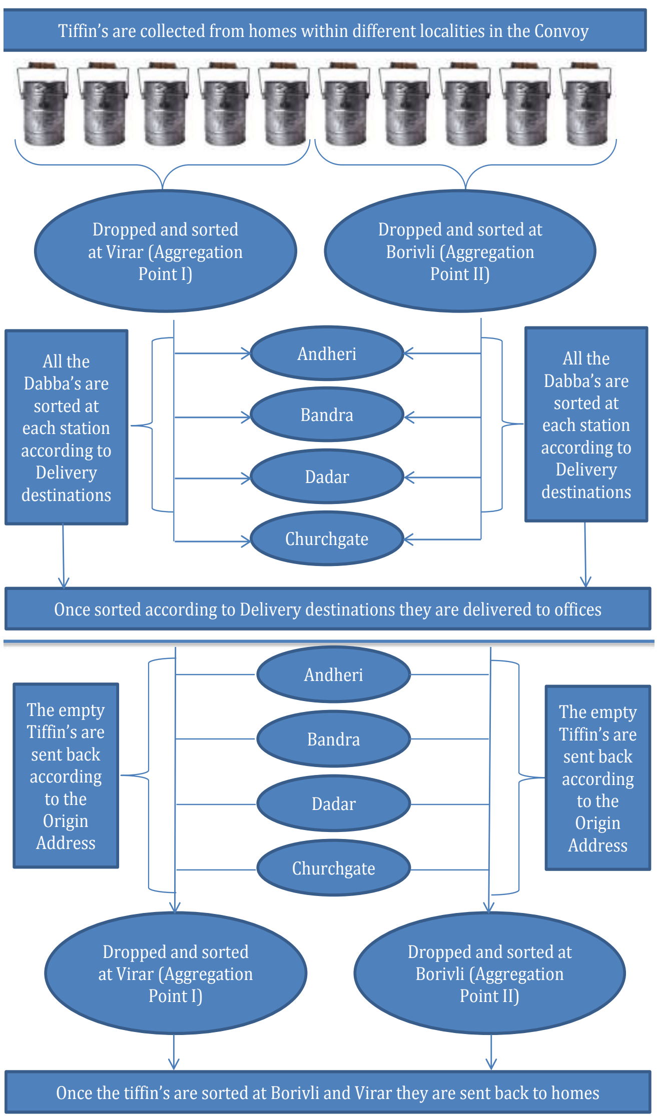
3. "Achieving Strategic Fit" (Chopra, Meindl, 2013): The final step is match the above two points with each other. To explain this further please have a look at the graph below which has been designed by Chopra and Meindl (2013) according to their theory of finding the zone of strategic fit:

   According to the Chopra and Meindl any company that is on the left side along the x-axis i.e. having certain demand should have an efficient Supply Chain, and any company that is on right side of the x-axis i.e. the demand of its goods is highly uncertain it should have a responsive supply chain. Hence, the Mumbai Dabbawala's who have a "low implied demand uncertainty" and a "highly efficient Supply Chain" is able to achieve strategic fit and belongs to the zone of strategic fit as shown in the graph.

Supply Chain Process Map

The Dabbawala's have a very unique Supply Chain; their supply chain starts from the Customer's house where the food is cooked by their wife or their mother or their cook. "A Dabbawala, starts his day at 8:30 am, spending approximately an hour collecting Dabba's (tiffin's) from the customer's houses and takes them to the local railway station where all the Dabbawala's from that locality meet and sort tiffin's according to the various destination areas. These tiffin's are then distributed to the Dabbawala's located in the area where the delivery has to take place, this process takes approximately 2 hours and all Dabbawala's start delivering Dabba's to the customer's offices who can then eat lunch from home(Patel & Vedula, 2006)". The delivery process takes approximately an hour after which the Dabbawala's themselves have lunch in half an hour and then roll out for collection of empty tiffin boxes from the customer's offices and report to the local railway station. Once they are back to the station where they originally had picked up the Dabba, they will start returning the tiffin's to the customer's house. This process is explained in section 12 i.e. Supply Chain Process Map.

According to Vineet Nayar, the CEO of HCL Technologies one of the fastest growing IT Companies in the world set a new philosophy in Management writing a book issued by Harvard Business Press in June 2010 says "Employees should be first and Customers should be second for a company, which has made HCL Technologies the fastest growing and profitable Information Technology companies globally". This philosophy can be seen to an extent in the Mumbai's Dabbawala's organization. The Dabbawala's have a very strong community and they are like family to each other mainly because most of the people belong to the same village. As soon as there is a requirement of a new Dabbawala in the organization, the Dabbawala in the locality with the requirement of a new recruit calls one of his family members to join the organization. This way the wisdom is passed from one Dabbawala to another in a way without any political office environments. A lot of the big organizations of the world invest a lot in Training and Development. However for the Dabbawala's this cost is minimal. The only Training and Development costs for the Dabbawala's is the computer labs created for their employees. One of key reasons of the success of the organization is that there employees are friendly with each other and treat each other as a part of their own family.



According to Joseph, Saranya & Sarumathi, the following is the process flow of a typical Dabbawala (2014):

FIG. 2: PROCESS FLOW OF DELIVERY SYSTEM

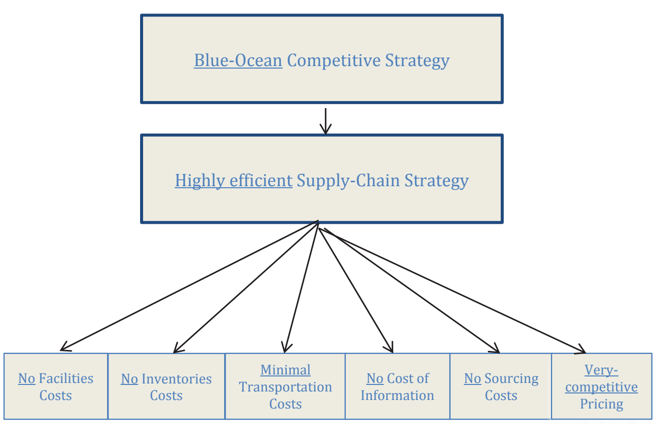
For simplicity to explain the Supply Chain Process of the Dabbawala's, let us assume a scenario of deliveries along the Western Line. The train starts from Virar and all areas before Virar along the Western Line bring all the tiffin's for deliveries at Virar. The train until Borivli is a slow train and stops at every station. The Dabbawala who started at Virar collects the other tiffin's along the way. In the transit time he sorts the Dabba's according to destination station. After Borivli the Train is a fast train i.e. it only stops at the main stations/hubs. For this reason he drops the Tiffin's to the head of convoy who is then responsible to make sure that tiffin's reach the destination areas within the convoy. The same Dabbawala who started from Virar drops all Tiffin's to the heads of Convoy until Churchgate which is the Last station and is one of the busiest areas of Mumbai. Once he reaches Churchgate, the same process as other localities of sorting the Tiffin's according to Destination is done and they are all out for deliveries to offices. This same process is followed backwards once the Tiffin's are collected from offices. This is explained in the process flow chart below:

To sum-up the Supply Chain Process of a Dabbawala, his day starts approximately at 8:30 am and gets over at 5 pm, in which he collects the customer's tiffin with home-made food, from his/her house and delivers it to the customer's office and the empty tiffin back from the customer's office to his/her house by the end of the day. According to Dr. Pawan Aggarwal's speech at the Indian Institute of Management Calcutta, "many of the customers trust the Dabbawala's so much, that when they get their salaries which is too risky too travel with in the local trains because of high number of pick pockets, they put their salaries in the empty tiffin's because they feel that this is much more safer". The Mumbai's Dabbawala's have created an excellent reputation over the past 129 years.

Supply Chain Analysis

According to Chopra and Meindl, the Supply Chain Decision-Making Framework which defines the Supply Chain Drivers and Metrics is as follows (2013):

The Mumbai's Dabbawala's have a "Blue Ocean" Competitive Strategy. Even though the courier companies if counted as competitors, it would make their strategy a "Red Ocean Strategy". The



Dabbawala's have differentiated their services vastly from that of the courier companies. The courier companies provide a lot of different kinds of services; they deliver Electronic products, Documents, Clothes, FMCG products etc. But the Dabbawala's just deliver tiffin's and at such a differentiated pricing strategy and a much differentiated business model that they actually tend to have a "Blue Ocean" Competitive Strategy.

The Mumbai's Dabbawala's have a Highly Efficient Supply Chain Strategy, in our opinion. A Supply Chain strategy of an organization depends on how responsive or efficient it is, and as seen in section 3, the association's implied demand uncertainty is fairly low and hence it needs to have an efficient supply chain strategy.

There are various factors for which we claim that the association has been very efficient and has saved costs to an extent that no other company could even think of competing against the Mumbai's Dabbawala's are as follows:

A. Logistical Drivers

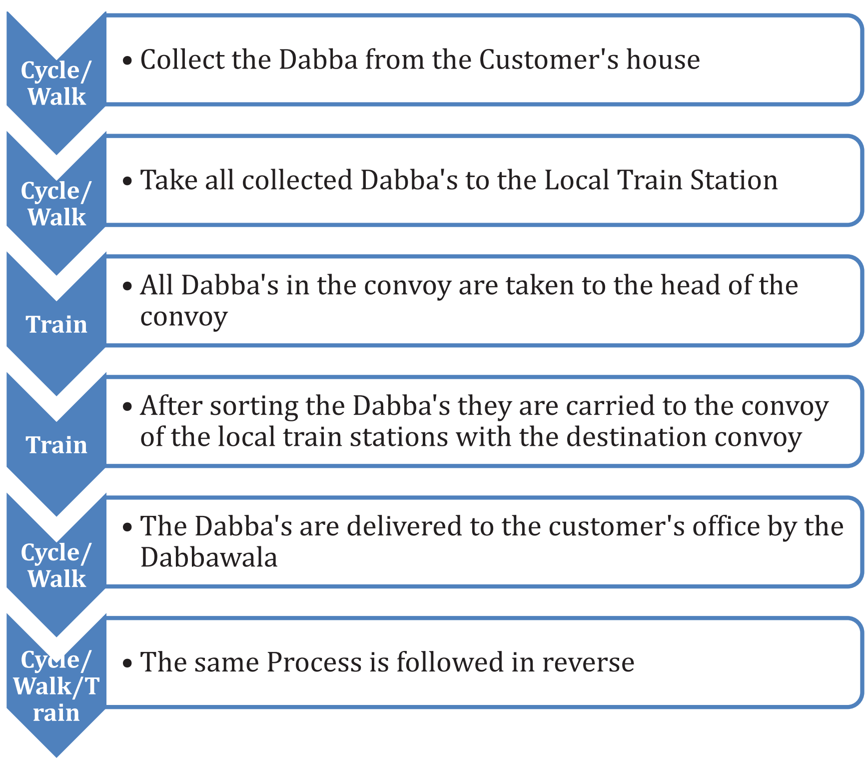
a. Facilities: The Mumbai's Dabbawala's business doesn't require any facilities. It doesn't require a warehouse or a retailer or a manufacturing facility. Mumbai's Dabbawala's actual distribution center is the local train station(s), which doesn't add on to any costs incurred for the Dabbawala's. Facilities is considered to be one of the highest costs of any supply chain, however, given the nature of the Dabbawala's business the need for any facilities is eliminated. Here the organization saves a lot of Supply Chain Costs and this definitely has a very positive impact on the company's Supply Chain Surplus. If we compare this to courier companies, this amount is fairly low for the Dabbawala's than the courier companies. For Courier companies even though there is no need for a retailer or a manufacturing facility, a distribution center and/

or a warehouse are a major investment. Although a courier company might not need the warehouse and/or distribution center for delivering the tiffin's but due to its additional courier activities it will need it and the facilities will become a shared cost. Hence the Dabbawala's have a very efficient supply chain strategy from the facilities perspective.

b. Inventories: Investopedia defines Inventories as "The finished goods, WIP goods and the raw materials required in a business and are classified as current assets". The finished goods in the organization are the Dabba's or the Tiffin's of the Customer, the WIP goods and the raw materials would be the costs incurred to cook the food but these are not a part of the Dabbawala's organization, and hence they are not accounted for in the books of the Dabbawala's. As far as the finished goods are concerned, their inventory turnover is one day if applicable. To apply this theory for the Dabbawala's would not add any value, as the inventories or in this case the finished goods are not adding to any costs for the Dabbawala's. The Dabbawala's don't actually store any of the finished goods as they are delivered to the customer's office and fro to the customer's house on the same day. Hence, the Dabbawala's have a very efficient supply chain strategy from the inventories perspective.

c. Transportation: As stated by Robello on Page 19 of the book Sao Paulo and Mumbai: The Impact of Rail-Based Networks on Two BRIC Mega Cities, "the fastest, most efficient, economical, and dependable mode of transportation available to the people residing in Mumbai is the Suburban Railway Network". Being from Mumbai, I would agree that the fastest and the most economical method of travelling in Mumbai is the Local Train. The Mumbai's Dabbawala's also have been utilizing this fact and using the Railway as their main mode of Transportation. However, the Mumbai's Dabbawala's have an Intermodal Transportation in place i.e. the use of more than one mode of transportation to deliver the Dabba's from the Customer's house to the Customer's office and back again. This system is a cross-docking system. This is explained by the graph below.

As we see there, Mumbai's Dabbawala's use an intermodal transportation i.e. a Cycle, the Train and by walking. As Patel and Vedula(2006), highlight in their paper "each Dabbawala is treated as a business partner they have to buy their own equipment's required for delivery. One



of major investments is two bicycles which cost approximately Rupees 4000, a wooden crate for tiffin's costing Rupees 500 and a railway pass for Rupees 300 per month" . We would classify the Wooden Crate in Transportation rather than a facility mainly because it's carried by the Dabbawala in the Train which doesn't really make it storage facility. However we can see the overall fixed cost of transportation incurred is approximately Rupees 4500 i.e. US$ 70, and Rupees 300 i.e. US% 5 approximately on a monthly railway pass which is the variable cost. If we compare these costs to any courier company, the Mumbai's Dabbawala's have been able to achieve a high level of efficiency by saving a lot of costs in Transportation by using local trains.

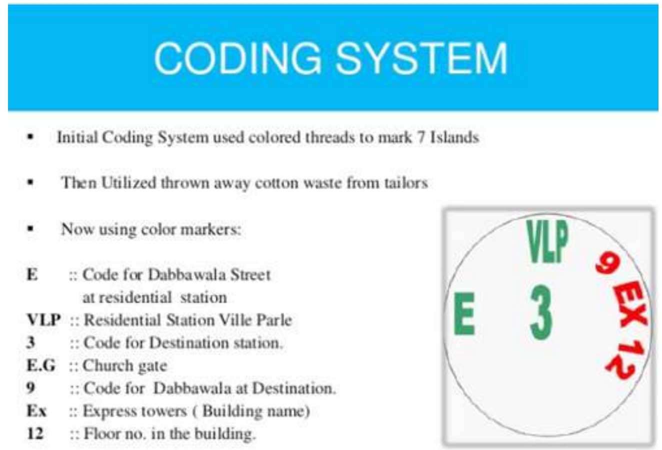
B. Cross Functional Drivers

a. Information: The Mumbai's Dabbawala's have a very unique coding system in place. But this is justifiable given the unique nature of their business. The Dabbawala's Coding System is identified by a lot of researchers, however Sandeep Mane shows in the following slide how the coding system has evolved in the past 129 years.

As Aggarwal, D. (2010) says in "the Mumbai's Dabbawala's are not only famous in the B schools in India, but also in Ivy League institutes such as Harvard and MIT Sloan, in appreciation of their Supply Chain efficiency without any technologies" .

(Mane, S., 2013)

The latest coding system unlike any other supply chain is one of the most innovative and is one of a kind. The Mumbai's Dabbawala's don't need any investment in technology, they don't need SAP or Oracle to align their supply chain and share information. All they need is a few colored



markers or chalks to share all the information that can make the supply chain a success. As we can see from the slide above the code "E" is the name of the street where the Dabbawala in the residential area will collect the tiffin in the morning. "VLP" represents the closest station to the residential area of the customer. "3" represents the station that is the closest to the customer's office. "E" written in green color represents the railway line on which the destination station stop comes. So "E.G." as mentioned in the slide indicates that Dabbawala has to get this Dabba on the Railway line which goes to Church gate (Last station of the Western Line). "Ex" represents the name of the building where the customer's office is located. "12" represents the floor within the building of the customer's office. This might seem like a lot of information; however, each Dabbawala when newly recruited is trained for 6 months to master the railway network and his area due to which he would never make any mistakes like the senior Dabbawala's. Hence, this coding system implies that the Mumbai's Dabbawala's are far more efficient compared to any courier companies and successful too.

b. Sourcing: For the Mumbai's Dabbawala's the sourcing strategy is applicable to a very different aspect. Firstly, their major sourcing needs lie in labor. As Sinha and Thomke(2010), highlight in their case-study, "whenever a new Dabbawala is needed, they recruit from approximately 30 villages only located near and within Pune in Maharashtra. They usually get new recruits from the families of the existing Dabbawala's families and belonged to the same cultures and principles" . However this type of sourcing can lead to management inefficiencies if not costing because the number of villages is very limited and in the case of the business facing a boom, sourcing issues could be a problem. This sourcing strategy not only allows them to save a lot of costs but also gain the trust of the employees/business partners making them highly efficient.

The Mumbai's Dabbawala's doesn't really have any other sourcing strategy in place, mainly because they don't have any purchasing needs. The only recurrent costs the Dabbawala's have is the railway tickets. They can't really have a different sourcing strategy for the rail because the Railway network is a government entity which is a Non-Profit-Organization and in Procurement we term these kinds of Suppliers as OEM. An OEM (Original Equipment Manufacturer) is referred to any supplier who solely provides the good or service (not necessarily a manufacturer) to the buying organization. Hence, in the case of Mumbai's Dabbawala's, the sourcing can't be classified as efficient or responsive.

c. Pricing: According to Sinha and Thomke(2010), "each customer is charged Indian Rupees 300, assuming twenty-five return trips, making it Rupees 6 per trip, however, if a customer had to use a courier company for deliveries of a Dabba, it would cost them Rupees 85 per trip or a total of making it a total of Rupees 4250 per month". This is the reason why the Dabbawala's are highly competitive in terms of pricing and are able to maintain a monopoly in the market. In the past 129 years, the Mumbai's Dabbawala's have definitely increased prices to adjust against inflation, but their pricing points are so low that no competitor has entered the market till date. Their pricing strategy helps them to avoid the threat of new entrants (one of Porter's five forces). The customers have happily accepted the new pricing points because the inflation in India is quite high and they understand that the Dabbawala's are still asking for less than what they are willing to pay for the service. Hence, the Mumbai's Dabbawala's see a consistent growth in demand year after year. This increase in Demand as compared to the increasing prizes is quite high and that is the main reason the Dabbawala's, in my view have an efficient pricing strategy. The pricing of the Dabbawala's can definitely be increased more if needed.

Key Issues in Designing and Implementing the Practice

The key issues in designing and implementing such a business are as follows:

A. The Supply Chain Design of the Dabbawala's is very rigid – The Mumbai's Dabbawala's though very successful in attaining customer satisfaction, their Supply Chain is very rigid in the sense that if one link breaks the whole supply chain falls apart. In a typical organization, except for the OEMs, the organization always has a backup supplier who can supply materials in case that their existing supplier can't meet the requirements. Let us compare this to the market we are examining in this paper. When the railway station of Mumbai stops working for any reason the Dabbawala's have a very good chance of not delivering its promise. Even though the Dabbawala's have never failed before,their consistency can break and they should always have a backup supply chain plan to make sure that the tiffin's are reached to the right customer.

B. Unsafe Mode of Transportation – The Dabbawala's can become a target of pick pocketers, knowing Mumbai, the local train is one of the biggest targets for pick pockets. As Dr. Pawan Aggarwal(2013) told in his speech, "some customers trust the Dabbawala's so much that they put their salaries in the empty tiffin boxes because they think it safer medium to reach home than to take it themselves". Such reasons increase the risk of the Dabbawala's being a target of the pick pockets. Even if one Tiffin/Dabba gets stolen this would vastly impact the reputation of the Dabbawala's. For this reason, local train is a very unsafe mode of Transportation. Even though, this has never happened in the past 129 years, it can happen if the Dabbawala's don't change their mode of transportation.

C. Highly labor-intensive – The business which is obviously too labor intensive, which makes it a push based supply chain. Let us explain why, the business hires a lot of employees/business partners. When a locality has 30 tiffin's for collection, one Dabbawala is required, however to manage any further demand a new person gets recruited. This would mean in the next 6 months of his training if he doesn't get a lot of customers, his income would be quite low as compared to the other Dabbawala's. The Mumbai's Dabbawala's don't actually wait for additional tiffin to recruit a new person. Since they manage the number of employees on prediction rather than on pulling according to demand, they have a push based Supply Chain. Since the business sources from a limited number of villages, it might not be able to meet its labor requirements if the demand increases at an increasing rate. This can increase load on the Dabbawala's which might lead to a supply chain failure.

D. The Supply Chain efficiency can reduce with new recruits coming from out of Mumbai – All the new recruits join from the same villages near Pune. When they join the Dabbawala's, they have no real knowledge about the geography of Mumbai and commuting around the localities. They are trained for approximately six months out of which most of the time they are with their senior family members learning about the geography of Mumbai. If the demand for tiffin deliveries increases at an increasing rate, and they recruit multiple Dabbawala's, because of the training period there could be supply chain inefficiencies. The new recruit might take longer routes if not trained properly, increasing lead times which is main pillar of the Mumbai's Dabbawala's. They should look at recruiting employees from Mumbai.

Major benefits, risks/costs of the practice

Risk Analysis:

Category	Benefits and Risks
Disruptions	Natural Disasters such as Floods and Terrorism can be a major risk given high level of interdependency among all the Dabbawala's along the Supply Chain.
Delays	Mumbai's Local Trains are known to be late; luckily for the Dabbawala's the trains usually delay 10 minutes. However longer delays of Trains can be a major risk as it can lead a delay along the whole Supply Chain.
Systems Risk	The innovative information system of the Dabbawala's doesn't depend on Information Technology and for this reason the Systems is a benefit for the Dabbawala's.

Category	Benefits and Risks
Forecast Risk	The only forecasting the Mumbai's Dabbawala's need is for managing Labor. They need to anticipate the increase in Demand and recruit new employees accordingly. Bad forecasting can be a minor risk for the company but since they have a monopoly this risk is negligible.
Intellectual Property Risk	The Dabbawala's only intellectual property is the cycle of the employees and the tiffin crates, but since the employees purchase these things themselves it is their responsibility and hence the risk is shifted from this organization to the Dabbawala's.
Procurement Risk	This risk is inter-related to Forecast risk in the case of the Dabbawala's. If the Forecast of required labor (supply is not accurate), the Dabbawala's would have a major risk in managing its Demand.
Inventory Risk	Neither a benefit, nor a risk.
Capacity Risk	Neither a benefit, nor a risk.

SWOT Analysis

The Strengths, Weaknesses, Opportunities and Threats are as follows:

Strengths	Weaknesses
1. Low costs of Operations	1. High Dependence on Local Trains
2. High Employee Satisfaction	2. Inflexible Timings
3. High Customer Satisfaction	3. Rigid Supply Chain Network
4. Efficient Time Management	4. Less Educated Employees
Opportunities	**Threats**
1. Can Provide Catering Services	1. Fast Food Chains
2. Yearly Subscription to service to receive payments earlier	2. Caterers who provide tiffin services
	3. Flexible Time Food Providers
3. Can utilize faster mode of transport at a premium	

Managerial Recommendations

Even though the Mumbai's Dabbawala's has made an international reputation with its services in Mumbai, there are a few things which can make them larger and a stronger organization:

1. Even though the organization has turned out to be one of the strongest organizations in the world, the employees should at least be educated up till junior school. This would give the Dabbawala's the insight to provide a better customer service by understanding the customer's perspective with a wider base of knowledge.
2. As of now their charges are approximately Rupees 300-400, they could actually start a premium service where each employee is responsible for only 5-10 tiffin's each and charge up to Rupees 1000 each customer. The time frames could be different in this model, where instead of collecting tiffin's at 8:30 am they can collect it by 10 am. Many of the families in Mumbai would be willing to pay that pricing point to the Dabbawala's for their service levels.

3. Have a few bikes as a backup for the heads of the convoys who can then manage things in the case the Local Trains in their areas are not operational.

Conclusion

The Mumbai Dabbawala's is a part of the charitable organization NMTBSA, who has over 5000 partners. The Dabbawala's are not actually employees working for NMTBSA but they are partners of the charitable trust and have only one ultimate goal that the customers get to eat hot home-cooked food and are healthy. The Dabbawala's is a tiffin (Dabba) delivering community which provides high levels of delivery services at very minute costs to the customers. The Dabbawala's is by far a Logistics Organization with one of the most efficient and successful supply chains in the world. The Charitable trust has received a lot of guests and certifications in appreciation of their immense time management skills and recognition of their service levels. The trust has been awarded a six sigma certificate in recognition of making just 1 mistake in 16 million deliveries. The organization recruits Dabbawala's from a limited and a fixed number of villages from families of the existing partners/employees of the organization. Due to this reason the trust saves large amounts on training. Their strategies could be summarized in the following table:

Strategies	Dabbawala's Service
Competitive Strategy	Blue Ocean
Product Development Strategy	One Product so not applicable
Marketing Strategy	Maintain relations with existing customer's
Supply Chain Strategy	Highly Efficient
Consistency	Highly Consistent

As Purohit rightly claims that "the Dabbawala's have zero % usage of fuel, zero % investment in technology, zero % disputes, 100% customer satisfaction, zero % investment and a 99.99999% accuracy in deliveries". The Dabbawala's have proven excellent service levels and will always motivate other companies to follow their supply chain strategies and has created a benchmark for best practices. At the end, we would like to highlight a comment from a customer showing how the Dabbawala's are not just a tiffin delivery organization but so much more than that. As highlighted by Percot, "a customer Lethika, who is a housewife said, "When the Dabba comes back, I open it quickly. If it is empty, I am happy. I think that he [my husband] liked the food. When there is something left I worry: maybe he is sick or he didn't like it. And when he comes back home that is the first thing I ask"".

Limitations and Future Scope

This study was limited to Mumbai only due to resource constraints. However, similar studies may be undertaken in other cities/states of India. Possibility of using Information, Communication and Technology for improving performance of Dabbawala supply chain may be explored in future. Similar studies may be conducted for other service sectors such as airlines, healthcare, FMCG, etc. Quality of such supply chains may be improved by using QFD, Six Sigma.

Acknowledgement

Authors would like to thank the anonymous reviewers for their valuable comments which have helped in improving the quality of this paper. Also, authors gratefully acknowledge the support rendered by Prof. Rakesh Raut, PIC-Research NITIE.

Appendix (Some Achievements and Pictures of the Mumbai's Dabbawala's)

The Mumbai's Dabbawala's is actually a part of the charitable organization 'Nutan Mumbai Tiffin Box Suppliers Association/Charity Trust' (NMTBSA). The NMTBSA has had the following achievements in recognition of the Dabbawala's service:

1. They are ISO Certified:

Certificate of Registration

This is to certify that
The Quality Management Systems
Of

NUTAN MUMBAI TIFFIN BOX
SUPPLIERS CHARITY TRUST

at

3, RAGHUNATH PATHAK CHAWL, SAMBHAJI NAGAR,
SAHAR ROAD, NEAR FLY-OVER BRIDGE,
ANDHERI (EAST), MUMBAI - 400 069 INDIA

Has been found to conform to the Quality Management System Standard

ISO 9001:2000

This certificate is valid for the following Product or Service ranges:

PICK & DROP TIFFIN BOX SERVICES

Place and Date:
NEW DELHI: 29/07/2006

the Accredited Unit:
P.C. Management System Pvt. Ltd.

This is a Single site Certification

CHAIRMAN / DIRECTOR

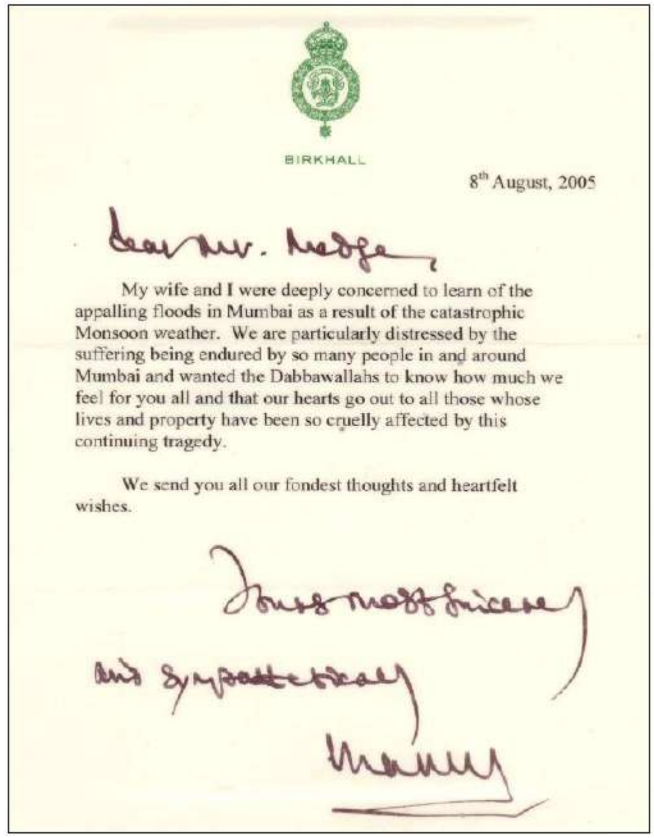
Issue: 2006.07.29

Expire: 2009.07.28

Regd. Off. - 134-A, IInd Floor, Taimoor Nagar , New Friends Colony, New Delhi - 110 065

(Thomke, S. & Sinha, M., 2010)

2. Prince Charles Letter to Mr. Medge the President of NMTBSA according to the Harvard Case Study by Sinha and Thomke:



BIRKHALL

8th August, 2005

Dear Mr. Medge,

My wife and I were deeply concerned to learn of the appalling floods in Mumbai as a result of the catastrophic Monsoon weather. We are particularly distressed by the suffering being endured by so many people in and around Mumbai and wanted the Dabbawallahs to know how much we feel for you all and that our hearts go out to all those whose lives and property have been so cruelly affected by this continuing tragedy.

We send you all our fondest thoughts and heartfelt wishes.

Yours most sincerely
and sympathetically
Charles

C. (Thomke, S. & Sinha, M., 2010)

3. A few Pictures to give an insight of NMTBSA's Mumbai's Dabbawala's as shown in Sinha and Thomke:

Prince Charles' Visit to Mumbai

Sir Richard Branson's Visit

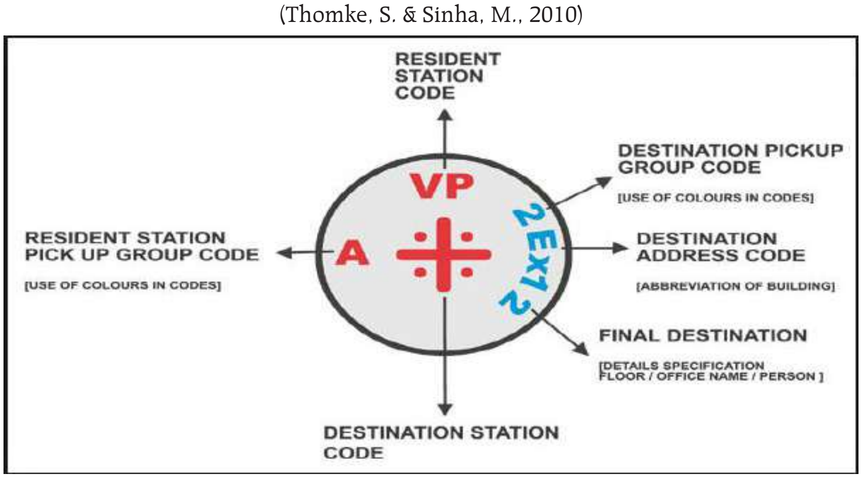
Wooden Crate Near Train Station

Pushing Handcarts

Fully-Loaded Cart

Fully-Loaded Bicycle

(Thomke, S. & Sinha, M., 2010)



(Baindur & Sinha, 2013)

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Cost Oriented Mixed Model Two-Sided Assembly Line Balancing – a Company Case Study Solved By Exact Solution Approach

Ashish Yadav[1], Pawan Verma[2], Sunil Agrawal[3]

The main aim of this paper is to develop a new mathematical model for the mixed model two-sided assembly line balancing problem (MTALBP) generally occurs in plants producing large-sized high-volume products such as buses or trucks. In this paper, the proposed mathematical model is applied to solve case study of two-sided mixed-model assembly line balancing problem to optimize the cost of machinery, worker and transportation in mated stations of an assembly line. Since the problem is well known as NP-hard problem proposed mathematical model is solved using a branch and bound algorithm on Lingo 16 solver using the exact solution approach. Based on the computational results of the assembly lines with cost-oriented objective are compared with the results of station oriented objective. From this study, it is observed that in terms of efficiency, the proposed cost-oriented approach provides better solution than the solution obtained by station oriented approach and help to reduce total worker cost and overall cost.

Keywords: *Two-sided assembly line balancing, Mixed model, Mathematical model, Case study problem, Lingo 16.*

Introduction

An assembly line is a production process where raw material transfer through conveyer, different workers and machine perform work on it and finally raw material converted into finished produced. In two sided assembly line product can be manufactured or assembled in parallel direction both at the left and right sides of the lines. The task in two sided assembly line will have direction restriction to perform because the use of both side of the line. The directions those are used in two sided assembly line are left side (L), right side (R), and either side (E). The two-sided assembly line was first introduced by Bartholdi in 1993, who conducted an iterative program with balancing algorithm using the first fit heuristic. The major difference between one sided and two sided assembly line is that the sequence of the tasks within a workstation is not important in one sided assembly line but in two sided assembly line play crucial role for an efficient assignment of tasks. In two sided assembly line when left side line task can interfere with right side line task through precedence constraints that might create idle time is called interference phenomenon. In this interference phenomenon workstation/worker needs to wait for the previous task completion process at the opposite side of the line.

Assembly lines in which more than one product model is assembled on the same line without any setup requirement between models are called as mixed model assembly line. Mixed model assembly lines provide the benefit of avoidance of constructing several lines, satisfied different customer demands, and minimized workforce need. Mixed-model assembly lines provide more flexibility of responding to consumer demands on time and to reach global markets in highly competitive scenario. With the solution of assembling more than one model on each adjacent line of two-sided assembly lines, we can obtain a new line system called mixed-model

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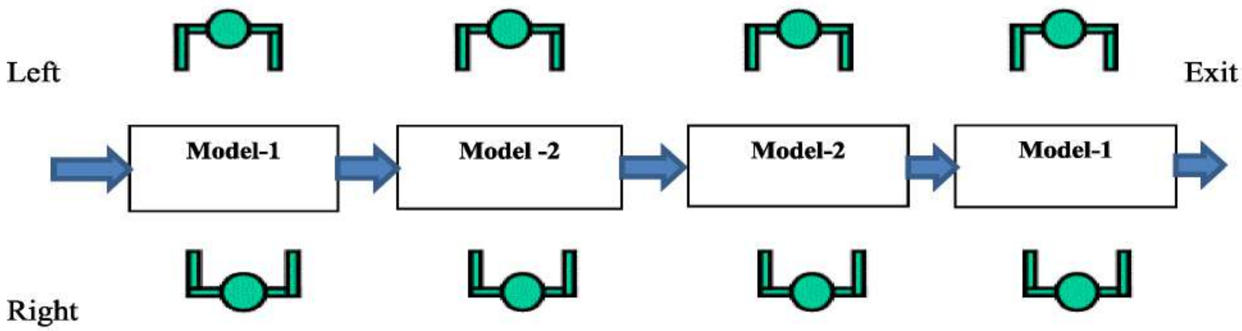
Fig. 1: Configuration of the mixed model two-sided assembly line balancing problem



two-sided assembly lines. In mixed model two sided assembly line worker is allowed to work on left and right side of single workstation performing different tasks. Generally such type of assembly line is used for high volume production in large industries. Figure 1 indicates the configuration of the mixed model two sided assembly line balancing problem.

The mixed model two sided assembly line has many advantages over simple assembly line those are mentioned below.

1. It can shorten the line length, i.e. space utilization improvement.
2. It can reduce the number of workers, since it minimizes the number of workstation.
3. It reduces the amount of work in process (WIP) throughput time.
4. It can lower material handling costs and setup time, since it reduces the need for workers to maneuver tools, parts, or the product.
5. There might be lowered cost of tool(s) and fixture(s) since workers working together in the same workstation can share tools or fixtures.

Literature Review

(Simaria et al., 2009) presented mathematical programming model with ant colony optimization algorithm for solving two-sided mixed-model assembly line balancing problem with an objective of minimize the number of workstations of the line. (Ozcan et al., 2009) addressed TALBP with the objective of minimizes the number of mated-stations as the first objective and minimizes the number of stations as the second one for a given cycle time They presented a formal mathematical formulation for the problem and developed simulated annealing algorithm for maximizing the weighted line efficiency and minimizing the weighted smoothness index.

(Chutima et al., 2012) presents a Particle Swarm Optimization with negative knowledge (PSONK) to solve multi-objective two-sided mixed-model assembly line balancing problem with the objective of minimizing the number of mated-stations for a given cycle time. PSONK employs the knowledge of the relative positions of different particles in generating new solutions. (Aghajani et al., 2014) addressed TALBP with the objective of to minimize the cycle time for a given number of mated stations. They presented a mixed-integer programming model for robotic mixed-model two-sided assembly line balancing and developed a simulated annealing (SA) algorithm as Meta heuristic method is proposed to solve the problem.

(Rabbani et al., 2014) In this paper author presents a novel multiple U-shaped layout is proposed to deal with the mixed-model two-sided assembly line balancing (MTALB) problems with mathematical formulation of two conflicting objectives including minimizing the cycle time and minimizing the number of workstations are considered under precedence, zoning, capacity, side, and synchronism constraints and developed genetic algorithms to solve it optimally.

(Kucukkoc et al., 2014) presented a new assembly line system configuration for companies that need intelligent solutions to satisfy customized demands on time with existing resources. An agent-based ant colony optimization algorithm is proposed to solve the problem. They presented a mathematical formulation for simultaneous balancing and sequencing and developed an agent-based ant colony optimization algorithm to solve it optimally.(Yuan et al., 2015) addressed TALBP with the objective of minimizing the number of mated-stations and total number of stations for a given cycle time. A Honey bee mating optimization (HBMO) algorithm is proposed to solve this problem.

(Zhang et al., 2016) In this paper author introduces mixed-model two-sided assembly line balancing Type-II problem benefiting from the real data gathered through an industrial case study. This paper also contributes to knowledge by incorporating incompatible task groups, different from negative zoning constraints. (Kucukkoc.,2016) addressed mixed-model two-sided lines with the objective for minimizing the cycle time of the line as well as the number of workstations. A real-world problem is solved using the proposed approach and the efficiency of the line is improved. They presented a real-world problem and developed ant colony optimization algorithm to solve it optimally.

(Delice et al., 2017) presented a new modified particle swarm optimization algorithm with negative knowledge is proposed to solve the mixed-model two-sided assembly line balancing problem with minimize the number of mated stations as the first objective and minimizing the number of stations as the second one for a given cycle time. (Li et al., 2018) addressed TALBP with two objectives those are simultaneously to be optimized; one is to minimize the combination of the weighted line efficiency and the weighted smoothness index. A novel multi objective hybrid imperialist competitive algorithm (MOHICA) is to solve this problem.

(Kucukkoc.,2018) addressed mixed-model two-sided lines with underground workstations here the objectives are minimize the number of mated stations as well as the number of stations. They presented a new ant colony optimization algorithm, in which the parameters are optimized using response surface methodology.(Rabbani et al.,2019) addressed multi objective mixed-model two-sided lines with sequencing problem in a make to order environment with customer order prioritization. Here genetic algorithm and particle swarm optimization are applied to solve this problem.

Although researchers have focused on two-sided assembly line balancing problems but the literature review suggests that very limited number of researchers focus on the mixed model two-sided assembly line balancing problem. MTALB problems with the objective of minimizing cost are very crucial in a number of industries and optimizing this objective is a very critical process. Hence, the main focus of this article is to optimize cost of mixed model two-sided assembly line.

This article mainly presents following contributions to the research field:

(1) A mathematical model of mixed model two-sided assembly line balancing problem is proposed with cost-oriented objective. It consists of the cost of worker, transportation cost in mated stations and the cost of machinery of assembly line. Each component of cost is further explained in the next section.

(2) The proposed mathematical model is tested on an industrial problem and is solved using Lingo -16 solver to obtain the optimal solutions.

(3) Results of the assembly lines with cost-oriented objective P(2) are compared with the results of station oriented objective P(1). From this study, it is observed that in terms of efficiency, the proposed cost-oriented P(2) provides better solution than the solution obtained by station oriented P(1).

The rest of the paper is organized as follows, in section 3 mixed model two-sided assembly line balancing mathematical formulation is mentioned with motivation, objectives, assumptions and constraints. Section 4 illustrates a case study problem data and computational results. Conclusions and future work are presented in section 5.

Mathematical Formulation

1. Motivation

The real world assembly line balancing problems such as space optimization, idle time minimization, cost optimization etc. motivates the author to think about improvement in this direction. Author found that the ABC assembly plant is not well structured and overall costs are high. Based on the recent research work in the area of mixed model assembly line balancing, the authors are motivated to reduce the cost of ABC plant assembly line. Here, authors developed the mathematical model according to the requirement of the plant and applied to solve the assembly line balancing ABC plant case study problem.

2 .Overview

The main objective of the proposed model is to assign the set of tasks to the stations of two-sided assembly line so that the overall cost associated with the system is minimized. Here, objective function consists of mainly three types of costs.

The first one is associated to worker cost. In this paper every task is assigned a wage rate (Table 1). Wage rate of every station is defined as the maximum wage rate among the wage rate of tasks assigned to that station. Multiplying the cycle time of the line by the wage rate will be the wage of the worker assigned to that station.

Table 1: Data of Wage rate (Roshani et al., 2014)

Tasks	Wage rate (money units per time unit)	Tasks	Wage rate (money units per time unit)
1	3	9	4
2	6	10	8
3	2	11	2
4	3	12	4
5	8	13	10
6	4	14	2
7	7	15	6
8	10	16	6

Second is associated to the cost of transportation facility that is directly connected to the length of the line. Length of two-sided assembly lines is based on total number of mated-stations, so costs of transportation facility are related to the total number of mated-stations. The total costs of the transportation facility (*vc*) per mated-station is kept fixed equal to 25 (money units per time unit). (Roshani et al., 2014)

Third is the cost of machinery. In assembly lines generally, number of machines are proportional to the number of single stations. The total costs of the machinery (*mc*) per single station is kept fixed equal to 20 (money units per time unit). (Roshani et al., 2014)

3. Assumptions

The MTALB problem in this study includes the following assumptions (Ozcan & Toklu, 2009):

- Models with similar production characteristics are produced on the same two-sided assembly line
- Workers perform tasks in parallel at both sides of the line

- Some tasks may be required to be performed at one-side of the line, while others may be performed at either side of the line
- The precedence diagrams of different models are known
- Task times are deterministic and independent of the assigned station
- Parallel tasks and parallel stations are not allowed.

4. Mathematical modeling

Decision Variables

Symbol	Description
x_{mijk}	Binary variable indicating if task i of model m is assigned to mated-station(j,k) $\begin{cases} 1 \text{ if task i is assigned to station (j, k)} \\ 0, \text{otherwise} \end{cases}$
st_{mi}	Start time of task i for model m
Z_{ih}	Binary variable indicating precedence relationships among the tasks in the same station $\begin{cases} 1 \text{ if task i is assigned before task h in the same station} \\ 0, \text{if task h is assigned before task i in the same station} \end{cases}$
ms_j	$\begin{cases} 1 \text{ if mated} - \text{station j is utilized} \\ 0, \text{otherwise} \end{cases}$
ss_{jk}	$\begin{cases} 1 \text{ if station (j, k) is utilized} \\ 0, \text{otherwise} \end{cases}$

Notations

Symbol	Description
I	Set of all assembly tasks
N	Total no. of tasks
J	Set of all mated-stations
M	Set of all models
i	Index of assembly task; *i = 1, 2, ... I*
j	Index of station; *j = 1, 2, ... J*
m	Index of model; *m = 1, 2, ... M*
k	Index of mated-station direction; $\begin{cases} 1 \text{ indicates a left direction} \\ 2 \text{ indicates a right direction} \end{cases}$
(j, k)	Index of station *j* and the associated mated-station direction *k*
P(i)	Set of immediate predecessors of task *i*

Symbol	Description
S(i)	Set of immediate successors of task *i*
t_{mi}	Completion time of task *i* for model *m*
μ	Large positive number
CT	Cycle time
w_{mi}	Wage rate assigned to task *i* for model *m*
$d1_i$	$\begin{cases} 0 \text{ if task } i \text{ is a right} - \text{side} \\ 1 \text{ otherwise} \end{cases}$
$d2_i$	$\begin{cases} 0 \text{ if task } i \text{ is a left} - \text{side} \\ 1 \text{ otherwise} \end{cases}$
vc	Total costs of the transportation facility
mc	Total costs of the machinery
R^+	Positive real number

Objective Function

$$\text{Minimize } Z = Z1 + Z2 + Z3 \quad (1)$$

$$Z1 = \sum_{j=1}^{J}\sum_{k=1}^{2} ct * \text{Max}(w_{mi} * x_{mijk}) \quad (2)$$

$$Z2 = vc * \sum_{j=1}^{J}\sum_{k=1}^{2} ss_{jk} \quad (3)$$

$$Z3 = mc * \sum_{j=1}^{J} ms_j \quad (4)$$

Objective (1) minimizes overall cost (Z) associated with the system. It consists of three parts those are dealing with three types of costs. The first part (Z1) indicate worker cost Second part (Z2) indicate transportation cost between the mated station and third part (Z3) indicate cost of machinery associated to a station

Constraints

$$\sum_{j=1}^{J}\sum_{k=1}^{2} x_{mijk} = 1, \ \forall\, i \in I \ \ \forall\, m \in M \quad (5)$$

$$\sum_{j=1}^{J}(d1_i * x_{mij1} + d2_i * x_{mij2}) = 1, \quad \forall\, i \in I \ \ \forall\, m \in M \quad (6)$$

$$\sum_{j=1}^{J}\sum_{k=1}^{2} j * x_{mhjk} - \sum_{j=1}^{J}\sum_{k=1}^{2} j * x_{mijk} \le 0$$
$$\forall\, a, b \in I, \ b \in p(a)\ \forall\, m \in M \quad (7)$$

$$\sum_{k=1}^{2} x_{mijk} * (st_{mi} + t_{mi}) \le j * ct \ \ \forall\, i \in I, j \in J \ \forall\, m \in M \quad (8)$$

$$\sum_{k=1}^{2}(x_{mijk} * (j-1) * ct) \le st_{mi} \ \ \forall i \in I, j \in J \ \forall\, m \in M \quad (9)$$

$$st_{mh} - st_{mi} + \mu(1 - \sum_{k=1}^{2} x_{mijk}) + \mu(1 - \sum_{k=1}^{2} x_{mhjk}) \ge t_{mi}$$
$$\forall\, i, h \in I, \ i \in p(h), \forall\, m \in M, \forall\, j \in J \quad (10)$$

$$st_{mh} - st_{mi} + \mu(1 - x_{mijk}) + \mu(1 - x_{mhjk}) + \mu(1 - z_{ih}) \ge t_{mi}$$
$$\forall\, i, h \in I, \ i \notin p(h), h \notin p(i), \forall\, m \in M, \forall\, j \in J \quad (11)$$

$$st_{mi} - st_{mh} + \mu(1 - x_{mijk}) + \mu(1 - x_{mhjk}) + \mu * z_{ih} \ge t_{mh}$$
$$\forall\, i, h \in I, \ i \notin p(h), h \notin p(i), \forall\, m \in M, \forall\, j \in J \quad (12)$$

$x_{mijk} = x_{pijk} \qquad \forall\, i \in I, \forall\, j \in J,\ \forall\, k \in K, \forall\, m, p\ \in M$ (13)

$\sum_{m=1}^{M}\sum_{i=1}^{N} x_{mijk} - N * ss_{jk} \le 0 \qquad \forall\, j \in J\ \forall\, k \in K$ (14)

$\sum_{m=1}^{M}\sum_{i=1}^{N} x_{mijk} - ss_{jk} \ge 0 \qquad \forall\, j \in J\ \forall\, k \in K$ (15)

$\sum_{k=1}^{2} ss_{jk} - 2 * ms_j \le 0 \qquad \forall\, j \in J$ (16)

$\sum_{k=1}^{2} ss_{jk} - ms_j \ge 0 \qquad \forall\, j \in J$ (17)

$x_{mijk}\ \in \{0,1\} \qquad \forall\, i\ \in I, \forall\, m \in M, \forall\, j \in J,\ \forall\, k \in K$ (18)

$ss_{jk} \in \{0,1\} \qquad \forall\, j \in J\ \forall\, k \in K$ (19)

$ms_j \in \{0,1\} \qquad \forall\, j \in J$ (20)

$z_{ih}\ \in \{0,1\} \qquad \forall\, i, h \in I,\ i \notin p(h), h \notin p(i)$ (21)

$st_{mi} \in R^{+} \qquad \forall\, i\ \in I, \forall\, m \in M$ (22)

Constraint (5) states that all tasks are assigned to only one station. Constraint (6) ensures the left or right-side assignment of the task. Constraint (7) is the precedence constraint, which ensures that precedence relationships among the tasks are not violated. Constraints (8) and (9) ensure that the start time of the task is within the time limit of the station on which it is assigned. Constraints (10) to (12) are specially designed for a two sided assembly line balancing. Constraint (10) will be active when task *h* is a precedence of task *i* and are assigned at same mated station on opposite sides otherwise the constraint will not be active. When this holds, the constraint is applied to $st_{mi} - st_{mh} \ge t_{mh}$ which ensures that task *h* is assigned before task *i*. Constraints (11) and (12) become active when tasks *h* and *i* do not have any precedence relationship and are assigned on the same station (*j, k*). If *i* is assigned earlier than *h*, then constraint (11) become $st_{mh} - st_{mi} \ge t_{mi}$; if not, then constraint (12) becomes $st_{mi} - st_{mh} \ge t_{mh}$ .Constraint (13) ensure the assignment of a task on same station for all the models. Constraints (14) and (15) ensure that $ss_{jk} = 1$ if any task is assigned to station (*j, k*) and 0 otherwise. Constraints (16) and (17) ensure that $ms_j = 1$ if any task is assigned to mated-station *j* and 0 otherwise. Constraints (18) to (22) are the binary constraints.

Solution Approach and Computational Results

1. Case Study Problem

In this section authors use ABC company data to solve mixed model two-sided assembly line balancing (MTALB) problem as depicted in Table 2. In this table, there are 16 tasks with their preferred side (Left, Right and Either). Further, it shows immediate predecessor and task processing time for both the models A and B.

Table 2: Data of Industrial Case Study problem (Kucukkoc et al., 2014)

Task No	Side	Processing Time (Time-units)		Immediate Predecessor(s)
		Model A	Model B	
1	E	6	0	-
2	E	5	2	-
3	L	2	0	1
4	E	0	9	1
5	R	8	0	2
6	L	4	8	3
7	E	7	7	4,5
8	E	4	3	6,7
9	R	0	5	7
10	R	4	1	7
11	E	6	3	8
12	L	0	5	9
13	E	6	9	9,10
14	E	4	5	11
15	E	3	8	11,12
16	E	4	7	13

2. Performance comparison

In this paper MTALBP is solved by Lingo 16 solver, and the results of task assignment are shown in figure 2 and figure 3. In figure 2, there are 5 mated stations in the optimal solution.

As can be seen in the figure 3, there are 5 mated stations in the optimal solution. In station 1 tasks 1, 3, and 6 are assigned to left side mated-station for model A and task 6 are assigned to left side of mated-station for model B , and tasks 2 are assigned to right side mated-station for model A and tasks 2 and 4 are assigned to right side mated-station for model B.

Fig. 2: Optimal task assignment of station oriented P (1) problem

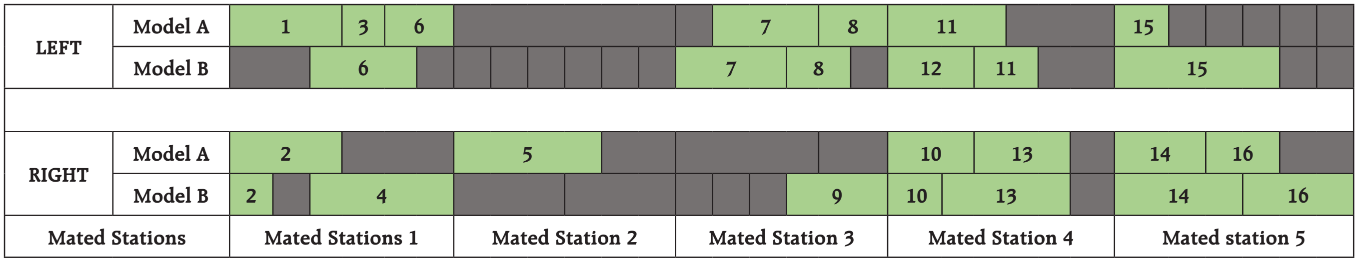
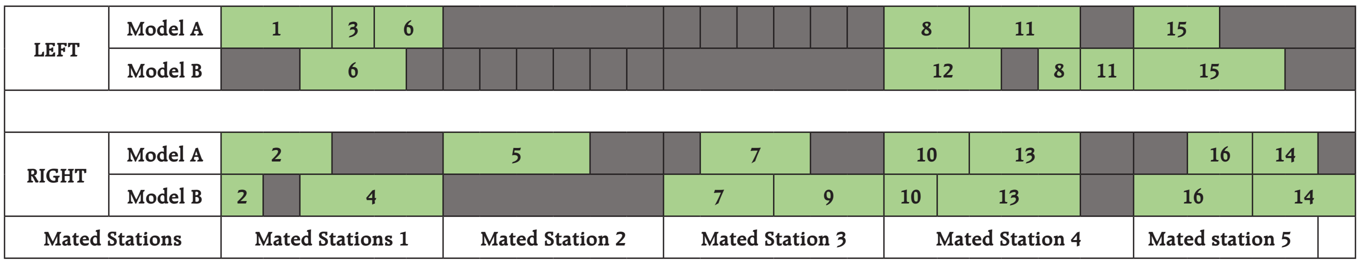


Fig. 3: Optimal task assignment of cost oriented P(2) problem



According to the solution obtained by Lingo-16 solver, the idle time of left side mated-station appears between the processing of tasks 6 and 8 for model A and tasks 6 and 12 for model B are more uniform for worker rest and other works. In fact, the idle time can be rearranged to the end of processing of task 6 without violating precedence relationship.

Table 3.indicate that cost oriented approach based efficiency P(2) is 69.79 % on the other hand station oriented approach based efficiency P(1) is 62.04 %. So cost oriented approach perform better than station oriented approach.

Table 3: Efficiency comparison result of problems

Problem	Efficiency
Station oriented approach P(1)	62.04%
Cost oriented approach P(2)	69.79%

Table 4 is the summary result for the application of the model to solve problem that indicate total cost of cost oriented assembly line P(2) is less as compare to

Table 4: Performance comparison of problems

	Mated station	Single station	Station oriented P(1)		Cost oriented P(2)	
			Task assigned	Wage rate	Task assigned	Wage rate
1	1	1 2	1,3,6 2,4	8 6	1,3,6 2,4	8 6
2	2	1 2	- 5	- 3	- 5	- 3
3	3	1 2	7,8 9	10 8	- 7,9	- 10
4	4	1 2	11,12 10,13	3 9	8,11,12 10,13	6 9
5	5	1 2	15 14,16	15 12	15 14,16	15 12
Total Worker cost			888		828	
Total no. of mated station			5		5	
Total no. of single station			9		8	
Total cost			1193		1113	

station oriented assembly line P(1). Total worker cost is less in cost oriented assembly line P(2) as compare to station oriented assembly line P(1) and total no. of single station is also less in cost oriented assembly line P(2).

Conclusions and Future Research

In this paper, author's present a mathematical programming model with cost oriented objective function that actually minimizing cost for given cycle time to solve case study problem of mixed model two sided assembly line. The proposed mathematical programming formulation is able to solve the numerical problem, with good solutions therefore authors applied this approach to solve case study problem. Results of the assembly lines with cost-oriented objective P(2) are compared with the results of station oriented objective P(1). Computational result in terms of efficiency indicate that the proposed cost-oriented P(2) provides better solution than the solution obtained by station oriented P(1).

Mixed model two sided assembly line balancing problem is well known NP hard problem. Authors considered here small size case study problem because large-size problem are hard to solve by Lingo-16 solver. According to the managerial aspect results help manager to take decision about layout and understand process for effectively accomplishing the goals and operations of the organization using worker, resources, equipment, and materials.

In future work a multi-objective model where more than one objective and stochastic model where task time are unknown can be developed for mixed model two sided assembly line balancing. This mathematical model can be applied with new meta-heuristic methods such as whale optimization and grey wolf optimization to get the optimal solution for the mixed model two sided assembly line balancing problem. Different assembly line layout such as U line, Parallel line can also be solved for mixed model assembly line balancing problem. According to the industrial aspect more realistic constraints such as resource constraint, distance constraint can be very helpful for future work in mixed model two sided assembly line balancing.

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1 21 4 34	Business Analytics (To be confirmed)	Hema Date	15 Hrs	18 Jan - 20 Jan
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1 21 4 26	Business to Business Marketing	M. K. Jha	15 Hrs	22 Feb - 24 Feb
1 21 4 14	AI/ML driven Customer Relationship Management	Purnima Sangle / Neeraj Pandey / Debabrata Das	15 Hrs	22 Feb - 26 Feb
1 21 4 35	Application of Time Series Modelling on Business Forecasting	Poonam Singh / Mainak Mazumdar / Ajaya Kumar Panda	15 Hrs	26 Feb - 7 Mar
1 21 4 15	Applications of AI/ML in Operations & Supply Chain Management	Sushmita A. / Priyanka Verma / Debabrata Das	15 Hrs	27 Feb - 14 Mar
1 21 4 32	Management of Sustainable Development Goals in post COVID-19 era	Shirish Sangle / V. V. Gedam	15 Hrs	1 Mar - 5 Mar
1 21 4 24	Managerial Decision Making	Vijaya Gupta / Utpal Chattopadhyay	15 Hrs	8 Mar - 10 Mar
1 21 4 31	Thinking Strategically; Business strategies to navigate VUCA world and attain competitive advantage	S S Bhattacharya	15 Hrs	12 Mar - 14 Mar
1 21 4 16	Decision Making in Supply Chain	P. Acharya / Priyanka Verma	15 Hrs	15 Mar - 19 Mar
1 21 4 33	Addressing Environmental, Social, & Governance (ESG) for Corporate Sustainability: Aligning SDG	Hema Diwan	15 Hrs	22 Mar - 25 Mar
1 21 4 36	Management of Intellectual Property (IP) for Gaining Competitive Advantage (Creation, Protection and Leveraging of IP)	B. Koteswara Rao Naik	15 Hrs	26 Mar - 30 Mar

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