A Mathematical Diagnostic of Design and Resource Utilization of a Warehouse

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Abstract

The main concern of this research is to address the problem of identifying contributory factors in making warehouse spaces functional and efficient, while providing a safe and comfortable environment for the workers to increase productivity and control, reduce operating costs, and to improve customer service. This research study, reports a before and after study of a Warehouse Management System (WMS) implementation at a selected warehouse where its impact on five major performance measures, namely service level, resource utilization, space utilization, cycle time and stock integrity are analyzed. A total of sixteen different KPIs have been evaluated separately and also together. Some areas have been further analyzed with sub sectors individually. Findings of the analysis are explicit; where it is proven statistically that fourteen of the sixteen KPIs have improved with twelve out them showing a significant improvement. The research paper discusses areas of improvement in the implementation of a WMS. Moreover, knowledge requirements, skills of employees and equipment requirements have been identified as necessary supporting features for successful implementation of a WMS.

Key words: Warehouse Management System (WMS), Key Performance Indicator (KPI)

1. Introduction[1]

In today's competitive business environment, Supply Chain Management (SCM) has become an essential approach to operational efficiency as well as to cost leadership. Businesses can be effectively managed in order to gain customer satisfaction and company success, as well as to achieve societal goodwill and quality of life by providing quality goods with zero damages [1].

A warehouse is a focal point of any supply chain and is also one of its most costly elements. Therefore, its proper design and effective utilization of associated resources plays a significant role in cost management. Nowadays millions of dollars are invested to construct and implement state of the art systems to improve operational efficiency and long-term cost efficiency of supply chains. Thus a Warehouse Management System (WMS) is more than a stock control system, or a data collection system. It is actually a system that helps to 'automate' warehousing operations as much as possible [2].

The continuous measurement of performance is absolutely necessary to monitor process improvement of the supply chain where the warehouse is usually the last link before final delivery to the customer. Therefore performance of a warehouse and its proper measurement becomes critical for organizations trying to achieve multiple objectives, such as cost minimization, on-time dispatches, and order accuracy and so on [3].

The basic approach of the research is the literature review of warehouse performance KPIs, before and after studies of previous research work and from the work study done at the selected warehouse of a leading FMCG dealer. Data was collected in the form of both primary and secondary data.

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2. Problem Statement

Fundamentally, warehouse resources can be categorized into three main areas as human resource, material and equipment and warehouse space resources it selves. Their uses have direct consequences in increasing productivity and control, on operating costs, and customer service capabilities. Therefore the research problem is to identify the contributory factors that would make warehouse spaces functional and efficient, while providing a safe and comfortable environment for the workers to increase productivity and control, reduce operating costs, and improve customer service.

3. Research Objectives

The research "A Mathematical Diagnostic of Design & Resource Utilization in a Warehouse" aims to develop a mathematical model for evaluating the design and resource utilization of any warehouse.

The mathematical model will be derived to achieve six objectives as follows.

- Objective 01- Identify significant range of warehouse performance measurements which are internationally acceptable to be used as benchmarks
- Objective 02 - Narrow down and specify the identified warehouse key performance indicators and the required primary data to be collected from the selected two warehouses.
- Objective 03 - Collect Primary and Secondary data required to identify the influences on warehouse performance.
- Objective 04 - Derive a formula to measure sensitivity of each parameter on warehouse performance and productivity.
- Objective 05 - Indicate conditions under which the derived formula can be used.
- Objective 06 - Indicate by how much the mathematical model can enhance business performances and profitability.

4. Purpose of Research

It is generally accepted that markets have become more volatile in recent years and this has prompted awareness on supply chain agility. However, the changing role of warehouses in agile supply chains has been largely visible in almost all industries. Warehouses are significant investments for many companies and are long term fixed assets by their nature. A company cannot easily change its warehouse network and thus warehouses often become sources of competitive advantage or disadvantage if they do not meet changing market conditions. Their role and design within the context of modern supply chains need to be therefore fully understood. Role of warehousing in Supply Chain Management can be identified simply by the following aspects.

1. Perfect matching of demand and supply is an improbable expectation
2. Even cross docking requires transit points; even if for few hours
3. Zero inventories is a myth
4. Both natural and man-made seasonality features dictate production in anticipation of demand
5. There is no perfect pull system in any supply chain. There will always be a push arm, however short.

Since warehousing cannot be eliminated from any supply chain, it is essential to maintain warehouses despite size and operational level. Therefore each and every supply chain has a requirement to hold a buffer inventory in a physical distribution system because economies of scale and reduction of set up costs require centralized and continuous manufacturing operations whereas demand is discontinuous and infrequent.

Eventually, it can be concluded that proper utilization of warehouse resources and design characteristics lead to minimizing total cost of the supply chain as a whole, while increasing service levels and customer satisfaction and a continuous supply of commodities.

5. Literature Review

5.1 Mathematical Diagnostic

The technical state of a system can be identified by the means of the changes of the so called (measurable) external and (non-measurable) internal parameters. Therefore the momentary technical state of the examined system can be shown mathematically as a point of multidimensional state space defined by external and internal parameters.

One of the main goals of such a mathematical diagnostics is the determination of the momentary location of the examined system and to forecast the direction and velocity of its movement in this multidimensional state space.

The other aim of mathematical diagnostics is investigation and description of system behavior in case of different technical situations and environmental conditions. Such mathematical diagnostic methods are sensitivity test, correlation family test, and mathematical modeling of prohibited duties of the examined system. Using mathematical models, influences of the manufacturing anomalies can be investigated and characterized as well [4].

5.2 Warehouse Design and Control

The ever increasing trend towards more product variety and short response times has placed a tremendous emphasis on the ability to establish smooth and efficient logistical operations. These operations even play a vital role in determining a company's competitiveness, since logistics costs constitute an important part of the overall production costs. The efficiency and effectiveness in any distribution network in turn is largely determined by the operation of the nodes in such a network, i.e. the warehouses. Indeed, the innovations in warehouse technology have been numerous during the last decade. With respect to warehouse management, topics like planning and control have drawn wide attention in both the popular and scientific literature. In contrast, a sound theoretical basis for a warehouse design methodology still seems to be lacking.

The logistics costs that are incurred inside a warehouse are, to a large extent already determined during the design phase. Typically, a design runs from a functional description, through a technical specification, to equipment selection and determination of a layout. In each stage, target performance criteria (costs, throughput, storage capacity, and response times) have to be met. As such, warehouse design is a highly complex task, where in each stage trade-offs have to be made between often conflicting objectives.

5.2.1 Warehouse characterizations

In order to provide a characterization, there are three different angles from which a warehouse could be viewed: processes, resources, and organization. Products arriving at a warehouse subsequently are taken through a number of steps called processes. Resources refer to all means, equipment and personnel needed to operate a warehouse. Finally, organization includes all planning and control procedures used to run the system.

5.2.1.1 Warehouse processes

The flow of items through the warehouse can be divided into several distinct phases, or processes.

- The receiving process is the first process encountered by an arriving item.
- In the storage process items are placed in storage locations. The storage area may consist of two parts: the reserve area, where products are stored in the most economical way (bulk storage area) and the forward area where products are stored for easy retrieval by an order picker. The transfer of items from the reserve storage to the forward storage is called replenishment.
- Order picking refers to the retrieval of items from their storage locations and can be performed manually or (partly) automated.

- At the shipping area, orders are checked, packed and eventually loaded in trucks, trains or any other carrier.

5.2.1.2 Warehouse resources

A number of resources can be distinguished:
- The storage unit, in (or on) which products may be stored. Examples of storage units are pallets, carton boxes and plastic boxes.
- The storage system. This may consist of multiple subsystems that store different types of products. Storage systems are very diverse; they may range from simple shelves up to highly automated systems, containing automated cranes and conveyors.
- The retrieval of items from the storage system can be performed manually or by means of pick equipment. An example of pick equipment that is often used is a reach tan ruck.
- Other equipment that supports the order picker is called order pick auxiliaries, for example bar code scanners.
- A computer system may be present to enable computer control of the processes by a warehouse management system.
- The material handling equipment for preparation of the retrieved items for the expedition includes sorter systems, palletizes and truck loaders.
- Finally, personnel constitute an important resource, since warehouse performance largely depends on their availability.

5.2.2 Warehouse organization

- The most important decision concerns the definition of the process flow at the design stage.
- At the receiving process, an assignment policy determines the allocation of trucks to docks.
- At the storage process, items are transported to the storage system and are allocated to storage locations.
- At the order picking process, orders are assigned to one or more order pickers. If a consolidation and sorting process is present, orders are allocated to output lanes by a sorter lane assignment policy.
- At the shipping process, orders and trucks are allocated to docks by a dock assignment policy.
- Finally, allocation of tasks to personnel and equipment are addressed by operator and equipment assignment policies [5].

5.3 The Before and After Study of WMS- Identifying Opportunities Savings

Savings from a WMS implementation can be generally found in any one or more of eight categories. Clearly, there are significant linkages or interdependence between the categories. Those are;
- Labor reduction/avoidance related benefits
- Equipment related savings
- Space related savings
- Inventory savings
- Transportation related savings
- Information systems related savings
- Employee related savings
- Customer service related savings [6]

6. Methodology

Since there were no specific related researches available for reference and guidance and applications differ with the warehouse type and arrangements, KPIs selection and sample size definition were done in a slightly different manner from one to another KPI, where different approaches were taken for different KPIs. However the same principle logic was used at all instances, before and after implementation of WMS and some KPIs were more thoroughly analyzed using spread sheets for more clarity and accuracy in those contributing factors.

It can be concluded that proper management of a warehouse has a direct link with the overall supply chain performance, and thus on a warehouse and its performances collaboratively. This dependency was the motivator to undertake this research in order to find out how WMS can contribute to overall supply chain performance while reducing costs, and identifying positive and negative impacts imposed with an WMS implementation. Further analysis of WMS implementation can be used to find out external factors of warehouse performances that have to be properly managed. Eventually, the sixteen KPIs under consideration have been prioritized based on the results of both qualitative and quantitative analysis.

6.1. Research Methodology Framework

The figure 1 is to be intended to mention the methods used to rationalize the design & resource utilization in a warehouse.

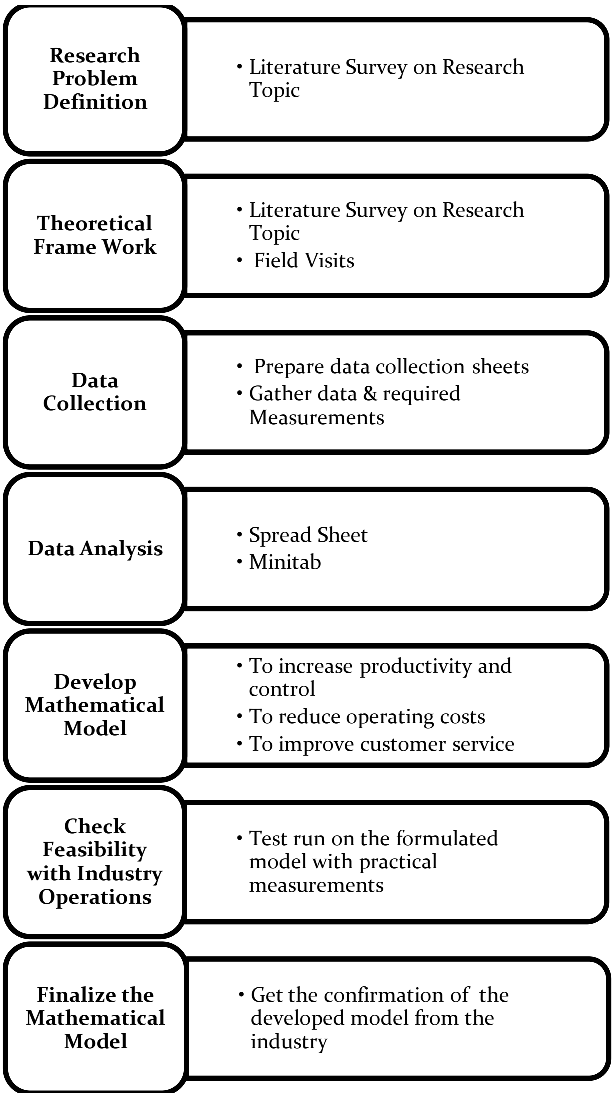

Figure 1: Methodology

6.2. Data Collection and Analysis

Data collection for the research was done as a work study, where the reference warehouse was an electric items warehouse of an agile supply chain. Almost all data were primary and the rest was gathered from the warehouse records which were different with the parameters of each KPI. For an instant KPI of hours per receiving process was calculated as time difference between put away completion time and arrival time of goods on site (hours) per number of incoming shipments during that period. Correspondingly, particular measurements were obtained for each KPI separately during a defined period of time and some of the common measures were number of orders, number of shipments, order dispatched time, order received time, orders dispatched on time, put away time, stock outs, total cases picked, total dispatched lines per month and so on.

Since this research falls into a case study category, sample sizes were defined based on the warehouse operational patterns, so, sample sizes for each KPI were different from one another according to the nature of the individual KPI. Analysis was carried out as before and after study of WMS implementation based on the selected sixteen KPIs and analysis was be composed of both qualitative and quantitative aspects. Primary observations and warehouse personnel verbal interviews were used for qualitative analysis and other gathered data was used for quantitative analysis. Minitab was used for the mathematical process of determining the increase/decrease of the considered KPIs performance as an analysis of mean comparison and significance value (p value analysis) considerations.

7. Results and Discussion

Cycle time is one of the critical aspects for a warehouse and for a supply chain. Therefore it could be taken for a sample discussion of one of the sixteen KPIs. The analysis of cycle times considered the average number of hours between the arrivals of goods on site and put away to storage location. In this assessment, performance of incoming shipments is taken into consideration. As previously mentioned, one door of the warehouse was totally allocated for incoming shipments with dedicated staff and most of the equipment's.

Primarily collected data and structured data are indicated in the table 2 as an example for all sixteen KPIs. Furthermore, hypothesis testing was conducted for each KPI considering situations before and after WMS implantation and sample analysis was done as described below [7].

Hypothesis testing for hours per receiving process

μ Mean of 'Hours per receiving process' before implementation of WMS

$\bar{x}$ Mean of 'Hours per receiving process' after implementation of WMS

Set the null and alternative hypotheses as:

H_0: There is no significant improvement in warehouse performance with the implementation of WMS where $\bar{x} = \mu$

H_1: There is a significant improvement in warehouse performance with the implementation of WMS where $\bar{x} >= \mu$

One-way ANOVA: Before, After

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Source  DF         SS         MS      F      P
Factor   1  0.0000127  0.0000127  66.28  0.000
Error    7  0.0000013  0.0000002
Total    8  0.0000141

S = 0.0004381   R-Sq = 90.45%   R-Sq(adj) = 89.08%


                                 Individual 95% CIs For Mean Based on
                                 Pooled StDev
Level   N       Mean      StDev  --+---------+---------+---------+-------
Before  5  0.0027372  0.0005650                          (---*----)
After   4  0.0003448  0.0001488  (----*-----)
                                 --+---------+---------+---------+-------
                                 0.0000    0.0010    0.0020    0.0030

Pooled StDev = 0.0004381
```

Table **Error! No text of specified style in document.**: ANOVA table for KPI of hours per receiving process

Sample sizes of before and after situations are 5 & 4 respectively. According to the test statistic, the F value of 66.28 statistic is much larger than the critical value (using = 0.05 that $F_{0.05;}$ 1, 7 = 5.591, so we can conclude that there is a (statistically) significant difference. However, calculated p-value is 0.000 < 0.05, therefore null hypothesis is rejected. The mean values of two samples are also different where, before it is 0.0027372 and after it has decreased to 0.0003448.

Table 2: Average number of hours between arrival of goods on site and putaway to storage location

Sample No.	Before				After			
	[Putaway time – Arrival time of goods on site] (Hours)	**[Putaway time – Arrival time of goods on site] (Mins)**	**Number of Incoming Shipments**	**Average number of hours between arrival time and putaway**	**[Putaway time – Arrival time of goods on site] (Hours)**	**[Putaway time – Arrival time of goods on site] (Mins)**	**Number of Incoming Shipments**	**Average number of hours between arrival time and putaway**
1	1:22	82	465	0.29%	2:00	120	8,949	0.02%
2	3:14	194	1003	0.32%	1:50	110	7,332	0.03%
3	3:57	277	2016	0.23%	1:45	105	3,174	0.06%
4	3:16	196	1637	0.20%	1:20	80	3,751	0.04%
5	1:41	101	520	0.32%				

7.1 Summary of Analysis

According to the summary of quantitative analysis fourteen out of sixteen KPIs have improved with the implementation of WMS. Moreover, twelve KPIs have improved significantly. These have led to an increased overall performance of the warehouse. However, warehouse performance does not entirely depend on a single system, but also on other external factors.

Table 3: Summary of analysis of before & after study of WMS

No.	***KPI***	***Sample Mean***		***Standard Deviation***		***F value***		***P value***	***Requirement***	***Remark***
		Before	***After***	***Before***	***After***	***Test Statistic***	***Table Value***			
1	Percentage of orders dispatched on time	68.42	92.00	47.11	27.69	5.090	3.998	0.028	Increase	Increased
2	Percentage of orders fully satisfied	37.99	43.10	32.12	12.46	0.560	4.016	0.455	Increase	Decreased
3	Stock availability in the warehouse	64.76	44.93	18.66	13.93	20.500	4.001	0.000	Increase	Increased
4	Order lead time	3.82	1.24	1.89	1.39	27.440	4.052	0.000	Decrease	Decreased
5	Number of cases picked per person hour	1.84	7.21	0.95	4.00	45.520	4.052	0.000	Increase	Increased
6	Number of order lines picked per person hour	0.19	1.49	0.21	0.90	51.400	4.057	0.000	Increase	Increased
7	Equipment uptime	98.31	98.76	2.46	0.99	0.610	4.079	0.440	Increase	Increased
8	Percentage of pallet storage capacity used in racks	86.09	98.81	4.24	0.84	69.170	4.057	0.000	Increase	Increased
9	Percentage of pallet storage capacity used in block stacking	43.40	75.92	7.44	5.48	99.070	4.057	0.000	Increase	Increased
10	Percentage of number of hours per day equipment is used – Reach Trucks & Fork Lifts	0.33	0.49	0.13	0.20	13.990	3.996	0.000	Increase	Increased
11	Percentage of number of hours per day equipment is used – Pallet Pickers	0.78	0.85	0.14	0.10	4.930	3.978	0.030	Increase	Increased
12	Percentage of number of hours per day equipment is used – RDTs	0.73	0.86	0.15	0.09	16.990	3.957	0.000	Increase	Increased
13	Number of standard hours worked	0.80	0.87	0.14	0.10	5.340	3.978	0.024	Increase	Increased
14	Percentage of locations with wrong stock	0.03	0.06	0.06	0.04	3.330	3.986	0.072	Increase	Increased
15	Percentage of SKUs with wrong stock	2.51	0.05	12.37	0.07	2.210	3.986	0.140	Increase	Decreased
16	Average number of hours between arrival of goods on site and putaway to storage location	0.0027	0.0004	0.0006	0.0001	66.280	5.591	0.000	Decrease	Decreased

7.2 External Contribution Factors on WMS Return on Investment

The following factors could be identified as critical external factors imposing a significant impact on warehouse performance.

1. Labour turn over
2. Absenteeism of employees or inability to work due to personal problems
3. Errors in demand forecasting of Inventory department
4. Lack of real time information availability
5. Cancellation of incoming shipments
6. Data entry errors and delays
7. Dedicated equipment for doors
8. Delays in transferring goods from bond warehouse to distribution centre
9. Workforce ignorance on their job
10. Not having enough time to charge equipments (Late work and/or early work)
11. Equipment shortage
12. Company policies
13. Labour Turn over (Due to recent labour changes, new pickers are not familiar with the places where the items are stored.
14. Lack of attention of management
15. Mismanagement of shipment allocation and not having outgoing shipments
16. Reduction of customer demand
17. Storage space availability issues
18. System failures

7.1 Prioritizing KPIs

Considering the overall analysis based on both qualitative and quantitative approaches, 16 KPIs has been prioritized to four categories as follows.

Table 4: KPIs Prioritizing

Rank		KPI
`	a.	Order lead time
1	b.	Percentage of orders dispatched on time
	c.	Average number of hours between customer order receipt and dispatch of goods
	d.	Average number of hours between arrival of goods on site and putaway to storage location
2	a.	Stock availability in the warehouse
	b.	Percentage of orders fully satisfied (i.e. all order lines supplied)
	c.	Number of standard hours worked
	d.	Number of cases picked per person hour
3	a.	Number of order lines picked per person hour
	b.	Stock-turn (number of weeks of inventory held in the warehouse)
	c.	Returns
	d.	Number of hours per day equipment is used
4	a.	Percentage of locations with correct stock
	b.	Percentage of SKUs with correct stock
	c.	Equipment uptime
	d.	Percentage pallet storage capacity used

Accordingly there are, four categories of four KPIs each. Rank 01 category is considered as the most critical for warehouse performances where operational efficiency relies on those factors. Then rank 02 represents the order fulfillment capability and cost efficiency of the warehouse, the second highest in importance. Rank 03 and Rank 04 represent the resource utilization factors and stock accuracy which have an indirect influence on operational performance and cost efficiency.

This ranking will be beneficial for improving overall performance of a warehouse and to achieve higher profit margins with a higher focus on each deficiency and bottleneck. Continuous performance monitoring and improvement will add more benefits for the organization ultimately resulting in higher customer satisfaction.

7. Future Research Areas

With the findings of this initial analysis, mathematical models could be derived to measure sensitivity of each parameter on warehouse performance and productivity which is benchmarked with the key performance measure; cost efficiency. Then conditions under which the derived formula can be used could be identified. Eventually the assessment could be carried out to enhance business performances and profitability.

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