An Empirical Warehouse Layout Design and Optimization Approach for Sri Lankan Practitioners

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Abstract— **Warehousing is a vital function for Sri Lanka, due to its trade-dependency. One of the most critical areas highlighted for development in Sri Lanka is infrastructure, of which warehouse holds a key bearing. This study will extend the theoretical framework of Warehouse Layout Designing published by Dissanayake and Rupasinghe, 2018 by incorporating viewpoints of the Sri Lankan practitioners. A focus group discussion with 5 prominent experts in the industry will be incorporated and extended questioner feedback from 10 other practitioners. This research focuses on bridging the theoretical gaps with respect to the warehouse design and optimization from the Sri Lankan context. Therefore, the objective of this paper is to (1) Obtain practitioners' feedback for not being able to use the theoretical approaches (2) Assess the warehouse designers approaches carried out by the practitioners (3) improvements to the theoretical framework based on the practitioners' approach.**

Keywords—warehouse design, design and operation of distribution center, ethnographic study, warehouse design experts

1. Introduction

Sri Lanka, situated in the Indian Ocean, lying in the middle of major trade route between East-West bears a strategic advantage as a key logistic hub in South Asia. But as per the World Bank Logistics Performance Index (LPI) published by the World Bank, Sri Lanka ranks at 92nd with a score of 2.60 out of 167 countries in 2018. One of the most critical areas highlighted for development is infrastructure, of which warehouse holds a key bearing.

Design of layouts have been assured in industrial engineering research, focusing on design of factories, warehouses and supply chains [1]. Warehouse design consist of a range of decisions which involves layout constraints and operative issues that affects the performance and logistics cost [2] . These areas have been published in research literature, providing insights to solve many related problems. Over 140 papers have been published on the Facility Layout Problem over the last 20 years [3]. But unfortunately, very few of these approaches deal with general warehouse design problems rather a more specific aspect [4] and have rarely being used by industry practitioners [5] with respect to Sri Lankan industries. As per [6], collaboration with expert warehouse designers has caused to rethink of the warehouse design process.

Therefore, this means that there is a disconnection between the research approaches and what is being practiced. A consistent conclusion has been that research is not "deployment-ready,"[6]. Since research results are scientifically derived and logical, over a period in collation with the experience and knowledge, it is a waste to not use it and further improve it.

Warehouse design approaches have been studied for decades. But its complexity has not facilitated the practitioners in its application. Therefore, a summarized practically implementable framework has being developed by the author taking into consideration of all the variables and approaches of past research. Its literature can be found in authors' previous paper [7].

Warehouse is a key node in logistics and Sri Lanka's infrastructure. Yet, as per the feedback from the practitioners, over 70% of the warehouses in and around the main port is of a size less than 50,000 sqft, at a one story high, low facilities for operation and manuaring.

Designing these facilities is an important engineering problem which requires the assistance of financial evaluation in deriving the right mix between the fixed and operating costs and arriving at the optimum layout design. However,, it is known that the cost is predominately determined at the design phase of a warehouse [8].

Therefore, the main aim of this research is to understand the approaches used by the warehouse practitioners in Sri Lanka, the reasons for selecting that approach is to compare and evaluate the approach against the scientifically proven framework derived in a previous paper [7]. Subsequently, to validate the variances and concerns in relation to the well-defined approaches and formulate a methodology which would satisfy the practitioners concerns and address the scientific approach towards a finer model.

Warehouse also play several roles in the supply chain such as raw material warehouse, distribution center, finished good warehouse, postponement warehouse, consolidation warehouse, retail warehouse [9]. The scope of this study is a consolidation operation in a finished goods warehouse.

2. Literature Review

Warehouse design, facility layout and capacity assessment can synchronize the demand and supply gaps and ensure a smooth flow of operation [10]. Many research papers and books were identified under the search of warehouse layout design. While some of them focus on the overall design approach, others focus on a specific area of the warehouse such as picking optimization [11],[12], [13], storage area optimization [14], [15], [16] which is not considered within the scope of this paper.

Considering the papers [2], [8], [17], [18] and [4] focused on the overall design approach, the approach differ one to

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another. However, even though the steps are not sequentially similar, majority of the design parameters overlap. The summary of the design parameters in a step wise top down approach has been identified in the research paper [7]. If the warehouse is designed from ground-zero, it is known to be a “green-field scenario” , while if it’s a modification of an existing is known to be a “brown-filed scenario” [2].

The warehouse operation consist of 5 main process steps as Receiving, Putaway, Storage, Order picking & Shipping [19], [18]. The receiving process itself is built up with many different steps/activities such as receiving/unloading (The activity performed in moving goods out of the vehicle), Staging (The goods are temporarily kept before moving to storage), value addition and putaway (Activity performed in moving goods from dock/staging to the storage area) [20],[21].

Material Handling Equipment is a machine that moves goods in a restricted area for the purpose of manufacturing or warehousing. Its proven to be one of the impotent assets in warehouse operation [22]. With the advancement of technology and engineering, innovative storage (especially high-density storage racks) and handling solutions are introduced. Some of them are selective racks, double deep racks, drive through or flow through racks [23].

3. Methodology

3.1. Approach

The first objective is to identify and assess the approaches followed by expert practitioners in designing a warehouse layout. Therefore, first five (5) consultants were identified from different companies as a focused group and discussion were carried out to understand their problems, approaches and experience. Discussions revealed that the process followed by the experts are not documented, unlike the results published in research literature which is logical and should have followed a scientific approach.

Thereafter, questionnaire was designed and shared to surface the key problems, differences in relation to the scientific approaches. This would assist in understanding their approaches and quantifying its impact. These finding were compared and analyzed against the well-defined framework in [7].

3.2. Preliminary Conclusions

Even though expertise plays a key role in designing the warehouse, the design process is difficult to define. Each practitioner would be constrained to the following conditions; 1) their own individual approach based on the information available, 2) their subfield of expertise which would be a specific industry, third party operations or a 3) specific warehousing type. (Raw material Warehouse, finished goods warehouse, fulfillment warehouse etc.[24])

The designers gained experience in the field by carrying out projects based on the situation. Results from long period of experience working on a variety of design problems, would influence their approach. Therefore, *the years of experience would be a key factor in selecting the experts for the study*. Hence, the practitioners that were selected were conditioned on their years of experience to be over 5 years in warehousing.

The *industry exposure* also seems to determine some of the approaches of the practitioners. Therefore, this too was captured as a key parameter.

Even though the warehouse is designed by experience individuals, it is usually the users or operators that really experience the impact of the design and these operators in-term needs to provide information to the designers. Therefore, it was revealed that not only the *warehouse designers but also the operators need to be questioned.*

3.3. Expert Selection

The study used the expert sampling technique – a non-probability sampling method that helps identify expert with specific requirements within the scope of study. These specified requirements are; 1) greater than 5 years of experience, 2) practitioners who have designed multiple projects 3) experience in multiple industries.

The identified practitioners are from many well-established companies & consultants in Sri Lanka. These companies are denoted from A to H in Table 1.

Designing of a warehouse usually happens only once in a lifetime of a warehouse operation. Therefore, finding practitioners who have designed multiple projects is very rear. Almost all of the selected participants are from leading 3rd Party Logistics providers in Sri Lanka. Each participant has a minimum of 5 years of experience and handled at least 2 projects.

Table 1. Details of practitioners chosen for the study

Company Name	A	B	C	D	E	E	E	F	G	H
Name	a	b	c	d	e	f	g	h	i	j
Expereince (Yrs)	32	26	27	11	12	22	17	14	6	14
No. of Projects	17	7	8	3	6	5	6	4	2	4
Nature of Business	Multi-facility warehouses from raw Material to Retail Warehouses	Perishables, Thread, Fabric finished goods to Retail Warehouses	FMCG, Tea, Lubricants back of factory to finished goods Warehouse	Pharmaceutical, Surgical Equiptment and FMCG Retail warehouses	Multi-facility warehouses (FMCG, Apparel, Hi-tech)	FMCG, Hi-tech, Apparel finished goods & Bonded facilities	Multi-facility warhouse (Apparel, FMCG & Lubricant)	Project Cargo, Tele-communication, FMCG	Pharmaceutical & Cold Storage warehouses	Apparel, FMCG Retail & Bonded facilities

3.4. Design of the Questionnaire

After discussions with the focused group, a detailed questionnaire was developed considering 3 categories of information. 1) Demographic information 2) Warehouse Designers feedback and 3) Warehouse Operators feedback. The warehouse designers, to provide their experience in designing a warehouse in terms of the approaches used, limitations & challenges. The operators would expose the practical drawbacks of the design, their experience & constraints. Most of the experts in Sri Lanka play both of these roles.

Based on the designers' feedback, and researches such as [25], the information was further categorized as to; 1) Pre-Designed Approach (their awareness and application of existing literature to the approach in designing the warehouse) or 2) Self-Designed Approach (whether they are aware and uses pre-defined approaches or solely depend on their expertise). The reasons for such choices were also analyzed.

Based on these discussions, the structure of the questionnaire was developed as shown in Fig. 1

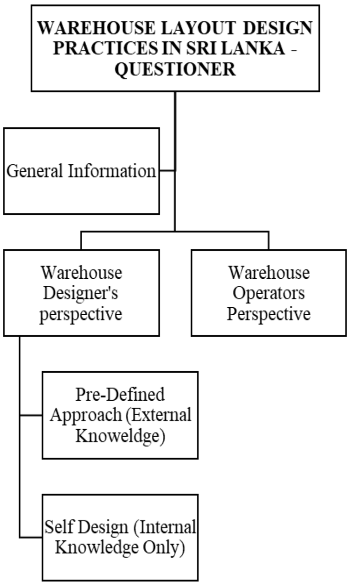

Figure 1. Design of the questionnaire

3.5. Data Collection

A sampling strategy was used to collect data from a range of different warehouse designers and operators. The participants were briefed of the nature of study and data collection procedure. Thereafter an online questionnaire was sent to the selected practitioners.

There were 4 questions under the "General Information" which gathered information regarding the practitioner's experience and their areas of experience and whether they monitor the performance of the warehouse in terms of the utilization and productivity. Thereafter, identifying if they have designed warehouses. There were 7 questions within the scope of a warehouse designer. The approach of design, the complexities faced, the constraints, the frequency of re-designing, the benefits realized were questioned. In addition, whether they are aware of any pre-defined approaches, and if they have used it. If pre-defined approach was not used, the approach used, the reasons for not using them were also questioned. From an operator's perspective, 4 questioned were asked to identify the design constrained and drawbacks of the layout.

3.6. Analysis

The research feedback was collected over two months. Below is the analysis of the feedback received from the experts.

Over 85% of the practitioners are aware of existing warehouse design approaches.

Over 65% uses the approach with some changes

Below are some of the challenges in using the defined approach.

One of the main challenges that the designers highlighted was the fact that they had to design warehouses which were not built for warehousing but instead for a factory or a converted old building ("brown-field scenario). This is seen as a significant drawback in applying the scientific approach of warehouse designing. The percentage of green-field projects was less than 10% to Brown Field warehouses designed which was over 90%.

In relation to using pre-defined approaches, the practitioners' feedback is that "most of the researches focus on the optimum storage solution, provided that the input parameters remain static, but unfortunately, most of the input parameters keep changing and changing the layout frequently would be costly". Therefore, it is required to identify the relationship between the input parameters/variables and the decision parameters/output of the layout design.

4. Evaluation of the Study

Based on the feedback received from the practitioners in relation to the approach, the consolidated feedback can be summarized as below.

4.1. Determine the Optimum Storage Solution

Below is the summarized approach combining all practitioners' experience that could improve the theoretical framework

1. Storage areas are sub-divided based on;
   a. Storage Condition (Ambient, air-conditioned, refrigerated),
   b. Nature of the product (Bulk/Drums/rods etc.)
   c. Compatibility (Soap, tea etc.)
2. Constraints and Compliance of the warheouse (95% of the desigs are done on existing facilities) such as stacking norms, docks, infrastrucutre and Compliance
3. Forecasted Volumes

The output of the optimum storage solution which is the "area required for a given volume" and the corresponding MHE (Material Handling Equipment) will be required for the next steps.

Table 2. Storage Solution Options

Opt	Type of Storage	No. of Pallets in Depth	No. of Pallets in Height	No. of Pallets Stored	Investment/stored pallet	Total Investment ('000)
A	Selective	1	6	7,402	1,000	7,402
B	Selective	1	6	5,354	1,000	5,354
	Double deep	2	6	2,048	1,500	3,072
C	Selective	1	6	5,566	1,000	5,566
	Pallet flow	36	6	1,836	2,000	3,672
D	Selective 8 level	1	8	7,402	1,200	8,882

The above Table 2 is the approach by the practitioners to evaluate the best storage solution. Here, they compare the investment against the storage capacity to arrive at the best storage solution. Suppose the required storage is 7,402 pallet positions. Even though the total number of pallets are the same, total investment cost (in Sri Lanka Rupees - a hypothetical value) differ based on the type of racks used. Majority of the practitioners would go for option A due to the low investment and the flexibility even when the input parameters change, but some practitioners would also consider the operating/handling cost before concluding on the storage solution.

Table 3. Material Handling Equipment Options

Storage	Depth	Height	Equipment	Time per pallet	Cost of Machine (Mn)
Drive-in Racks	6	4	Folk lift (FL)	3.3	10
Double Deep Racks	2	6	Double Deep Reach Truck	4.5	20
Pallet Flow	36	6	Reach truck	4.1	40
Pallet Flow	13	5	Reach truck	3.4	35
Selective Racks (G+5)	1	6	Reach truck (RT)	4.1	5
Selective Racks (G+7)	1	8	Reach truck	5.5	7
VNA Racks	1	6	Reach truck (VNA)	1.4	55
Floor	4	2	Folk lift	1.1	-
Stackable	4	3	Folk lift	1.6	-

Based on the storage solution, the type of machine used will also differ. Below Table 3 shows some of the MHE options for given storage racks. Here the rack with 6 levels are referred to as "G+5" which means ground level plus 5 levels. Similarly, "G+7" is 8 level high racks. Here the cost of the machine is given in Sri Lankan Rupees. Selective Rack with VNA (Very Narrow Aisle) is where a specific truck (VNA) which can operate within a narrow aisle.

Some of the practitioners would obtain the possible options for the machines to be used in addition to the storage solution, prior to deciding on the best option.

4.2. Determine the Optimum Product/Material Flow

Now that the storage solution and the corresponding machines are defined, next the practitioners would identify the operation flow based on the requirement and the key steps of the process & its corresponding areas within the warehouse. Some would directly transfer the goods to the storage whereas some would stage it. This would be based on their experience. There is no approach as to how the optimum product flow is defined.

Firstly, as per the receiving process, the goods need to be unloaded at a dock. Therefore the number of docks need to be determined. [26], is a research that helps to determine the number of docks. However, the practitioners would consider the average volumes received and calculate the number of docks required as below.

Number of Pallets can be unloaded/day/bay = x

Total Pallets required to be unloaded per day = y

Total number of docks required = y/x rounded up

Based on this, the area required for docking will be calculated. Similarly, the rest of the space areas will be identified in modules. The total of these areas would give the required size of the warehouse as shown in Table 4. The construction cost per square foot would be used to calculate the total construction cost of the warehouse facility. Thereafter, some practitioners would use an Entity Relationship Diagram or a Spaghetti Diagram to define the placement of the different areas in order to minimize the travelling distance within the warehouse.

Table 4. Determine size of Warehouse

Parameter	Space (Sqm)
Docks (In and Out)	A
Staging Area (In and Out)	B
Value Addition Area	C
Bulk Storage Area	D
Picking Area	E
MHE Charging Area	F
Office	G
Total Area	**Sum (A to G)**

4.3. Handling Cost (staff, machines)

The corresponding cost related to staff and machines were identified for each stage of the product flow as per Activity Based Costing and tabulated in Table 5. The total minute per pallet is derived based on a time study. The corresponding storage solution and machines required (considering Table 2 and Table 3) for the activity along with its cost per move is also defined. (Staff/machine cost per minute x minutes per pallet = cost per pallet/move) Based on this, the total handling cost of the operation can be calculated.

Table 5. Activity Based Costing

Activity/ Resource	Volume (Pallets)	Minutes/ Pallet	Staff Cost per move	Machine Cost per move	Total
Unloading	y	x	z		
Putaway					
…					
Total					

4.4. Model Comparison

Based on the storage cost and handling cost, the practitioners would pick three options, taking into consideration the possible changes in future which would impact some parameters such as risk factor in reaching high levels, flexibility of the racking type, investment cost, orientation of the existing building, security, compliance etc. These could also be considered as constraints of the design which cannot be quantified.

Based on the above options, the practitioners would determine the best 3 options for final evaluation. The total investment derived from Table 2, 3 & 4, the annual operating cost derived from table 5 would be the basic information. Thereafter, considering the minimum investment as the base model, the other 2 options will be derived. Finally, the option with the minimum payback period will be selected as the best option for designing the warehouse layout.

Table 6. Model Comparison

	Alternative		
Category	**A**	**B**	**C**
Type of Storage	X	Y	Z
Total investment	21,290,213	22,314,213	23,126,213
Difference from the base	-	1,024,000	1,836,000
Annual operating costs	5,854,800	6,543,600	4,821,600
Difference from the base	-	688,800	-1,033,200
Payback Period		1	-2

Discussion

In order to get the best output, warehouse design practitioners were selected based on their years of experience, number of warehouse design projects handled, and diversified business industries covered. Due to the limitation in local experts and information, carrying out the study was a challenge. All experts follow an approach to design a warehouse layout either through their own experience or through knowledge gained by pre-defined approaches (65%), but they do not follow the same sequence of steps.

The practitioners use a lot of their expertise to derive the design of the layout. Some of these cannot be quantified or justified, but as a research finding, the process selection could be derived based on a mathematical approach, which could be an opportunity for future research.

5. Conclusions

The key challenges faced in using the research defined approaches are, (1) over 90% warehouses designed are brown-field scenarios, and (2) require an agile solution over an optimum due to the volatility of the supply chain.

Assessing the practitioners' approach, consist a lot of similarity to the research approaches except for the qualitative inputs to the model in relation to service levels, compliance, safety and security. Furthermore, the final decision of a particular design is selected by shortlisting 3 models options given in Table 6. But this approach could be improved by using a mathematical model to optimize and derive the best option.

Some of the key areas that are covered in the practical approach which could be used to improve the optimization framework which was derived in a previous paper [7] are as below;

1. Storage Items need to be sub-divide based on storage conditions, nature of the product and compatibility.
2. The warehouse need to consider forecasted volumes for each type of storage category.
3. Infrastructure constraints – over 90% of the warehouse designs are done on existing warehouses. Therefore, these warehouses would have infrastructure constraints which would need to be considered in the design.
4. The optimum product flow within the warehouse need to be considered in identifying the operational activities and operational cost
5. The available industrial storage solutions and equipment along with their return on investment need to be considered in the design.

These would be the pre-steps that need to be followed prior to determining the costs elements of each process which is updated in Figure 2.

This study may contribute to improving the theoretical approach of warehouse layout design as well as assist the practitioners in using the theoretical approach in a more practical means. This research study could also contribute as guidance for many upcoming studies related to warehouse design & optimization.

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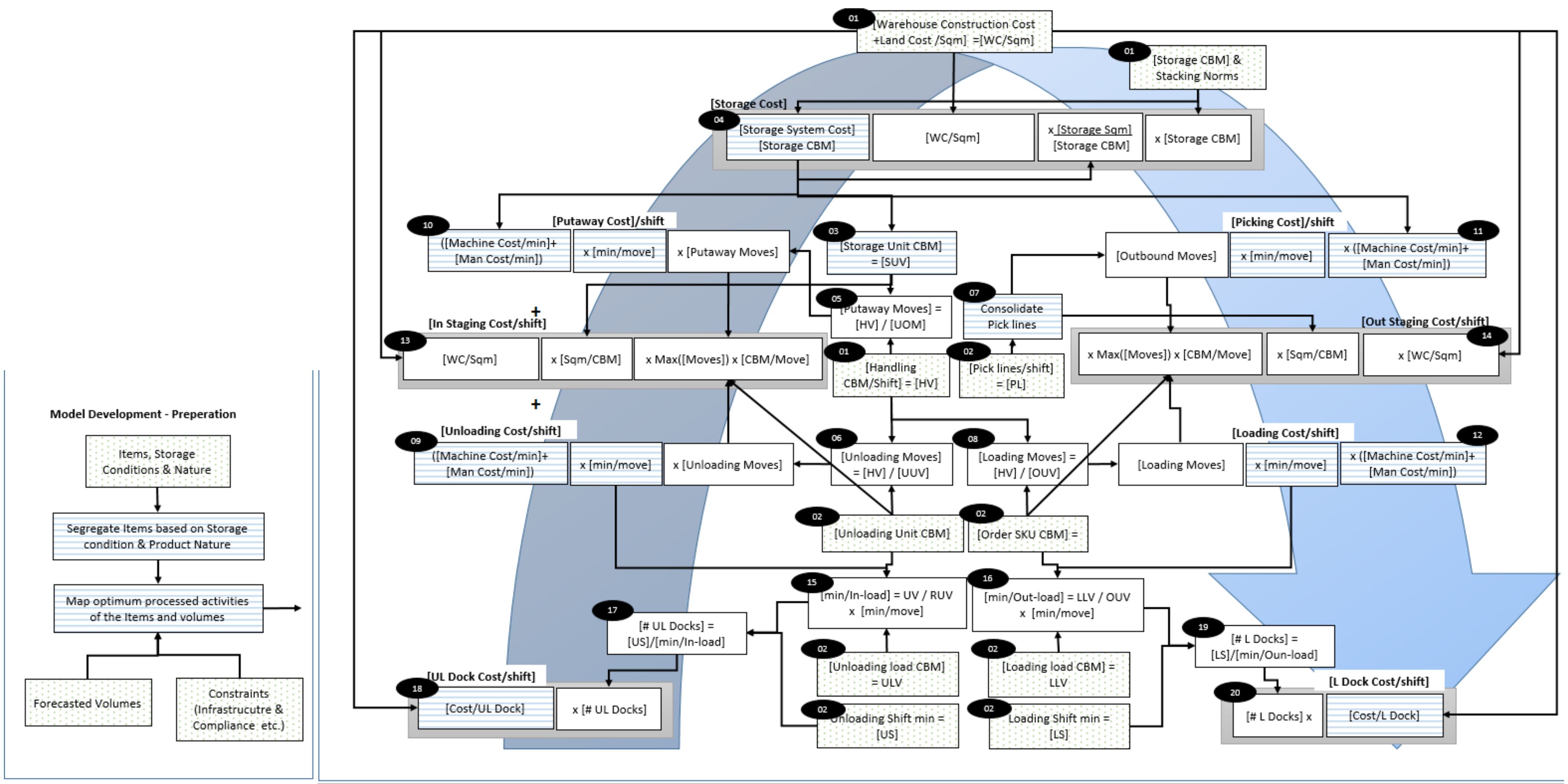
Fig. 3 – Improved Framework based on practitioner's feedback



Horizontal line Cells – Functional and Technical Specification (Step 3) which could be derived based on isolated model optimisations since they consist of many options (Machine cost =Material Handling Equipment cost)
Gray Cells – Cost elements that sum up for the objective function (Cost reduction)
Dotted Cells – Data Collection (Step 1)
Orange Arrow – Process flow (Unloading dock, Unloading, In-staging, Putaway, Storage, Picking, Out-Staging, Loading, Loading Dock)