Towards lean warehouse: transformation and assessment using RTD and ANP

Sanjay Sharma
National Institute of Industrial Engineering (NITIE), Mumbai, India, and
Bhavin Shah
Department of Computer Engineering and Information Technology, Shi S'ad Vidya Mandal Institute of Technology (SVMIT), Bharuch, India

Received 15 April 2015
Accepted 29 July 2015

Abstract

Purpose – The purpose of this paper is to represent a unique combined Real time Delphi (RTD) – analytic network process (ANP) approach considering efficient decision making with practical validation.
Design/methodology/approach – An ANP model encounters invisible relationship and interdependency among qualitative and quantitative criteria for assessment. RTD supports continuous assessment and improvement in team building, modeling, developing, implementing and validating the procedure. To illustrate practical validation of the model, the authors apply it in a manufacturing firm. A case illustrating the model, finds improved results and judgments followed by conclusion.
Findings – A case illustrating the model, finds improved results and judgments. This model improves warehouse performance by integrating lean and people issues. The outcome results in an efficient decision making and consensus judgments. It also fosters high trust and coordination level among people in warehouse.
Originality/value – Previous studies have assessed leanness either at enterprise or manufacturing level. As lean transformation and assessment both are continuous and long-term procedure, first the concept should apply to single function and should lead toward enterprise level. A web-based approach and multi criteria decision-making techniques like analytic hierarchy process, and ANP had been applied individually to measure leanness at enterprise level. Because of the warehouse contributing significantly to the total wastes and costs for an organization, such operations are considered presently.

Keywords Supply chain, Decision support systems, Analytic network process, Lean warehouse, Lean transformation, Lean assessment, Lean decision support system, Real time Delphi

Paper type Technical paper

1. Introduction

Lean manufacturing is widely used and an accepted philosophy across all industries (Womack *et al.*, 1990). Almost all lean practices were first introduced by the Toyota Company in manufacturing industry (Tang *et al.*, 2005; Pil and Fujimoto, 2007). Initially an objective of the Toyota philosophy was to eliminate waste and enable cost reduction at the manufacturing level (Hicks, 2007; Anand and Kodali, 2008; Vinodh and Balaji, 2011). From research, the waste identified in the manufacturing function are over production, over processing, waiting time, transportation, defects, inventory, storage (Hines and Rich, 1997; Pattanaik and Sharma, 2009) and under utilization of employees (Vinodh and Balaji, 2011). Sharma and Shah (2015) assessed leanness of warehousing waste and suggested a clustering-based framework to improve overall picking productivity. Over a period of time organizations recognize the importance of lean and adopt it throughout an enterprise to remain competitive. Lean enterprise can be defined as the collective and synchronized effort of people, to continuously improve the

International Journal of Productivity and Performance Management
Vol. 65 No. 4, 2016
pp. 571-599

1741-0401
DOI 10.1108/IJPPM-04-2015-0061

efficiency of all the functions. It involves lean methods, culture and partnerships of an enterprise (Cil and Turkan, 2012). To survive in this era of globalization every organization needs to achieve leanness through better performance, business policies, strategies and working environments. Achieving a lean enterprise is related to an improvement in the way of performing operations at different levels and functions using lean principles and practices. Leanness cannot be achieved in a short time span; it is a long-term process requiring changes in every function (Narang, 2008) of an enterprise. For efficient decision making any system should be in alignment with lean goals (Cottyn *et al.*, 2011). This process of performing every operation efficiently in alignment of warehouse goals is referred to as lean transformation. The lean transformation can be started by implementing lean philosophy at a single functional level followed by other cross-functions and later covering the whole enterprise.

This study focusses on warehouse operations as it contributes substantially to the vital portion of total waste and costs (de Koster *et al.*, 2007) in any manufacturing firm. Warehouse design and control are identified as crucial tasks in warehouse management (Baker and Canessa, 2009). Although there is not any precise definition of lean warehouse, it can be defined as a collective approach of factors applied to improve warehouse functions. From the study given below we identify warehouse factors in terms of direct or indirect involvement of people at every level, lean principles and performance criteria. These criteria are further categorized into design, operational and decision issues affecting warehouse performance (Rouwenhorst *et al.*, 2000). In the existing literature researchers have emphasized more resource optimization; unfortunately practitioners are unable to differentiate "lean" and "efficiency" thinking. The "efficiency" thinking suggests the best way of using available resources, assets and technologies to gain more profits with least resources which are not necessarily a long-term profitable strategy (Ohno, 1988). The current state-of-art in warehousing literature adopts "efficiency" thinking and tries to optimize one or more performance measure while forfeiting others which leads to an unbalanced system. Exhaustive research has been conducted to optimize design and operational issues such as layout, zoning, picking, batching and routing (refer Gu *et al.*, 2007, 2010; de Koster *et al.*, 2007; Gagliardi *et al.*, 2012, for more detail). The objective of lean warehouse is to serve customers faster, with less storage space, less inventory and more accuracy. The difference between warehouse optimization and lean warehouse is that lean engages all functional/cross-functional people along with technological and decision issues at each level for continuous improvement. Together they should improve issues like dispatching, order picking, order return, layout planning, order batching, storage allocation and resource (e.g. manpower, time, space, forklifts, etc.) utilization using lean practices and tools, which were not properly resolved by warehouse optimization (refer to Lean warehousing, 2015). Therefore, this paper focusses on maximizing the value for people involved and improving warehouse performance through lean practices. Creating and maximizing value for people, e.g., operators, customers, supervisors, leaders and other employees is a most challenging task in warehousing as it requires cultural (Hines *et al.*, 2004) and environmental changes which take a long time to achieve. Before any decision is taken by experts or leaders, precise understanding of the problem is required to avoid conflicts. A lean principle – GEMBA can be used to resolve this conflict and convince the employees to adopt the change for a long time (refer Lean warehousing, 2015). For this reason concerned people (e.g. supervisor, operator, IT people, etc.) are required to discuss the real situation in the assessment process. Managers and leaders of an organization are not always knowledgeable and domain experienced such as experts. Experts can only suggest which tool to use, at which time, to solve which problem (Cil and Turkan, 2012). Thus continuous involvement and collaboration among experts and managers is required in the assessment process.

2. Literature review

Lean assessment and transformation in the warehouse is a continuous practice that requires a number of changes and improvements in several functions at the same time. Scales are required to measure qualitative and quantitative criteria like performance, delivered value, wastes and costs in warehouse called leanness. Much research has been conducted for lean transformation and measurement using models like analytic hierarchy process (AHP), analytic network process (ANP) and fuzzy and survey-based methods.

In a warehouse decision there are lots of qualitative criteria that do not have any fixed numerical value and that represent ambiguous or vague characteristics (Doolen and Hacker, 2005). In such cases linguistic assessment using fuzzy tools can be used (Beach *et al.*, 2000). AHP in the form of a multi-grade fuzzy approach has been used to assess leanness and identify the needed improvement areas for a manufacturing firm (Vinodh and Chintha, 2011). Bayou and De Korvin (2008) presented research using a fuzzy logic approach for lean assessment and benchmarking in a manufacturing firm. The decision making under interrelationship consideration can be addressed by ANP (Lesmes *et al.*, 2009). The fuzzy-ANP approach has been found competent for decision making under consideration of interdependent criteria (Chen and Yang, 2011; Sevkli *et al.*, 2012). Fuzzy-ANP has been applied to determine weights under consideration of complexity, vagueness and mutual interactions among criteria (Dağdeviren and Yüksel, 2010). A number of tools and methods have been used for lean assessment but interdependency among various issues has been unaddressed (Cil and Turkan, 2012). This shortfall was overcome by using an ANP-based assessment model (Cil and Turkan, 2012). Assessment is a tedious task and also includes lots of manual calculations, time and errors. Therefore the need for a computerized system was identified in previous research work. To overcome these issues and improve decision-making capability the decision support system for fuzzy logic-based leanness assessment model has been developed (Vinodh and Balaji, 2011). Seyedhosseini and Ebrahimi-Taleghani (2015) have presented group fuzzy ANP to assess the lean level in auto manufacturing industry.

Tanco *et al.* (2013) applied several techniques to analyze leanness like value stream mapping (VSM), overall equipment efficiency, spaghetti diagrams, work balance and discrete event simulation. Wu *et al.* (2015) presented a multi-attribute group decision-making framework to assess lean practices for logistics distribution centers. To our knowledge, this is the first time warehouse performance has been evaluated on the basis of lean assessment; however at the enterprise level many studies are available. Although there are various tools and techniques available for lean assessment, it is a very difficult and challenging task to decide which tools to use for improving warehouse performance. It is a cumbersome task for managers to identify exact problem in the warehouse and apply lean technique to resolve it. Almost every organization faces problems in deciding warehouse design and operations at every level. Even if the problem and solution are identified it might not be possible for the manager to resolve due to some constraints (e.g. picking delays can be improved by changing layout with space constraint). Furthermore, the enterprise should also know the application order of lean tools-practices and cause-effects relationships (Cil and Turkan, 2012) criteria in warehouse. All previous research provides static systems with fixed survey-based questions and lean solutions for which it does not provide counter solutions and continuous improvement methods (Hallam, 2003). Therefore there is a need for facilitating managers with a dynamic system allowing standard practices, methods and tools to improve leanness at the time of design and operation of warehouse. This facility is provided by the Real time Delphi (RTD) system for real time suggestion, decision making and collaboration with experts. The simple survey-based Delphi method was first proposed by Gordon and Helmer (1964) of the RAND Corporation. With a simple Dephi method, real time input and tracking is required to map the progress. RTD facilitates leaders to identify exact problem, lean tools for solution, improve data visibility and prepare action plans resolving the existing problems (Wan and Chen, 2009). It has been shown that RTD improves the process efficiency, expert availability and reduces drop-out-rate (Gnatzy *et al.*, 2011). A well-organized and professional technical setup of the online Delphi system also ensures user friendliness (Steinert, 2009). Domain experts provide the required knowledge and judgments for improvement while the internal workforce can clearly discuss exact problems. Collective expert opinion identifies significant aspects of any problem and can be used to develop strategies (Schuckmann *et al.*, 2012). Therefore this model considers both judgments and suggestions of experts and functional/non functional people. It is useful for managers and employees pursuing continuous study and improving their knowledge about lean practices and techniques. The model identifies lean performance and people issues as interdependent elements of the lean warehouse. An ANP identifies and calculates interdependency of criteria accurately. It practically validates rankings of RTD because the survey model requires the necessary evidence.

An ANP-based lean transformation model applied (Cil and Turkan, 2012) at the beginning of transition, has been proved more effective in attaining lean outcomes. But, a requirement of combining ANP with other survey-based method was identified in earlier research (Cil and Turkan, 2012) for better evaluation. Therefore this study proposed a combined RTD-ANP model for lean assessment which is required for decision making, lean assessment and continuous improvement. The RTD is a survey-based method providing continuous criteria to rank the real time decisions, and knowledge; and end up with a common consensus. An ANP provides practical validation and enhancement to the results of RTD. Furthermore the uniqueness of this model is that; for the first time an online application is used to prepare questionnaire and model survey procedure. It involves experts in collaboration with employees to better understand the real situation and problems. An ANP model encounters invisible relationships and interdependencies among qualitative and quantitative criteria for assessment. RTD supports continuous assessment and improvement from team building, modeling, developing, implementing and validating the procedure. To illustrate practical validation of the model, we apply it in a manufacturing firm. A case implementing the model finds improved results and judgments. Eventually this model improves warehouse performance by integrating lean and people issues. The outcome results in efficient decision making and unilateral judgments. It also fosters trust and coordination among the people in the warehouse.

The requirement and importance of the study are explained in this section. The literature survey and overview of RTD, ANP and lean assessment have also been discussed in the current section. The remaining paper is organized as follows.

Section 3 describes the conceptual model and generalized steps required for continuous lean assessment. The proposed model is demonstrated using a case example followed by findings in Section 4. Finally the study is concluded with future research direction in Section 5.

3. Methodology

The first step is to identify lean and people issues influencing warehouse performance. People issues are concerned with the task performed and value added or attained by direct or indirect parties involved in warehouse functions. Lean issues are lean tools, techniques or practices that can be used to improve performance. Warehouse performance issues include design, operation, control function criteria and decisions made by people at each organization level. People, lean and performance issues are interrelated and interdependent. Therefore, an objective of this study is to maximize warehouse performance, people value delivery and real time decisions level. This section discusses the conceptual model and research procedure in detail, designed for lean warehouse.

3.1 Conceptual model

In order to create and implement the lean philosophy at the warehouse level, a conceptual model is designed including RTD and ANP as shown in Figure 1. RTD is carried out via a web-based survey tool, to design structure and questionnaire, decide weights of each criterion with respect to other and improve accuracy of real time group decision. Assessment is also executed using RTD till consensus is achieved to decide about weight or priority of any criterion. Whereas ANP is used for accurate results and practical validation of the values achieved using RTD. The major reason to involve experts and functional/cross-functional employees is that experts are generally knowledgeable about lean philosophy and domain knowledge, while functional/cross-functional employees are aware of specific situations, can explain real problems and the

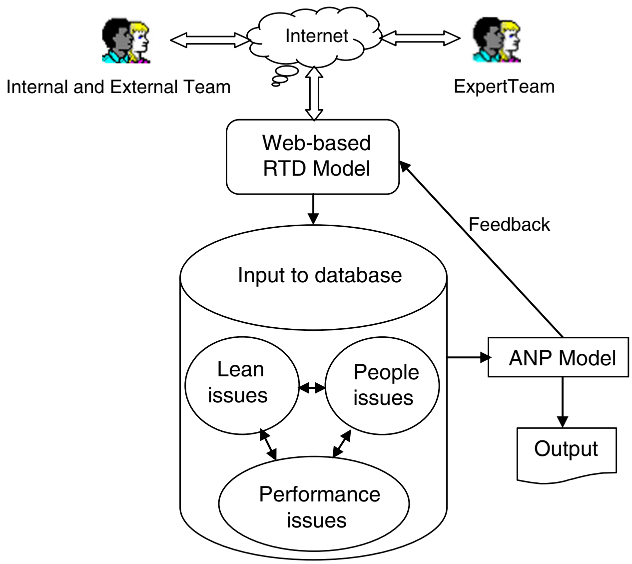


Figure 1.
Conceptual model

followed countermeasures very well. Therefore, a collaborative approach of the team leads better toward lean assessment, real time decision and action plan implementation to overcome the problem. Using the internet or intranet both expert and internal/external team can access the online real time application. An interactive web-based application is required for voting, opinion submission and discussion. The lean decisions, alternatives and relationships among them are stored into the database also through RTD. The output of ANP is again given as feedback to RTD for further refinement. A relational database is required to store and process the data. The detailed implementation steps of this model are discussed in the next section.

3.2 Proposed methodology

The methodology followed in this paper to achieve the lean warehouse is shown in Figure 2. The phases derived from the conceptual model include steps such as; identify and form a team, modeling, development, implementation, assessment, validation and improvement. The steps assessment, validation and improvement are repeated continuously using RTD and ANP to obtain agreed, refined, accurate and valid priorities ranking and improved lean suggestions. Each phase is described in detail as follows.

3.2.1 Identify and form an expert team. Expert team members are the participants who are continuously involved throughout the study. Expert selection is a significant task in such experiments as decision depends on the right opinion at the right time.

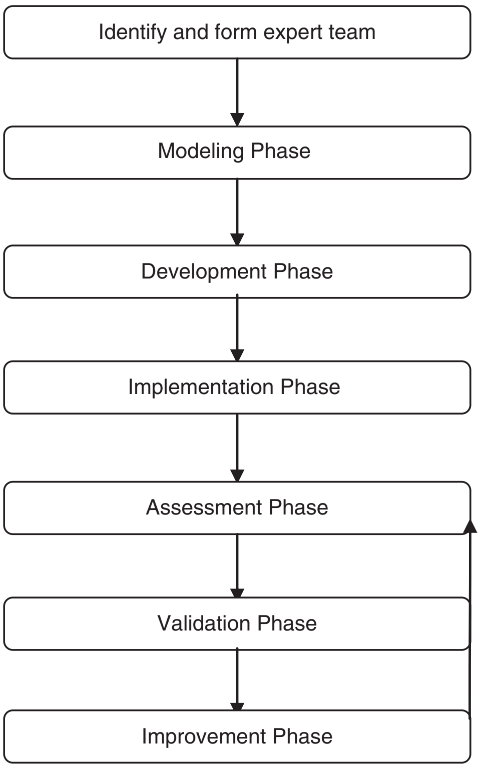


Figure 2.
Detailed procedure

Furthermore experts not only assess, but also take part in designing, developing, modeling and evaluating the system. As RTD is an online descriptive survey method, before design it requires qualified experts to be selected that are associated with the concerned study domain. The expert selection can be carried out using data collection through online databases, communities, private and public organizations. These members can be selected as individual, group or whole organization including working professional, domain proficient, consultant, researcher or academician. Experts together with external and internal team members decide issues and influencing factors for the study, give their opinion, and refine ANP output for further improvement and suggestion.

3.2.2 Modeling phase. Generally survey administrators design and structure the questionnaire for a study, while in this approach RTD is used for modeling and assessment as well. Overall objective of this phase is to design the study structure, criteria and questions for the survey in collaboration with experts and employees of an organization. The process is as follows:

- Conduct meetings and conferences for internal employees: for clarification of warehouse issues, such as roles and values of each functional and cross-functional employee, internal meetings are conducted before starting the survey. Conferences are arranged to improve the awareness, knowledge and coordination among employees. This helps in collaboration and discussion with experts to make action plans for leanness.

- Arrange seminars and programs for the expert team: at the same time advance awareness of the study is also required among experts before participation. Seminars can be conducted to prepare problems and related solutions of the study. This results in better judgments and enough time for consideration.

- Collect warehouse information for lean assessment: information such as operations influencing factors, functional and decisional criteria at different organization levels is collected for assessment.

- Prepare questionnaire for modeling: after information collection and conversation with experts and functional/cross-functional employees, the administrator decides the issues and problems to include in the study. The survey questionnaire is then designed.

- Determine performance issues: from the information we classify warehouse design, operation criteria and resource decisions into performance issues, which affect the leanness. This classification structure may vary from survey to survey, and organization to organization.

- Determine people issues: similarly, every value gained or attained by functional or cross-functional employee can be categorized in people issues.

- Identify and form lean issues for the warehouse: all possible lean tools, techniques and practices are included in this category. It may also include different alternatives for improving leanness.

- Repeat above steps till consensus is reached: before development, the above questionnaire preparation steps are repeated till consensus is reached among experts and employees.

3.2.3 Development phase. The next task after modeling is to develop a software system for RTD and ANP. The software should integrate the application and database. Direct integration among ANP and RTP is preferred as ANP output is given back as input to RTD, but sometimes isolated ANP application can also be used. This phase is devised as follows:

- Create database: the database and relationship among tables or attributes can be designed on the basis of collected information and lean criteria. It can be developed using database like MS-SQL, ORACLE or MySQL. Data security can be assured with role-based security and communication channels.
- Create model base: implement ANP model for processing of criteria weights, relationship and calculate the priorities among them. Web-based application like Super decisions or ANP application can be used. RTD can be implemented using any server side script or language. User anonymity for RTD is preserved using authentication by administrator.
- Create dialogue base: interactive application is required for survey and communication. Good user interface can be designed by technologies like ASP. NET, JSP, HTML or PHP.

3.2.4 Implementation phase. Once the model is developed, ANP can be prepared and implemented as follows:

- Identify clusters and its elements: after consensus in phase 2, each issue or component like lean, people or performance is termed a cluster and each resource, decision or lean criteria is treated as an element. This step requires proper identification of each cluster and its related elements.
- Identify interdependency among elements of each cluster: it is important to identify with which intensity elements depend on each other. It is not necessary that all elements depend on each other. As an example, one node may depend on itself or on other node in performance issues. Similarly, for people and lean issues.
- Identify intra dependency among clusters: like a node, a cluster may also depend on itself or on other cluster. This dependency weight is required to be identified properly. As some node of performance cluster may fully or partially depend upon people or lean cluster.
- Develop the relationship among clusters and elements: determine the relationship that exists to be assessed for lean warehouse among people, performance, lean issues and their criteria.
- Develop model for hierarchical network: design a relationship network for each node of a cluster with respect to other nodes, of same or other clusters. Graphical representation may help better understanding of relationships and dependencies.
- Prepare ANP tool or software for assessment: select a tool or application providing feasible integration with RTD and database. The communication between ANP and RTD should be achieved with little software changes.

3.2.5 Assessment phase. A real survey is conducted in this phase for lean assessment. Once the cluster, criteria and their dependency are obtained, all participants are informed for the survey. The online survey can be conducted synchronously with predefined session time and duration or it can be allowed in asynchronous mode, where a participant can be flexibly logged into the system at anytime from anywhere. They are allowed to view, vote and change their opinions and comments. Depending upon requirements, the administrator can allow selected functional member participation for better collaboration, understanding, and solutions of problems while preserving anonymity. The process is executed as follows:

- Prepare questionnaire for assessment: with discussion among all the members the questions are prepared asking relative importance, opinion and comment.
- Identify relationship value for pair wise comparison: from the cumulative results of survey average, pair wise comparison value can be obtained for further super matrix and cluster priority calculations.
- Increase involvement of team members: for better outcomes and refined suggestions, all participants are requested to log in as much time as possible. Different communication ways such as e-mail, telecall using voice over internetworking protocol and video conference can be used for this purpose (Gordon and Pease, 2006).
- Use suggestions and feedback for augmentation: for achieving results of the survey, suggestions are taken from functional/cross-functional team members and feedback is given to experts for augmentation (Gordon and Pease, 2006).
- Repeat above steps till consensus: the above steps are repeated till an agreed situation is achieved among all experts and team members.
- Assess lean performance of warehouse using RTD: finally, the average values of RTD are obtained and used as input to ANP for practical validation.

3.2.6 Validation phase. Although consensus state of RTD gives average rank or priority for each criterion, comparison, and question which are descriptive in nature, practical validation is still required. These are the details:

- Assign weights and relation value to ANP: the rank values are applied as input to the ANP software or web application.
- Evaluate assessment using ANP: the outcome of the ANP software is processed and evaluated. The assessment gives final validated priorities for each cluster and criteria.
- Determine each element and cluster priorities: list out final priority from the outcome and prepare an action plan for implementation.

3.2.7 Improvement phase. The lean warehouse assessment and transformation is a continuous process which results in improved stages over a period of time. So in this method we utilize the calculated output as input to RTD as follows:

- Repeat the steps for continuous improvement: the practically validated priorities are again given as feedback to RTD, for further improvement. The same steps of assessment and validation are again repeated till consensus among all team members and experts is reached.
- Find out and suggest improvement areas: this gives final refined and accurate priorities and also identifies the required areas for improvement.

4. Example

The previous section focussed on the RTD and ANP-based combined model and procedural steps for implementation. For practical validation of the proposed model in the real world, we conducted a lean study at a warehouse of a large scale fiber-manufacturing firm. In order to preserve confidentiality upon request from the management, the name of the firm is not disclosed. In this section we discuss the existing scenario and the analysis of the warehouse functions. Then we show the implementation and improved results of RTD and ANP-based model at the warehouse premises. Finally, some suggestions and findings of the study are shown. Further detailed functions are explained below.

4.1 Existing scenario and case analysis

The organization studied is a multinational company having a number of plants and employees worldwide. It processes chemically raw material like good quality wooden pulp and produces fiber which is also raw material for fabrication purposes. The plant is located in Gujarat state of India. As far as the respondents are concerned, they are employees of the plant. The other reviewers and experts are executives of other plants, corporate office having knowledge of the company and also other experts from internet domain. The model is illustrated for an organization having different warehouses for storing raw material and finished goods. The plant processes raw material, converts it into yarn, packs and sells it in domestic and international yarn fabrication market. Raw material is imported as fixed unit weight packages and stored in the warehouse. After being processed chemically, the finished goods are stored in another warehouse. The company uses third party logistics, to transport raw material from port to plant. It is the customer's responsibility to transfer the finished goods from the plant to their required locations. Each warehouse is of 5,000 sq. mt. size with 5,000 packages storage capacity. The packages are stored randomly on production date basis. The order-processing system follows a pull model, where the goods are manufactured as per customer specifications. Picker to part policy is adopted to pick and ship the goods using forklifts. The organization implements the proposed model for improving operations to achieve lean warehouse. The existing scenario is shown in the form of the warehouse layout in figure (refer to Appendix 5).

4.2 Application of model

The following steps represent the practical implementation for the proposed model. As per goal requirement, a decision can be taken by an administrator to change the procedural phase or detailed step. Each phase of the proposed model is implemented and described as follows. All respective snapshots are represented in Appendices 1-5.

4.2.1 Identify and form expert team. In coordination with the organization management a generic approach is adopted to form the expert team. Team members were selected from academicians of reputed institutes and members from online community support. Organization also hired one experienced consulting company for active participation and to provide suggestions. In this way the study started with an expert team selection procedure followed by agreement to information confidentiality and privacy agreement among each party.

4.2.2 Modeling phase. The organization conducted an information sharing seminar for the experts. Several meetings were also conducted within the organization to implement a lean system in the warehouse. Employees involved directly and indirectly were the members of the meeting. After brainstorming and discussion they decided the problems and issues requiring clarification for the study. As an outcome of these meetings and seminars, the administrator decided questions, options or criteria to be included. Appendix 1 describes the process in detail.

By collecting these ranking data, each issue was classified into three clusters namely people-[PI0], performance-[PR0] and lean-[LI0] issues. Team members and experts shared their knowledge and also referred to related articles for the study. Apart from the database, we also referred to other sources to determine the criteria for lean warehouse. Each concerned stakeholder either gained or attained some value from the process and was able to be part of the functional or cross-functional process. As shown in Table I, we classified people into internal and external teams. Directly involved employees in the warehouse functions were Laborers, Supervisors, Operators, Contractors, etc. Cross-functional roles affecting warehouse operations like quality people, HR, IT, Finance, etc. were members of the internal team. Similarly some external entities like customers, suppliers, transporters, investors, etc. were part of the external team. This categorization was on the basis of consensus results and study requirement. The purpose of this category was to map relative dependency of each entity to the other and also to other issues of lean performance. People issues aimed to maximize value creation and delivery for lean performance. Issues like customers, suppliers, society, leaders and unions were referred to from Cil and Turkan (2012), while others are specified from the study.

The factors affecting warehouse performance were grouped into lean issues as shown in the list below:

- [LI1] Implement 5S (workplace organization);
- [LI2] continuous improvement using Kaizen;
- [LI3] reduce waste using TIMWOOD assessment;
- [LI4] eliminate wrong dispatch using POKA YOKE (error proofing);
- [LI5] improving activities flow using VSM;
- [LI6] analyzing and solving root causes using Fish bone;
- [LI7] apply Pareto rule to improve storage allocation;

Internal team members	External team members
[PI1] Unions	[PI14] Customers
[PI2] Leaders (including managers, VP, etc.)	[PI15] Suppliers
[PI3] Contractors	[PI16] Transporters (inbound and outbound)
[PI4] Laborers	[PI17] Society
[PI5] Supervisors	[PI18] Investors and promoters
[PI6] Operators	
[PI7] Quality people	
[PI8] Manufacturing people	
[PI9] HR people	
[PI10] IT people	
[PI11] Finance people	
[PI12] Procurement people	
[PI13] Sales and marketing people	

Table I.
People issues [PI0]

- [LI8] reducing man and material movements using FLOW charts;
- [LI9] use SPHAGETTI charts to reduce forklift movements;
- [LI10] reducing searching time through software application;
- [LI11] reducing storage and retrieval time through BAR code application;
- [LI12] reducing order picking time by PROXIMITY analysis and cluster storage;
- [LI13] implement TQM;
- [LI14] standardization for work system;
- [LI15] improving visibility for material flow in and out of warehouse;
- [LI16] improving visibility for logistics operation;
- [LI17] improving storage utilization by changing zones;
- [LI18] order fulfillment by contingency planning;
- [LI19] achieve optimal capacity utilization using strategic layout changes;
- [LI20] checklist for total workflow;
- [LI21] evaluate layout design and utilization;
- [LI22] establishing an efficient material handling and eliminating incoming and outgoing storage;
- [LI23] applying automation technologies in handling operation;
- [LI24] establishing leveled production;
- [LI25] establishing JIDOKA for quality control at the source;
- [LI26] establishing long-term contracts and pull system with suppliers;
- [LI27] involvement of supplier in product design and development, and quality improvement;
- [LI28] evaluation of investment needs and resources;
- [LI29] optimizing number of staff required for line balancing;
- [LI30] problem solving using plan, do, check and act cycle;
- [LI31] apply GEMBA principle to adopt culture and process changes;
- [LI32] cross-functional training to reduce WAITING time;
- [LI33] six sigma training for operators and supervisors;
- [LI34] team leadership training and evaluation;
- [LI35] training to improve coordination, motivation and trust among employees;
- [LI36] applying Deming's 14 points;
- [LI37] implementation of suggestion system and applying team awarding systems;
- [LI38] delegating responsibilities to working teams and expansion of autonomy;
- [LI39] job rotation to improve multi skill ability;

- [LI40] improving order processing through online order and payment option;
- [LI41] improving customer satisfaction by using online feedback and grievance; and
- [LI42] applying Hoshin planning for goal alignment.

This category included the related principles or alternatives affecting performance. It also included lean practices, tools or techniques that could be used to improve leanness. To collect these issues we referred to several database sources and articles. The purpose was to find out relative interdependencies among each other, on other cluster issues, and also to maximize warehouse performance using specified alternatives in this category. Some issues were specified as per requirement and some were taken with modifications (e.g., [LI1]-[LI6]) form online sources (refer Ackerman, 2006). Similarly some storage- and layout-related issues were also taken with modification (e.g., [LI17]-[LI21] and [LI36]). To implement lean warehouse, The House of Toyota uses foundation, pillars and contents structure. The foundation referred to operational stability, while contents referred to tool for people empowerment. Pillars referred to tools for quality improvement and smooth information and material flow. Some issues (e.g., [LI34]-[L39] and [LI42]) were found directly related to the current study. Basic lean practices (e.g., [LI1]-[LI6] and [LI29]-[LI32]) were referred from case studies. Lean practices (e.g., [LI22]-[LI25], [LI37] and [LI38]) to improve material flow and production system were also used (Cil and Turkan, 2012). The rest of the issues were derived from the study survey.

The third cluster contained performance nodes as listed in Table II. The performance issues [PR0] were divided into design [PR1], operation [PR2] and control [PR3]. Design criteria nodes were further divided into structural, dimension, layout, equipment and utilities. All identified operational criteria were grouped into receiving, storing, picking and shipping. All design and operation issues were included in [PR1] and [PR2], while controlling issues contained planning and decisional criteria at each level of an organization. The objective of this criterion was to find out the relationship among clusters, within nodes, and maximize the performance using lean issues to deliver high values to people. All utility issues and some of layout issues (e.g. [PR136]-[PR139]) were considered as important criteria affecting performance (refer Ackerman, 2006). At the same time, some decision criteria at strategic and operational level (e.g. [PR31]-[PR310]) were also considered and taken. These were important as they controlled the performance of the warehouse. The rest of design and operation criteria were taken from Gu *et al.* (2007) with more or less modifications. Some of the controls criteria [PR311]-[PR318] were taken from warehouse framework study (Rouwenhorst *et al.*, 2000).

4.2.3 Development phase. An Interactive RTD application was created using PHP. The reason for choosing PHP is its freeware availability and easy server side scripting. Likewise MySQL, an open source package was used to design the database. For cluster-level ANP calculation we have used manual calculations while complex interdependencies priorities among nodes and clusters were calculated using ANP software. To achieve integration among RTD and ANP software excel file was used to store and retrieve the required data. In a session, each user was allowed to create an account with anonymous identification and could view, vote or update their opinions as shown in Appendix 1.

4.2.4 Implementation phase. Although consensus state of modeling phase identified final clusters, their nodes and relationship among them, exact value of dependency or

[PR1] Design	*[PR2] Operation*
[PR11] Structural	[PR21] Receiving
[PR111] Location and number of warehouse	[PR211] Capacity assignment
[PR112] Warehouse facility type and interactions among them	[PR212] Truck assignment
[PR113] Flexibility for changes or expansion	[PR213] Dock assignment
[PR114] Distribution channel	[PR22] Storing
[PR115] Transportation medium	[PR221] Type of storage system
[PR12] Dimension	[PR222] Type of storage units
[PR121] Capacity	[PR223] Space allocation
[PR122] Unit load	[PR224] Storage assignment strategy (random, class, full turnover, frequency or dedicated)
[PR123] Departments	[PR225] Storage class specification
[PR13] Layout	[PR226] Replenishment task assignment
[PR131] Stacking pattern	[PR227] Reserve area
[PR132] Aisle configuration	[PR23] Picking
[PR133] Zoning (progressive, synchronized)	[PR231] Picking method (sort while pick, pick and sort, wave picking, pick and pass)
[PR134] Number and location of doors	[PR232] Picking system (human or auto or semi auto)
[PR135] Number and location of docks	[PR233] Order batch assignment
[PR136] Floors and yard pavement	[PR234] Batch size
[PR137] Roof systems and bay sizing	[PR235] Picking task assignment
[PR138] Walls and landscaping	[PR236] Routing policy (S, L, return, mid point, largest gap, blocks)
[PR139] Land coverage and future use	[PR237] Chute assignment
[PR14] Equipment	[PR238] Sorting for orders
[PR141] Automation level	[PR24] Shipping
[PR142] Storage equipment	[PR241] Docks assignment
[PR143] Picking equipment	[PR242] Order truck assignment
[PR144] Handling equipment	[PR243] Dispatching schedule
[PR145] Handling mechanism	[PR234] Loading and Unloading policy
[PR15] Utilities	
[PR151] Material flow	
[PR152] Heating and cooling	
[PR153] Electricity and fuels	
[PR154] Packaging	
[PR155] Waste disposal	
[PR156] Container	
[PR157] Fire protection systems	
[PR3] Control	
[PR31] Lean index	[PR310] Inflation and cost-cutting
[PR32] Goals at each level	[PR311] Software and IT infrastructure
[PR33] Buying equipment	[PR312] Match supply and demand
[PR34] Choosing lift trucks	[PR313] Information visibility and security
[PR35] Order selection tools	[PR314] Cost analysis
[PR36] The make or buy decision	[PR315] Space analysis
[PR37] Option in supply chain software	[PR316] Time analysis
[PR38] Sources of advice	[PR317] Work force planning
[PR39] Vendor selection	[PR318] Inventory management

Table II. Performance issues [PR0]

priority were decided after assessment. Therefore, for the ease of relationship understanding and priority calculation graphical model representation was required. In the study it was shown that the picking process contributed around 38 percent (Garcia, 2004) and 50-75 percent (Coyle *et al.*, 1996) of total warehouse operating time and cost, respectively. Picking was found to be the major influencing operation for performance, so we designed relationship and dependency network with respect to picking as shown in Figure 3. The picking process directly depends on itself and other clusters like people and lean issues. It was influenced by Kaizen, TIMWOOD, POKA YOKE, VSM, Fish bone, Pareto, FLOW and SPHAGETTI charts, PROXIMITY analysis, etc. Picking depended on [LI1]-[LI12], [LI15], [LI17], [LI19], [LI21]-[LI23], [LI28] and [LI31]-[LI41] nodes of lean cluster. Different people like operators, contractors, laborers, supervisors, IT people, etc. were either directly or indirectly involved in the picking process. All people issues on which picking depends were [PI3]-[PI7], [PI10], [PI13], [PI14] and [PI16]. It also depended upon other clusters like control and design of performance. In control cluster picking was influenced by nodes [PR31]-[PR35] and [PR311]-[PR318]. All other nodes and their relationships are shown in detail in Figure 3. This relationship was determined from the modeling phase.

4.2.5 Assessment phase. In this phase, some members of internal team and experts participated in asynchronous mode, where at any time they could view or update their opinions and also clarify the reasons for it. After feedback again and again the process

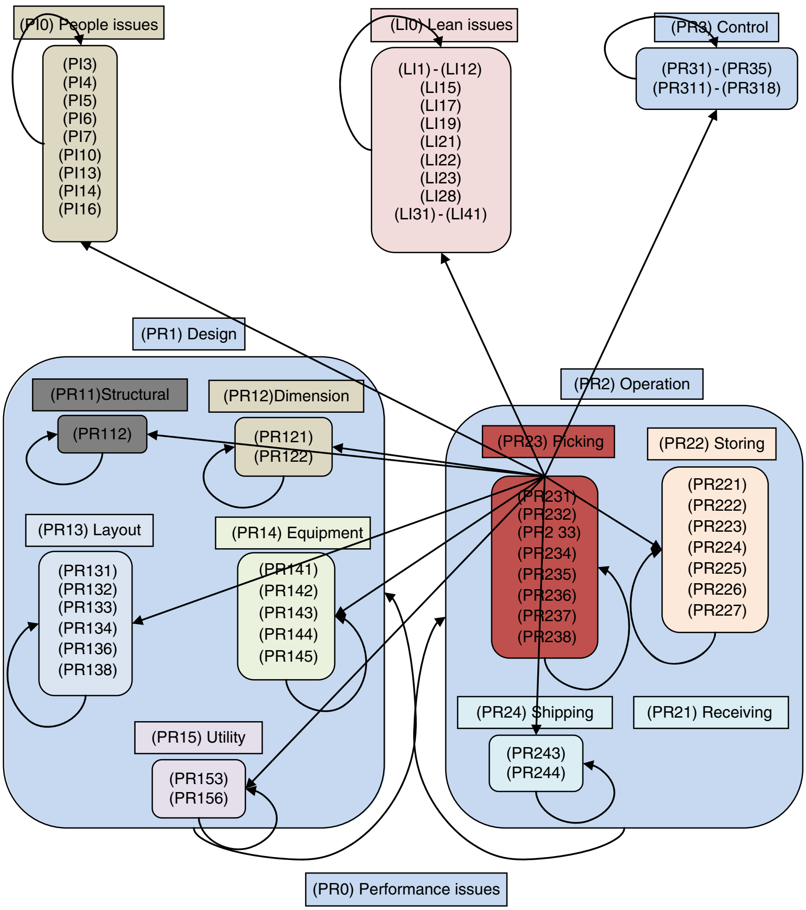


Figure 3.
Relationship and dependency network in the context of picking process

was repeated till consensus. Finally from the database we obtained the values of each criterion and cluster interdependency, which was stored in an excel sheet for ANP calculations. The working model is described in Appendix 2.

4.2.6 Validation phase. The consensus voting and dependency values derived from RTD were stored in the database. Each cluster value was retrieved from the database for ANP calculations in excel. The calculation for consistency checking was executed using Excel formulas. The final complex ranking of interdependencies was carried out by the ANP software, which was used by RTD for further improvement. We followed simple ANP procedure for consistency checking of average values received from the survey. The participants used voting scales invented by Saaty (2008) as shown in Table III. Due to space limits, we have shown only one example representing cluster comparison between storing [PR22] and picking [PR23] within the performance cluster. The pair wise comparison of nodes [PR221]-[PR227] within the storing [PR22] cluster, with respect to [PR231] node of picking [PR23] is shown below. The participants submitted their ranks for the asked questions and these values were extracted in excel sheet for consistency checking as shown in Table IV.

The generalized ANP procedure is explained (Saaty, 1999) for ranking priorities, consistency checking and Eigenvector calculation, as follows:

- A pair wise comparison matrix A in Table V, was formed with rankings derived in Table IV, for the nodes [PR221]-[PR227].
- Matrix A is square and each row was normalized to find out Eigen array called E0, as in Table VI. Consistency checking was done to validate rankings received from RTD. Tables V and VI represent row sum, average and normalized process to calculate Eigenvector.
- Again set A = A2, and square the matrix to find out normalized E1, as shown in Table VII.

Table III. Saaty scale

Value	Importance
1	Equal
3	Moderate
5	Strong
7	Very strong
9	Extreme
2, 4, 6, 8	Intermediate

Table IV. RTD ranks

Criteria	Avg. scale
PR221	7
PR222	5
PR223	7
PR224	9
PR225	6
PR226	2
PR227	3

- Table VIII shows A×X, calculation to find out λ value (Table X) which was found larger than n.
- Validation phase represents λ, CR and CI values to validate RTD rankings. Table IX shows all Eigenvectors to represent "Picking" – "Storing" relation, unweighted matrix W89.

	PR221	PR222	PR223	PR224	PR225	PR226	PR227	Row sum
PR221	1.0000	1.6666	1.0000	0.7778	1.4000	7.0000	2.3333	15.1777
PR222	0.8571	1.0000	0.8571	0.6667	1.2000	6.0000	2.0000	12.5810
PR223	1.0000	1.1667	1.0000	0.7778	1.4000	7.0000	2.3333	14.6778
PR224	1.2857	1.5000	1.2857	1.0000	1.8000	9.0000	3.0000	18.8714
PR225	0.7143	0.8333	0.7143	0.5556	1.0000	5.0000	1.6667	10.4841
PR226	0.1429	0.1667	0.1429	0.1111	0.2000	1.0000	0.3333	2.0968
PR227	0.4286	0.5000	0.4286	0.3333	0.6000	3.0000	1.0000	6.2905
Total								80.1793

Table V. Matrix A

	PR221	PR222	PR223	PR224	PR225	PR226	PR227	Row sum	(E0)
PR221	7.428514	9.166533	7.428514	5.777733	10.39992	51.9996	17.3332	109.5340152	0.193263791
PR222	6	7.428514	6	4.666667	8.4	42	14	88.49518095	0.156142492
PR223	7	8.6666	7	5.444444	9.8	49	16.33333	103.2443778	0.182166241
PR224	9	11.14277	9	7	12.6	63	21	132.7427714	0.234213738
PR225	5	6.190429	5	3.888889	7	35	11.66667	73.74598413	0.130118743
PR226	1	1.238086	1	0.777778	1.4	7	2.333333	14.74919683	0.026023749
PR227	3	3.714257	3	2.333333	4.2	21	7	44.24759048	0.078071246
Total								566.7591168	1

Table VI. Matrix A2

	PR221	PR222	PR223	PR224	PR225	PR226	PR227	Row sum	(E1)
PR221	370.18	458.0873	370.18	287.9178	518.252	2,591.26	863.7534	5,459.630699	0.193230026
PR222	299.1422	370.18	299.1422	232.6661	418.799	2,093.995	697.9984	4,411.923141	0.156149027
PR223	348.9992	431.8767	348.9992	271.4438	488.5989	2,442.994	814.3315	5,147.243664	0.182173865
PR224	448.7133	555.27	448.7133	348.9992	628.1986	3,140.993	1,046.998	6,617.884711	0.234223541
PR225	249.2851	308.4834	249.2851	193.8884	348.9992	1,744.996	581.6653	3,676.602617	0.130124189
PR226	49.85703	61.69667	49.85703	38.77769	69.79984	348.9992	116.3331	735.3205234	0.026024838
PR227	149.5711	185.09	149.5711	116.3331	209.3995	1,046.998	348.9992	2,205.96157	0.078074514
Total								28,254.56693	1

Table VII. Matrix [A2×A2]

Eigenvector (X)	A×X
0	1.364337
0	1.10252
0	1.286273
0	1.65378
0	0.918767
0	0.183753
0	0.55126

Table VIII. A×X

- Both E0 and E1 sum to 1 and Table IX shows Eigenvector X (Table X).
- Table XI represents λ, CI and CR values. CR = 0.0077, which is tolerable (Saaty, 2001) and the rankings done in the survey are consistent.
- Table XII shows Eigenvector D1 formed by pair wise comparison of each node of storing with respect to [PR231] criteria of picking cluster. Similarly for all the criteria [PR231]-[PR238], pair wise comparisons questions were asked and the vectors formed.
- This D2-D8 Eigenvectors of two cluster comparison make unweighted matrix W89, represented in Table XIII.

Final super matrix in Table XIV, called the component matrix, is calculated by software which gives final priorities.

	D1 = X
D1	0.19323
	0.156149
	0.182174
	0.234224
	0.130124
	0.026025
	0.078075

Table IX.
X

	λ
λ	7.06069
	7.06069
	7.06069
	7.06069
	7.06069
	7.06069
	7.06069

Table X.
L

λ	0.06069
CI	0.0101
CR	0.0077

Table XI.
CI

D1 =	0.19323
	0.156149
	0.182174
	0.234224
	0.130124
	0.026025
	0.078075

Table XII.
D1

4.2.7 Improvement phase. The output results obtained from ANP software were given back as input to RTD for improvement. Participants again voted and conversations with internal-external team members to refine the judgments. As shown in Appendix 4, the model gave improved results after every cycle. In the same way the lean or people issues could be assessed and improved using combined approach of RTD and ANP.

4.3 Findings and suggestions

The experiment was executed for all issues to implement, assess and improve leanness in the warehouse. To optimize space utilization, consensus results on picking process are shown in Appendix 4. From the study we found, some lean issues like (refer [LI2]-[LI12], [LI17], [LI19], [LI23], [LI28], [LI31], [LI32], [LI35], [LI37], [LI39]-[LI41]) directly related to picking process and warehouse performance. So it was suggested to further improve these decisions and solve problems. Similarly stakeholders like contractors, laborers, supervisors and operators (refer [PI3]-[PI8], [PI10], [PI12]-[PI14] and [PI16]) were directly related to warehouse operations and strongly affected the performance. Customers, suppliers and transporters were also indirectly related to performance or warehouse and their values needed to improve.

Criteria like [PR223], [PR224], [PR225], [PR231], [PR232], [PR236], [PR243] and [PR244] were found to be more important for improving the picking operation. After assessment some of the changes made in order to improve warehouse picking performance were:

- a forward-reserve storage allocation policy was adopted to improve picking time;
- IT people were concerned for more integrated and robust application to link up all functions;

	D1	D2	D3	D4	D5	D6	D7	D8
W89 =	0.193230026	0.2	0.2918	0.119	0.17	0.2666	0.219	0.012
	0.156149027	0.1363	0.1	0.1364	0.2224	0.1466	0.002	0.17
	0.182173865	0.1788	0.02	0.31	0.12	0.1	0.224	0.1242
	0.234223541	0.1227	0.128	0.132	0.18	0.22	0.1886	0.28
	0.130124189	0.1422	0.1862	0.1226	0.11	0.0034	0.0637	0.232
	0.026024838	0.056	0.124	0.1	0.0514	0.1434	0.1227	0.1808
	0.078074514	0.164	0.15	0.08	0.1462	0.12	0.18	0.001

Table XIII. W89

	[PI0]	[LI0]	[PR11]	[PR12]	[PR13]	[PR14]	[PR15]	[PR22]	[PR23]	[PR24]	[PR3]
[PI0]	W11	W12	W13	W14	W15	W16	W17	W18	W19	W110	W111
[LI0]	W21	W22	W23	W14	W25	W26	W27	W28	W29	W210	W211
[PR11]	W31	W32	W33	W34	W35	W36	W37	W38	W39	W310	W311
[PR12]	W41	W42	W43	W44	W45	W46	W47	W48	W49	W410	W411
[PR13]	W51	W52	W53	W54	W55	W56	W57	W58	W59	W510	W511
[PR14]	W61	W62	W63	W64	W65	W66	W67	W68	W69	W610	W611
[PR15]	W71	W72	W73	W74	W75	W76	W77	W78	W79	W710	W711
[PR22]	W81	W82	W83	W84	W85	W86	W87	W88	*W89*	W810	W811
[PR23]	W91	W92	W93	W94	W95	W96	W97	W98	W99	W910	W911
[PR24]	W101	W102	W103	W104	W105	W106	W107	W108	W109	W1010	W1011
[PR3]	W111	W112	W113	W114	W115	W116	W117	W118	W119	W1110	W1111

Table XIV. Component matrix

- internal workforces were involved in deciding warehouse operation policies;
- operators and supervisors were convinced using GEMBA principle before any process or cultural change (e.g. utility or equipment selection, job rotation and change in function);
- picker to part method was preferred;
- PROXIMITY cluster analysis and class-based storage was used for zoning;
- quality people were recommended to improve quality reports;
- bar coding application were adopted to eliminate wrong dispatch;
- tools like TIMWOOD, Pareto, Fish bone, VSM, FLOW and SPHAGETTI charts were used to improve forklift performance and reduce wastes;
- graphical software and Wi-Fi technique were used to reduce package search time;
- training was required to boost coordination, motivation and trust level; and
- customers, suppliers and transporters were allocated with online order placement, tracking, payment and service supports.

Furthermore, after conducting this study with the proposed model, all priority rankings or consensus values were compared with individual RTD and ANP method. The detailed values are shown in Table XV. For lean transformation, assessment and continuous improvement in warehouse operations the combined approach of RTD with ANP proved more effective rather than applying RTD or ANP individually. RTD provided more effective and real time decision-making capabilities with consensus among experts and team members. The rankings derived from RTD were practically supported, validated, and refined by ANP. As shown in Table XV, some lean issues have been found to be important to apply in warehouse transformation and assessment by either RTD or ANP, and these are also supported by the combined approach. These issues and their values are highlighted. Issues like TIMWWOD, POKA YOKE, VSM, Pareto, FLOW chart, SPHAGETTI, PROXIMITY, JIDOKA, DEMING's cycle, etc. are found to be more important for lean warehouse as their overall weight is more than 0.80. All these values were refined and improved by the proposed model rather than using only ANP or RTD. Some issues like "[LI34] Team Leadership training and evaluation," "[LI39] Job rotation to improve multi skill ability" and "[LI40] Improving order processing through online order and payment option" represented more importance in both RTD and ANP, but in the combined approach we find that both do not guarantee for lean transformation in warehouse. While some lean issue like "[LI29] Optimizing number of staff required for Line Balancing" are strongly supported and suggested by experts in RTD with 0.90 value but not recommended by ANP and combined approach as well. The proposed model also finds out the important issues unaddressed by only RTD method. For example, "[LI32] Cross functional training to reduce WAITING time" shows 0.60 by RTD but recommended by ANP with 0.92 value, which later also is supported by the combined approach. Finally, this combined approach has been proved more effective than individual RTD or ANP. It determines

Lean issues [LI0]	RTD	ANP	RTD +ANP
[LI1] Implement 5S (workplace organization)	0.50	0.51	0.55
[LI2] Continuous improvement using Kaizen	0.40	0.42	0.41
[LI3] Reduce waste using TIMWOOD assessment	*0.78*	*0.75*	*0.85*
[LI4] Eliminate wrong dispatch using POKA YOKE	*0.76*	*0.69*	*0.80*
[LI5] Improving activities flow using value stream mapping	*0.65*	*0.70*	*0.84*
[LI6] Analyzing and solving root causes using Fish bone	0.56	0.50	0.70
[LI7] Apply Pareto rule to improve storage allocation	*0.56*	*0.61*	*0.85*
[LI8] Reducing man and material movements using FLOW charts	*0.45*	*0.78*	*0.88*
[LI9] Use SPHAGETTI charts to reduce forklift movements	*0.78*	*0.80*	*0.90*
[LI10] Reducing searching time through software application	*0.60*	*0.80*	*0.90*
[LI11] Reducing storage and retrieval time through BAR code application	*0.77*	*0.80*	*0.81*
[LI12] Reducing order picking time by PROXIMITY analysis and cluster storage	*0.56*	*0.58*	*0.98*
[LI13] Implement TQM	0.67	0.55	0.50
[LI14] Standardization for work system	0.77	0.56	0.67
[LI15] Improving visibility for material flow in and out of warehouse	0.45	0.67	0.56
[LI16] Improving visibility for logistics operation	0.70	0.56	0.66
[LI17] Improving storage utilization by changing zones	*0.78*	*0.45*	*0.90*
[LI18] Order fulfillment by contingency planning	0.50	0.67	0.56
[LI19] Achieve optimal capacity utilization using strategic layout changes	*0.56*	*0.77*	*0.80*
[LI20] Checklist for total workflow	0.23	0.45	0.67
[LI21] Evaluate layout design and utilization	*0.40*	*0.60*	*0.80*
[LI22] Establishing an efficient material handling and eliminating incoming and outgoing storage	*0.78*	*0.67*	*0.85*
[LI23] Applying automation technologies in handling operation	0.56	0.67	0.67
[LI24] Establishing leveled production	0.45	0.85	0.68
[LI25] Establishing JIDOKA for quality control at the source	*0.69*	*0.45*	*0.81*
[LI26] Establishing long-term contracts and pull system with suppliers	*0.76*	*0.78*	*0.82*
[LI27] Involvement of supplier in product design and development, and quality improvement	0.45	0.78	0.56
[LI28] Evaluation of investment needs and resources	0.20	0.92	0.51
[LI29] Optimizing number of staff required for line balancing	0.90	0.67	0.58
[LI30] Problem solving using plan, do, check and act cycle	0.60	0.44	0.45
[LI31] Apply GEMBA principle to adopt culture and process changes	0.34	0.50	0.80
[LI32] Cross-functional training to reduce WAITING time	0.60	0.92	0.83
[LI33] Six sigma training for operators and supervisors	0.50	0.45	0.34
[LI34] Team leadership training and evaluation	0.80	0.88	0.56
[LI35] Training to improve coordination, motivation and trust among employees	*0.80*	*0.82*	*0.85*
[LI36] Applying Deming's 14 points	*0.78*	*0.84*	*0.90*
[LI37] Implementation of suggestion system and applying team awarding systems	0.43	0.44	0.88
[LI38] Delegating responsibilities to working teams and expansion of autonomy	0.45	0.32	0.85
[LI39] Job rotation to improve multi skill ability	0.80	0.88	0.45
[LI40] Improving order processing through online order and payment option	0.90	0.92	0.40
[LI41] Improving customer satisfaction by using online feedback and grievance	0.88	0.86	0.86
[LI42] Applying Hoshin planning for goal alignment	0.45	0.56	0.66

Table XV. Consensus rankings for lean issues [LI0]

the significant lean issues for warehouse assessment, transformation and improvement. It also addresses some unidentified issues of RTD or ANP. It helps in improving decision making, cost, performance, stakeholder value and quality.

In the same manner, the issues and their dependency for each individual function can be determined by this study.

5. Conclusion and future scope

The study offers evidence for enhancing the results of using individual RTD or ANP. With the collaborative approach of experts and employees more accurate results can be achieved. As shown in Appendix 4 after each round of experiment the results are refined and improved using RTD, which are later validated and supported using ANP. Online study improves information transparency, knowledge, consensus and real time decision making at each level of an organization. RTD helps to solve the problems with lesser amount of time through expert conversation. Warehouse resources like equipments, forklifts, manpower, etc., can be also utilized at an optimal level through proper planning. The practical ANP validation of judgments resolves complexity, improves trust and coordination among employees. This study helps to determine areas for improvement, make advance action plans to resolve problems and implement lean philosophy.

The data collection, survey implementation and conduct of this study are cumbersome and complex task at some levels. The other limitation of this model is integration of ANP software and RTD. Certain IT investments are required to develop and integrate RTD and ANP software. But once designed it is usable for longer period of time with substantial knowledge and decision-making power.

This study focussed on the performance to achieve lean warehouse, which is just a single function. Lean supply chain or lean enterprise can be achieved by extending this model. Further, this is a specific study pertaining to single warehouse and very rare studies are available at warehouse level but in future more are expected. The results of this model can be compared with the results of ANP, RTD or Fuzzy AHP for better understanding and future research. In future, resource tradeoff management is also expected by extending the proposed model with combination of multi criteria decision-making methods like goal programming or TOPSIS. A large scale web-based approach improving real time decision-making efficiency of an organization may also be the next research area. Extended features are expected in the form of expert system where, an organization assesses leanness, compare number of warehouses, rank them and notify areas for benchmarking toward excellence.

References

Ackerman, K. (2006), *Lean Warehousing*, K.B. Ackerman Company, Columbus, OH.

Anand, G. and Kodali, R. (2008), "Selection of lean manufacturing systems using the PROMETHEE", *Journal of Modeling in Management*, Vol. 3 No. 1, pp. 40-70.

Baker, P. and Canessa, M. (2009), "Production, manufacturing and logistics warehouse design: a structured approach", *European Journal of Operational Research*, Vol. 193 No. 2, pp. 425-436.

Bayou, M.E. and De Korvin, A. (2008), "Measuring the leanness of manufacturing systems – a case study of Ford Motor Company and General Motors", *Journal of Engineering and Technology Management*, Vol. 25 No. 4, pp. 287-304.

Beach, R., Muhlemann, A.P., Price, D.H.R., Paterson, A. and Sharp, J.A. (2000), "A review of manufacturing flexibility", *European Journal of Operational Research*, Vol. 122 No. 1, pp. 41-57.

Chen, J. and Yang, Y. (2011), "A fuzzy ANP-based approach to evaluate region agricultural drought risk", *Procedia Engineering*, Vol. 23, pp. 822-827.

Cil, I. and Turkan, Y.S. (2012), "An ANP-based assessment model for lean enterprise transformation", *International Journal of Advanced Manufacturing Technology*, Vol. 64 Nos 5-8, pp. 1113-1130.

Cottyn, J., Landeghem, H.V., Stockman, K. and Derammelaere, S. (2011), "A method to align a manufacturing execution system with lean objectives", *International Journal of Production Research*, Vol. 49 No. 14, pp. 4397-4413.

Coyle, J.J., Bardi, E.J. and Langley, C.J. (1996), *The Management of Business Logistics*, West St Paul, MN.

Dağdeviren, M. and Yüksel, I. (2010), "A fuzzy analytic network process (ANP) model for measurement of the sectoral competititon level (SCL)", *Experts Systems with Applications*, Vol. 37, pp. 1005-1014.

de Koster, R., Le-Duc, T. and Roodbergen, K.J. (2007), "Design and control of warehouse order picking: a literature review", *European Journal of Operational Research*, Vol. 182 No. 2, pp. 481-501.

Doolen, T.L. and Hacker, M.E. (2005), "A review of lean assessment in organizations: an exploratory study of lean practices by electronics manufacturers", *Journal of Manufacturing Systems*, Vol. 24 No. 1, pp. 55-67.

Gagliardi, J.-P., Renaud, J. and Ruiz, A. (2012), "Models for automated storage and retrieval systems: a literature review", *International Journal of Production Research*, Vol. 50 No. 24, pp. 7110-7125.

Garcia, F.C. (2004), "Applying lean concepts in a warehouse operation", *IIE Annual Conference and Exhibition*.

Gnatzy, T., Warth, J.A., von der Gracht, H. and Darkow, I.-L. (2011), "Validating an innovative real-time Delphi approach – a methodological comparison between real-time and conventional Delphi studies", *Technological Forecasting & Social Change*, Vol. 78 No. 9, pp. 1681-1694.

Gordon, T. and Pease, A. (2006), "RT Delphi: an efficient, 'round-less' almost real time Delphi method", *Technological Forecasting & Social Change*, Vol. 73 No. 4, pp. 321-333.

Gordon, T.J. and Helmer, O. (1964), "Report on a long-range forecasting study", The Rand Corporation, Paper No. P-2982, Santa Monica, CA.

Gu, J., Goetschalckx, M. and McGinnis, L.F. (2007), "Research on warehouse operation: a comprehensive review", *European Journal of Operational Research*, Vol. 177 No. 1, pp. 1-21.

Gu, J., Goetschalckx, M. and McGinnis, L.F. (2010), "Research on warehouse design and performance evaluation: a comprehensive review", *European Journal of Operational Research*, Vol. 203 No. 3, pp. 539-549.

Hallam, C.R.A. (2003), "Lean enterprise transformation: measuring and accelerating the transition to lean, lean aerospace initiative", available at: http://web.mit.edu/lean (accessed July 30, 2015).

Hicks, B.J. (2007), "Lean information management: understanding and eliminating waste", *International Journal of Information Management*, Vol. 27 No. 4, pp. 233-249.

Hines, P. and Rich, N. (1997), "The seven value stream mapping tools", *International Journal of Operations and Production Management*, Vol. 17 No. 1, pp. 46-64.

Hines, P., Holweg, M. and Rich, N. (2004), "Learning to evolve-a review of contemporary lean thinking", *International Journal of Operations and Production Management*, Vol. 24 Nos 9-10, pp. 994-1011.

Lean warehousing (2015), "Lean Warehouse", available at: http://leanaust.com/services/lean-warehousing (accessed July 2015).

Lesmes, D., Castillo, M. and Zarama, R. (2009), "Application of the analytic network process (ANP) to establish weights in order to re-accredit a program of a university", *Proceedings of the International Symposium on the Analytic Hierarchy Process, Pittsburgh, PA, July 29-August 1*.

Narang, R.V. (2008), "Some issues to consider in lean production", *First International Conference on Emerging Trends in Engineering and Technology, ICETET*, *Nagpur*, *July 16-18*. doi: 10.1109/ICETET.2008.113.

Ohno, T. (1988), *The Toyota Production System: Beyond Large Scale Production*, Productivity Press, Portland, OR.

Pattanaik, L.N. and Sharma, B.P. (2009), "Implementing lean manufacturing with cellular layout: a case study", Vol. 42 Nos 7-8, pp. 772-779.

Pil, F.K. and Fujimoto, T. (2007), "Lean and reflective production: the dynamic nature of production models", *International Journal of Production Research*, Vol. 45 No. 16, pp. 3741-3761.

Rouwenhorst, B., Reuter, B., Stockrahm, V., van Houtum, G.J. and Mantel, R.J. (2000), "Warehouse design and control: framework and literature review", *European Journal of Operational Research*, Vol. 122 No. 3, pp. 515-533.

Saaty, T.L. (1999), "Fundamentals of the analytical network process", *ISAHP*, *Kobe*, *August 12-14*, available at: http://chern.ie.nthu.edu.tw/IEEM7103/937805-paper-1-may6.pdf (accessed July 30, 2015).

Saaty, T.L. (2001), *Decision Making with Dependence and Feedback: The Analytic Network Process*, 2nd ed., RWS Publications, Pittsburgh, PA.

Saaty, T.L. (2008), "Relative measurement and its generalization in decision making why pair wise comparisons are central in mathematics for the measurement of intangible factors the analytic hierarchy/network process", *RACSAM*, Vol. 102 No. 2, pp. 251-318.

Schuckmann, S.W., Gnatzy, T., Darkow, I.-L. and von der Grach, H.A. (2012), "Analysis of factors influencing the development of transport infrastructure until the year 2030 – a Delphi based scenario study", *Technological Forecasting and Social Change*, Vol. 79 No. 8, pp. 1373-1387.

Sevkli, M., Oztekin, A., Uysal, O., Torlak, G., Turkyilmaz, A. and Delen, D. (2012), "Development of a fuzzy ANP based SWOT analysis for the airline industry in Turkey", *Expert Systems with Applications*, Vol. 39 No. 1, pp. 14-24.

Seyedhosseini, S.M. and Ebrahimi-Taleghani, A. (2015), "Group fuzzy ANP procedure development for leanness assessment in auto part manufacturing companies", *Journal of Global Business Advancements*, Vol. 8 No. 2, pp. 157-175.

Sharma, S. and Shah, B. (2015), "A proposed hybrid storage assignment framework: a case study", *International Journal of Productivity and Performance Management*, Vol. 64 No. 6, pp. 870-892.

Steinert, M. (2009), "A dissensus based online Delphi approach: an explorative research tool", *Technological Forecasting and Social Change*, Vol. 76 No. 3, pp. 291-300.

Tanco, M., Santos, J., Roddriguez, J.L. and Reich, J. (2013), "Applying lean techniques to nougat fabrication: a seasonal case study", *The International Journal of Advanced Manufacturing Technology, Vol*, Vol. 68 Nos 5-8, pp. 1639-1654.

Tang, Z., Chen, R. and Ji, X. (2005), "An innovation process model for identifying manufacturing paradigms", *International Journal of Production Research*, Vol. 43 No. 13, pp. 2725-2742.

Vinodh, S. and Balaji, S.R. (2011), "Fuzzy logic based leanness assessment and its decision support system", *European Journal of Operational Research*, Vol. 49 No. 13, pp. 4027-4041.

Vinodh, S. and Chintha, S.K. (2011), "Leanness assessment using multi-grade fuzzy approach", *European Journal of Operational Research*, Vol. 49 No. 2, pp. 431-445.

Wan, H.-D. and Chen, F.F. (2009), "Decision support for lean practitioners: a web-based adaptive assessment approach", *Computers in Industry*, Vol. 60 No. 4, pp. 277-282.

Womack, J., Jones, D. and Roos, D. (1990), *The Machine That Changed The World*, Simon & Schuster UK Ltd, New York, NY.

Wu, Z., Xu, J. and Xu, Z. (2015), "A multiple attribute group decision making framework for the evaluation of lean practices at logistics distribution centers", *Annals of Operations Research*, pp. 1-23.

Further reading

Hsu, C.-W., Hu, A.H., Chiou, C.-Y. and Chen, T.-C. (2011), "Using the FDM and ANP to construct a sustainability balanced scorecard for the semiconductor industry", *Experts Systems with Applications*, Vol. 38 No. 10, pp. 12891-12899.

Ling, F.Y.Y., Edum-Fotwe, F.T. and Ng, M.T.H. (2008), "Designing facilities management needs into warehouse projects", *Emerald*, Vol. 26 No. 11, pp. 470-483.

Womack, J.P. and Jones, D.T. (1996), *Lean Thinking: Banish Waste and Create Wealth in Your Organization*, Simon and Shuster, New York, NY.

Appendix 1

This phase is shown deciding performance issues of picking process using RTD. Questionnaire is prepared asking all team members and experts, about the decisional criteria to improve picking performance in the warehouse. Each member anonymously ranks available options. They can also update their priorities over a period of time and suggest other possible options like order sorting, to be included.

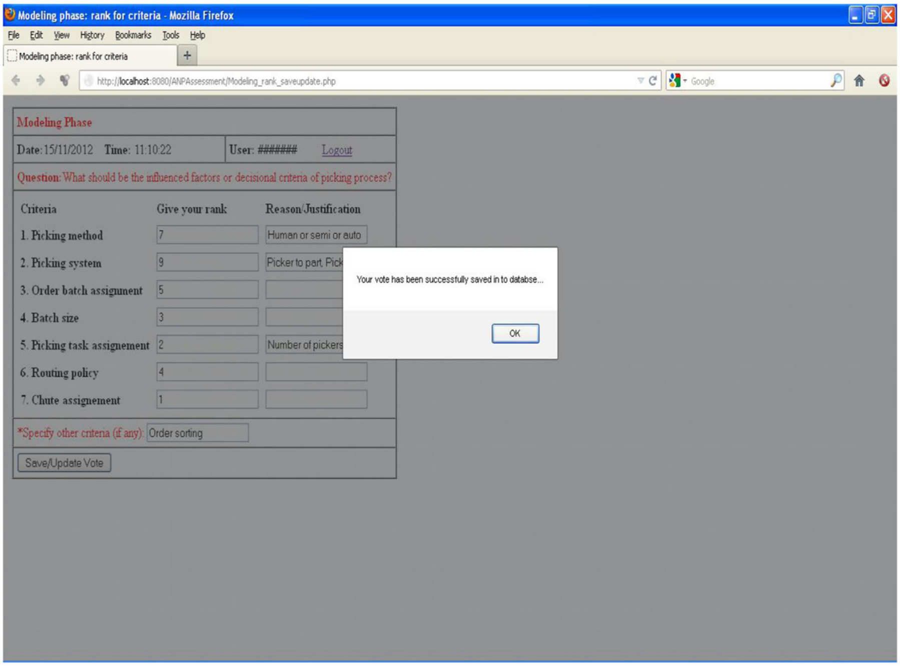


Figure A1.
Ranking criteria for picking process

Appendix 2

Assessment phase using RTD where user relates "Storing" and "Picking" clusters. User does pair wise comparison within "Storing" cluster with respect to "Picking method" criteria of "Picking" cluster. For the asked question, user enters 7, forwards value, comments and stores the opinion as shown. All users are given user id to log into system with confidentiality. Users are asked to enter their voting values. They can compare the clusters and nodes with each other and vote for it. Later on as shown in Appendix 3, they can also view other's voting and comment about it. There is a tag showing average and total voting values as well. There is forward and backward options for every question, where user can select backward to vote inverse value like 1/7.

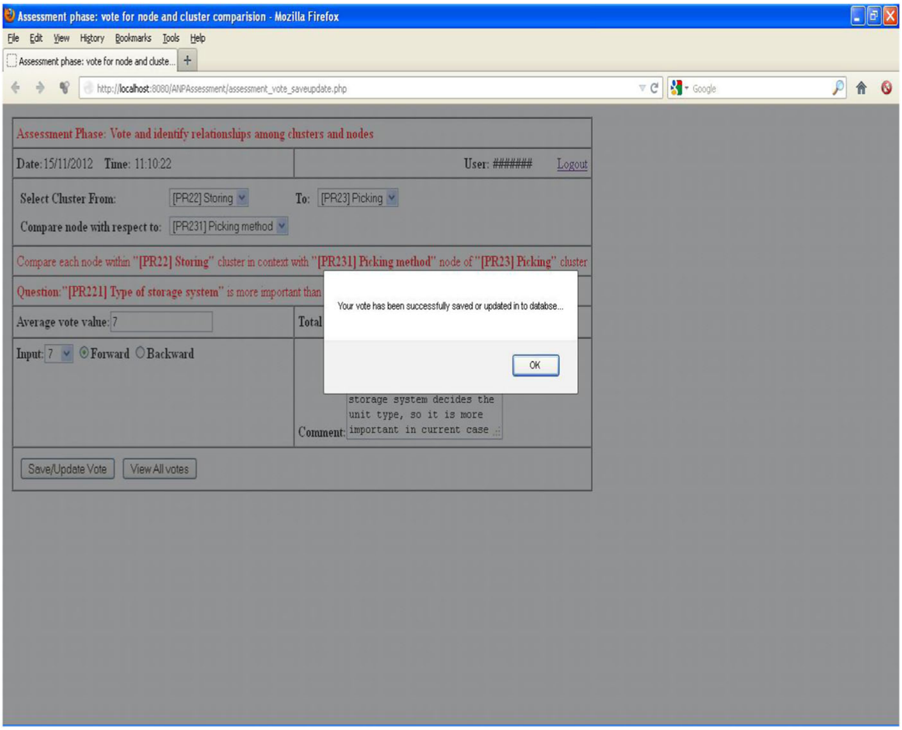


Figure A2.
Assessment phase

Appendix 3

RTD-based assessment phase where user views all other votes and justifications for selected question.

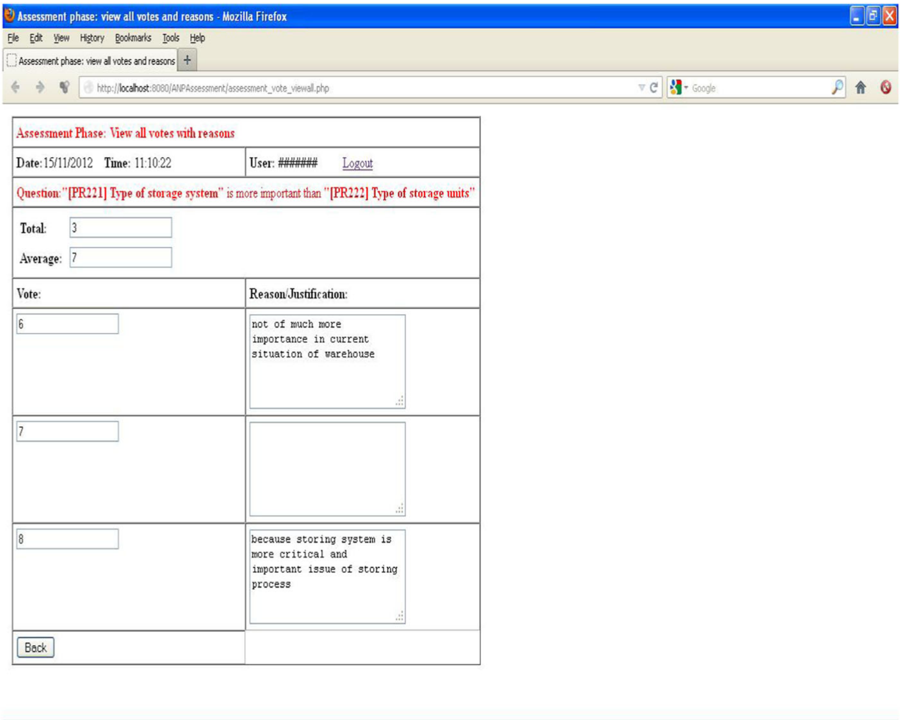
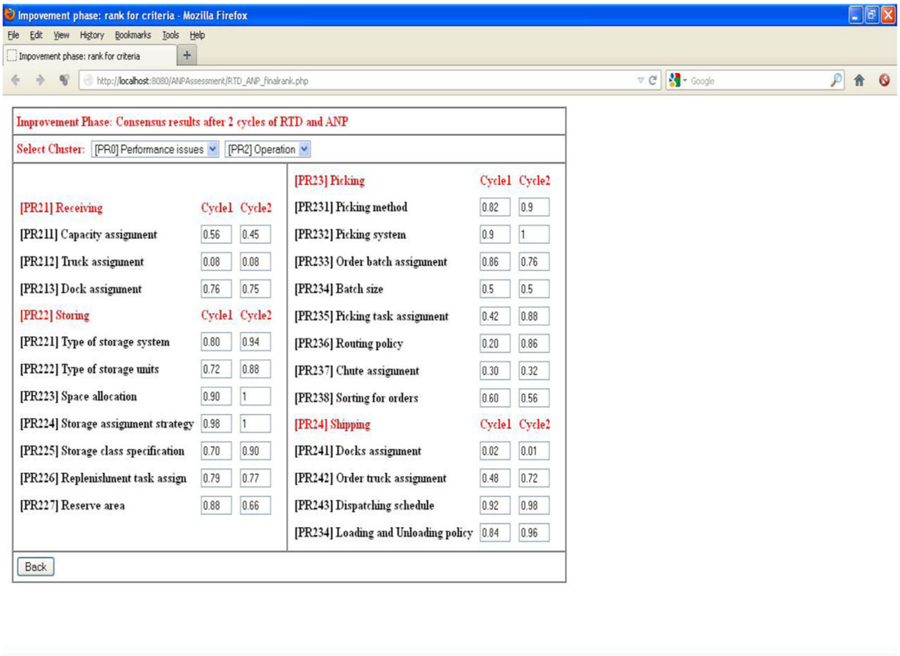


Figure A3.
Assessment phase: review votes

Appendix 4

Improvement phase using RTD represents consensus state after two rounds. In "Performance issues" for selected cluster "Operation," results are shown. After collaboration it has been proved that for each criterion results are improved in second cycle. We can refer the refined values and find out that with respect to storage utilization. Picking process is directly related to space allocation scheme, storage class and adopted storage assignment policy. Storage assignment policy can be random, class, full turnover, dedicated or any other depending upon the requirement of space and available layout. At the same time picking system and method used are also important like sort while pick, pick and sort, wave or pick pass method. Routing policy and loading/unloading policy also affect the storage while doing picking operation. These issues are not identified by only ANP study. With expert collaboration and consensus the results and improvement area can be found out by this approach only.



[PR21] Receiving	Cycle1	Cycle2
[PR211] Capacity assignment	0.56	0.45
[PR212] Truck assignment	0.08	0.08
[PR213] Dock assignment	0.76	0.75
[PR22] Storing	**Cycle1**	**Cycle2**
[PR221] Type of storage system	0.80	0.94
[PR222] Type of storage units	0.72	0.88
[PR223] Space allocation	0.90	1
[PR224] Storage assignment strategy	0.98	1
[PR225] Storage class specification	0.70	0.90
[PR226] Replenishment task assign	0.79	0.77
[PR227] Reserve area	0.88	0.66

[PR23] Picking	Cycle1	Cycle2
[PR231] Picking method	0.82	0.9
[PR232] Picking system	0.9	1
[PR233] Order batch assignment	0.86	0.76
[PR234] Batch size	0.5	0.5
[PR235] Picking task assignment	0.42	0.88
[PR236] Routing policy	0.20	0.86
[PR237] Chute assignment	0.30	0.32
[PR238] Sorting for orders	0.60	0.56
[PR24] Shipping	**Cycle1**	**Cycle2**
[PR241] Docks assignment	0.02	0.01
[PR242] Order truck assignment	0.48	0.72
[PR243] Dispatching schedule	0.92	0.98
[PR234] Loading and Unloading policy	0.84	0.96

Figure A4.
Assessment phase: criteria ranking

Appendix 5

Following figure represents the existing layout of warehouse to understand the working environment and problem scenario.

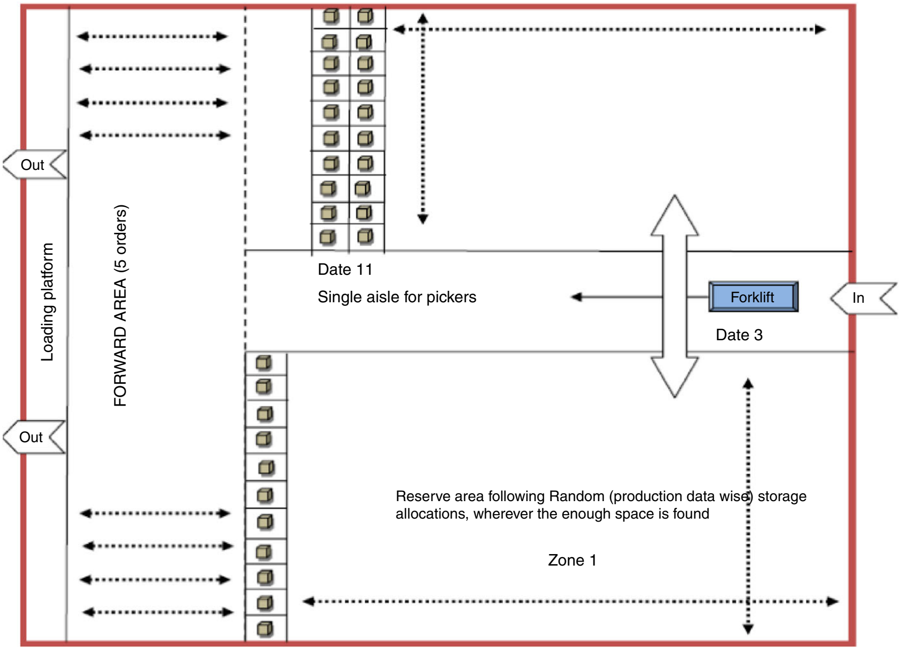


Figure A5. Existing warehouse layout

Corresponding author

Sanjay Sharma can be contacted at: s_nsit@rediffmail.com