# AN EVALUATION OF WASTE IN STEEL PIPE RACK INSTALLATION

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## ABSTRACT

The new emerging philosophy of lean construction has been increasingly advocated because of the significant outcomes of its application in different projects. Its waste minimization focus is declared to be beneficial in addressing the inherent challenges of construction, i.e. quality failures, low productivity, and cost and schedule overruns. This research aims to identify the common waste factors and unearth the most significant contributors to waste in steel pipe rack installation process. Data collection was through 6 interviews, followed by a questionnaire survey of 43 professionals involved in pipe rack projects. The findings revealed that waiting for equipment and prefabricated steel elements, repair works and inspection time could be considered as the main waste factors. Moreover, poor planning, weak communication, financial problems, lack of coordination-based workflow, poor contractor practices and poor job site management are recognized to be the most prominent root causes of waste generation.

## KEYWORDS

Lean Construction, Waste, Waste Causes, Steel Pipe Rack, Petroleum Industry.

## INTRODUCTION

Over the past two decades, lean construction has been evolved into a novel management approach moving towards overcoming construction problems and improving performance in form of increased productivity, reductions in project schedule and cost, improvements in management and control, increased turnover, sustainability, etc (Alarcon et al. 2008, Conte and Gransberg 2001, Garnett et al. 1998, Huovila and Koskela 1998). As the main focus, lean construction proposes a broad definition of waste and endeavors to minimize it (Alarcon 1994). Evaluation of waste could be rewarding in pipe rack installation as a common operation in oil, gas and petrochemical projects which constitutes a great portion of construction works and it consumes a lot of time, money and resources (Dehghan et al. 2009). The study could serve as a base for future efforts regarding waste elimination while the repetitive nature of the process (Lee et al. 1999, Huang et al. 2004) would help obtain more reliable and realistic information from professionals.

## WASTE ACCORDING TO LEAN THEORY

Lean theory emphasizes on minimizing non value-adding activities (wastes) in all forms (Ohno 1988, Alarcon 1994, Spear and Brown 1999). Considering value as the

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delivery of the customer’s needs, value-adding activities conduce to value by conversion of material and information into products and contrarily, non value-adding activities use time, resource or space (similar to value adding activities) without creating any value (Koskela 1992, Alarcon 1994, Formoso et al. 2002, Bin Ibrahim et al. 2010). One comprehensive definition of waste is “the loss of any kind of resources (materials, time, labor, equipment and capital) produced by activities that generate direct or indirect costs, but do not add any value to the final product from the point of view of the client”(Formoso et al. 1999 and 2002). Reviewing the studies shows that the first perception of construction waste is limited to material waste and its related environmental or economic aspects (Formoso et al. 1999 and 2002). However, wastes could be in forms of time, capital, material, labor or equipment loss. Many researchers seem to have agreement on “the classic list of seven wastes” (Ohno 1988) and they have introduced some extra wastes to it (Table 1).

Table 1: Summary of waste factors

| **Waste Factors** | Ohno (1988) | Borcherding & Alarcon (1991) | Alarcón (1994) | Gavilan. & Bernold (1994) | Serpell et al. (1995) | Bossink, & Brouwers (1996) | Faniran, & Caban (1998) | Formoso et al. (1999) | Lee et al (1999) | Koskela (2000) | Garas et al. (2001) | Nakagawa & Shimizu (2004) | Ekanayake & Ofofri (2004) | Dainty & Brooke (2004) | Koskela (2004) | Esin & Cosgun (2007) | Begum et al. (2007) | Wang et al. (2008) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Delay (waiting/idle/stoppage) | * | * | * | | * | | | * | * | * | * | * | | | | | | |
| Poor quality (correction/rework/repairs/not meeting requirements) | * | * | * | | * | | | * | * | * | * | * | | | | | | |
| Waste of material | | | * | * | | * | * | | | * | * | * | * | * | | * | * | * |
| Inventory | * | | * | | | | | * | * | * | * | * | | | | | | |
| Slow/ ineffective/ not completed work | * | * | * | | * | | | | | | * | | | | | | | |
| Movement of people/ materials | * | | * | | | | | * | * | | * | * | | | | | | |
| Transportation/ travelling | | * | | | * | | | * | * | | | * | | | | | | |
| Overdoing/ Overproduction | * | | * | | | | | * | * | | * | * | | | | | | |
| Processing | * | | | | | | | * | | | | * | | | | | | |
| Substitution | | | | | | | | * | | | | | | | | | | |
| Supervision | | | * | | | | | | | | | | | | | | | |
| Poor safety/ accidents | | | | | | | | * | * | * | | | | | | | | |
| Clarifications | | | * | | | | | | | | * | | | | | | | |
| Theft/ vandalism | | | | | | | | * | | | * | | | | | | | |
| Abnormal wear and tear of equipment | | | * | | | | | | | | * | | | | | | | |
| Waste in management and planning | | | | | | | | | | | | * | | | | | | |
| Making-do | | | | | | | | | | | | | | | * | | | |
| Other (lack of constructability, suboptimal working condition, etc) | | | * | | * | | | * | * | * | | | | | | | | |

## KEY CAUSES OF CONSTRUCTION WASTE

Several researchers have endeavored to determine the source of waste in construction projects. Alarcon (1994) proposed a cause-effect matrix to identify the main causes of each type of waste and Serpell et al. (1995) pinpointed the controllable causes of waste, associated to flows, conversions, or management. Erroneous or incomplete contract documents, design changes, contractors' lack of knowledge about construction, wrong procurement, errors of labors and lack of control are proposed by Bossink and Brouwers (1996). Love and Li (2000) considered that rework and its consequent non productive time are attributable to design or construction generated causes and Formoso et al. (2002) postulated that flow activities such as material delivery, inventories and internal transportation and handling are the main contributors to waste of material and consequently waste of other resources. Polat and Ballard (2004) emphasized on late and not satisfactory material procurement and imperfect planning as the main contributors to waste of time and material which are usually reacted by short-term solutions rather than long-term preventive actions. In addition to a set of waste sources of different material, Wang et al. (2008) suggested some general management causes of waste including lack of management skills, lack of environmental awareness, multi-layered construction activities and lack of training.

## VALUE STREAM MAPPING (VSM)

The main approach to identify and minimize construction wastes in a process is step-by-step analysis of the entire process and observing value creation from customer's point of view (Garnett, et al. 1998). Value stream mapping (VSM) is a powerful technique for visualizing waste and its source in any process; hence it shows the sequence of works in a supply chain or in internal operation, involving both value-adding and non value-adding activities better than any other tool (Sullivan et al. 2002, Loong et al. 2010). Indeed, it is a snapshot from the current state, together with the future state map illustrating the situation after eliminating wastes (Sullivan et al., 2002). Nevertheless, Garnett et al. (1998) believe that unlike manufacturing, construction processes are not generic and easily recognizable, so this may render the mapping process difficult. In addition, this method may be less advantageous for non repetitive and unstructured works.

## RESEARCH METHODOLOGY

The common practice in steel pipe rack installation was first reviewed through six face-to-face semi-structured interviews with professionals directly involved in pipe rack projects. The interviews helped map the process and identify the potential wastes. A questionnaire was then designed in two parts: waste factors and source of waste, using a five-point rating scale (Likert scale) and were distributed in the form of hard copies and emails among a target group of 58 experts. Among them, 43 copies were returned and used for further analysis, resulting in a response rate of 74.1%. Table 2 shows the demographic profile of the respondents.

Table 2: Respondents demographic profile

| Experience | Freq. | % |
|---|---|---|
| 3-5 yrs | 4 | 9% |
| 6-10 yrs | 25 | 58% |
| 11-15 yrs | 11 | 26% |
| +15 yrs | 3 | 7% |
| **Organization** | **Freq.** | **%** |
| Owner | 9 | 21% |
| Fabricator | 5 | 11% |
| Engineer (Supervisor) | 8 | 19% |
| Contractor/ Subcontractor | 21 | 49% |

| Occupation | Freq. | % |
|---|---|---|
| Project Mgr | 8 | 19% |
| Project Executive Mgr | 3 | 7% |
| Project Control Mgr | 6 | 14% |
| Procurement Planning Mgr | 1 | 2% |
| Site Mgr | 2 | 5% |
| Inspection Supervisor | 1 | 2% |
| QA Mgr | 1 | 2% |
| Technical Expert | 21 | 49% |

## DESCRIPTION OF THE PIPE RACK INSTALLATION PROCESS

Based on the interviews with 6 professionals in two under construction pipe rack projects (A and B), the common installation practices in industry are discussed as follow. For each project, the process activity map is then developed which visualizes the entire process (figure 1 and 2).

### PROJECT A

In this project, the fabrication and installation works have been awarded to two different contractors. Fabrication including cutting, welding, testing, sandblasting and coating of the elements is performed in fabricator's shop. The elements are stored in shop and transported to the main site at least once a weak. Custom formalities and releasing goods usually take some time and then the elements are unloaded to the steel structure yard. The gap between the delivery of the elements and commencement of erection generally depends on the policy of the owner and availability of financial resources. When the erection time arrives, the contractor sends material inquiry verification (MIV) to the warehouse, asking for approval to handle the elements to the pipe rack location. All the required resources such as crane(s), bolts and nuts and the erection crew should become available to commence the work. The elements are then erected according to their number and position. The erection process starts with tying-up the element, hoisting and erecting it in position. The element is fixed on position by preliminary tightening of the bolts and the crane is released and swing back to loading position. Plumbness and levelness should be carried out, inspected and certified. Then the snug tightening of the bolts is performed with full effort (full-bolting) which again should be approved by inspector. Final inspection would be conducted after full-bolting of all elements to ensure the quality of work and any repair and modification would be performed.

### PROJECT B

The main difference between project A and B is that in project B, a single contractor is responsible for both fabrication and installation of steel pipe rack. The owner procures the materials and delivers them to contractor's fabrication shop which is located next to the main site. Unlike the previous case, the interviewees stated that fabrication usually falls behind erection process. The elements are directly transported to the main site right after fabrication and no inventory exists for fabricated elements in main job site. The erection process is quite similar to case A.

In the diagrams, non value-adding activities (wastes) are illustrated in red color, including waiting, delay, rework, double handling and unnecessary inventory which should be completely eliminated. Yellow boxes show non-value adding but necessary activities such as inspection, transportation and approvals. Effort is required to improve these activities in the process and enhance the performance of them. Green boxes are value-adding activities constituting only a few steps in the process.

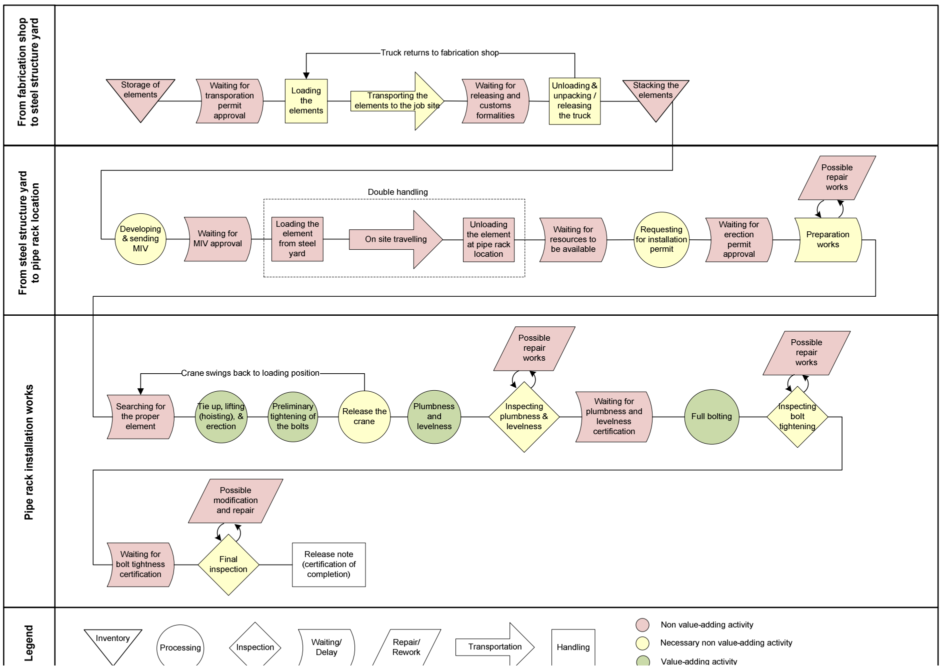


Figure 1: Process activity map for project A

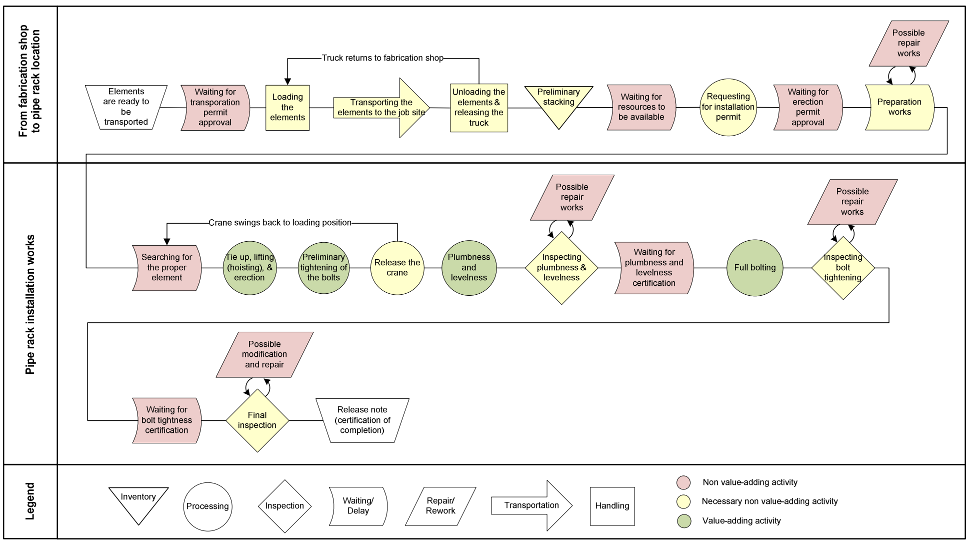


Figure 2: Process activity map for project B

## RESEARCH FINDINGS

### A. WASTE FACTORS IN PIPE RACK INSTALLATION PROCESS

Off-site prefabrication which is normally used in the process is believed to result in higher quality and safety, reduced space requirements, less congestion on site, less material waste and time and cost savings (Jergeas and Van der Put 2001, Tam et al. 2007), so it could be regarded as a waste minimization approach. Using bolted connections instead of welded connections also suits the waste minimization policy because it is easier to perform, has fewer defects and needs less control. However, the list of identified waste factors (Table 3) shows that there are still deficiencies in the process which require careful attention of the management. The main findings in each waste category are discussed as follow.

Table 3: Descriptive statistics of waste factors

| Waste Factor | Category | Mean |
|---|---|---|
| Waiting for equipment to be available | 1 | 3.884 |
| Repair works on site | 5 | 3.535 |
| Supervising and inspecting time | 4 | 3.511 |
| Waiting for elements and materials to be available | 1 | 3.442 |
| Non-productive movement of workers | 2 | 3.279 |
| Rework | 5 | 3.233 |
| Stacking of the elements on steel structure yard | 3 | 3.163 |
| Preparation works (checking drawings, cleaning, etc) | 1 | 3.140 |
| Waiting for others to complete their work | 1 | 3.093 |
| Waiting for/ Receiving instructions | 1 | 2.907 |
| Waiting for the clarifications/ responses to TQs | 1 | 2.884 |
| Waiting for the permits and approvals | 1 | 2.884 |
| Double handling of the steel elements/ materials | 2 | 2.837 |
| Unnecessary transportation of workers, equipment and materials | 2 | 2.698 |
| Waiting for the personnel to be available on site | 1 | 2.651 |
| Searching for proper element/material/ equipment | 1 | 2.651 |
| Stacking of the elements on pipe rack location | 3 | 2.605 |
| On-site accidents | 7 | 2.581 |
| Stacking of the elements on fabrication shop | 3 | 2.326 |
| Unnecessary over-qualified equipment | 6 | 2.070 |
| Repair works requiring return to shop | 5 | 2.069 |
| Unnecessary over-order of materials | 6 | 2.000 |
| Unnecessary over-qualified workers | 6 | 1.956 |
| Vandalism / robbery / theft | 7 | 1.698 |

**1. Delay 2. Unnecessary Transportation/ Movement 3. Inventory 4. Extra Supervision and Inspection**

**5. Repair/Rework 6. Overdoing 7. Other**

### A.1. Delay (Waiting / Idle / Stoppage)

Acquiring the necessary resources such as steel elements or equipment (especially crane, as stated by practitioners) is usually time-wasting. This factor is not limited to the time waiting for equipment to become available, but also the time wasted due to equipment breakdown, repair or replacement. Some preparation works (e.g. checking the drawings and dimensions, setting equipments at proper locations, verifying safety requirements and removing dirt and oil from contact surfaces) and waiting times (e.g. waiting for others to complete their work, waiting for instructions, permits and approvals) do not, in fact, add any value to the work. A crane stays idle while erection crew is rigging-up and the crew may stay idle when the crane is being stabilized. They may wait for clear instructions by supervisor or foreman or wait for answers to technical queries from engineer. In addition, delivery and stacking of the elements are often not based on erection schedule, requiring considerable time searching for the right element among the stacked elements.

### A.2. Unnecessary Transportation/ Movement

Non-productive movement of workers represents the time the workers move between locations to check the work, measure, bring tool, roam, etc which is ranked 5th important waste factor.  Double handlings of the elements between the warehouse and permanent location or unnecessary movement of crane due to improper stacking of elements at site are examples of waste. Inappropriate transportation and handling not only waste time and money, but may also cause defects such as deformation of the elements which in turn requires repair and leads to extra time and money waste.

### A.3. Inventory

The practitioners stated that the steel elements may be stored at fabrication shop, steel yard, and job site for some time and in some cases for weeks and months. They are bulky and require a big area for storage. In addition, the poor storage condition may cause damage and deformation of them.

### A.4. Extra Supervision and Inspection

Because of the importance of facilities in oil, gas and petrochemical projects, strict supervision and inspection procedures are used to ensure the project is according to standards and carried out effectively. However, according to lean construction concept inspection time is considered as non value-adding.

### A.5. Repair/Rework

In spite of firm inspection in fabrication and erection process, there are still defects requiring repair works. Simple repair works such as misalignment of the bolt holes or paint touch-up are quite frequent and usually fixed in place. In case of any significant deficiency, the element may even be returned to the fabrication shop, intensifying waste of time. Moreover, any non-conformance to the specifications or any design variation requires rework which imposes extra time, money and material waste.

### A.6. Overdoing

The factors belonging to this category have low ranks in the list which shows that they are not very significant in the process. The respondents didn't believe that over qualified resources or over-order of material widely exist in projects.

### A.7. Other

Steel structure erection is dangerous in nature due to working at height and generally has high rate of accident. Another high potential accident is the electric shock of welding process when piping crew simultaneously work in completed parts of pipe rack which may lead to loss of time, money and most seriously human resource. Vandalism and robbery has the lowest rank in the list mainly because steel elements are bulky and heavy so less likely to be stolen.

## B. Waste Causes

Main waste causes are ranked and discussed in following four categories (Table 4).

Table 4: Descriptive statistics of waste causes

| Waste Cause | Category | Mean |
|---|---|---|
| Poor planning and scheduling | 1 | 4.023 |
| Weak communication among project participants | 2 | 3.767 |
| Financial difficulties | 1 | 3.628 |
| Lack of a coordination-based workflow among participants | 1 | 3.488 |
| Poor contractor/ subcontractor practices | 3 | 3.256 |

| Waste Cause | Category | Mean |
|---|---|---|
| Poor job site management | 1 | 3.209 |
| Lack of competent workforce with required experience/ skills | 3 | 3.187 |
| Late decision making | 1 | 3.140 |
| Weak supervision / Inexperienced supervisors | 3 | 3.116 |
| Poor site layout / Congested working area | 3 | 3.070 |
| Ineffective resource management | 1 | 3.000 |
| Improper interface management | 1 | 2.907 |
| Inappropriate construction methods | 3 | 2.860 |
| Bureaucracy/ Excessively complicated regulations | 2 | 2.744 |
| Unclear/ defective/ wrong information (contract, drawings, etc) | 2 | 2.651 |
| Poor design/ Design changes | 2 | 2.651 |
| Inclement weather | 4 | 2.605 |
| International sanctions and embargos / Inflation / etc | 4 | 2.535 |
| Lack of an integrated management information system | 2 | 2.256 |
| Obsolete equipment | 3 | 2.116 |

**1. Management Factors 2. Information Factors 3. Execution Factors 4. External Factors**

### B.1. Management Factors

Much of waste in the process is attributable to managerial factors. Pipe rack installation is the predecessor of many other works such as piping, so it requires accurate planning, especially for resource procurement. However, poor planning is considered as the most important waste-generating factor. Financial problems and monetary shortcoming resulting from poor prioritization and financial planning of the projects of a program and portfolio may stop the project for a while and impose huge waste of time and money to it. Additionally, late payments to the contractor and its consequences such as claims and dispute may result in further waste. In petroleum mega projects, where different participants, layers of contractors and variety of trades work simultaneously, lack of a coordination-based workflow, poor job site, resource management and late decision making contribute to huge waste.

### B.2. Information Factors

Communication is ranked as second important waste-causing factor by respondents. Culturally, there is usually unwillingness to communicate and share information with other people. Unclear, wrong and late information, together with inefficient means of communication between project parties and different disciplines intensify the problem. In other words, the traditional means of communication and flow of information between the participants is not effective and the bureaucracy in and between organizations hinders the smooth flow of information between parties.

### B.3. Execution Factors

Lack of constructability, high rate of defects, reworks and accidents are directly resulted from poor contractor and subcontractor practices which necessitates revising the contractor selection process as well as training programs. Moreover, disqualified supervisor may conduct improper and negligent supervision so the quality of work would be threatened and extra supervision and rework may become necessary. Congested site and non-optimized distances and space between the facilities, fabrication shop and warehouse impede the smooth flow of resources and affect the waiting times, transportation and handling of elements, issuance of safety and erection permits and even supervision and inspection.

### B.4. External Factors

Inclement weather has adverse effect on construction in open site projects where high wind and rain may stop the erection. Furthermore, severe weather condition would decrease the productivity of the workforce and increase non productive time. Pipe rack projects are not highly influenced by international sanctions since the main parts of them are locally procured. However, the accessories and some parts may be difficult to purchase and thus waste some time. Inflation is an influential factor which may render the procurement difficult leading to waste.

## CONCLUSION

Waste evaluation in steel pipe rack installation process revealed that waiting for equipment, repair works, supervising and inspecting time and waiting for steel elements are the most salient waste factors, respectively. The study also highlighted poor planning, weak communication, financial issues, lack of coordination-based workflow, deficient contractor and subcontractor practices and job site management as the most influential causes contributing to waste. The limitation of the study is being based on a survey rather than direct observation and the rank and significance of the factors might slightly vary in different projects because of the unique characteristics of each project. Nevertheless, the findings could give an insight to the managers regarding waste and serve as a base for future studies regarding waste elimination and performance improvements. It is hoped that the future researches on the applicability of lean tools on waste reduction in pipe rack installation as well as in pre-fabrication could pave the way for removing the major performance weaknesses and advance the efficiency of project delivery.

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