Fundamental Principles of Site Material Management

H. Randolph Thomas[1]; David R. Riley[2]; and John I. Messner[3]

Abstract: This paper was written to fill a void created by the absence of fundamental principles of site construction management. Efficient material management is essential to managing a productive and cost efficient site. For more than 25 years, the senior author has been observing and writing about inefficient labor productivity practices resulting from poor site material management. Using deductive reasoning, fundamental principles were developed to avoid poor practices. A construction site should be portioned into three areas or zones: semipermanent (exterior) storage, staging areas, and workface (interior) storage. Each has a unique function relative to site material management. Using these areas as a framework, fundamental principles are stated and illustrated using a case study project accompanied by numerous photographs and narratives.

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Introduction

The discipline of project management is often ill defined particularly when it comes to site operations. There is considerable knowledge about the things that go wrong and the consequences of ineffective decision making, but there is limited published information about what procedures and steps to follow to avoid cost overruns and time delays. This is particularly true of site material management practices (Thomas et al. 1989, 1999; Thomas and Sanvido 2000).

Objective and Scope

The objective of this paper is to present fundamental (guiding strategic) principles of managing materials on the construction site. The goal is to begin developing suitable practices and procedures that will define the discipline of site project management. Site material management is defined as the allocation of delivery, storage, and handling, spaces and resources for the purposes of supporting the labor force and minimizing inefficiencies due to congestion and excess material movement.

The paper is not intended to be a comprehensive guide to all aspects of material management. Its focus is on site management for medium-size and smaller projects. Many other topics related to material management are not addressed. These include information management, information technology, containment of material management risk and uncertainty, supply chain management and integration, and others. The topics covered herein are limited to those for which the authors have data or experiences sufficient to justify the formulation of fundamental principles. Accordingly, all the principles cited are grounded on data or experiences that show that adherence to a principle will contribute to better labor performance.

Literature Review

The literature review covers two broad categories: site layout and planning and general site management practices.

Site Layout

Mawdesley provides a good discussion of the factors considered during site layout and planning (Mawdesley et al. 2002). The factors include access and traffic routes, material storage and handling, administration buildings and welfare facilities, and equipment workshops and services. The published literature on developing a site layout can be characterized as "black box" solutions. Some involve the development of an extensive knowledge base (Zouein and Tommelein 1999), whereas others do not rely on an extensive knowledge base (Mawdesley et al. 2002). Most algorithms relate to the positioning of temporary facilities and storage areas, whereas others are more limited, such as the best location of cranes (Warskawski and Peled 1987).

All authors recognize the complexity of the site layout problem. All generally agree that there are multiple selection criteria, multiple constraints, and the plan changes over time. The site plan used at the beginning of the project may not be suitable for the middle or latter part of the project.

For simplicity sake, the most comprehensive algorithms use the selection criteria as the minimum travel distance or minimum transportation cost (Zouein and Tommelein 1999; Mawdesley et

[1]Professor, Dept. of Civil Engineering, Pennsylvania Transportation Institute, Penn State Univ., 203 Transportation Research Bldg., University Park, PA 16802.

[2]Associate Professor, Dept. of Architectural Engineering, Penn State Univ., 104 Engineering Unit A, University Park, PA 16802.

[3]Assistant Professor, Dept. of Architectural Engineering, Penn State Univ., 104 Engineering Unit A, University Park, PA 16802.

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al. 2002; Tam et al. 2002). The algorithms concentrate on positioning facilities to satisfy the constraints while satisfying the objective. While applying multiple criteria and addressing other features of the layout problem are perhaps possible, the problem can quickly become quite complex. Further, for a small site, where the site layout is especially important, travel distances and transportation costs may be of secondary importance. The adherence to principles that assure safety, adherence to the project schedule, and good labor productivity may be of primary importance, so the link between site layout and material management should not be lost. Yet none of the articles in the literature seem to adequately address this issue. These objectives are not easily expressed mathematically. It would appear that a general heuristic approach might be more satisfactory in allowing the planner to adapt to the uniqueness of each site.

Site Material Management

There have been relatively few articles dealing with site material management practices. Work by Stukhart on bar coding was done to allow for easy identification and retrieval, but this work seems more applicable to larger industrial sites (Stukhart 1990).

Material management involves storage, identification, retrieval, transport, and construction methods. Each is indelibly linked to safety, productivity, and schedule performance. Thomas showed the affects on productivity of poor storage practices (Thomas et al. 1989). The difficulties in retrieval were readily obvious. In a later article, he also showed the affect of delivery methods (Thomas et al. 1999). It was shown that the erection of structural steel directly from the delivery truck was the preferred way. Doing so also saved on-site storage costs and eliminated most double handling. In essence, just-in-time material deliveries were preferred in this instance, but it did require more coordination with the fabricator.

In another article on site material management practices, Thomas showed that effective site management practices can have a significant affect on schedule performance (Thomas and Sanvido 2000). The schedule slippage on the installation of windows, precast panels, and ducts ranged from 50 to 129%.

Riley, Thabet, and Tommelein have described workspace use and patterns in construction (Thabet 1992; Tommelein et al. 1992; Riley and Sanvido 1995, 1997). Riley used case studies to define work area patterns as linear, random, horizontal, vertical, spiral, and building face (Riley and Sanvido 1995). He argued that space need patterns changed over time and that for effective use of resources, space needs must be predictable and rationally planned.

Lean Construction Principles

In recent years, many researchers have championed lean construction as offering principles related to material management. Unfortunately, many of these principles are vague, difficult to comprehend, and hard to implement at the site level (Thomas et al. 2002b). However, one aspect is clear. Any interruption to the normal flow of materials will result in causing serious degradations on performance and labor productivity (Thomas et al. 2002a). In studies involving more than 125 projects, the most frequently documented cause of disruption was problems associated with material management.

Research Methodology

Over the last 25 years, the senior author has been measuring site labor productivity. The productivity database for this paper contains more than 125 projects from six continents. There are almost 6,000 workdays involving over 300,000 work hs. In the process of measuring labor productivity, site conditions affecting the work were documented. In particular, material management deficiencies have been observed as the most frequently occurring disruption. It has been observed that, in general, for all types of material management deficiencies, there is a reduction in daily productivity of about 40% (Thomas and Smith 1992). Deficiencies include running out of materials, improper storage, double handling, sporadic and out-of-sequence deliveries, inefficient methods, poor housekeeping, and others.

It has been documented that when these deficiencies occur, there are negative impacts on labor productivity. Using deductive reasoning, it is concluded that these deficiencies must be avoided, and principles are proposed for doing so. The principles have been intentionally kept general so as to assure applicability to the widest range of site conditions.

Some principles are illustrated with a single case study project. The case study project is ideally suited for this purpose because it was a small site and is representative of the type of project found in many locales.

Division of Site into Three Primary Areas

The principles of site material management are summarized in Table 1. Relative to storage of materials, a site should be divided into three areas:

1. Semipermanent (outside) storage area—these are areas, sometimes called laydown areas, where materials are stored prior to being used in the project.
2. Staging area—this area is next to the exterior of the facility. It is in this area that materials are lifted into the facility. Materials that are off loaded directly into the facility also use this area.
3. Workface—this is the area inside the facility where the work of the craftsmen takes place. Each of the above areas has a different use and must be managed differently and different principles will apply.

Case Study Description

The case study project is a three-story municipal office building in downtown State College, Pa. The structural frame of the building is structural steel (above-ground stories) and reinforced concrete basement walls. The site area is 70,000 ft^2 (200×350 ft), and the first plan area is approximately 18,750 ft^2 (75×250 ft). The project was estimated to cost about \$10 million, and the planned construction schedule was 16 months.

Site Characteristics

The site plan of the project is shown in Fig. 1. It shows that the site had limited space for material storage and laydown areas and other facilities. Fig. 1 shows how the contractor utilized the limited space. The use of storage and laydown areas was based on a “first come, first served” philosophy. When the study began, steel

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Table 1. Principles of Site Material Management

Number		Principle
1.		Semi-permanent (outside) storage area
	1.1	Do not store materials close to the building.
	1.2	Locate parking areas, tool sheds, trailers, spoil piles elsewhere or as far from the building as possible.
	1.3	Mark stored materials so they can be readily distinguished from similar materials.
	1.4	Materials should be stored to permit easy access and retrieval.
	1.5	Materials should be stored on timbers or pallets to permit easy retrieval and protected to prevent damage from mud and water
2.		Staging area
	2.1	Reserve areas next to the building for materials deliveries or materials being moved to the workface areas.
	2.2	Backfill around the building as quickly as is practical to permit the area to be used as a staging area.
3.		Workface (interior) storage area
	3.1	The amount of material stored inside should be kept to a minimum.
	3.2	Preassemble components into larger components or subassemblies.
	3.3	Integrate the sequence of work with the storage plan so interior space can be used without interfering with the work.
	3.4	Ancillary tasks like unpacking, cutting, reshaping, preassembly, etc. should be done away from the workface when practical.
	3.5	Maintain good housekeeping.
	3.6	Arrange for removal of waste from the building on a continuous basis.
4.		Vendor relations and deliveries
	4.1	Whenever possible, erect deliveries directly from the delivery trucks.
	4.2	Assure deliveries are properly sequenced to be consistent with the work plan.
	4.3	Make sure the delivery rate from vendors is compatible with the installation rate of the field crew.
5.		General
	5.1	Avoid the use of earthen ramps into below grade areas.
	5.2	Make use of elevators.

reinforcement, structural steel, concrete block, and other materials were already stored on site. There was congestion and interference with trucks or deliveries entering the site.

Description of Work

Scope of Work

The activity reported herein is the ductwork installation, and the operation covered four floors from the basement to the third floor. (The reinforced concrete basement walls were also studied.) Overall, the project was studied in depth for almost 4 months over a 10 month period. The ductwork activity consisted of three subtasks, that is, hangers, duct erection, and connection. There were four major types components involved in the work: small feeder, large feeder, branch duct, and fire dampers.

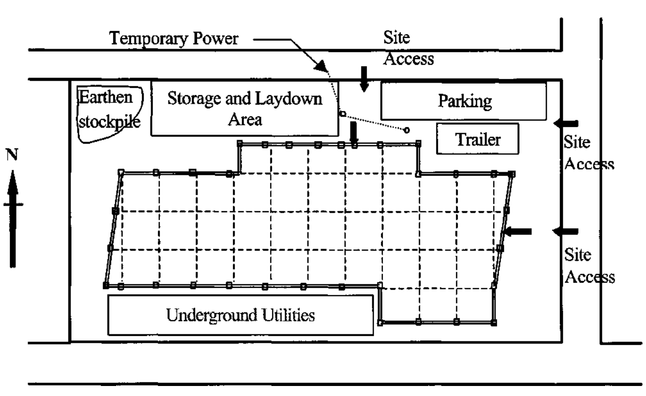

Fig. 1. Site plan

Construction Methods

The crew included one foreman and two workers. During the first 2 weeks, there was enough workspace for the crew to preassemble three or four pieces of duct together on the floor and used a lift to install the preassembly. However, as the job progressed, the first floor became congested with framing and drywall, and masonry partitions interfered with the work in the basement. This meant that the duct was installed one piece at a time instead of as a preassembly.

Fig. 2 shows the productivity for the first 33 working days of the ductwork activity (Han and Thomas 2002). The work was frequently disrupted, especially after the first 2 weeks. During the first 2 weeks, the productivity was frequently in the range of 0.30–0.35 work h/ft. Thereafter, the productivity on undisrputed days was more in the range of 0.50–0.60 work h/ft. The case study and data from other projects form the basis for Principle 3.2 (see Table 1), that is, preassemble components into subassemblies to maximize productivity. Not being able to use subassemblies on the case study project resulted in more than a 50% loss of productivity.

Material Management Practices

There was no material management plan for this project. Materials were stored on site in accordance with the layout shown in Fig. 1. The site was very small and site access was at the three locations shown. There were trailers, a tool storage shed, excavated spoil, and a parking lot. Material was transported into the building in two places as shown in Fig. 1. Fig. 3 shows the material storage area on the north side of the building. This area was also used to stockpile excavated soil, trash, and miscellaneous materials. Because of the limited site storage, duct and other materials were stored inside the building. This aspect is shown in Fig. 4. The south side of the building was unavailable for storage because underground utilities were being installed.

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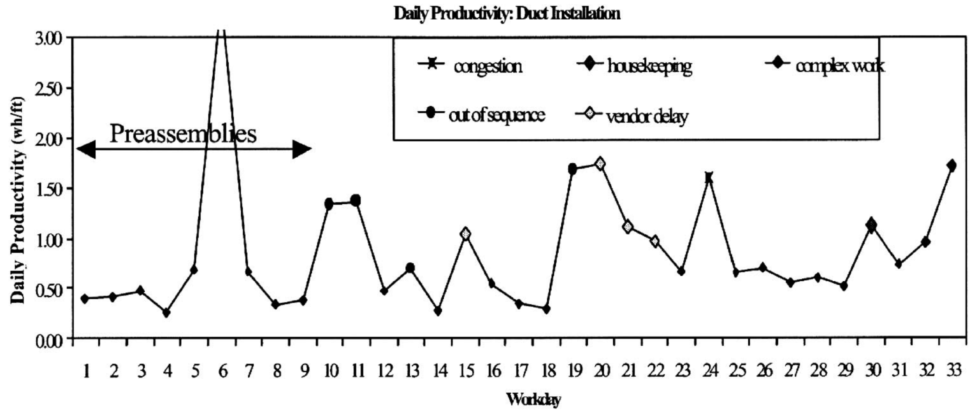

Fig. 2. Daily productivity

Waste materials were removed periodically, but often the building interior was untidy. There was no plan of waste removal.

The disorderly storage practices on the interior affected the duct installation in several ways. Duct could not be erected as a preassembly. Also, the framing, masonry partitions and piping were done out of sequence. Several of these aspects are shown in Fig. 5. As can be seen in Fig. 2, there are numerous disruptions caused by congestion, interferences, and out-of-sequence work. Overall, the labor performance of the duct installation was poor.

Principles of Site Material Management

In examining this and other projects, it is possible to formulate fundamental principles of site material management using deductive reasoning. The principles are summarized in Table 1.

Semipermanent (Outside) Storage

Semipermanent storage areas (usually outside) are areas where materials are stored for an extended period of time, say several weeks or more. Importantly, materials should not be stored next to the building (Principle 1.1) as these can impede the normal access requirements, including access for cladding, material deliveries, etc. (see Figs. 6 and 7). Also, other uses should not infringe on this area. One can see that in Fig. 1, parking areas, spoil piles, trailers, and tool sheds all occupy valuable storage space. Clearly some judgment must be applied in the location of trailers and tool sheds, but these should be located as far away from the building as is practical (Principle 1.2). Conversely, other options are possible for spoil piles and parking areas. The real estate in a restricted site like the case study project is much too valuable for these uses.

Materials in the storage areas should be clearly marked (Principle 1.3) so they can be readily distinguished from other similar materials. For example, a 21 ft piece of steel reinforcement should be easily distinguishable from a 22 ft piece. Fig. 7 shows an example of very poor storage practices. The labor productivity of the steel erection crew on this project was much worse than on comparable projects, and the cause was the material storage practices (Thomas et al. 1989).

Materials should be stored in such a manner that will allow easy access by lifting and transporting equipment (Principle 1.4). This is clearly not possible on the project as is shown in Fig. 7. The materials are not marked or segregated and access for retrieval was difficult at best. Fig. 8, from the case study project, shows a mixture of good and marginal storage practices. Some reinforcement is marked and stored on timber; some is not. Principle 1.5 has been violated in Fig. 9 because easy retrieval is not possible. Materials should also be stored on timbers or pallets to

Fig. 3. Outside storage of materials

Fig. 4. Storage of materials in building interior

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Fig. 5. Duct and wall framing interference

prevent damage from mud and water (Principle 1.5). Figs. 10 and 11 show two projects where it will be nearly impossible to protect materials from mud and water. The performance on both projects relative to time and cost was poor.

Staging Areas

Areas immediately adjacent to a building perimeter are needed for several functions. Considerable work to the exterior cladding, windows, etc., is performed here, as are crane locations and concrete discharge points. Also, open areas are needed to assure easy access for deliveries of equipment and materials and for waste removal. Materials stored in the staging areas are more likely to require double handling leading to Principle 2.1, which is to store materials elsewhere (see Fig. 7).

Stockpiles of excavated material should be located away from the building and backfilling around the building should be done as soon as is practical (Principle 2.2). On a small site, consideration should be given to stockpiling excavated material off site, as the stockpile will occupy valuable space. The location of the excavated stockpile on the case study project can be observed in Figs. 1 and 3. Late backfilling around the perimeter of a building can be observed in Fig. 12. This violates Principle 2.2 (see also Fig. 17.)

Fig. 6. Congested staging area, Walker building

Fig. 7. Poor material storage practices, Rider building

Workface (Interior) Storage Practices

Obviously, some materials must be stored inside a building. However, the amount stored here should be kept to a minimum (Principle 3.1). Only 1 or 2 day's supply should be stored inside until areas are no longer needed. In the case study project, storage practices such as those shown in Fig. 4 impeded progress. The consequences are clearly seen in Fig. 2. Fig. 13 shows another example of inside storage that can impede progress. This project underwent considerable distress.

The sequence of the work should be integrated with the storage plan (Principle 3.2). Riley has written at length about the need to do so (Riley and Sanvido 1995, 1997). In the case study project, the basement area could have been utilized for inside storage. Instead, the masonry walls in the basement were erected early, thereby negating the opportunity to potentially utilize a sizeable secure storage area.

If care is not taken, the workface area can become cluttered with excess material and waste. Tasks such as unpacking, cutting and reshaping materials, etc. should be limited in workface areas. Assign these tasks to other locations like the staging or storage areas. Fig. 14 shows an example of a very untidy workface area. This work could easily be done elsewhere.

Housekeeping is important function that should be given close attention (Principle 3.5). Poor housekeeping impedes productivity

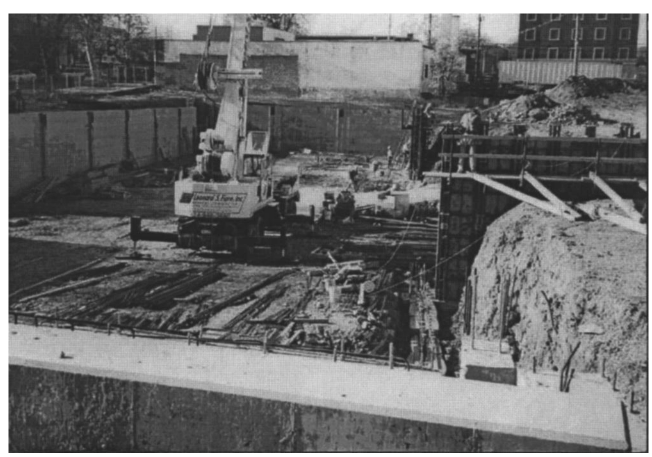

Fig. 8. Good and marginal material storage practices, State College municipal building

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Fig. 9. Inaccessibility to stored materials, Walker building

Fig. 10. Muddy and wet working conditions, ES & M building

Fig. 11. Muddy site and storage conditions, Walker building

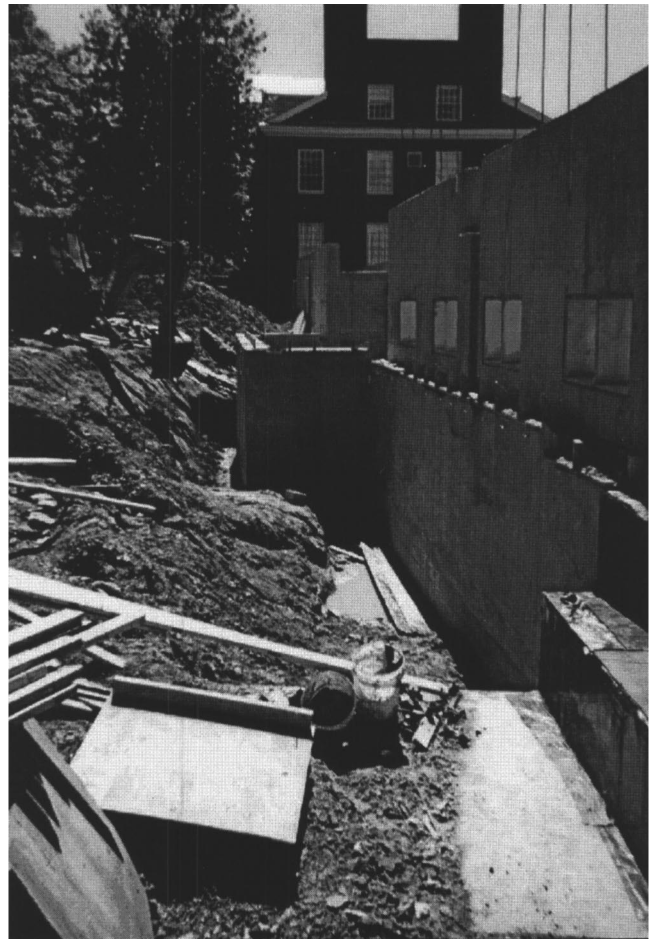

Fig. 12. Late backfilling, O'Leary

Fig. 13. Library storage, West Point school renovation

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Fig. 14. Untidy workface area, Copper Beach Townhouses

and safety. Figs. 14–16 show examples of poor housekeeping. On each of these projects, the performance of the particular activity was impaired by poor housekeeping.

Vendor Relations and Deliveries

Several technical papers have been written about material deliveries and vendor relations. In one related to structural steel deliv-

Fig. 15. Poor housekeeping, Hampton Inn

Fig. 16. Poor housekeeping, Sassafras Project

eries, it was concluded that the most productive method of delivery was to erect the steel directly from the truck as it is delivered (Thomas and Sanvido 2000). This eliminates the need for sizeable storage areas on site, but to use this method, control of the staging area must be maintained.

The delivery rate from vendors must be compatible with the installation rate in the field. All to often, these two functions are not coordinated. In Fig. 2, Workdays 15 and 19–22 are shown as

Fig. 17. Use of forklift to move materials into building, Pattee Library

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out-of-sequence work and interferences with other crews. These disruptions were caused because of delayed and unsequenced deliveries of duct from the vendor. The negative impact is clearly evident. Thomas showed the results of three case studies where deliveries from vendors were not coordinated Thomas and Sanvido (2000). The productivity losses ranged from 17 to 57%.

General Principles

Several principles are important as they relate to transporting materials from the storage or staging areas to the workface areas. The first relates to projects with below grade excavations such as basements. The use of earthen ramps should be avoided as these often impede the completion of basement walls that may in turn affect the entire project schedule. The interference between wall construction and the ramp has been observed on several projects. The completion of basement walls was slowed in Figs. 8 and 11. An economic analysis may be justified.

Another principle is that contractors should make extensive use of elevators and hoists. On some projects, cranes and forklifts have been used. On some of these projects, it has been observed that materials were manually moved from one floor to another because forklifts would not reach the top floors. Notice that in Fig. 17, the staging area must be clear and there is a limit to the height that can be reached. This approach is not always adequate as the work activity occupies staging area space and the right equipment may not be available when needed. Tight control of the staging area is required. Moving materials into the facility after regular working hours may be discouraged because of overtime pay. An economic analysis is also warranted.

Applicability to Construction Practice

The principles presented in this paper have broad and immediate applicability to construction practice. Following these principles will alleviate practices that have been documented as causing poor project performance relative to cost, schedule, and labor productivity. The principles are easy to understand and observe and easy to implement by practioners. They will produce positive results. There is no “black-box” solution and no need to master scientific modeling principles.

Conclusions

Ineffective material management practices are evident on many projects and cause considerable waste in time and money. The application of the practices listed herein will reduce the likelihood of time and cost overruns.

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