Waste-Based Management in Residential Construction

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Abstract: The strength of housing construction has a profound effect on the national economy and the society. As a consequence, achieving high productivity, quality, and safety are considered of high priority for this industry segment. This paper proposes to replace the traditional management approach for site operation with a management philosophy that has as its sole and unifying objective the elimination of process waste. It will be demonstrated that a waste-based management philosophy creates a culture of continuous improvements and innovative progress driven by the goal to reduce wastes from injuries to unproductive work activities. Wall framing and masonry construction are used to demonstrate how the waste-based management approach functions. The results of the test case application provide evidence that paying attention to minimizing resource wastes at all levels, from laborer to site manager, will produce drastic effects on productivity, safety, and quality of residential construction.

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Introduction and Background

The health of residential construction is centrally important to the economic health of the United States' economy. Over 10 million people are employed in the construction industry. Therefore, productivity changes within it have direct effects on the economic health and the potential for future growth of the United States economy (Allmon et al. 2000). Since there is "always a better way" to do things, it can be expected that there are practices and technologies that lead to further productivity advancements of in the field of construction.

As many field investigations have shown (Ogelsby et al. 1989), the main source of low productivity in construction is laborer's time spent on wasteful work or waiting for needed resources. Injuries and accidents are also associated with wasteful time caused by caring for the injured, closing the site for an investigation, cleaning the site, and repair. Furthermore, poor quality requires time for fixing or redoing the "product," resulting in wasted time as well as materials. Thus, one promising avenue for improving productivity in construction is the elimination of the inefficient use of resources.

Residential Construction in the United States

The houses built in early America by the first European immigrants were made out of solid logs but, over time, these heavy timbers were reduced in size. One reason for this change was caused by the realization that too much material was used per house. Another reason was the introduction of new technologies, such as the mechanical saw, that allowed for the increase in the efficiency of time and materials used in construction. Today, most houses in the United States are made of wood frames with facades of wood, vinyl or brick siding, and roofing shingles. The rapid growth of the U.S. population in the early nineteenth century resulted in small towns mushrooming all over the country leading to the adoption of standard architecture and building techniques (Cavanagh 1999). In the early nineteenth century, the American pioneer beginning a farm or business near the Mississippi River moved into an area already populated by the French, Spanish, and other Europeans. As a result of merging the advantages of different building methods from these various cultures and the emergence of mass-produced nails, a fast and cheap method of construction, called the balloon frame, gradually emerged.

The balloon frame formed a "basketlike structure of surprising strength" that was made up of small boards, no larger than 2 by 12 inches, spaced 16 to 24 inches across. Each individual nailed connection added to the strength of the entire building. Since no single joint was critical for the structural soundness, an individual joint could fail without affecting the entire structure. The introduction of this new method of many joints, when compared to the old frame houses, required little skill and saved many hours of work (Cavanagh 1999). Fig. 1(a) shows a sketch of a balloon frame where the wall studs reach from the foundation all the way to the roof.

The balloon frame structure experienced uneven settlement caused by the differences in shrinkage of the wood as it dried. These problems led to the method of construction used today, the platform frame. As seen in Fig. 1(b), the platform-frame consists of a sill, the box sill, which is "constructed for the exterior support of the ends of the floor joists by laying down a timber the same size as the joists and setting another one on the extreme edge in a vertical position" (Walsh 1923). This forms an angle that makes a resting box into which the floor-joists can be framed. A double plate timber is placed as floor joists. The flooring can

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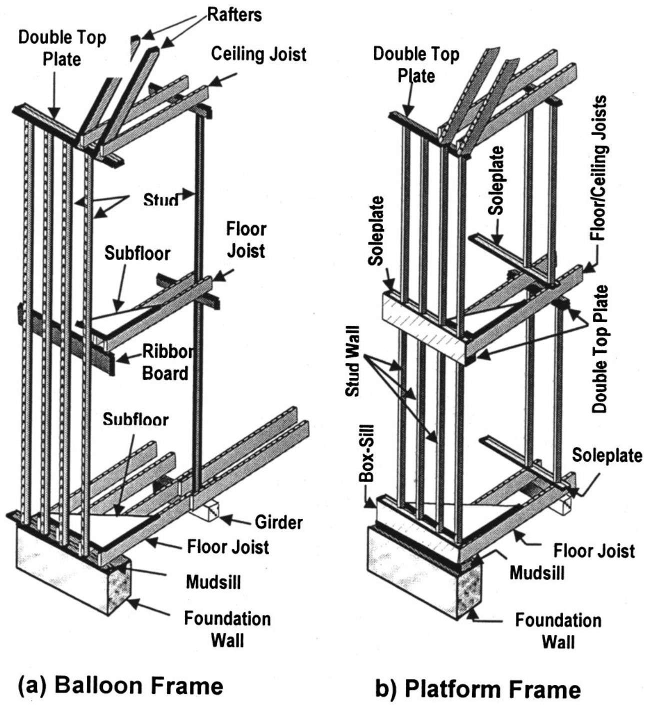

Fig. 1. Framing concepts in the U.S.

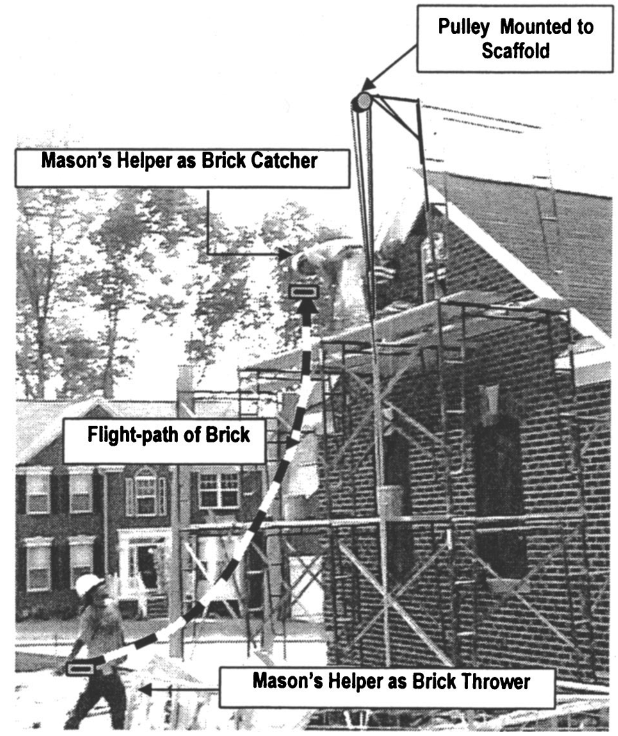

Fig. 2. Common material supply for brick veneer construction

then be nailed on top of the floor joists. Stud wall frames make up the exterior and interior walls. Each floor is built on top of the previous one in the same manner. The amount of cross section of wood in any one bearing partition is identically the same as in any other, eliminating the uneven settlement (Walsh 1923).

At the same time, European buildings were made out of stone or brick, heavy and permanently affixed to the ground. Europeans felt that the American wooden houses would not last long. While this is true, the adopted method requires less initial investment, which enables more Americans to own their own home. North Americans have developed their own way of building houses that is a distinct part of their culture (Cavanagh 1999). While Romans used veneer masonry extensively applying it to massive brick or concrete, Americans veneer to a skeleton wood frame, as shown in Fig. 2, making it appear to have the structural soundness of a load bearing brick wall. The members of the Brick Value Builder Program guarantee that their brick homes will add no more than three to five percent to the cost of vinyl-sided equivalents (Wallace 1999).

Lean Construction—A Revitalization of Old Management Principles

The cost of housing is as important as mortgage rates in encouraging house ownership by individuals. While the introduction of power tools and new materials has led to some improvements, no significant changes in productivity in housing construction have been observed in the last several decades. One concept that has recently been introduced as a potential remedy is lean construction; an adaptation from manufacturing. Following the main objectives of waste reduction and product perfection, lean construction concentrates on the elimination of waste while improving project performance. Waste is defined by the performance criteria for the production system (Howell 1999). Using more materials than needed is waste, failure to meet the quality standards is waste, and idle time of labor and/or machines is waste. There have been clear indications, however, that the different instances of waste are effects of the same cause. For example, Gavilan and Bernold (1994) found that material waste was closely linked to the traditional source of low productivity and safety, namely lack of detailed planning. Because of this linkage, minimizing construction waste may in fact be viewed as the overarching effort to maximize construction productivity, safety, and quality.

From Target to Real-Time Management

Traditional construction planning and control focuses mainly on setting and meeting targets, particularly the schedule and budget. As a result, a reactive management style of management by exception has evolved as a pre-eminent method. The concept of lean construction offers an alternative to this target-based management in that it makes the elimination of waste its main objective. While it mimics living systems, continuous waste minimization (e.g., letting go of inefficient traits) guarantees survival; it represents a philosophical change in construction management. Every level and every branch of a dynamic system has the tendency to be wasteful, as they try to adapt to their constantly changing environment. Material, as the most commonly mentioned waste in construction, has its equivalent in other essential resources such as idle equipment, unreadable drawings, and damaged tools. Thus, the minimization of resource waste has to be a ceaseless and continuous effort by anyone who is part of the system that is involved in construction. As a consequence, reactive management by exception will be replaced with active and ever engaged planning and control.

The following section will introduce the underpinning for waste-based management in construction. Two examples will be used to demonstrate its effectiveness.

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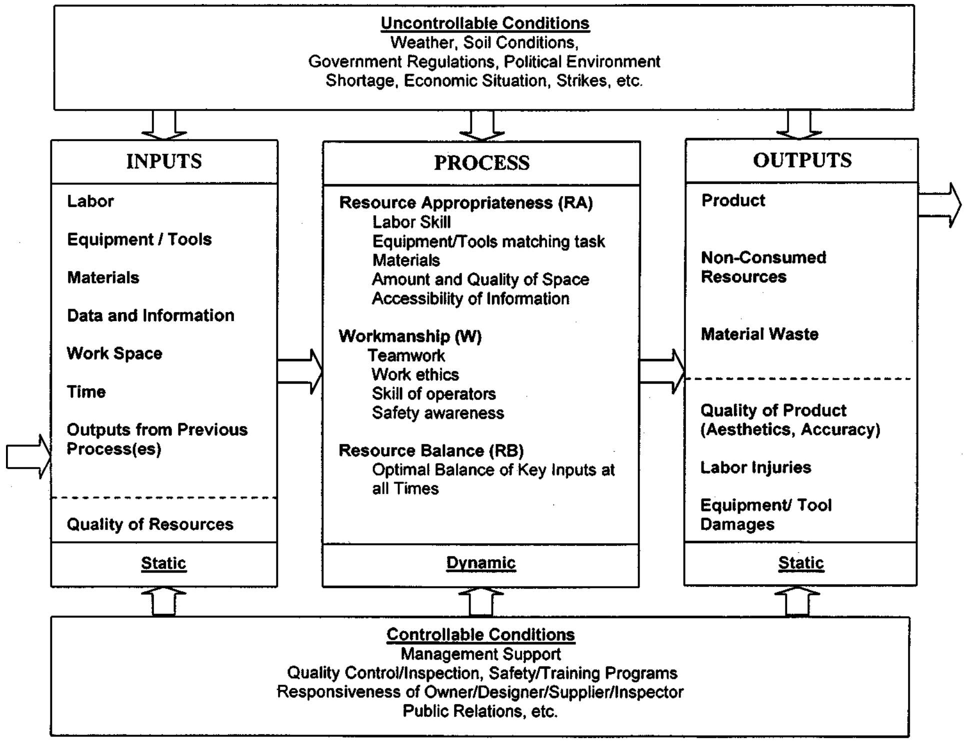

Fig. 3. Aggregated process model (Based on Salim and Bernold 1995)

Aggregated Process Model

Koskela and Huovila (1997) have proposed thinking of construction as: (1) A process of converting inputs to outputs; (2) a flow of information and materials; and (3) the generation of value for customers. It seems rather artificial to separate the two first concepts since both information and materials are inputs to the construction process. Depicted in Fig. 3 is a more inclusive model composed of five interlinked modules: (1) Inputs; (2) process; (3) outputs; (4) uncontrollable conditions; and (5) controllable conditions (Salim and Bernold 1995). While inputs are converted into outputs by the process, changing conditions may effect the performance of system elements within every module. For example, a defective piece of equipment, while still operating, will make it impossible to keep up with a fully functional piece. The defect, however, could very well be the result of nonexisting preventive maintenance. Thus, poor productivity or quality of the process is the consequence of a controllable condition, a managerial decision not to maintain the equipment preventively.

The fact that one process is only one within a comprehensive network is indicated by the dark flow arrows leading in and out of each APM. Fig. 3 also tries to point out that process outputs includes material that were not consumed and material that has been wasted. Other categories of "wasted resources" are injured laborers or tools/equipment that have been damaged.

From an operational point of view, the process is considered dynamic in that it has to constantly adapt itself to the changing conditions "presented" by the environment or its inputs (e.g., delivery of the wrong steel element.) Thus, in-process adaptive control is essential for keeping the process "optimal." As shown, three managerial concerns have been identified as most critically responsible for its outcome: (1) Resource appropriateness; (2) workmanship; and (3) resource balance. Each one of the three issues requires planning and control before, during, and after the completion of each process, therefore defining the realm of waste-based planning and control (WBPC) of processes.

Waste-Based Planning and Control of Process Resources

Process planning is a term commonly used in the manufacturing industry, defining the function that establishes which machining processes and parameters are to be used from engineering drawings (Chang and Wysk 1985). It dictates the process by presenting guidance aiming at "how to do a task right the first time," its basic functions are to make certain that resources needed to accomplish a process are available, appropriate, in good quality, and well organized. Because of the dynamic nature of construction environment, the control functions need to be integrated with the planning framework, which is then used to identify and correct for deviations from the plan. Waste-based planning builds on the traditional process planning in that it focuses on the process but adds system-wide and uninterrupted engagement by everybody. It represents the framework for a continuing planning and control effort organized into five distinct phases, as depicted in Fig. 4. Formal process planning and control are interwoven with arranging all of the resources. Early process planning questions include: "What needs to be done?" and "How will we do it?". It is undertaken by construction planners as they make initial preparation for the process (i.e., scheduling, safety plan, materials requirement plan). The key tasks in this phase are: (1) Review of information flow; (2) determination of methods; sequences of the operation; and (3) safety and quality assurance. With the sights set on minimizing waste, long-lead time resources (e.g., crane) have to be ordered and mobilized only after the process plan has been completed, guaranteeing the least effort for material handling (e.g., delivery and staging of material on site.) Mobilization has to include an assessment of the prework site, the quality of the previous process

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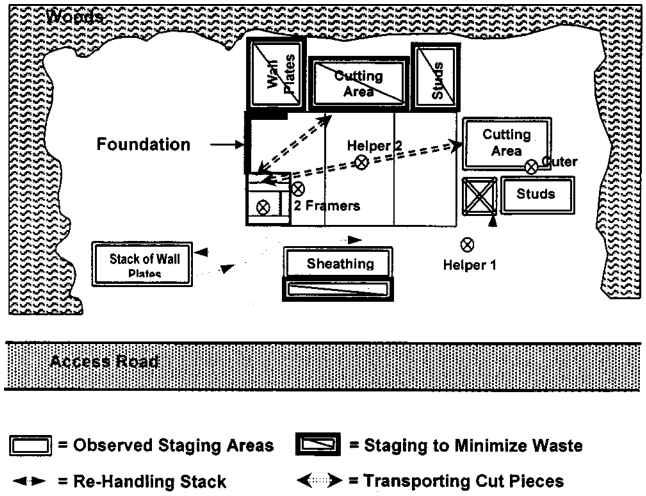

Fig. 4. Material staging plans for wall framing

outputs, and all of the needed resources. Situations that have the potential to create "waste" in the areas of resource staging, layout of the work site, and quality/appropriateness of the available resources have to be examined for their potential to cause waste after the actual start of the work. Examples of "wasteful" situations that can be remedied at this point are: (1) Missing or broken tools/equipment; (2) lack of sufficient information; (3) misstaged material; and (4) preceding work that has not been totally completed. Should the discrepancy between plan and actual be too severe, corrective actions, if possible, or replanning activities could be initiated.

Since, by definition, WBPC includes everybody involved in the process; the start of the actual operation signals a drastic increase in the number of people who are expected to participate in waste management. Now, the craftsman or the helper is as important as the foreman in minimizing waste, reaching from cutting the lumber to the accurate lengths to using the tools as designed.

In fact, the "struggle" does not end until all nonconsumable resources are cleaned, repaired, and/or demobilized. Also, quality assessment of the output has to be an indispensable element of waste-based management. Therefore, WBPC defines all of the measures that are required to prepare, execute, monitor, and close-out a construction process. Under this regimen, planning and control go hand in hand in a continuous and helical "relay."

Managing With Critical Success Factors

An almost infinite set of factors, conditions, and cause-and-effect relationships have to be considered when planning construction operations. Factors (e.g., skill) that have a strong positive relationship to a desired outcome (e.g., high productivity) are referred to as success factors (SFs) while success is defined as the degree to which a specific goal is met. Whenever a large set of factors have a bearing on an outcome, a minority of factors have a "majority" impact on success. Based on this principle, it makes sense that the manager focuses his attention on the small number relationships that are most closely related to success, the critical SFs. For this purpose, ten managers in residential construction were asked to rate a list of impact factors according to their perceived importance. Each had to be subjectively rated using a five-point system: "No influence" is measured as a value of 1 while "major influence" is measured as a value of 5. Based on each questionnaire, average point values were computed. Table 1 presents the top-rated factors in descending order.

Table 1. Summary of Success Factor Rating Questionnaires

Rank	Points	Factor description
1	4.9	Planning and control
2	4.7	Communication/coordination
3	4.6	Labor (availability, skill, motivation, etc.)
4	4.4	Equipment and tools (appropriateness, quality, etc.)
5	4.4	Working methods (sequences, technology, etc.)
6	4.0	Site conditions
7	3.9	Material delivery, staging and site transportation
8	3.5	Weather
9	3.3	Safety programs
10	2.6	Government regulations

Note: Scale: 1=No influence; 2=little influence; 3=some influence; 4=big influence; and 5=major influence.

As shown in Table 1, the surveyed experts felt that the most significant factor for waste reduction is planning and control. Effective communication/coordination was also rated critical since the field personnel depend on accurate and timely information for operation. The third highest factor is skill, motivation to be productive, and workmanship of laborers. From this list, factors whose average values are higher than 4.0 are regarded as the critical process SFs for the reason that they seem to have major influences on the success of construction processes.

All in all, the survey supported the hypothesis that planning and control has to be considered most important in managing residential construction efficiently. The remaining part of this paper will be taken up by demonstrating, with the help of two cases, the potential impact of WBPC on safety and productivity.

Test Case 1. Wall Framing

In the summer of 2000, a randomly selected residential building site in Raleigh, North Carolina was observed. The 8 h of videotaped wall framing, performed by a five-person crew (2 framers, 2 helpers, and 1 cuter) was subsequently analyzed. As indicated by the observed layout in Fig. 4, two framers nailed and tilt up the wall frames at the work face, while helper 1 rehandled material by picking up wall plates from the stack on the left side of the building and transporting them to the cutting area on the right side. Helper 2, without a clear job assignment, shifted between helping the framers and supplying cut lumber. However, for a large portion of his time, he was observed to be loitering around. This in turn had a severe impact on the cutter who was forced to interrupt his bottleneck task in order to deliver the lumber pieces by himself.

In order to quantify the time spent by each worker, two productivity measurement methods were used: (1) Productivity ratings; and (2) continuous time study.

Analysis of Field Data

Productivity Ratings. Three main categories of work were created: (1) Direct or effective; (2) essential contributory; and (3) ineffective. Effective work involves the activities of the crew that are directly involved in the actual process of putting together or adding to a unit being constructed (Oglesby et al. 1989). Essential

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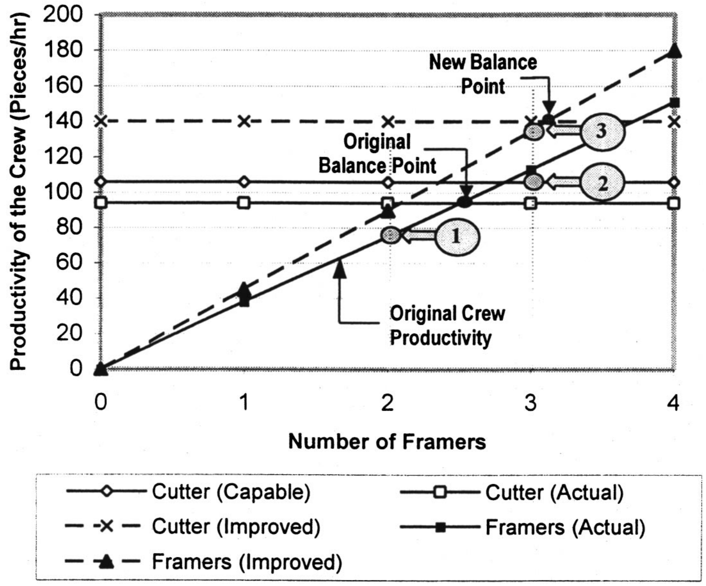

Fig. 5. Resource balance diagrams for framing crew

contributory work includes all elements that lead to the finishing, while not adding directly to the unit being constructed. Ineffective stands for doing nothing or doing something not essential to complete the end product.

The five-person crew was observed randomly 10 times, with 18 observations each time, which resulted in a total of 900 observations. It was found that Helper 1 spent 59% moving lumber from one place to another and 30% of the total time returning empty handed, both ineffective work. The cutter and the framers spent 39% (20%) doing ineffective work consisting of: (f) Walking empty handed (9%); (h) searching for materials (7%); and (i) waiting for materials, tools, etc. (12%). Helper 2, as expected, was observed to be idle for 23%, and ineffective for 50% of his work time.

Continuous Time Study. The continuous time study was based on observing 20 cycles for each individual crew member, except Helper 2 since he did not work repetitively. The result of this study confirmed the outcome of the productivity ratings:

1. Helper 2 is idle 47% (compared to 43% using the productivity ratings).
2. The cutter spent 20% cutting, 27% measuring, and the rest on supplying cut lumber, etc.
3. 76.7 s was the average cycle time for the cutter producing two pieces of lumber each cycle.
4. The cycle time for Framer 1 and Framer 2 (nailing one piece of lumber) is 93.7 and 97.9 s respectively. The average productivity of framers is 75 lumber pieces/h.

The results of productivity ratings and continuous time study clearly indicate several wastes of labor hours. Table 1 gives the necessary clues as to how one may best to eliminate the labor wastes as it lists four factors that could possibly have led to the observed situation: (1) Lack of planning and control; (2) lack of skilled/motivated labor; (3) management (in-) competence; and (4) poor material staging and site transportation. The following will present the outcome of an effort to apply waste-based management approach.

Strategies to Minimize Process Waste

In the observed wall-framing process, site layout—especially material staging points—are not appropriate for the intended operation. At the time when materials were delivered to the site, management still had not set up the site layout plan. Therefore, materials were placed randomly around the site, unsorted, causing great inconveniences and ineffective use of labor. In addition, the lack of a clear job assignment resulted in an unbalanced crew.

Effect of Proactive Site Layout Planning. Fig. 4 presentes staging areas for delivering wall plates, studs, and sheathing material that could be given to the supplier's truck driver.

The effect of placing the materials into the indicated staging areas is as follows:

1. The total unproductive work of Helper 1 is avoided.
2. The unproductive work of the cutter in subcategory; (h) searching for materials, and (i) waiting for materials is eliminated.
3. The unproductive work of both the framers in subcategory (g) carrying materials outside the staging area, and (h) searching for materials is eliminated.

Balancing Production Resources. The proximity of the cutting area to the lumber material, in fact, eliminates the need for Helper 1 which in turn could be replaced by an additional framer. The better organization of the cutting area also reduces the need for the cutter to search and wait for material, thus increasing his productivity from 94 to 106 lumber pieces per hour. As indicated in Fig. 5, the crew productivity will thus jump from P1 to P2. A proper labor plan established during the PPC phase would assign a helper to both the framers and the cutter. The continuous time study showed that his idleness reached 47%. From Fig. 5, we learn that the cutter represents the bottleneck resource (horizontal line), thus any improvement in his production rate might directly influence crew productivity. By assigning Helper 2 to deliver the cut pieces of lumber to the work face, this leaves the cutter more time for productive work, which in turn results in a productivity that soars from 106 to 140 pieces/h, reflected by the dashed horizontal line. A further amount of the helper's remaining idleness is assigned to help the framers, drastically reducing their unproductive time. As a consequence, the slope of the framers productivity line increases leading to a new balance point and the crew productivity raises from P2 to P3.

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Table 2. Comparative Productivity Ratings for Framing Crew

Work category	Cutter OP	Cutter WBP	Framer 1 OP	Framer 1 WBP	Framer 2 OP	Framer 2 WBP	Helper 1/ Framer 3 OP	Helper 1/ Framer 3 WBP	Helper 2 OP	Helper 2 WBP
	Percent of total time in work category									
Effective	21	41	47	55	38	55		55	32	32
Contributory	41	49	34	32	31	32	1	32	18	56
Waste	39	11	19	13	31	13	99	13	50	12

Note: OP=observed operation; and WBP=with waste-based planning.

Comparative Analysis of Labor Waste

A convenient measure for assessing the effectiveness of minimizing labor waste is productivity ratings. Furthermore, a direct comparison between observed and modified operations, as shown in Table 2, provides an effective tool to show the impact of the simple changes in material staging.

For example, Table 2 epicts that a large portion of unproductive and wasted time is reallocated proportionally among more productive categories of work. In particular, the 28% of the cutter's 39% unproductive time is turned into effective and contributory work. As a consequence, he will spend 41% of this total time on effective, 49% on contributory, and 11% on ineffective work. The job reassignment for Helper 2, supplying lumber pieces to the three framers as well as helping the framers in between (32%), reduces his wasted time from 50 to 12%.

As in any integrated system, changing one system parameter may have a secondary synergistic effect on one of the other components. Test Case 2 exemplifies how a small change provided an opportunity for a drastic improvement.

Test Case 2. Masonry

While bricks and masonry sand have to be ordered and supplied similar to lumber, heavy mortar needs to be batched and transported onto the scaffold. Despite the many lifting technologies available, residential building contractors depend heavily on manual labor for those tasks.

Traditional Brick Staging and Distribution

As can be seen from Fig. 2, mason's helpers were observed throwing brick onto the scaffold and using wheelbarrows and a manual pulley with rope to lift five-gallon buckets of mortar. Similar to Test Case 1, the masonry subcontractor had to transport bricks by wheelbarrow from the point of delivery to the base of the scaffold. One helper would then throw two to three bricks at a time to a second helper standing on the scaffold. This represents not only an unsafe method but it is also very demanding ergonomically. Hence, helpers were forced to continually lift, carry, and push the heavy material, especially the mortar associated with increases in back injuries (Krizan et al. 1993; Goldsheyder 2000). With the goal to address this potentially wasteful operation, a technical solution was considered that would not only eliminate the safety problems, but satisfy the constraints of contractors who do not want to have expenses for large equipment.

Innovative Material Handling Technology

Fig. 6 depicts a two-dimensional (2D) cable crane consisting of two hoist cables connected at their ends but operated by two independent winches A and B. Its design allows objects to be lifted from the ground to any point on the scaffold. Thus if masonry material is staged anywhere along the footprint of the 2D plane, the system is able to pick up brick directly from the stockpile and deliver them to the where the mason is working. The same holds true if the mortar mixer is placed within the reach of the crane hook. In order to address the questions related to the productivity of this crane system, experimental tests were conducted. The design and outcome of the laboratory experiments will be discussed in the following section.

Experimental Productivity Assessment

Key variables that were considered in the experiments were: (1) Height, (2) horizontal location on the scaffold, and (3) type of brick carrying mechanism. The following section will present three lifting attachments that were tested.

Brick Tongs [Fig. 7(a)]. The brick tongs allowed eight bricks to be lifted directly from the stockpile and released onto the ma-

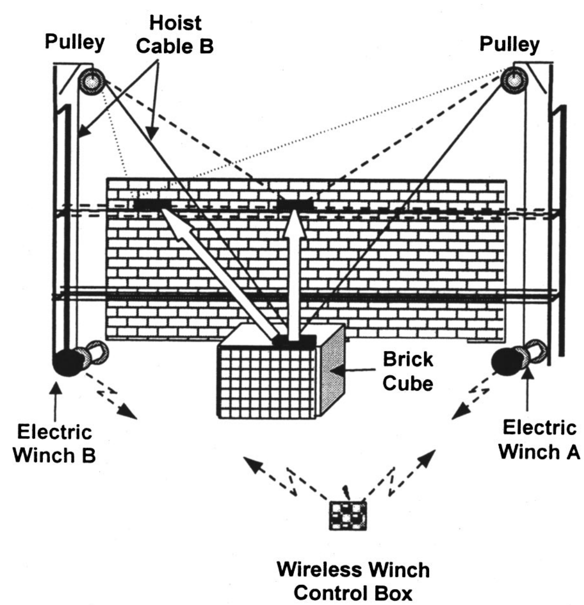

Fig. 6. Schematic of two-dimensional crane system for masonry work

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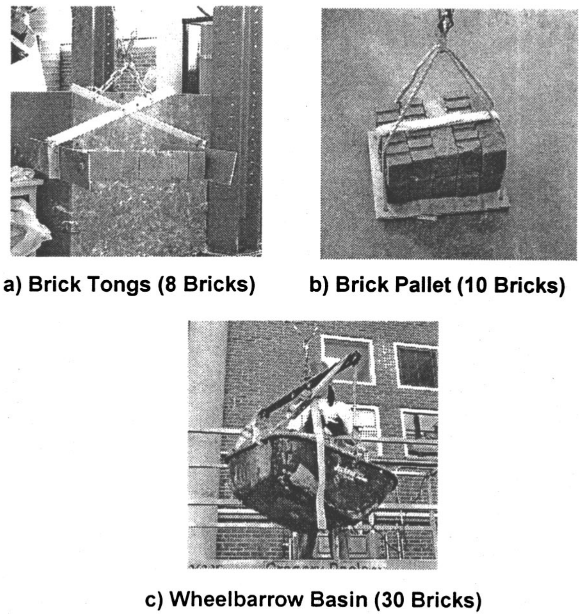

Fig. 7. Lifting attachments used for experimental tests

son's stack. For safety reasons, a metal plate was placed under the row of brick and attached with velcro.

Brick Pallet [Fig. 7(b)]. A brick pallet was made of plywood and ropes just large enough to safely hold ten bricks. As with the brick tongs, a velcro strap wrapped around the brick prevented any accidental drops.

Wheelbarrow Basin [Fig. 7(c)]. The wheelbarrow basin lifted 30 bricks at a time. A spreader bar was attached with straps to the basin which allows for the maximum number of bricks to be lifted at one time. However, it required manual loading and unloading like the brick pallet.

Bricks were lifted to the center, 6 ft (1.83 m) to the left, and 6 ft (1.83 m) to right of center onto small scaffold at heights of 6 ft (1.83 m) and 12 ft (3.67 m). Lifting was repeated at each location from two to six times in order to minimize its randomness and to reduce the learning effect. For each cycle, the time it took to lift a set of bricks to the scaffold level and place them in a stack for the mason's use was measured. The average time for each position was taken and used to calculate productivity using the following equation:

$$\text{Productivity}\left(\frac{\text{brick}}{\text{man hour}}\right) = \frac{\text{No. of bricks lifted}}{\text{time(man s)}}\left(\frac{3{,}600 \text{ man s}}{1 \text{ man h}}\right) \tag{1}$$

Table 3 presents the productivities for each position and lifting device.

Qualitative Outcome of the Experiments. As expected, an increase in height resulted in a lower number of hoisting cycles per hour, from 22 to 16 and 32 to 28, respectively, and productivity of delivery. The significant increase in the number of cycles per hour when lifting with the pallet (32 cycles) instead of the tongs (22 cycles) was unexpected. It is the drastic effect of the problem associated with securing the brick to the tongs after they have been lifted off the stack. The time it took to attach the plate to the clamp was rather long, and did not outweigh the advantage of not having to handle the bricks by hand. It is also very easily understood that by having an entire stack of cheap and reusable pallets to create "prepackaged" bricks to be hooked up, the productivity of this solution could be further boosted.

Table 3. Productivity Comparison in Bricks/Person/h

Supply location	Left	Center	Right	Average
Brick tongs (eight bricks)				
6 ft. (1.83 m)	179	209	159	**182** (22)
12 ft (3.67 m)	116	132	139	**129** (16)
Brick pallet (ten bricks)				
6 ft (1.83 m)	327	350	289	**322** (32)
12 ft (3.67 m)	280	288	269	**279** (28)
Wheelbarrow basin (30 bricks)				
6 ft (1.83 m)		861		**861** (29)
Field observations				
6 ft (1.83 m)				**361**
12 ft (3.67 m)				**374**
RSMeans (2001)				
				186

The special configuration of the 2D crane, caused by the horizontal force component in Cables A and B, will result in forces that reach way beyond the weight of the material thus requiring a far greater capacity of the geared winch motors as the loads they have to lift. This fact was discovered during the experiment of the wheelbarrow basin. Because of the limitation of the winch, only the center position for the lower height was tested. Still, the productivity of the wheelbarrow basin was averaged at 861 bricks/man h at the this height with an average of 29 cycles/h. By interpolating the number of cycles to 25, a productivity of 750 bricks/man h for a 12 ft (3.67 m) height results.

Quantitative Results

The observed productivity for brick supply was based on the average time it took one helper to move brick from the staging point (30 ft away) to the scaffold, using a wheelbarrow, and to toss brick by brick to another helper standing on the scaffold at the mason's level (see Fig. 2). As shown in Table 3, this traditional delivery method is approximately equivalent to delivering the bricks with the help of a pallet holding 10–12 bricks. Even though it was the prevalent method on the sites visited, tossing brick is not a safe practice.

While not categorized by scaffold height, the average productivity rate shown in Means Residential Construction Cost Works (RSMeans 2001) is approximately 50% of the average observed in the field. This discrepancy is consistent with other observations where lower productivity might be related to a safer operation.

Overall, the experimental comparison of different concepts for the vertical delivery of bricks to the masons on the scaffold demonstrated that the achievable productivity will meet but most probably surpass such rates measured in the field. Still, the key benefit of the innovation is undoubtedly the ergonomics, because the laborers no longer have to lift, twist, and toss. In addition, placing the mortar mixer in line with the footprint of the crane adds the opportunity to deliver mortar in the same manner.

Summary and Conclusions

This paper introduces a process- or site-oriented approach that defines the minimization of resource waste as its key objective.

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Contrary to traditional management which focuses on setting and meeting targets (i.e., schedule, budget, etc.), waste-based management emphasizes the importance of an ongoing continuous effort that includes everyone who is in any way involved in planning, controlling, and executing the work. A survey of local building experts to prioritize critical factors that influence productivity of residential construction found that planning, control, and communication were considered the most important factors. By extending the concept of process planning and combining it with the I/O production model, an aggregated process model has been developed that provides the theoretical underpinning for a WBPC system. It expands the idea of waste-based construction management by including all process inputs as potential sources of waste.

The effectiveness of WBPC as a concept to minimize resource waste was assessed using two test cases in residential building. The driving impetus of the analysis was the question of whether the purposed proactive planning concept would result in any improvements. The study was done by comparing productivity of: (1) The observed field operations, with (2) a "lean" operation where resource wastes were minimized by "proactive planning/preventive control" or by "reactive planning/corrective control."

The result of the comparative evaluation of the wall-framing operation, one of the two test cases, showed that WBPC improves crew productivity by 75%. Masonry construction, the second test case, highlighted the drastic impact of process-oriented staging of brick and mortar. By staging masonry material close to the scaffolding, the need for carrying and rehandling bricks and mortar is eliminated. Staging material with its final use in mind opened the door for an innovative lifting technology allowing supplies to be "craned" directly from the staging area using a simple cable system.

The paper highlights the potential impact of shifting the present management focus in construction away from meeting "far-away" targets to focusing on what can be done "now" to minimize process waste by every individual in the organization. It is argued that the proposed paradigm shift would indeed allow the industry to achieve those large productivity gains it has been seeking for a long time.

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