Submitted for review to IGLC-9, Singapore

INTEGRATED PRODUCT-PROCESS DEVELOPMENT BY A LIGHT FIXTURE MANUFACTURER

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ABSTRACT

This paper describes a brand of indirect light fixtures, developed by a process-oriented manufacturer whose product development efforts have supported supply-chain performance. To help explain the relationship between product and process design, the paper outlines the light-fixture supply chain with several key stakeholders and handoffs. The manufacturer's choices are then viewed from the perspective of meeting requirements and creating value for customers, namely owners, designers, and electrical contractors.

Electrical contractors have found this manufacturer's short lead times, delivery reliability, and installation ease to be valuable in planning and executing work. Owners who select this manufacturer's products appreciate the low total-installed-cost and the lead times that contribute to shortening the overall project schedule. The manufacturer's strategic materials selection, outsourcing decisions, and modular design, supporting a commitment to a 10-day lead time for standard products, provide good examples of work-structuring contributions towards the implementation of a lean project delivery system.

KEY WORDS

lean construction, work structuring, product design, process design, operations design, methods analysis, indirect lighting, light fixture, electrical contractor, supply chain management, value, waste

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INTRODUCTION

Two common means of illuminating office space are direct lighting and indirect lighting. Direct parabolic lighting (Figure 1) is often installed into a suspended ceiling grid and shines light directly into the room. Indirect lighting (Figures 2 and 3) is suspended from the ceiling and shines light up against the ceiling and the walls so that reflected light illuminates the room. Hedge et al. (1995) showed that workers more favorably rated indirect lighting on many subjective lighting impression scales. Approximately two-thirds of the surveyed workers preferred working under indirect light. Indirect light results in less glare on computer screens so workers have fewer problems with eyes getting tired or focusing. Nevertheless, parabolic lighting was the norm until 15-20 years ago and only in recent years has indirect lighting been gaining significant market share. Demand for indirect lighting has increased because computers, and thus glare problems, became ubiquitous.

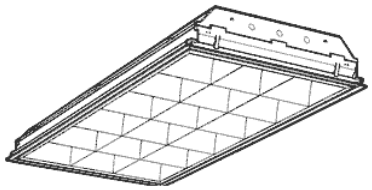

Figure 1: Direct Parabolic Light Fixture (Williams 2001)

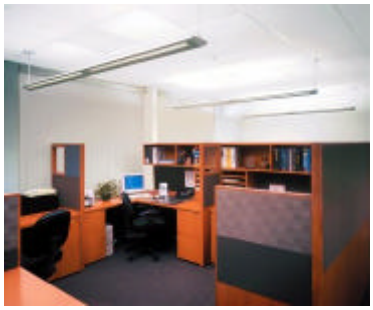

Figure 2: Indirect Light Fixture (Linear Lighting 2001)

Figure 3: Indirect Light Fixtures Installed (Finelite 2001)

This paper focuses specifically on products made by one manufacturer of indirect lighting. Finelite, founded in 1991, is a relative newcomer in the market who set out to deliver an indirect lighting product that would compete with parabolics. The company has aligned its product design to better support process design in order to meet the requirements of its customers. It worked to develop fixtures that give better lighting, are easier to lay out and install, ship in 10 working days, and are competitively priced on a total-installed-cost (TIC) basis (Finelite 2000).

LIGHTING SUPPLY CHAIN

In the United States, many parties make up the lighting supply chain. Figure 4 illustrates the major players in this case study, their contractual relationships, site access during construction and after turnover, communication beyond contractual relationships, and flows of goods.

CONSTRUCTION CONTRACTS

Typically, an owner assigns the architect the task of developing the project, including lighting plans and specifications. The architect, in turn, may contract with lighting designers and interior designers to assist with different components of the design. The owner may provide design criteria based on its own needs or that of future tenants. The owner then contracts with the general contractor to be in charge of the entire construction process. The general contractor, in

turn, will hold contracts with numerous specialty contractors, including the electrical contractor who is to procure and install the fixtures.

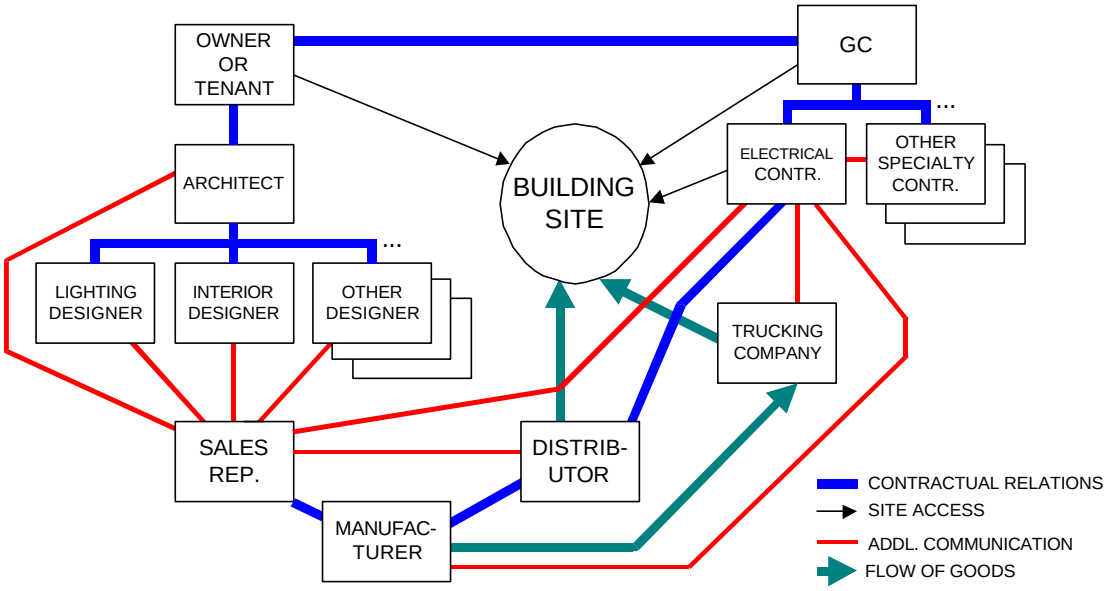

Figure 4: Lighting Supply Chain

FLOWS OF INFORMATION

The architect develops the basic lighting scheme by deciding which fixtures to use and where they should be located to fit in with the rest of the building. The lighting designers then calculate the illumination levels by doing point-by-point calculations based upon photometric data provided by the manufacturer and using architectural backgrounds. Sales representatives will often assist with this step, and possibly even perform it at no cost to the designer. If areas are too bright or dark, the lighting designer must adjust the fixtures and their locations to satisfy the lighting requirements. Once the design is set, it is passed back to the architect. The architect then incorporates the lighting design into the electrical design.

Should the products of a specific fixture manufacturer be named in the design, the contract for supplying that product will most likely go to that manufacturer because it is difficult to make substitutions. Consequently, manufacturer sales representatives stay in constant communication with designers to persuade them to specify the manufacturers they represent. In some cases, representatives assist designers with point-by-point illumination calculations. Meanwhile, representatives keep tabs on the manufacturers' capacities as well as any new products being planned, which can be marketed to designers. Sales representatives will also be in touch with electrical contractors because contractors solicit bids for supplying materials.

Electrical contractors often get distributors to supply the materials that cover the entire scope of the electrical design. Distributors generally have a better financial credit line and more clout with the manufacturers than contractors do. Once the electrical contractor picks an electrical distributor to supply the lighting materials, the contractor will issue purchase orders directly to the distributor. As a result, the sales representatives must go through the distributor to find out what the status is of purchase orders, and they are keen on seeing orders as the manufacturer pays them on that basis. Once a purchase order is issued, the manufacturer works with the

contractor to review the architect's design drawings and obtain manufacturer shop drawing approval. Upon approval, the manufacturer will withdraw fixtures from inventory or produce them to order and then arrange for delivery to the electrical contractor, usually by shipping directly to the site. Because of product variety, needed customization, and cost, distributors seldom keep fixtures in inventory, so they hold contracts with manufacturers to supply fixtures. Should the electrical contractor have any difficulty with the fixtures, they can contact the sales representative or the manufacturer, depending on the agreement.

FLOWS OF GOODS

After producing the light fixtures, the manufacturer will pass the fixtures to a trucking company for delivery of the fixtures to the electrical contractor at the building site. If the electrical contractor has access to the location(s) where fixtures will be installed, fixtures may be staged there and require only a single step of re-handling for installation.

CUSTOMER REQUIREMENTS

Light fixture manufacturers have three primary customers: owners, designers, and electrical contractors. Owners are important to manufacturers because their requirements greatly influence how designers select light fixtures. Once the lighting design is complete, owners can also authorize changes if they feel adjustments are worthwhile. Designers are important to manufacturers because they recommend choices to the owner and they ultimately specify what fixtures will be used in a building. Electrical contactors are important to manufacturers because they procure and install the fixtures, and thus control how the fixtures are prepared for end use. If an electrical contractor's installation has quality defects, the product may develop a bad reputation, even though the product shipped by the manufacturer may have been good. Designers are then likely to make a different choice on future products to avoid repeat problems.

Each customer has different and sometimes conflicting goals, requirements, and appreciation of value for the fixtures. To name but a few, depending on the nature of the building, owners want fixtures that are inexpensive (or perhaps expensive to show prestige), blend into the interior design (or perhaps stand out as a highlight), are easy to maintain, and can be obtained without delaying the project. Designers select fixtures based on architectural qualities, performance (e.g., the quality of the light and energy consumption), life-cycle issues (e.g., maintenance needs and durability), and cost. Electrical contractors prefer fixtures that are easy, quick, and safe to install. They value timely and reliable delivery, and they appreciate packaging that prevents breakage during handling.

FIXTURE FEATURES THAT CREATE CUSTOMER VALUE

This light fixture manufacturer's products clearly reflect an effort to integrate product and process design considerations. Selected features of this manufacturer's light fixtures are described next, to show how they provide value to customers throughout the supply chain. Additional features are described in Finelite (2000).

1. 10-Day Lead Time

The manufacturer promises to deliver its standard products to site with a 10-day lead time from receipt of the contractor's release order, following the approval of shop drawings. A short lead time is especially useful for quick projects, such as 2-3 month tenant improvement projects,

where competing manufacturer's lead times may even exceed the project duration. Competing manufacturers may take on the order of 4 weeks to deliver products.

To achieve this lead time, the manufacturer analyzed what functions were best done in-house as opposed to outsourced (Venkatesan 1992). The company now outsources the cutting, rolling, punching, and painting of the fixtures components, and performs final assembly and wiring in its facilities. These last two steps do not take very long, and wiring must always be done to order (wiring is a function of how many and where switches are located in a room). Thus the manufacturer postpones the customization of its products (Feitzinger and Lee 1997, Signorelli and Heskett 1984) and manages raw materials inventory in "vanilla box" configurations (Lee 2000).

This dependable lead time helps to make the work flow reliable for electrical contractors. It allows them to better synchronize deliveries with installation tasks. In terms of scheduling work, they can 'pull' fixtures from the manufacturer in a time frame that falls within their 4-to-6-week lookahead planning window. The short lead time also helps electrical contractors reduce laydown space and double handling because they can plan to store the fixtures on the building site for shorter amounts of time. Furthermore, reliable deliveries help electrical contractors to install fixtures as planned (rather than doing out-of-sequence work due to limited materials availability), resulting in shorter cycle times.

The manufacturer's main facility is located in the San Francisco Bay Area. In order to handle increasing sales and maintain the 10-day lead time for East Coast orders, it opened an additional manufacturing facility in Pennsylvania in June 2000.

2. Rolled Steel Instead of Extruded Aluminum

Traditionally, indirect light fixtures have been made from extruded aluminum, an expensive material. These fixtures therefore developed a reputation for being a luxury item and were reserved to light important spaces such as conference rooms. Light fixtures made of rolled steel were newcomers to the market. Steel is a significantly less expensive alternative: it costs one-third the cost of aluminum. Since it is stronger, less steel is required to provide the same structural support. As a result, some architects perceived it to be inferior in quality by comparison and preferred specifying extruded aluminum fixtures.

A challenge in cold-forming steel is achieving the high tolerance required of light fixtures, as parts must fit without allowing light to stray, but the process of changing sheet steel into a finished fixture body is faster and more flexible than the process involving extruded aluminum. Steel is more readily available and several vendors can roll, bend, punch, and paint it. Other manufacturers need to procure raw materials from aluminum extruders. Since extrusion profiles are expensive and take a long time to make, those manufacturers must contract with a limited number of extruders that work with their profiles.

After having decided to use cold-formed steel, the manufacturer focused on finding means to prepare and paint it so that it would resemble extruded aluminum. It then had to convince architects that its products only looked the same as extruded aluminum, in addition to being aesthetically attractive and performing similarly as well in terms of illuminating a space.

The manufacturer's use of cold-formed steel helps to achieve reliable work flow because its raw materials procurement effort does not contain as many uncertainties and long lead items as that of its competitors. The manufacturer can 'pull' its raw materials when it is ready to fill orders, so it can achieve shorter cycle times.

3. Integer Lengths

When the manufacturer entered the indirect lighting market, competitors provided light fixtures that were not exact integers in length. The lamps used in office fixtures are 4' (1.2 m) long, so most fixtures were slightly larger[4]. This made it difficult to install fixtures on 4-foot modular ceiling grid T-bars. Electrical contractors would have to drill holes through the ceiling grid in order to install the fixtures. To improve the installation process for electrical contractors, the manufacturer developed fixtures that are exactly 4'-0" or multiples in length, made within a tolerance of 0.005" (0.1 mm), to match the ceiling grid and thereby improve the installation process. With modular fixture lengths, contractors do not need to measure and mark installation locations. Rather, they can count ceiling grid T-bars to determine where the fixtures will go. Accordingly, no labor or equipment is wasted on measuring, and installation can proceed quickly thus reducing the cycle time.

4. Pre-Wiring

Light fixtures often require custom wiring. Wiring is typically done by the electrical contractor based on the wiring diagram for each room. To help reduce the time electrical contractors spend on wiring, the manufacturer pre-wires light fixtures. For each run of light fixtures, the manufacturer has a system of starters, joiners, enders, and independents. Starters are the fixtures that connect directly to the electrical source. Enders are the fixtures that conclude a run of light fixtures. Joiners are any fixtures that fit in between starters and enders. Independents are light fixtures that are not connected to any other fixtures. The wiring of a light fixture establishes it as a starter, joiner, ender, or independent.

The manufacturer secures wires inside the fixture using a channel. Pre-wiring by the manufacturer moves work from electricians to shop workers. Shop work costs less than on-site work, and shop workers are able to achieve better quality control since they are not subjected to interference by other trades and they work in a factory environment. Since fixtures are pre-wired, work flow on the building site is more reliable as the electricians do not have to do this work anymore, except at the power feed locations.

5. Mated Plugs and Joining

The manufacturer developed mated plugs and die-formed interlocking parts so that the electrical contractor can quickly and easily connect light fixtures to each other, thereby reducing on-site labor normally spent on stripping wires and connecting them from one fixture to the next. This makes connecting fixtures much faster and much more reliable, and thus reduces installation cycle time. With 0.005" (0.1 mm) tolerance for its joiner pieces, the manufacturer is able to prevent light from leaking through the joints and make the seams almost invisible. The procedure of connecting starter, joiners, and enders while sharing the same power feed allows for long runs (in 4-foot increments) of indirect light fixtures to uniformly illuminate practically any length of indoor space.

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[4] The newer, high-efficiency T5 lamps, are shorter in length. When they came on the market in the US a few years ago, competing manufacturers could easily develop fixtures to match the ceiling grid.

6. Mounting System

To further take advantage of modular lengths, the manufacturer developed a mounting system that attaches directly to the ceiling grid T-bars. Electrical contractors now can install fixtures before the ceiling tiles are brought in, which improves installation flexibility. In addition, the ability to mount the clips at any location on a T-bar gives contractors more leeway to properly align the fixtures during installation. Use of the clips in effect de-coupled the electrical contractors' work from ceiling tile installation. Contractors no longer have to wait for the ceiling tiles to be installed and they no longer have to drill any holes in ceiling tiles. In addition, it takes only 5 minutes to install a mounting clip. The manufacturer has thus eliminated labor time wasted on drilling holes and reduced the cycle time in the process.

The mounting system is designed so that ceiling tiles lay flat when placed over the mounting clips, whereas some other manufacturer's clips result in tilted tiles. The mounting system also allows the ceiling tiles to remain removable for maintenance or replacement efforts in the future.

7. Hanging Support Package

The manufacturer has developed a hanging support package for fixtures that must be installed in open ceilings. An open ceiling is considered to be an 'unknown site condition' because there is no ceiling grid that could be used as a reference point for hanging fixtures. The hanging support package contains cables and accompanying parts. Cables come in 8 standard lengths in from 6" up to 150" (15 cm up to 380 cm) and they are delivered in bags of 100 for faster count verification. These cables need to be pre-cut because they end on one side with a safety crimp that needs to be attached with a high-tonnage press. Due to the unknown site conditions, electrical contractors need to order one of the standard lengths and then cut the cables to the appropriate length on site. For example, there may be a fire sprinkler in the way that requires additional cable length to maneuver around.

8. Leveling

Leveling of indirect light fixtures, which comprise a linear series of connected fixture pieces (Figure 3), is not an easy task. Electrical contractors attach hanging cables to the fixtures and twist the cables to level the fixture in order to get each one aligned correctly before attaching the next connecting fixture. Once the fixture is leveled, a top lock nut is used at the end to hold the cable in tightly. A typical procedure for a fixture installer is to suspend the first fixture, level both ends, attach the second fixture, level the free end, and then level the connected end. This system provides a quick technique for leveling, capable of achieving 0.5" (about 1 cm) tolerance. The leveling system allows electrical contractors to quickly adjust the suspension heights of the fixtures should last-minute design changes or other causes make that necessary.

9. Pre-lamping

Many parabolic fixtures and competing indirect light fixtures require the installation of lamps on the building site. The manufacturer has developed fixture body and packaging designs that allow fixtures to ship pre-lamped from the manufacturing shop. Pre-lamping is optional and costs extra, but many electrical contractors prefer it because it reduces installation cycle time. Pre-lamping eliminates the effort required for storing and handling lamps on site. It transfers the task of lamp installation from electricians to factory workers who work more efficiently at table height, in a safer environment, and at a lower pay scale. This frees up site space and time for electricians. The manufacturer wraps plastic around the lamped fixture to keep it clean during

construction, so that the lights can be used during construction. This assumes that owners will not object to lights having been used prior to building occupancy. We have anecdotal evidence of an owner demanding that 'used' lights be replaced at turnover!

10. Packaging, Palletizing, and Sequencing

The manufacturer developed new packaging using cardboard or styrofoam boxes to minimize breakage and to allow for stacking and palletizing of its fixtures. Using this packaging, fixtures can be transported and re-handled with a very low rate of breakage (no data is available on delivered fixtures that are defective). Palletizing removes the need to manually re-handle each individual light fixture. These boxes can be reused once the fixtures have been installed. Electrical contractors may return the boxes by stacking them on the manufacturer's pallets and then moving the pallets to a loading area for the manufacturer to pick up on its own. Most electrical contractors do not ask to be reimbursed for the time it takes to collect and prepare the used packaging because the effort required is minimal and recycling also help them dispose of waste. This system works well for repeated deliveries (delivery truck returns with empty packaging) and in areas where the manufacturer has several projects going on at the same time.

For electrical contractors who plan with greater reliability, the manufacturer can package light fixtures onto pallets to match certain installation sequences. This requires that contractors plan in more detail and longer in advance than is common, and also assumes that a given sequence will not be impeded by trade interference or other project uncertainties. Similarly, Bernold and Salim (1993) showed that rebar can be micro-bundled ahead of time by the steel supplier to match site use plans.

Electrical contractors have found that palletized indirect light fixtures reduce the handling required to move the pallets into place. In addition, the styrofoam packaging allows electrical contractors to easily remove individual fixtures from the middle or bottom of a stack. This gives electrical contractors greater flexibility when they install light fixtures, should advance sequencing not be feasible or unreliable. There is no difference in cost in ordering styrofoam or cardboard packaging. If they do not anticipate installing the fixtures for 4 to 6 months, electrical contractors might prefer cardboard packaging to protect the fixtures from construction debris.

In reviewing these product and product-support features, it is apparent that much of this manufacturer's efforts have focused on improving delivery time and delivery time reliability. Ensuring delivery time reliability is crucial to help downstream processes proceed as planned.

WORK STRUCTURING

Work structuring is the effort to develop a project's process design while trying to align engineering design, supply chain, resource allocation, and assembly efforts (Tsao et al. 2000). It considers how to develop a product and process design that best meets the owner's needs. Work structuring questions whether or not certain work chunks are necessary. If a work chunk is necessary, then it determines who would be best prepared to take care of executing that work chunk. In this case, the manufacturer identified a short lead time as something that owners value. As a result, it worked to align its product features to support a shorter lead time.

The manufacturer also recognized the need to provide value to the electrical contractors that install its fixtures. Electrical contractors value simpler and quicker installation procedures. Consequently, the manufacturer strived to develop features that make it easier and quicker to install. In spite of these achievements, it is up to electrical contractors to take full advantage of the manufacturer's capabilities (e.g., palletizing fixtures based on installation sequence).

Although some of the tasks that the manufacturer performs (e.g., pre-wiring, mated plugs and joining, pre-lamping) actually take away work normally performed by electricians (Howell et al. 1993), electrical contractors profit from the added markup on fixture procurement and from the reduced labor risk. The manufacturer's fixtures cost more to procure, but they cost less to install. The TIC of the fixtures is therefore competitive with the TIC of parabolic fixtures (Finelite 2000).

Whether or not contractors will continue to handle the procurement function, the coordination risk between installation and delivery will remain, though it becomes smaller thanks to the manufacturer's short lead time and high reliability of deliveries.

The manufacturer takes 6 to 12 months to develop and introduce new product families. This duration is driven in part by development capabilities, but much more by market opportunities. By choosing not to compete in the 100% custom lighting market, the manufacturer has been able to create a production system that strongly competes based on other value elements.

CONCLUSIONS

This paper has presented the outcome of an integrated product- and process-development effort implemented by a light-fixture manufacturer. It has described selected product features that lead to improved supply chain performance and increased customer value. The manufacturer's combined product and process design, specifically its outsourcing decisions, commitment to a 10-day lead time for standard products, and modularized design, reflect work structuring. It is through product-process design integration that lean project delivery can be achieved.

ACKNOWLEDGMENTS

This research was funded by grant SBR-9811052 from the National Science Foundation, whose support is gratefully acknowledged. Any opinions, findings, conclusions, or recommendations expressed in this report are those of the authors and do not necessarily reflect the views of the National Science Foundation.

The authors would also like to thank Terry Clark and Darrin Stone of Finelite, Jim Elder of Associated Lighting Representatives (ALR), Allen Reaves of Shaper Lighting, Bob Stokes of Taylor/Stokes Lighting, Peter Ngai, Angela Lawrence, and Steve Odom of Peerless Lighting, Lilian Rodriguez of Horton Lees Brogden Lighting Design, David Malman of Architectural Lighting Design, and Mike Jurewicz, Steve Harvey, Victor Garcia, Frank Thomas, Wayne Wood, Eric Sullivan, B.J. Hanahcy, and Sotame Niualiku of Frank Electric for their help with our study of product and process development of light fixtures.

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