JUST-IN-TIME CONCRETE DELIVERY: MAPPING ALTERNATIVES FOR VERTICAL SUPPLY CHAIN INTEGRATION

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ABSTRACT

This paper explains concepts underlying a just-in-time production system. Just-in-time production systems as implemented by Toyota are pull systems in which 'kanban' convey the need to replenish the right inventory at the right time and in the right amount. In this paper, symbols from manufacturing are introduced to map resource flows in order to help distinguish traditional- from lean production processes. These symbols are then applied to construction. Ready-mix concrete provides a prototypical example of a just-in-time construction process. Ready-mix concrete is a perishable commodity, batched to specifications upon customer demand. This makes just-in-time delivery necessary. Based on data from industry case studies, alternative forms of vertical supply chain integration were investigated. The most common one is where the batch plant also delivers the mix to the contractor's project site. An alternative is for the contractor to haul the mix from the batch plant to the project site with their own revolving-drum trucks. One alternative is favored over the other depending on the amount of control the contractor wants in terms of on-time site delivery of concrete and the variability in the contractor's demand for concrete project after project. Insights can be gained from these two examples on how the construction industry has adopted a just-in-time production system for at least one part of the concrete supply chain. The examples provided will help the reader think through issues pertaining to the need for having information, materials, and time buffers at strategic locations in construction processes.

KEY WORDS

Supply-chain mapping, vertical supply-chain integration, ready-mix concrete, pull-driven scheduling, just in time, JIT, kanban, lean construction.

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INTRODUCTION

The term 'Just-In-Time' (JIT), used for instance to describe the delivery of materials to a construction site, suggests that materials will be brought to their location for final installation and be installed immediately upon arrival without incurring any delay due to storage in a laydown or staging area. JIT is a concept developed by the Japanese who created the Toyota Production System, later translated into English as the lean production system. The ultimate objective of JIT production is to supply the right materials at the right time and in the right amount at every step in the process.

Toyota achieves JIT production by implementing a pull system using 'kanban,' loosely translated from Japanese as 'cards.' Kanban are designed to prevent overproduction and ensure that parts are drawn from process to process, in reverse order. They thus implement a replenishment system designed to control production quantities. Parts are taken and replenished only when needed and in the right amount.

Instead of using special-purpose kanban, one can take advantage of reusable packaging means (such as containers, racks, or pallets) that are color coded and sized to designate a specific material. Leaving the empty packaging for the supplier to pick up from an agreed-upon location then implies a request to replenish with product of the same quantity and type[3]. This system obviates the need for any oral or written communication.

The pull of product from upstream is illustrated by means of a **withdrawal kanban** as shown in Figure 1. The **customer process** withdraws parts from a **supermarket**, which is a place of limited capacity for storing product that is output by the **supplying process**. The supermarket gets replenished by issuing a **production kanban** when inventory is too low. The production kanban thereby instructs the supplying process to produce more product. The supplying process produces only enough product to replace what was withdrawn. This method prevents overproduction but allows a tightly-bound inventory to build up between the supplying and the customer process (for more detail, see Hopp and Spearman 1996 and Rother and Shook 1998).

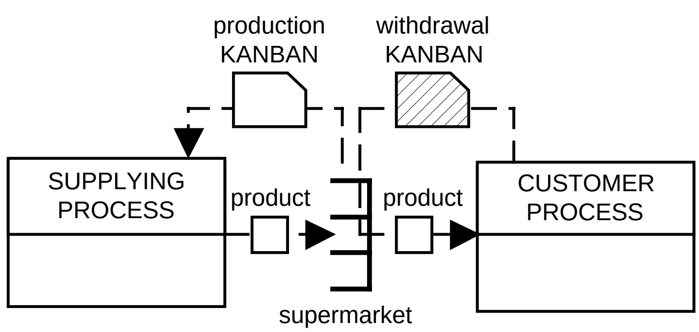

Figure 1: Kanban System (after Rother and Shook 1998 p. 42)

3 An example of a pull system like this one used to be the daily milk run! Kanban has jokingly been referred to as 'milk-run logistics.'

In a more general sense, a pull system may comprise a feedback mechanism for a station downstream to notify a station upstream that more product is needed. Product then is fabricated and shipped to meet this specific need. The alternative is to produce product in anticipation of a need, i.e., based on a forecast need, as is the case in push systems. Tommelein (1997, 1998) compared and contrasted the delivery and installation of pipe spool at a construction site subject to various uncertainties using pull- and push-driven scheduling methods. Push systems tend to increase the amount of waste (e.g., long wait times, excessively large inventories) because they are estimate driven and include fudge factors to compensate for anticipated uncertainty. Uncertainty may or may not manifest itself during project execution. When it does, push systems have no means to adapt to changing system requirements whereas pull systems do.

In this paper, the batching and delivery of ready-mix concrete are used to illustrate a pull system. Ready-mix concrete is a prototypical example of a batch process, where a customer process (the contractor) releases an order to batch to the supplying process (the batch plant) and receives product as a result (Figure 2). This batch process does not allow any inventory of product to be maintained because the product is perishable.

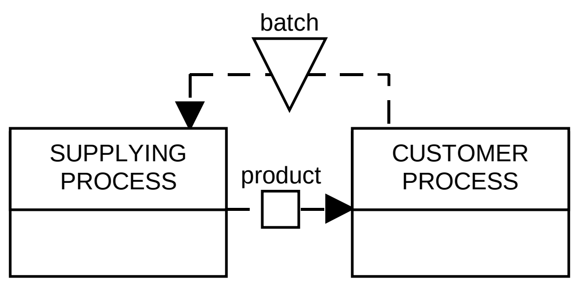

Figure 2: Concrete Batching Process

To investigate industry practice in more detail, we collected data describing the operation of a ready mix plant. Ready mix plants serve their customers not only by mixing but also by transporting concrete and delivering it to the location for placement on site. We illustrate this example by using value stream mapping symbols that have been used for some time to describe alternative states of manufacturing facilities and to identify opportunities for making their processes leaner (Rother and Shook 1998). For comparison, we also interviewed a contractor specialized in placing concrete for road repair who acquired his own revolving-drum trucks to transport concrete to his projects. These two examples illustrate alternative forms of vertical supply chain integration. They differ in who owns and therefore controls the scheduling of ready mix trucks. One alternative is favored over the other depending on the amount of control the contractor wants in terms of on-time site delivery of concrete and the variability in the contractor's demand for concrete project after project.

READY-MIX CONCRETE

Concrete is a very common construction material. Projects ranging from a single family home to a high-rise building all may need concrete for their foundation, slabs, columns, beams, walls, etc. to be constructed. In urban settings, the task of delivering concrete more often than not has been delegated to ready-mix batch plants and contractors have to rely on the timing and reliability of their service. Although this set-up puts the contractor's project somewhat at the mercy of the batch plant, most batch plants perform at their very best to meet their customers' schedules. On-time delivery is part of the product they sell.

The interplay between contractors and batch plants is interesting. On one hand, the contractor must order a large enough quantity, sufficiently long ahead of time to ensure available batch plant capacity and timely delivery service in order to maximize productivity of their placing crew. On the other hand, the batch plant tries to time its deliveries so that all projects are served according to the contractors' needs and the plant as well as the trucks and drivers have little idle time. This balancing act between the two parties is not always achieved due to the nature of concrete and the nature of the production systems being used.

In addition to contractors and batch plants, this balancing act also involves the suppliers of raw materials to the batch plant, crews on site that erect formwork and tie reinforcing bars in preparation for concrete placement, as well as others. Although the interdependence of all these parties typically results in uncertainties rippling through the supply chain, the focus of this paper is limited to the downstream-, namely the contractor vs. batch plant relationship.

NATURE OF CONCRETE

Although batching and delivering concrete are common tasks, they are driven by many material-specific considerations.

- **Concrete is a Perishable Material:** Concrete consists of coarse aggregates, fine aggregates, cement, and water, plus admixtures if specified. Aggregates, cement, and admixtures separately can be stored for long periods of time. Concrete itself, though, is a perishable material. Once water has been added to the mix of dry materials, concrete only has a mere hour and a half or so (unless retarders are used) before the hydration process will form a gel that, if disrupted, would jeopardize the ultimate strength of the concrete. Hence, fresh concrete leaves little room for variability in terms of time for delivery and placement after water has been added.
- **Concrete is a Custom Specified Material:** Designers, usually civil/structural engineers, performing the structural calculations for a project determine the strength and other quality requirements for concrete. They may specify a concrete mix design or performance and then leave it up to the batch plant to propose a design that meets the specifications. Different mixes may be needed in different quantities on a single project because of different uses for the concrete (e.g., shear wall vs. foundation slab) and a priming mix is needed prior to pumping. Not all projects require a uniquely designed mix, however. Standard mixes are specified for instance by government agencies for public works such as sidewalk and road paving. Accordingly, most batch plants have an on-line database with recipes for hundreds if not thousands of mixes that they can load to program their facility. This makes it easy not only to add new mixes or find those that meet an engineer's requirements, but also to name them based on customer preferences.
- **Availability of Ingredients:** While finding a suitable mix recipe may be easy, a batch plant may not stock all aggregate types or admixtures in quantity or at all (e.g., color

additives). When given the project specifications, the contractor must recognise when special ingredients are needed and notify the batch plant in a timely manner so that it will have enough lead time to obtain them.

CONCRETE PRODUCTION SYSTEM

The production system for concrete is governed by the plant operator's equipment, the contractor's placement method, and of course, their individual schedules as well as the coordination of those schedules between them.

- **Batch Plants have Limited Capacity:** A batch plant's capacity is determined by either batching capacity or delivery capacity.
- **Batching Capacity:** is determined by the time needed to measure, dispense, and mix ingredients, then load them into a truck. The quantity mixed and thus the batch time is limited by the actual amount needed, the amount a truck can carry (typically 10 yd3), or weight limitations that may be imposed during transportation or on site.

Today's ready-mix batch plants are fully automated and computer controlled so ingredients can be measured and mixed on demand and in virtually no time. This makes it possible to batch one truckload at a time, and load one truck after another with a different mix each time when appropriate.

- **Delivery Capacity:** is determined by the number of trucks and drivers that service the batch plant. Typically, a batch plant may own 25 or 30 or so trucks and the plant operator will try to keep them busy at all times. Batch plants may also load concrete into pickup- or revolving drum trucks owned by a third party.

A plant's batching capacity usually is larger than its delivery capacity. The batch time is on the order of a few minutes. By contrast, the cycle time for a truck, including the load time, may be on the order of 30 minutes up to an hour or two. A quick, deterministic calculation based on a 2-minute load time and 30-minute truck cycle time yields 15 trucks possibly being served by the plant; a 1-hour cycle yields 30 trucks. Because of the significant variability in cycle time, the batch plant will be idle at times when waiting for trucks to return, while trucks will experience 'bunching' at other times when having to line up at the plant.

Trucks as well as the plant itself tie up a lot of capital; they are the fixed cost to the operator. Drivers' and operators' pay, truck operating costs, as well as materials make are the variable cost. A batch plant operator will thus vary the actual number of drivers working on any given day and vary their work hours to meet demand (e.g., for delivery at night or on a weekend day). Delivery thus tends to be the limiting capacity factor.

Other factors affecting plant capacity are availability of materials and space to clean out trucks. However, in normal operating conditions, these will not govern.

- **Demand Fluctuation:** Demand for concrete fluctuates throughout the day, week, and year. Even when the total amount of concrete for a specific placement or a project can be estimated reasonably well, the timing of the needed delivery often remains uncertain because completion of prerequisite work at the site is difficult to forecast reliably and may not be known exactly up until a day or so prior to placement. Schedule uncertainty may pertain to work directly related to concrete placement, but also to work further upstream in the work sequence such as erecting steel and placing decking on which then a rebar mesh is placed and a concrete slab cast. Placing concrete also is subject to unforeseen circumstances such as weather conditions. From the plant's perspective, orders are called in randomly by contractors, so forecasting the actual plant workload for any day is difficult to do.

The main challenge for cost-effectively and reliably batching and placing concrete lies in scheduling. At the time a contractor calls in an order to a batch plant, many unknowns remain to be revealed. How a batch plant and the contractor handle these unknowns can be the determining factor for making or losing money.

- **Placement Size:** Large placements require uninterrupted supply of concrete in order to avoid unplanned construction joints. For instance, joints of any kind would be unthinkable in large foundation mats requiring several thousand cubic yards of concrete. A delivery sequence for uninterrupted supply at a site may require a loaded truck to always be on standby for concrete to be available when the preceding truck has been emptied.

  To achieve the required continuity of delivery, plant and site must communicate in real time to relay when a placement is being delayed and to prevent that trucks would 'bunch' at the site. This communication is to a large extent implemented by means of a pull mechanism: each empty truck that returns to the plant is like a kanban, denoting successful placement and therefore a request for additional batching. If a truck does not return to the plant in a timely fashion, the plant will know it needs to hold off on mixing more concrete for that placement. This pull mechanism may be misleading if a truck encounters road problems on the way back to the plant. To get more accurate, real-time data on truck travel and site conditions, state-of-the-art plants now use geographical information systems (GIS) based on local wireless telephone networks (rather than satellite-based systems).

  Large placements may tie up a considerable number of trucks and thus a plant's capacity. A plant may even have to make arrangements with nearby plants to provide additional capacity or at least a backup in case problems with its production system were to arise.

- **Total Quantity Ordered of a Specific Mix:** Raw materials for the batch plant (aggregates and cement) are typically restocked daily. Extra deliveries can be arranged if the need so dictates. Materials are loaded into computer controlled bins that feed scales, emptying onto conveyor belts that lead to the mixer. Excess sands and gravels may be stored in open-air compartments, often located at the perimeter of the plant and moved with a loader to conveyors that get them into the bins when needed.

  It is conceivable for a plant to run out of materials though this rarely happens. When it does, it is seldom due to a poor replenishment system (most batch plants have close relationships with their upstream suppliers) but rather because of equipment failure.

- **Delivery Cycle and Location:** Since concrete should be placed no later than ninety minutes after the addition of water, travel from the batch plant to a site should not take much more than half an hour or so. A plant's operating radius therefore tends to be limited based on the nature and condition of haul roads.

Depending on the plant's practices, drivers may rinse their vehicle after loading but prior to leaving the plant in order to avoid road spills of any kind. The time a ready-mix truck may sit in traffic during peak hours is a significant consideration when scheduling site deliveries. Time must also be added to the truck cycle to account for finding the site and gaining access to the location for offloading, as well as for testing the mix before placement can start. Whenever possible, the plant operator will try to assign drivers that have been to a specific site to return to that site as their familiarity with getting there may slightly improve cycle time. A significant unknown is when a truck will be released by the contractor and able to depart from the project site. Upon return to the plant, a driver must wash out any remnants in the truck drum prior to taking on another mix. (Routine maintenance of trucks requires that hardened concrete be jack-hammered out of the drum every several weeks).

To buffer against schedule slippage during the day, many batch plants have adopted a system with 2-hour time slots with only a limited number of orders being recorded per slot. They may guarantee on-time delivery only during certain times of the day, e.g., in the early morning provided roads with traffic delays can be avoided.

- **Contractor Ordering and Timing of Delivery:** As noted, the contractor must plan and prepare for the arrival of the concrete. When a contractor calls for a concrete delivery, he needs to be ready to place that concrete once it arrives. However, same day orders for delivery at a specific time can seldom be guaranteed by a plant due to limited delivery capacity.

  On-time delivery of concrete is essential to a contractor. If a truck arrives early, the concrete placement crew may not yet be ready. Trucks are expected to spend some time on site during off loading, but the contractor will be charged for standby time beyond a few minutes per cubic yard delivered. Worse, gelling concrete may lose its window for placement and the entire load may have to be disposed of. If a truck is late, the crew may stand around waiting.

  A typical order lead time is three to four days before the day of the placement so that the plant has time to procure materials, reserve batching capacity, and mobilise drivers and trucks. The sooner the batch plant knows about an order, the more likely that order can be scheduled for delivery as requested.

  Batch plants can fill orders on the spot provided trucks are available and the mix requires no out of the ordinary ingredients. Adding an order to batch in an already busy schedule is relatively easy to do, since batching capacity seldom governs a plant's operation. However, order fulfillment typically is limited by truck availability. Contractor orders may be turned down by the plant in busy times because their concrete delivery schedules cannot be met. For example, many contractors like to place concrete at the end of a week, so that the weekend days during which no other site work is done are used productively for curing concrete. Batch plants therefore tend to be very busy on Fridays, Thursdays, and possibly Saturdays, and less so during other days of the week.
- **Accuracy in Order Quantity:** Accuracy in order quantity is important. Batch plants charge contractors for everything they order. This includes of course the excess concrete remaining in trucks that return to the plant once a placement has been

completed (the plant operators we interviewed estimated they waste about 400 cubic yards a month or 1.6% of their total volume in this way), but also, when no more concrete is needed, the remainder of the same-day order that gets cancelled prior to mixing. The latter cancellations come at an opportunity cost for the plant and compensation is therefore in order. Plants tend to be accommodating, though, if an order gets cancelled at least one day prior to its original timing.

Contractors may thus tend to order a little less than what they actually expect to need and count on being able to get an extra truck on short notice should one be needed in the process of finishing a placement. This requires real-time communication with the batch plant and of course works only if a plant is willing to mobilize quickly and able to deliver such extras. The game is tricky for the contractor as concrete delay may result in difficult bonding between concrete layers. Shortage of concrete will result in unwanted construction joints that may jeopardize strength, water-tightness, appearance, or durability of the concrete.

SYMBOLS FOR VALUE STREAM MAPPING

Special symbols are used in this paper to depict the ready-mix concrete value stream (Rother and Shook 1998). Boxes denote value-adding processes or tasks, such as ordering raw materials, mixing concrete, and transporting a mix to a site. A triangle denotes work in progress or inventory. It represents an accumulation of product (materials or information) possibly of unlimited amount and for an indeterminate duration. An inverted triangle is an order to batch. Kanban (introduced in Figure 1) denote orders to withdraw or produce product, in order to deplete or replenish a supermarket. A supermarket, represented by, refers to controlled inventory in terms of how much material is kept on hand and how replenishment takes place. The FIFO symbol denotes the first-in-first-out release of resources output by a task. The circular arrow denotes a physical pull of materials from a supermarket. It differs from the withdrawal kanban in that it pertains to the amount of product needed at the time of the withdrawal and not necessarily a predetermined fixed quantity. A dashed line with an arrow designates the flow of product. A solid white line is transportation of product to the customer site. A black-and-white dotted line shows that product is pushed into inventory.

MAPPING OF CONCRETE BATCHING AND DELIVERY

We have mapped two cases with their respective processing steps for batching and delivering ready-mix concrete. Four major players (the design engineer, the ready-mix batch plant, the raw material provider, and the contractor) are identified together with the processes they perform. Note that no time line is implied from left to right in any map as processes are cyclical.

CASE 1: INTEGRATION OF BATCHING AND DELIVERY OF CONCRETE

Case 1, depicted in Figure 3, describes the typical, ready-mix batch plant scenario. The batch plant owns a batching facility as well as a fleet of revolving-drum trucks. Based on a schedule with contractor orders, the plant prepares the mix one truckload at a time and then promptly delivers it to the appropriate site for placement of the concrete.

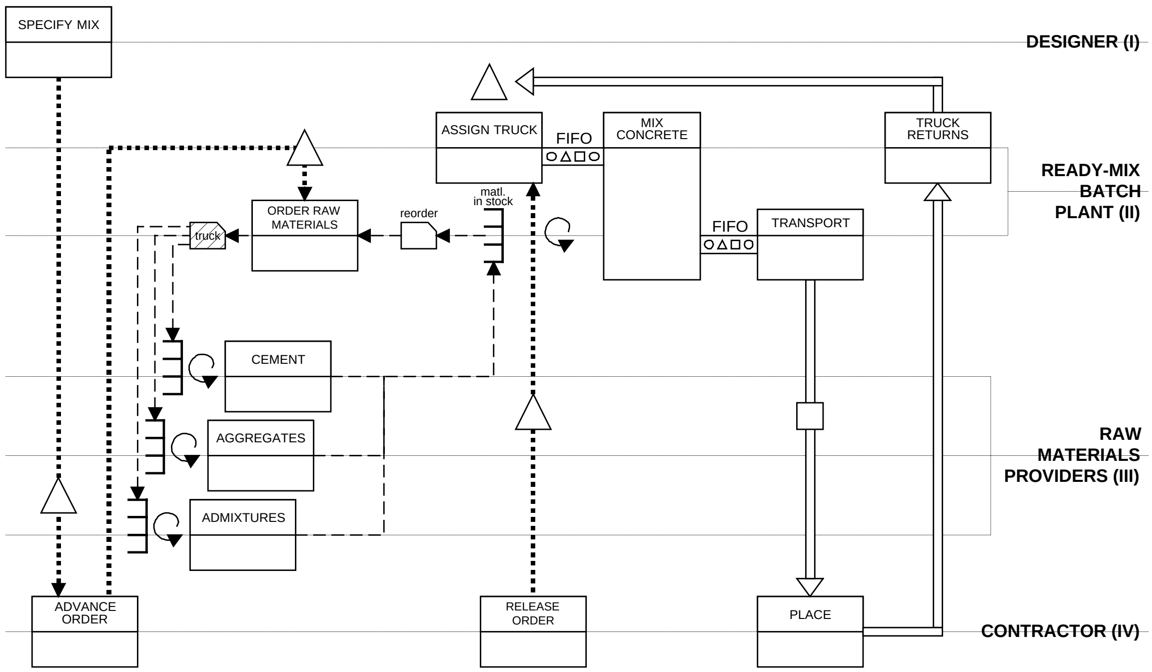

Figure 3: Concrete Batching and Delivery by Ready-Mix Plant

Designers (line I) specify concrete mixes either by recipe or performance. They spell out the requirements in construction documents that are subsequently made available to contractors, e.g., as part of the bid documents. The contractor (line IV) draws information from those specifications when taking off concrete quantities on a project-by-project basis. The contractor also decides on placement sizes and methods. In order to or after identifying the ready-mix plant that will supply the concrete, the contractor then schedules advance orders with approximate quantities and delivery times with the plant. This way, plant capacity will be reserved on the day(s) needed. Doing so is especially critical during busy times of the week and when a large order is being placed that requires uninterrupted delivery so that multiple trucks will have to be synchronized.

The batch plant (line II) uses the advance order for its raw materials inventory planning. Especially mixes that require special aggregates or additives must be ordered with a lead time from suppliers (line III) for the plant to be able to order and receive those special items by the time batching is to take place. Water is considered to be a material 'in stock' but is not shown here as a separate ingredient for the batching process.

A few days up to a day prior to batching, the contractor (line IV) must call in a release order to the batch plant (line II) to confirm the previously-agreed delivery of concrete at the specified time of the specified day. More often than not, the contractor will ask for some modification to the order on record because project conditions will by then have changed relative to what had been anticipated at the time of the advance order.

Ready-mix production exemplifies a pull system because concrete is batched upon demand only. The contractor's release order conveys the pull, except that the batch plant ultimately determines the actual timing of contractor-ordered batch. Ready-mix batch plants prefer to get advance orders but in any case need the contractor to call in a release order so they can schedule a time slot for delivery, then assign a truck and driver, prepare and load the mix, and ship it to the project site shortly before the requested delivery time.

ALTERNATIVE SCENARIOS FOR SUPPLY CHAIN INTEGRATION

Figure 3 clearly depicts who plays what role in the concrete supply chain. Alternative scenarios for supply chain integration are plausible in light of the batch plant's capacity constraint on delivering concrete, namely:

1. The batch plant could, in order to level its load, vary its unit price of ready-mix concrete based on the time and day of the week at which concrete is to be delivered. This would illustrate a market mechanism at work, however, we are not aware of such differential pricing being advertised in the industry today.
2. The batch plant operator could obtain a contractor's license and act as a specialty contractor by self-performing concrete work, especially on days of the week when their plant is less busy filling other contractors' orders. We interviewed one operator who did exactly that. However, he pointed out to us that this solution is not a popular one because it places the concrete supplier in direct competition with his own customers. In fact, this operator ended up self-performing barely any work at all. Perhaps this scenario will be more successful for the batch plant operator who can use most of the plant capacity on self-performed work. This situation then becomes more akin to one where portable batch plants are set up centrally to support a single, large (e.g., new highway construction) or remote (e.g. power plant) projects, or on site, in a building's basement.
3. The batch plant could expand its delivery capacity by using third-party trucks which may or may not be within its control:

3.1 The batch plant could work with on-call, independent truck drivers that own a revolving-drum truck. We observed this practice in Michigan (Williams 1993) but have not heard of it being done in California. A possible reason may be large seasonal fluctuation in demand for concrete due to Michigan's harsher climate.

3.2 Contractors could provide their own means for transporting concrete to their job sites. We document an example of this scenario in the next case, which describes a contractor specialised in concrete road repair.

CASE 2: INTEGRATION OF DELIVERY AND PLACEMENT OF CONCRETE

The second case study pertains to a private contractor who bids on projects from the City and County of San Francisco, the Public Utilities Commission, as well as the Water Department (Figure 4). Most of these jobs include concrete of a well-defined and widely-used kind (we call it 'commodity concrete') though quantities are usually small in comparison to what is needed for residential or office building projects.

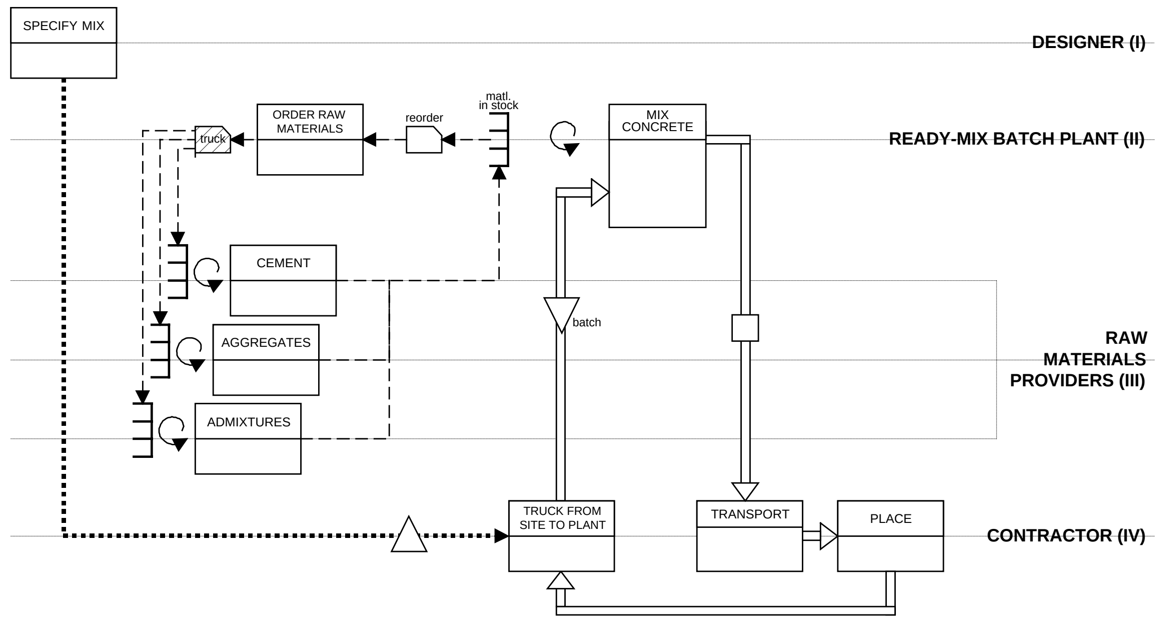

Figure 4: Integrated Concrete Delivery and Placement by Contractor

As one can imagine, the City imposes limits on working hours in order to avoid congestion during peak traffic times, excessively long closure of a road for vehicular- or of a sidewalk for pedestrian traffic, undue inconvenience of road users, and complaints about noise from citizens or area residents. In addition, contractors must obtain a work permit (or working tag) from the city in order to work at a specific location.

This contractor's main concern has been the tardiness of deliveries made by batch plants. Because most of these jobs have restricted working hours, punctual delivery of concrete is of paramount importance. However, because each order is small (a few cubic yard at a time), this contractor cannot get any plant's attention. When plant trucks arrive late to his jobs, he loses that time for the concrete to set and may therefore not be able to open the site to traffic when needed.

To achieve on-time performance, this contractor has acquired a fleet of small (5 to 7 yd^3) revolving-drum trucks as well as dump trucks (used to fill 'potholes' with concrete) to meet his projects' concrete transportation needs. The latter trucks are not so good as the former for transporting concrete as the mix may segregate.

This contractor has its trucks pull into any batch-plant during operating hours and order concrete. The contractor-owned trucks simply join the line of plant trucks waiting to be loaded (line II). The driver then goes to the operator's walk-up window and orders the needed mix design and quantity. The batch plant fills these trucks in the same way as it fills its own, in a first-in-first-out manner. The contractor then gets billed on a regular basis for exact amounts loaded. At the site, the driver works with the crew in placing concrete.

Providing one's own ready-mix trucks does not mean that the unit price of concrete is any cheaper but it overcomes many scheduling hassles. No advance order needs to be placed to reserve plant capacity as only a few cubic yards of commodity mix are needed each time. By taking control over the transportation process and using trucks as kanban each time concrete is needed (line IV), the contractor's crews can work at their own pace and not have to fret over when concrete would arrive. This kanban system works well especially on these projects where timing of need is not dictated exclusively by the contractor, but, as is the case here, also to a significant extent by the owner.

This contractor thus controls what is otherwise a system variable controlled by an upstream supplier, namely the batch plant's delivery of concrete. As a result, the contractor can better schedule his work and be more reliable in making project due dates. Should one batch plant not be available to serve his needs, he can easily go elsewhere (though the number of plants covering any one geographical area is usually limited). The contractor pays for this ability. He now needs to have capital tied up in trucks and is responsible for hiring and training drivers. Because he has a fairly steady need for concrete from one project to the next (contrary to many other contractors who need concrete only for one phase of their work) he can keep them gainfully employed.

CONCLUSIONS

Ready-mix concrete is a prototypical example of a JIT production system in construction. Two practices regarding ready-mix batching and delivery were described in this paper and depicted using value stream mapping symbols. Each case highlighted the presence of buffers of information, materials, and time as well as production order and withdrawal mechanisms positioned at strategic locations to meet specific system requirements, as defined by the nature of the contractor's work. One alternative is favored over the other depending on the amount of control the contractor wants in terms of on-time delivery of concrete and the variability in the contractor's demand for concrete project after project.

While these practices clearly exemplify JIT production, the paper was limited in scope. No data was included to characterize the actual performance in terms of timeliness, buffer sizes, error rates, etc. Moreover, the paper focused on batching and delivery, which are only parts of the entire concrete production system. Current practices for managing the concrete supply chain upstream in terms of raw materials acquisition or prerequisite work on site are not geared toward JIT production. Further investigation is therefore warranted and significant process improvements may be achieved by those working towards fully implementing a lean construction system.

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