Design and implementation of the storage layout and internal material flow at the new General Motors Powertrain Uzbekistan Greenfield manufacturing plant

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“Design, Build and Sell the World’s Best Vehicles”
The Vision of General Motors
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Abstract

The aim of this Master thesis is to explore the impact of design parameters on material flow efficiency in terms of space and time (labor or person-hours) utilization. The factory material flow design process is an essential part of any manufacturing. The challenge for this project was to expose the components for the assembly operator within the space designated for materials at the workstation, meanwhile minimizing non-value-adding work and creating good ergonomics so that operators can achieve high workstation performance. In this study a new General Motors Powertrain Uzbekistan (GMPT-UZ) Greenfield manufacturing plant was considered as a case study for the design of internal material flow and implementation of lean principles. The research work was based on action research strategy where the researcher starts with a particular problem that he wants to solve, or understand better, usually within the environment where he is working. The findings underline the importance of each design parameter in the application of lean principles. The main conclusion to be drawn from this study is that the material flow design process can still require a continuous improvement based on production targets and the best practices from other companies.

Keywords: materials flow, system design, supply chain, lean production, automotive, manufacturing, Uzbekistan.
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<tr>
<td>3PL</td>
<td>A third-party logistics provider</td>
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<tr>
<td>AGC</td>
<td>Automated Guided Cart</td>
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<td>AS/RS</td>
<td>Automated storage-and-retrieval systems</td>
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<td>BPD</td>
<td>Business Plan Deployment</td>
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<td>CMA</td>
<td>Central Material Area</td>
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<td>DC</td>
<td>Distribution Center</td>
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<td>DLOC</td>
<td>Delivery location</td>
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<td>DOHC</td>
<td>Dual Over-Head Cam</td>
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<td>EPS</td>
<td>Electronic Pull System</td>
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<td>FEFO</td>
<td>First-Expired-First-Out</td>
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<td>FIFO</td>
<td>First-In-First-Out</td>
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<td>GM</td>
<td>General Motors</td>
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<td>GMPT-UZ</td>
<td>General Motors Powertrain Uzbekistan</td>
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<td>GMS</td>
<td>Global Manufacturing System</td>
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<tr>
<td>JIT</td>
<td>Just-in-time</td>
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<td>OEM</td>
<td>Original Equipment Manufacturer</td>
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<td>PDCA</td>
<td>Deming’s Plan-Do-Check-Act Cycle</td>
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<td>PFEP</td>
<td>Plan for Every Part</td>
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<td>POU</td>
<td>Point of Use</td>
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<td>PPS</td>
<td>Production Pull System</td>
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<td>RFID</td>
<td>Radio Frequency Identification</td>
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<td>SC</td>
<td>Supply Chain</td>
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<td>SKU</td>
<td>Stock Keeping Unit</td>
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<td>SOHC</td>
<td>Single Over Head Cam</td>
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<td>SPS</td>
<td>Set Part Strategy</td>
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<td>ULOC</td>
<td>Usage location</td>
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<td>VAP</td>
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1. Introduction

1.1 Background

The factory material flow design process is an essential part of any manufacturing. From the perspective of lean manufacturing, this process can still require a continuous improvement based on best practices from other companies. In this study a new General Motors Powertrain Uzbekistan (GMPT-UZ) Greenfield manufacturing plant was considered as a case study for the design of internal material flow and implementation of lean principles.

General Motors

General Motors Company (NYSE:GM, TSX: GMM), one of the world’s largest automakers, traces its roots back to 1908. With its global headquarters in Detroit, GM employs 209,000 people in every major region of the world and does business in more than 157 countries. GM and its strategic partners produce cars and trucks in 31 countries, and sell and service these vehicles through the following brands: Buick, Cadillac, Chevrolet, GMC, Daewoo, Holden, Isuzu, Jiefang, Opel, Vauxhall and Wuling. GM’s largest national market is China, followed by the United States, Brazil, the United Kingdom, Germany, Canada and Russia. GM’s OnStar subsidiary is the industry leader in vehicle safety, security and information services.

GM Powertrain Uzbekistan

GM Powertrain Uzbekistan is a joint venture between General Motors and Uzavtosanoat. The powertrain operation builds on the existing cooperation between GM and Uzavtosanoat which established the vehicle joint venture, GM Uzbekistan, in October 2007. GM Uzbekistan currently builds Chevrolet and GM Daewoo vehicles including Captiva, Epica, Lacetti, Nexia, Matiz and Damas in Asaka in the Andijan province.

GM holds the majority 52 per cent stake in the General Motors Powertrain Uzbekistan CJSC which will be a separate entity but run in coordination with GM Uzbekistan.

Construction of the manufacturing operations began in the Tashkent Region in late December 2008 with start of production due to commence in November 2011. The GM Uzbekistan vehicle joint venture operation employees more than 5,000 people and the GM Powertrain Uzbekistan joint venture will create 1,200 additional jobs.

The capacity of the plant will initially be matched to meet demand from GM Uzbekistan, with a maximum capacity of 360,000 units a year as demand in the region grows. GM Powertrain Uzbekistan will run on a three-crew, three-shift manufacturing model with six production days a week.

GM Powertrain Uzbekistan will manufacture GM’s 1.0, 1.2, 1.4 and 1.5 liter gasoline engines which are currently produced by GM operations in South Korea and China predominantly for the Asia Pacific market.
**Engine types**

There are two BDOHC engine types: B12D (Fig. 1.1a) and B15D (Fig. 1.1b) with 1.2 L (82 hp) and 1.5 L (115 hp) volumes respectively.

B type DOHC means Dual Over-Head Cam, as opposed to SOHC engine (Single Over Head Cam). The engine has 2 camshafts that are located within the cylinder head at the top of the engine. Advantages to having a DOHC engine over a SOHC is that the engine has twice as many intake and exhaust valves as a SOHC motor. This makes the engine run cooler and more smoothly, quietly, and efficiently. But the downfall is that DOHC engines cost more for repairs. There are other advantages to both SOHC and DOHC such as ease of maintenance, elimination of push rods, smoother running motor, and typically overhead cam motors use rubber timing belts. This eliminates chains or gears usually found in other motors.
1.2 Research method and strategy

A research strategy was chosen as action research where the researcher starts with a particular problem that he wants to solve, or understand better, usually within the environment where he is working (Cunningham 1995).

1.3 Overall Research Aim and Individual Research Objectives

The overall aim of this research is to explore the impact of design parameters to material flow efficiency in terms of space and time (labor or person-hours) utilization.

Central to this research is the need to answer the question, what are the key design parameters for material flow efficiency of the factory/plant in terms of space and time (labor or person-hours) utilization?

Specifically, within the context of lean manufacturing, the objectives of this research are to:

(i) identify the forces driving and the barriers to the successful factory material flow process.

(ii). critically evaluate the models and frameworks relevant to the defined targets.

(iii). investigate best practices (benchmarking) related to factory material flow.

(iv). formulate recommendations based on practical findings.
1.4 Value of this Research

This research should be useful to both researchers and practitioners who deal with material flow in designing facility layouts.

1.5 Delimitations

The proposed material flow approach is not finalized yet and requires more optimization with computer software as a full three-shift regular production is planned next year.
2. Literature review

2.1 Warehouse function

There are two main target functions of warehouses:

1. To better match supply with customer demand, and
2. To consolidate product to reduce transportation costs and to provide customer service.

2.2 Types of warehouses

Warehouses can be categorized by type, which is primarily defined by the customers they serve.

1. A retail distribution center typically supplies product to retail stores. The immediate customer of the distribution center is a retail store, which is likely to be a regular or even captive customer, receiving shipments on regularly scheduled days. A typical order might comprise hundreds or thousands of items; and because the distribution center might serve hundreds of stores, the flow of product is huge. The suite of products changes with customer tastes and marketing plans; but because the orders are typically known a day or more in advance, it is possible to plan ahead. Some product may be pushed from the distribution center to the stores, especially in support of marketing campaigns.

2. A service parts distribution center is among the most challenging of facilities to manage. They hold spare parts for expensive capital equipment, such as automobiles, airplanes, computer systems, or medical equipment. Consequently, one facility may represent a huge investment in inventory: tens or even hundreds of thousands of parts, some very expensive. (A typical automobile contains almost 10,000 parts.) Because of the large number of parts, total activity in the DC may be statistically predictable, but the demand for any particular part is relatively small and therefore hard to predict. This means that the variance of demand can be large and so relatively large quantities of safety stock must be held, especially since there can be usually long lead times to replenish parts to the warehouse. Indeed, sometimes there is as much safety stock as cycle stock, and so, in aggregate, these skus require much space. This in turn increases travel distances and makes order-picking less efficient.

3. A catalog fulfillment or e-commerce distribution center typically receives small orders from individuals by phone, fax, or the Internet. Orders are typically small, for only 1–3 items, but there may be many such orders, and they are to be filled and shipped immediately after receipt. Because customer orders require instant response, such distributors typically try to shape demand by offering special prices for ordering at certain times or in certain quantities or for accepting more variable delivery dates.

4. A 3PL warehouse is one to which a company might outsource its warehousing operations. The 3PL provider might service multiple customers from one facility,
thereby gaining economies of scale or complementary seasons that the customers would be unable to achieve on their own. 3PL facilities may also be contracted as overflow facilities to handle surges in product flow.

5. A perishables warehouse may handle food, fresh flowers, vaccines, or other product requiring refrigeration to protect its very short shelf life. They are typically one link in an extended cold chain, along which perishable product is rushed to the consumer. Such DCs are distinctive in that product dwells within for very short times, frequently only hours. Also, there is a great emphasis on using space effectively because, with refrigeration, it is so expensive. They face many challenges in inventory management, including requirements to ship product according to FIFO (First-In-First-Out) or FEFO (First-Expired-First-Out). Also, there are typically many restrictions on how product is handled. For example, chicken cannot be stacked on top of anything else, to protect against juices dripping onto product below and contaminating it. Finally, appropriate temperatures must be maintained and this can be different for different kind of products. A typical food DC operates separate areas for ambient temperatures, chilled (around 2 degrees C, 35 degrees F), and frozen product (-18 degrees C, around 0 degrees F). To protect stored product, it is important to avoid bringing in anything warmer. This type of warehouse will become more common as China, India, Brazil, and other rapidly industrializing countries build a middle class, which will increasingly want fresh fruit, vegetables, meat, and dairy.

2.3 Material flow

The “supply chain” is the sequence of processes through which product moves from its origin toward the customer. These processes can be compared to fluid flow where warehouses represent storage tanks along the pipeline. The fluid model immediately suggests other general guidelines to warehouse design and operation, such as:

- Keep the product moving; avoid starts and stops, which mean extra handling and additional space requirements.
- Avoid layouts that impede smooth flow.
- Identify and resolve bottlenecks to flow.

It is worth remarking that the movement to “just-in-time” logistics is roughly equivalent to reducing the diameter of the pipe, which means product flows more quickly and so flow time and in-transit inventory are reduced.

A product is generally handled in smaller units as it moves down the supply chain. A stock keeping unit, or sku, is the smallest physical unit of product that is tracked by the organization. Upstream in the SC, flow is in larger units, like pallets (Figure 2.1). Product is successively broken down into smaller units as it moves downstream. Thus a product might move out of the factory and to regional distribution centers in pallet-loads; and then to local warehouses in cases; and finally to retail stores in inner-packs or even individual pieces, which are the smallest units offered to the consumer. This means that the fluid model will be most accurate downstream, where smaller units are moved.
Figure 2.1: A product is generally handled in smaller units as it moves down the supply chain.

Warehouse management is all about careful use of space and time (that is, labor or person-hours). Both space and time are expensive and so one would like to use as little of each as possible in delivering product to customers.

Figure 2.2 shows a plot of the popularity (number of times requested, or picks) of each sku of a warehouse together with the physical volume (flow) of the sku moved through the warehouse during one month. There is little correlation between popularity and flow, and this is one of the challenges of warehouse management, because it is hard to design processes
that work well with skus that may be any combination of popular/unpopular and low-volume/high-volume.

Figure 2.2: Among these 25,000 skus there is little correlation between popularity and physical volume of product sold.

Figure 2.3 plots just the popularity of the same set of about 25,000 skus, here ranked from most popular to least. This is typical of such plots in that a small fraction of the skus account for most of activity. It is easy to design processes for these skus because they are fairly predictable. If popular yesterday, such a sku is likely to be popular again tomorrow.

On the other hand, consider all the skus in the so-called long-tail, in this case the 20,000 skus that are requested infrequently. It is impossible to know whether any particular sku will be requested tomorrow. Such skus, by their sheer number, occupy most of the space in a warehouse. This effect is further magnified by safety stock, which is held to protect against stockout in the face of customer demand that is highly variable in comparison to the amounts held.

Figure 2.3: Popularity among these 25,000 skus varies enormously, which presents special challenges to effective management.

Each warehouse then is, in a sense, two warehouses. The first is organized around a small set of predictably popular skus that are easy to plan for and for which the challenge is to manage flow. The other warehouse is much larger, and for which the work is predictably only in aggregate. This makes it much harder to plan and one is forced to hedge decisions. The first warehouse is where labor is concentrated; and the second consumes space.
Each storage location in a warehouse is assigned a unique address. This includes both fixed storage locations, such as a portion of a shelf and mobile locations such as the forks of a lift truck. Storage locations are expensive because they represent space, with consequent costs of rent, heating and/or air-conditioning, security, and so on. In addition, storage locations are typically within specialized equipment, such as shelving or flow rack, which are a capital cost. These costs impel us to use storage space as efficiently as possible.

There are two main strategies used in storing product. The simplest is dedicated storage, in which each location is reserved for an assigned product and only that product may be stored there. Because the locations of products do not change, more popular items can be stored in more convenient locations and workers can learn the layout, all of which makes order-picking more efficient.

The problem with dedicated storage is that it does not use space efficiently. This can be seen by tracking the amount of inventory in a given location. If the inventory level would be plotted, measured for example by volume, there could be seen a sawtooth shape such as in Figure 2.4 (which represents an idealization of the inventory process.) In one cycle the storage location is initially filled but empties as product is withdrawn to send to customers. As a result, on average this storage location is half empty.

![Figure 2.4: An idealization of how the inventory level at a location changes over time](image)

A warehouse may have thousands or tens-of-thousands of storage locations. If using dedicated storage, each will have an assigned product. Each product may have a different replenishment cycle and so, upon entering such a warehouse, one expects to see many storage locations that are nearly empty, many that are half-full, and many that are nearly full. On average the storage capacity is only about 50% utilized.

To improve on this, one can use a strategy of shared storage. The idea here is to assign a product to more than one storage location. When one location becomes empty, it is available for reassignment, perhaps to a different product. This space then can be filled again, rather than waiting until the original product is replenished (presumably when the last of the warehouse supply has been exhausted). The more storage locations over which a product is distributed, the less product in each location, and so the sooner one of those locations is emptied and the sooner that space is recycled. Therefore we expect better utilization of space when shared storage is used.

Unfortunately, shared storage also has some disadvantages. Most immediately, the locations of products will change over time as locations are emptied and restocked with other
products. This means that workers cannot learn locations and so must be directed to locations by a warehouse management (software) system. Another disadvantage is that it becomes more time-consuming to put away newly received product because it has to be taken to more locations. There can be other, social complications as well. For example, imagine an order picker who has been directed to the other side of the warehouse to pull a product for a customer. That order picker may be tempted to pick the product from a more convenient location, thus creating discrepancies between book and physical inventory at two locations. For these reasons, shared storage requires greater software support and also more disciplined warehouse processes.

Shared storage is generally more complicated to manage because it introduces many possible trade-offs. In particular, one can manage the trade-off between space and time (labor) on an activity-by-activity basis. For example, one can retrieve product from the least-filled location (to empty and recycle that location as soon as possible) or from the most convenient location (to save labor). Similarly, one can replenish product to the most nearly empty location to fill that empty space or to the most convenient location to save labor time.

**Theorems**

**Theorem 1.** When a sku is stored in $k$ locations of equal size the average space utilization is $k/(k + 1)$.

Consequently,

- Increasing the number of locations increases utilization (e.g. moving from 1 location to 2 locations, improves utilization from 50% to 66%), but the improvement diminishes as $k$ increases.
- Increasing the number of locations also increases the management required.

**Theorem 2.** (Little’s Law). For a queuing system in steady state the average length $L$ of the queue equals the average arrival rate $\lambda$ times the average waiting time $W$, i.e. $(L = \lambda W)$.

A queuing system is a model of the following structure: Customers arrive and join a queue to await service by any of several servers. After receiving service the customers depart the system.

A warehouse may be roughly modeled as a queuing system in which skus are the customers that arrive at the receiving dock, where they join a queue (that is, are stored in the warehouse) to wait for service (shipping). If the warehouse is at steady state the product will be shipped at the same average rate at which it arrives. Then Little’s Law applies and the average amount of product in the warehouse equals the arrival rate of product multiplied by the average time product is resident in the warehouse.
2.4 Warehouse operations

A warehouse reorganizes and repackages product. Product typically arrives packaged on a larger scale and leaves packaged on a smaller scale. In other words, an important function of this warehouse is to break down large chunks of product and redistribute it in smaller quantities. For example, some skus may arrive from the vendor or manufacturer in pallet quantities but be shipped out to customers in case quantities; other skus may arrive as cases but be shipped out as eaches; and some very fast-moving skus may arrive as pallets and be shipped out as eaches. In such an environment the downstream warehouse operations are generally more labor-intensive.

This is still more true when product is handled as eaches. In general, the smaller the handling unit, the greater the handling cost. It can require much labor to move 10,000 boxes of paper clips if each box must be handled separately, as they may when, for example, stocking retail stores. Much less labor is required to handle those 10,000 boxes if they are packaged into cases of 48 boxes; and still less labor if those cases are stacked 24 to a pallet.

Even though warehouses can serve quite different ends, most share the same general pattern of material flow. Essentially, they receive bulk shipments, stage them for quick retrieval; then, in response to customer requests, retrieve and sort skus, and ship them out to customers.

The reorganization of product takes place through the following physical processes.

- Inbound processes
  - Receiving
  - Put-away

- Outbound processes
  - Order-picking
  - Checking, packing, shipping

Many warehouses also must handle returns, which run about 5% in retail. This will become a major function within any warehouse supporting e-commerce, where returns run 25–30%, comparable to those supporting catalog sales.

Another trend is for warehouses to assume more value-added processing (VAP), which is additional work beyond that of building and shipping customer orders. Typical value-added processing includes the following:

- Ticketing or labeling (For example, New York State requires all items in a pharmacy to be price-labeled and many distributors do this while picking the items in the warehouse.)
- Monogramming or alterations (For example, these services are offered by Lands End, a catalog and e-mail merchant of clothing)
- Repackaging
- Kitting (repackaging items to form a new item)
- Postponement of final assembly, OEM labeling (For example, many manufacturers of computer equipment complete assembly and packaging in the warehouse, as the product is being packaged and shipped.)
- Invoicing
Such work may be pushed on warehouses by manufacturers upstream who want to postpone product differentiation. By postponing product differentiation, upstream distributors, in effect, see more aggregate demand for their (undifferentiated) product. For example, a manufacturer can concentrate on laptop computers rather than on multiple smaller markets, such as laptop computers configured for an English-speaking market and running Windows 2000, those for a German-speaking market and running Linux, and so on. This aggregate demand is easier to forecast because it has less variance which means that less safety stock is required to guarantee service levels.

At the same time value-added processing is pushed back onto the warehouse from retail stores, where it is just too expensive to do. Both land and labor are typically more expensive at the retail outlet and it is preferable to have staff there concentrate on dealing with the customer.

A general rule is that product should, as much as possible, flow continuously through this sequence of processes. Each time it is put down means that it must be picked up again sometime later, which is double-handling. When such double-handling is summed over all the tens-of-thousands of skus and hundreds-of-thousands of pieces and/or cases in a warehouse, the cost can be considerable.

Another rule is that product should be scanned at all key decision points to give “total visibility of assets”, which enables quick and accurate response to customer demand.

Receiving may begin with advance notification of the arrival of goods. This allows the warehouse to schedule receipt and unloading to coordinate efficiently with other activities within the warehouse. It is not unusual for warehouses to schedule trucks to within 30-minute time windows.

Once the product has arrived, it is unloaded and possibly staged for put away. It is likely to be scanned to register its arrival so that ownership is assumed, payments dispatched, and so that it is known to be available to fulfill customer demand. Product will be inspected and any exceptions noted, such as damage, incorrect counts, wrong descriptions, and so on.

Product typically arrives in larger units, such as pallets, from upstream and so labor requirements are not usually great. (However, mixed pallets may need to be broken out into separate cartons; and loose cartons may need to be palletized for storage.) All-in-all, receiving accounts for only about 10% of operating costs in a typical distribution center – and RFID is expected to further reduce this.

Before product can be put away, an appropriate storage location must be determined. This is very important because where you store the product determines to a large extent how quickly and at what cost you later retrieve it for a customer. This requires managing a second inventory, not of product, but of storage locations. You must know at all times what storage locations are available, how large they are, how much weight they can bear, and so on.

When product is put away, the storage location should also be scanned to record where the product has been placed. This information will subsequently be used to construct efficient pick-lists to guide the order-pickers in retrieving the product for customers.

Put-away can require a fair amount of labor because product may need to be moved considerable distance to its storage location. Put-away typically accounts for about 15% of warehouse operating expenses.
On receipt of a customer order the warehouse must perform checks such as verifying that inventory is available to ship. Then the warehouse must produce pick lists to guide the order-picking. Finally, it must produce any necessary shipping documentation and schedule the order-picking and shipping. These activities are typically accomplished by a warehouse management system, a large software system that coordinates the activities of the warehouse. This is all part of the support to expedite the sending of the product to the customer.

The outbound processes of the warehouse are initiated by receipt of a customer order, which may be thought of as a shopping list. Each entry on the list is referred to as an order-line and typically consists of the item and quantity requested. The warehouse management system (WMS) then checks the order against available inventory and identifies any shortages. In addition, the WMS may reorganize the list to match the layout and operations of the warehouse for greater efficiency. For example, if a customer has ordered 15 of a particular item, the warehouse management system (WMS) may check to see how the item is packaged. If 12 of the item comprise a carton, the WMS may convert the order-line for 15 eaches to two pick-lines, one for 1 carton and the other for 3 eaches. In many warehouses, each-picking and carton-picking are separate processes, and the pick-lines are diverted appropriately.

Pick-lines are instructions to the order-pickers, telling them where and what to pick and in what quantity and units of measure. Each pick-line (or, more briefly, pick or line) represents a location to be visited, and since travel is the largest labor cost in a typical warehouse, the number of pick-lines is an indication of the labor required.

Note that a pick (line) may require more than one grab if, for example, several items of a sku are to be retrieved for an order. Generally, this represents a much smaller proportion of the labor, because it is controllable by appropriate packaging (for example, pick one carton rather than 12 eaches).

The WMS organizes pick-lines into pick-lists to achieve still more efficiencies, so that an order-picker may be able to concentrate on one area of the warehouse and so reduce travel. In addition, the WMS may sequence the pick-lines so that the locations to be visited appear in the sequence in which they will normally be encountered as the picker moves through the warehouse.

The pick-list may be a physical sheet of paper, or merely a sequence of requests communicated by a stream of printed shipping labels, or by light, RF, or voice transmission.

The most labor-intensive order-picking is the picking of less-than-carton quantities, referred to typically as broken-case or split-case picking. Broken-case picking is labor-intensive because it requires handling the smallest units of measure in the warehouse and this is generally resistant to automation because of the size and variety of skus to be handled. In contrast, carton-picking (picking full cartons) can sometimes be automated because of the relative uniformity of cartons, which are almost always rectangular and packed to resist damage.

The pick face is that 2-dimensional surface, the front of storage, from which skus are extracted. This is how the skus are presented to the order picker. In general, the more different skus presented per area of the pick face, the less travel required per pick. An informal measure of this is sku density, which counts the number of skus available per unit of
area on the pick-face. If a warehouse has a suitably high sku density then it will likely
achieve a high value of **pick density**, or number of picks achieved per unit of area on the pick
face, and so require less travel per pick.

Sometimes it is useful to interpret the informal measures sku density and pick density
as measuring skus or picks per unit of distance along the aisle traveled by an order-picker.
One can then talk about, for example, the pick density of an order. An order that is of high
pick density does not require much travel per pick and so is expected to be relatively
economical to retrieve: we are paying only for the actual cost of retrieval and not for travel.
On the other hand, small orders that require visits to widely dispersed locations may be
expensive to retrieve because there is more travel per pick.

Pick density depends on the orders and so we cannot know it precisely in advance of
order receipt. However, it is generally true that pick density can be improved by ensuring
high **sku density**, which is number of skus per foot of travel.

Pick density can be increased, at least locally, by storing the most popular skus
together. Then order-pickers can make more picks in a small area, which means less
walking.

Another way to increase the pick density is to **batch** orders; that is, have each worker
retrieve many orders in one trip. However, this requires that the items be sorted into orders
either while picking or else downstream. In the first case, the pickers are slowed down
because they must carry a container for each order and they must sort the items as they pick,
which is time-consuming and can lead to errors. If the items are sorted downstream, space
and labor must be devoted to this additional process. In both cases even more work and
space may be required if, in addition, the orders themselves must be sorted to arrive at the
trailer in reverse sequence of delivery.

It is generally economic to batch single-line orders. These orders are easy to manage
since there is no need to sort while picking and they can frequently be picked directly into a
shipping container.

Very large orders can offer similar economies, at least if the skus are small enough so
that a single picker can accumulate everything requested. A single worker can pick that order
with little walking per pick and with no sortation.

The challenge is to economically pick the orders of intermediate size; that is, more
than two pick-lines but too few to sufficiently amortize the cost of walking. Roughly
speaking, it is better to batch orders when the costs of work to separate the orders and the
costs of additional space are less than the extra walking incurred if orders are not batched. It
is almost always better to batch single-line orders because no sortation is required. Very
large orders do not need to be batched because they will have sufficient pick density on their
own. The problem then is with orders of medium-size.

To sustain order-picking product must also be replenished. Restockers move skus in
larger units of measure (cartons, pallets) and so a few restockers can keep many pickers
supplied. A rule of thumb is one restocker to every five pickers; but this will depend on the
particular patterns of flow.

A restock is more expensive than a pick because the restocker must generally retrieve
product from bulk storage and then prepare each pallet or case for picking. For example, he
may remove shrink-wrap from a pallet so individual cases can be retrieved; or he may cut individual cases open so individual pieces can be retrieved.

A customer order may be picked entirely by one worker; or by many workers but only one at a time; or by many at once. The appropriate strategy depends on many things, but one of the most important is how quickly must orders flow through the process. For example, if all the orders are known before beginning to pick, then we can plan efficient picking strategies in advance. If, on the other hand, orders arrive in real time and must be picked in time to meet shipping schedules then we have little or no time in which to seek efficiencies.

A general decision to be made is whether a typical order should be picked in serial (by a single worker at a time) or in parallel (by multiple workers at a time). The general trade-off is that picking serially can take longer to complete an order but avoids the complications of coordinating multiple pickers and consolidating their work.

A key statistic is flow time: how much time elapses from the arrival of an order into our system until it is loaded onto a truck for shipping? In general, it is good to reduce flow time because that means that orders move quickly through our hands to the customer, which means increased service and responsiveness.

Packing can be labor-intensive because each piece of a customer order must be handled; but there is little walking. And because each piece will be handled, this is a convenient time to check that the customer order is complete and accurate. Order accuracy is a key measure of service to the customer, which is, in turn, that on which most businesses compete.

Inaccurate orders not only annoy customers by disrupting their operations, they also generate returns; and returns are expensive to handle (up to ten times the cost of shipping the product out).

One complication of packing is that customers generally prefer to receive all the parts of their order in as few containers as possible because this reduces shipping and handling charges. This means that care must be taken to try to get all the parts of an order to arrive at packing together. Otherwise partial shipments must be staged, waiting completion before packing, or else partial orders must be packaged and sent.

Packed product may be scanned to register the availability of a customer order for shipping. This also begins the tracking of the individual containers that are about to leave the warehouse and enter the system of a shipper.

Shipping generally handles larger units than picking, because packing has consolidated the items into fewer containers (cases, pallets). Consequently, there is still less labor here. There may be some walking if product is staged before being loaded into freight carriers.

Product is likely to be staged if it must be loaded in reverse order of delivery or if shipping long distances, when one must work hard to completely fill each trailer. Staging freight creates more work because staged freight must be double-handled.

The trailer is likely to be scanned here to register its departure from the warehouse. In addition, an inventory update may be sent to the customer.

Most of the expense in a typical warehouse is in labor; most of that is in order-picking; and most of that is in travel (Figure 2.5).
2.5 Storage and handling equipment

There are many types of special equipment that have been designed to reduce labor costs and/or increase space utilization.

Storage and retrieval equipment can reduce labor costs by

- Allowing many skus to be on the pick face, which increases pick density and so reduces travel per pick, which means more picks per person-hour.
- Facilitating efficient picking and/or restocking by making the product easier to handle (for example, by presenting it at a convenient height and orientation).
- Moving product from receiving to storage; or from storage to shipping.

Storage equipment can increase space utilization by:

- Partitioning space into subregions (bays, shelves) that can be loaded with similarly sized skus. This enables denser packing and helps make material-handling processes uniform.
- Making it possible to store product high, where, up to about 30 feet (10 meters), space is relatively inexpensive. (Above this height, the building requires additional structural elements.)

Common storage modes include pallet rack for bulk storage, carton flow rack for high-volume picking, and (static) shelving for slower, lower-volume picking.

Within the warehouse the largest standardized material-handling unit is generally the pallet, which is just a rigid base on which cartons can be stacked. Most are made of wood, but some are made of durable plastic.

Pallets are available in a range of qualities and prices. In general order of quality and price, they include string pallets, block pallets, and perimeter base pallets. Any pallet expected to be handled by automation will generally have to be of high quality. As supply chains get longer, there is an incentive to use higher quality pallets.

The simplest way of storing palletized product is floor storage, which is typically arranged in lanes. The depth of a lane is the number of pallets stored back-to-back away from the pick aisle. The height of a lane is normally measured as the maximum number of pallets that can be stacked one on top of each other, which is determined by pallet weight, fragility, number of cartons per pallet, and so on. Note that the entire footprint of a lane is
reserved for a sku if any part of the lane is currently storing a pallet. This rule is almost always applied, since if more than one sku was stored in a lane, some pallets may be double-handled during retrieval, which could offset any space savings. Also, it becomes harder to keep track of where product is stored. For similar reasons, each column is devoted to a single sku. This loss of space is called honey-combing.

Pallet rack is used for bulk storage and to support full-case picking (Figure 2.6). Pallet length and width are reasonably uniform and pallet rack provides appropriately-sized slots. The height of slots can be adjusted, however, as pallet loads can vary in height. The advantage of rack storage is that each level of the rack is independently supported, thus providing much greater access to the loads, and possibly permitting greater stack height that might be possible in floor storage.

![Figure 2.6: Simple pallet rack](image)

The most common types of rack storage are:

**Selective rack or single-deep rack** stores pallets one deep, as in Figure 2.6. Due to rack supports each pallet is independently accessible, and so any sku can be retrieved from any pallet location at any level of the rack. This gives complete freedom to retrieve any individual pallet but requires relatively more aisle space to access the pallets.

**Double-deep rack** essentially consists of two single-deep racks placed one behind the other, and so pallets are stored two deep. Due to rack supports each 2-deep lane is independently accessible, and so any sku can be stored in any lane at any level of the rack. To avoid double-handling, it is usual that each lane be filled with a single sku, which means that some pallet locations will be unoccupied whenever some sku is present in an odd number of pallets. Another disadvantage of deep lanes is that slightly more work is required to store and retrieve product. However, deep lanes have the advantage of requiring fewer aisles to access the pallets, which means that the warehouse can hold more products. A special truck is required to reach past the first pallet position.

**Push-back rack.** This may be imagined to be an extension of double deep rack to 3–5 pallet positions, but to make the interior positions accessible, the rack in each lane pulls out like a drawer. This means that each lane (at any level) is independently accessible.

**Drive-In or drive-through rack** allows a lift truck to drive within the rack frame to access the interior loads; but, again to avoid double-handling, all the levels of each lane must be devoted to a single sku. With drive-in rack the put-away and retrieval functions are performed from the same aisle. With drive-through rack the pallets enter from one end of the
lane and leave from the other, so that product can be moved according to a policy of First-In-First-Out (FIFO). Drive-in/through rack may be thought of as floor-storage for product that is not otherwise stackable. It does not enable the flexibility of access that other types of pallet rack achieve. In addition, there are some concerns; for example, in this rack each pallet is supported only by the edges, which requires that the pallets be strong. In addition, it requires a more skilled forklift driver to navigate within the lane, and such a person will be more expensive.

**Pallet flow rack** is deep lane rack in which the shelving is slanted and lines with rollers, so that when a pallet is removed, gravity pulls the remainder to the front. This enables pallets to be put-away at one side and retrieved from the other, which prevents storage and retrieval operations from interfering with each other. Because of weight considerations, storage depth is usually limited to about eight pallets. This type of rack is appropriate for high-throughput facilities.

Except for automated storage-and-retrieval systems (AS/RS), some type of lift truck is required to access the loads in pallet rack; and specialized racks may require specialized trucks. The most common type of lift trucks are:

**Counterbalance lift truck** is the most versatile type of lift truck. The sit-down version requires an aisle width of 12–15 feet (3.7–4.6 meters), its lift height is limited to 20–22 feet (6.1–6.7 meters), and it travels at about 70 feet/minute (21.3 meters/minute). The stand-up version requires an aisle width of 10–12 feet (3.1–3.7 meters), its lift height is limited to 20 feet (6.1 meters), and it travels at about 65 feet/minute (19.8 meters/minute).

**Reach and double-reach lift truck** is equipped with a reach mechanism that allows its forks to extend to store and retrieve a pallet. The double-reach truck is required to access the rear positions in double deep rack storage. Each truck requires an aisle width of 7–9 feet (2.1–2.7 meters), their lift height is limited to 30 feet (9.1 meters), and they travel at about 50 feet/minute (15.2 meters/minute). A reach lift truck is generally supported by “outriggers” that extend forward under the forks. To accommodate these outriggers, the bottom level of deep pallet rack is generally raised a few inches (approximately 10 centimeters) off the ground so that the outriggers can pass under.

**Turret Truck** uses a turret that turns 90 degrees, left or right, to put-away and retrieve loads. Since the truck itself does not turn within the aisle, an aisle width of only 5–7 feet (1.5–2.1 meters) is required, its lift height is limited to 40–45 feet (12.2–13.7 meters), and it travels at about 75 feet/minute (22.9 meters/minute). Because this truck allows such narrow aisle, some kind of guidance device, such as rails, wire, or tape, is usually required. It only operates within single deep rack and super flat floors are required, which adds to the expense of the facility. This type of truck is not easily maneuverable outside the rack.

**Stacker crane** within an AS/RS is the handling component of a unit-load AS/RS, and so it is designed to handle loads up to 100 feet high (30.5 meters). Roof or floor-mounted tracks are used to guide the crane. The aisle width is about 6–8 inches (0.15–0.20 meters) wider than the unit load. Often, each crane is restricted to a single lane, though there are, at extra expense, mechanisms to move the crane from one aisle to another.
Simple shelving is the most basic storage mode and the least expensive (Figure 2.7). The shelves are shallow: 18 or 24 inches (0.46 or 0.61 meters) are typical, for example, but 36 inch (0.91 meter) deep shelf is sometimes used for larger cartons. Because the shelves are shallow, any significant quantity of a sku must spread out along the pick-face. This reduces sku-density and therefore tends to reduce pick density, increase travel time, and reduce picks/person-hour.

Skus which occupy more than one shelf of bin-shelving are candidates for storage in another mode that will enable greater sku-density. A typical pick rate from bin-shelving is 50–100 picks/person-hour.

With shelving, both picking and restocking must be done from the pick-face and so, to avoid interference, must be scheduled at different times. This can mean working an additional shift.

**Gravity flow rack.** Flow rack is a special type of shelving with shelves that are tilted, with rollers, to bring cases forward for picking. The shelves may be 3–10 feet deep (0.91–3.0 meters). This means that only one case of a product need be on the pick face, which means that many skus can be available in a small area of pick-face. This means high sku-density, which tends to increase the pick-density, decrease travel, and increase picks/person-hour.

Frequently the picking from flow rack is accelerated by supporting technology such as a pick-to-light system, by which a centralized computer lights up signals at every location within a bay from which product is to be picked. After the worker picks the appropriate quantity and then pushes a button to signal the computer. There are several benefits of this: The order-picker is freed from handling a paper pick-list; he does not have to search for the next storage location; and because picking is guided, it is more accurate. A typical pick rate from flow rack is about 150–500 picks/person-hour, but this varies widely.

Flow rack is restocked from the back, independently of picking. This means that restocking never interferes with picking, as is the case for static shelving, for which picking and restocking must alternate. However, additional aisle space is required to access the back of flow rack for restocking.
Figure 2.8: Side views of the shelves of three styles of carton flow rack. Each successive configuration presents the product more conveniently but at the cost of consuming more space. Configurations (b) and (c) occupy more horizontal space than (a) and configuration (c) also occupies more vertical space.

There are several subtypes of carton flow rack, as shown in Figure 2.8:

- Square front, vertical frame flow rack is suited to picking full cases, such as canned goods. (This is a specialized use, however, because it requires full-cases in and full-cases out, which suggests excessive handling.)
- “Layback frame” presents the forwardmost carton more fully to the order picker by reducing the overhang of upper shelves, which might otherwise interfere with picking. This style of rack is suited to picking from open cases when those cases vary in size, such as health and beauty aids; but this rack occupies more space than vertical frame rack of equal capacity.
- Layback frame with front-tilted shelves tips the forwardmost cartons forward at a greater angle so that the entire carton is accessible. This is best suited to picking from open cases when those cases are similar in size, such as liquor or books.

Conveyors. Main points:

- Conveyors change the economics of travel: Storage locations close to the conveyor are, in terms of labor, close to shipping.
- Conveyors partition the warehouse into zones. The track restricts movement of workers and product because it is hard to cross; and so create problems of balancing work among zones. To alleviate this, conveyors are run up high whenever possible.
- Issues: How many products are conveyable? What is capacity, especially surge capacity, of conveyor?
- Guidelines for layout: Store conveyable product far from shipping because it can travel “for free”. Reserve locations that are physically close to shipping for non-conveyables because they will have to be carried (for example, fork lift).

Sortation equipment is an expensive form of automation that is typically integrated with a conveyor system and installed downstream from picking. It is used mostly when picking cartons, because they tend to be fairly uniform in dimension and weight.

A sortation system enables pick lists to be constructed purely for efficiency. For example, if twenty customers all want sku A, it might make sense to send one order picker to pick all the requested sku A in one trip and rely on the sortation system to separate it all out for the customers.
Naturally this requires scanning technologies (bar codes or RFID) and significant IT support for real-time control.

There are many different types of sorters, depending on required speeds and types of material to be handled. One common sorter is a push sorter, which simply pushes a passing carton off the main conveyor and onto an alternative path, such as onto a spur at which an order collects. A tilt-tray sorter is used for material that cannot be easily pushed but can slide, such as apparel. Also, a tilt-tray sorter does not need to know the orientation of the item it carries, while a push sorter typically must know the size and orientation.

Tilt trays serve as both conveyor and sorter; but they must circulate and so must be built as loop. In contrast, a belt conveyor can be run from one point to another and so can be cheaper.

It is a challenge to design an effective sortation system because it must handle a range of sizes, shapes, and textures; and it must have sufficient capacity as well as the ability to handle surges. Another important design issue is to decide how many spurs are required, because this limits the number of orders that can be picked at a time. As with all automation, there is an element of risk: A broken sorter can idle the entire warehouse. There are also challenges in deciding how orders should be assigned to spurs and how recirculation should be managed.
3. Lean manufacturing at General Motors: GM Global Manufacturing System

There is significant evidence that many companies globally are already trying to implement lean manufacturing concepts in their business. Along with Toyota Production System, General Motors also started to develop its own lean philosophy named General Motors Global Manufacturing System (GMS) in 1996 consisting of five principles and thirty-three elements (Figure 3.1).

![Figure 3.1: Global Manufacturing System](image)

Figure 3.1: Global Manufacturing System has been depicted as an atom: the structure contains protons, neutrons, and electrons. Removing one of these will effectively change the structure of the atom. The system was designed with the parts required to work together. It is a fragile system, one that will begin to fail if all of the elements are not in place.

The fundamental goal of any lean system is to improve system performance, to provide more from less, and GMS is no different. General Motors applies lean thinking to all of value streams within GM and uses the Deming’s Plan-Do-Check-Act Cycle (Figure 3.2).

![Figure 3.2: GM’s Product & Service Value Streams](image)

- **Plan** – Plan improvements to current processes / practices
- **Do** – Apply the plan - execution of GMS initiatives
- **Check** – Monitor initiatives to ensure they are achieving performance to the requirements of customers
- **Act** – Standardize the activities that are achieving business results and problem-solving when results aren’t achieved starting the whole cycle again.
The cycle of PDCA is nothing more than a larger method to drive standardized continuous improvement to be shared and improved as the method of implementation driving continued business success. PDCA allows for major 'jumps' in performance ('breakthroughs' often desired in a Western approach), as well as Kaizen (frequent small improvements). A fundamental principle of the scientific method and PDCA is iteration—once a hypothesis is confirmed (or negated), executing the cycle again will extend the knowledge further. Repeating the PDCA cycle can bring us closer to the goal, usually a perfect operation and output.

The PDCA cycle is a common tool used to manage the elimination of waste. The key to eliminating waste is to identify it. GMS categorizes waste into seven types:

- Correction (the effort involved in inspecting for and fixing defects)
- Overproduction (production ahead of demand)
- Motion (people or equipment moving or walking more than is required to perform the processing)
- Material movement (moving products that is not actually required to perform the processing)
- Waiting (waiting for the next production step)
- Inventory (all components, work in process and finished product not being processed)
- Processing (resulting from poor tool or product design creating activity)

Eliminating the seven types of waste helps to improve the company's business in the five categories of Business Plan Deployment (BPD) – safety, people, quality, cost and responsiveness and drive the goal of profit improvement for overall business (Figure 3.3). These are long term categories which do not change much over time. In this way, each department, each area, each group is focused on the same general goals.

Figure 3.3: The balance between results and culture
Each GMS principle and elements are briefly considered in appropriate subsections.

1. People Involvement
2. Standardization
3. Built-in Quality
4. Short Lead Time
5. Continuous Improvement

3.1 PEOPLE INVOLVEMENT
Elements:

1. Corporate Vision & Values
   The Corporation’s desired state as well as attitudes, mindsets, beliefs, and behaviors each of which is critical to the success of the organization.

2. Mission
   A local statement that conveys a mental image of the goal or desired state for a specific plant or function.

3. Health, Safety, & Environment Priority
   Implementation of behaviors, actions, policies, and practices that ensures employees a healthy, injury/illness free environment and environmental management is a manufacturing imperative.

4. Qualified People
   People at all levels of the organization that possess the required profile and skills to perform, thrive, and grow within a competitive manufacturing environment.

5. People Support System/Team Concept
   Small groups of employees that are empowered to function as the owners and basic work unit who share common tasks, support each other, and achieve common goals through continuous improvement.

6. People Involvement
   Systems, procedures, practices, and programs that involve all employees as active participants in continuous improvement activities.

7. Open Communication Process
   Behaviors and practices that create an environment that fosters a free and open flow of communication at all levels.

8. Shop Floor Management
   The behavior of management and support groups to go to where the work is performed, to understand, support, and manage the operations.
3.2 STANDARDIZATION

Elements:

9. **Workplace Organization**
The safe, clean, and orderly arrangement of the workplace environment that eliminates waste provides a specific location for everything, contributes to higher quality, and the opportunity to standardize and increase efficiency.

10. **Management by Takt time**
A measurement system that regulates and levels the production output to meet sales demand:

\[
\text{Takt Time} = \frac{\text{Production time available per period (sec)}}{\text{Customer demand per period (pcs)}}
\]

\[
\text{Actual Takt time} = \frac{\text{System Uptime* (\%)} \times \text{Takt time (sec)}}{}
\]

* System Uptime includes allowance for equipment downtime, production stops, material shortages, quality problems (including Andon stops and non-conforming material), and planned tool/die changes.

11. **Standardized Work**
The documentation of work functions performed in a repeatable/standard method sequence, which are agreed to, developed, followed, and maintained by the functional organization. This work can be divided into two types, Cyclic and Non-Cyclic.
Cyclic Standardized Work: Work consisting of a sequence of job elements that are performed within repeated product cycle throughout the course of a work day.
Non-Cyclic Standardized Work: Work consisting of tasks that are performed according to a prescribed method that consist of many steps that may or may not be followed in a sequence.

12. **Visual Management**
A process in which standards and actual conditions become quickly visual in the workplace.

3.3 BUILT-IN QUALITY

The Built-In Quality Motto:

1. Satisfy your Customer.
2. Solve problems through teamwork.
3. Do not Accept, Build, Ship a Defect.

Elements:

13. **Product Quality Standards**
Measurable requirements for product characteristics, which when satisfied, ensure our products meet internal/external customer requirements.

14. **Manufacturing Process Validation**
The method by which processes are prepared and validated before starting full volume production on new products and post-SOP on current products.
15. **In-Process Control & Verification**
The system of building quality in station through prevention, detection, and containment of abnormalities.

16. **Quality Feedback/Feedforward**
The communication of quality expectations and results between customers and suppliers through standardized communication pathways.

17. **Quality System Management**
Common documentation, practices, procedures, and organizational structure that support managing the quality system.

3.4 **SHORT LEAD TIME**
Elements:

18. **Simple Process Flow**
A process that incorporates a constant drive to attain a simple sequential process flow of material and information.

19. **Small Lot Packaging**
Determining, assigning or designing the appropriate standard quantity and container.

20. **Fixed Period Ordering System/Order Parts**
Pre-determined, fixed period for parts ordering allowing for the effective supply of material on a leveled basis.

21. **Controlled External Transportation**
Scheduled logistics pipeline with established controls managed by a lead logistics provider.

22. **Scheduled Shipping/Receiving**
Transportation carriers arrive/depart at designated time.

23. **Temporary Material Storage (CMA – Central Material Area)**
A fixed part location in a designated area before delivery to the point of use.

24. **Pull Systems**
A replenishment system where the user authorizes the manufacture and/or delivery of a product at a specific time, place, and quantity based on consumption.

25. **Level Order Schedules**
Order Scheduling Method that meets customer demand by incorporating predetermined vehicle order scheduling criteria limits and a no-change schedule time horizon.
26. **Supply Chain Management**  
Process to plan requirements, ensure compliance, and improve the performance of the material pipeline business partners.

3.5 **CONTINUOUS IMPROVEMENT**

Elements:

27. **Problem Solving**  
A structured process that identifies, analyzes, and eliminates the discrepancy between the current situation and an existing standard or expectation, and prevents recurrence of the root cause.

28. **Business Plan Deployment**  
A process that enables the total organization to set targets, integrate plans, and remain focused to achieve company-wide goals and manage change.

29. **Andon Concept Process**  
An operational floor process control system (that can be activated manually or automatically) to communicate the need for assistance when abnormal conditions occur as well as communicate relevant information.

30. **Lean Design of Facilities, Equipment, Tooling and Layout**  
Lean Design is the continuous improvement of facilities, equipment, tooling and layouts that utilizes the best practices of lean manufacturing and enables effective use of the GMS principles and operating practices as a basis to achieve company goals, principles, and key elements.

31. **Early Manufacturing and Design Integration (Design For Manufacturing/Design For Assembly)**  
The utilization of the combined input of design and manufacturing operations in the earliest stages of product and process development.

32. **Total Productive Maintenance**  
An activity to maximize equipment, tooling and machine productivity through the sharing of standardized maintenance responsibilities between maintenance, production, and engineering.

33. **Continuous Improvement Process**  
An improvement process that creates and utilizes the mindset to understand the need and recognize and accept change in order to meet new business challenges and to support the ongoing effort to identify and eliminate waste.
4. Analysis and results

According to Monden (1998), all manual operations fall into one of three categories: pure waste, operations without added value (non-value-adding), and net operations to increase added value (value-adding). Operations without added value is further divided to include essential but wasteful operations that may be necessary under current operating procedures Monden (1998). Hines & Rich (1997) develop Monden’s theory by renaming the categories non-value-adding, necessary but non-value-adding, and value-adding activities. The two definitions both emphasize the waste in product flows and the fact that activities that do not increase value should be regarded as waste; these should therefore be eliminated in order to increase the proportion of value-adding activities in the flow. In manual assembly processes, the dominating value-adding activity is assembly of components to the product. In its stringent interpretation, the value-adding activities constitute a very small portion of time. Thus, in materials supply, it is hard to categorise any activities as value adding, as no value is added to the customer’s product. However, the activities are necessary in order to be able to assemble or manufacture the product. Further, the distinction between non-value-adding and necessary non-value-adding is far from clear with all other that the least resource consuming is wasteful and thereby not necessary non-value adding (Finnsgard et al. 2010).

From perspective of mass manufacturing an application of lean principles are oriented towards the assembly operator and the value-adding activities (Liker, 2004; Monden, 1998; Ohno, 1988). Therefore a materials exposure system should help assembly operators and cater for every requirement without the need for the operator to move away from the assembly object (Baudin 2004, Liker 2004, Wanstrom and Medbo 2009). In addition, container sizes should be adapted to components to help reduce walking distance (Liker 2004).

The challenge is to expose the components for the assembly operator within the space designated for materials at the workstation, while at the same time minimizing non-value-adding work and creating good ergonomics so that operators can achieve high workstation performance (ibid.).

4.1 Production capacity

The capacity of the plant will initially be matched to meet demand from GM Uzbekistan (vehicle plant), with a maximum capacity of 360,000 units a year as demand in the region grows. GM Powertrain Uzbekistan will run on a three-crew, three-shift manufacturing model with six production days a week.

4.2 Supplier footprint

All assembly parts are imported from the remote countries as depicted in the Figure 4.1. These countries are China, Costa Rica, India, Japan, France, South Korea, Netherlands, Russia, UK and USA. The most of parts are transported from South Korea where the material consolidation center is organized.
There are two inbound routes for the transportation of parts from South Korea (Figure 4.2). The first one goes mainly through China, another one – through Russia. The transit time of both routes is approximately 27 days. The outbound route ends in Asaka city where GM Uzbekistan’s vehicle assembly plant is located. Transit time of outbound route takes about one day.
4.4 Plant Material Flow

![Plant Material Flow Diagram](image)

Figure 4.3: Plant material flow: numbers in circles show storage days of the part

4.5 Floor space

The total floor space for the storage is 6577 m². More specific details are given below:

<table>
<thead>
<tr>
<th>Space, m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outbound</td>
</tr>
<tr>
<td>Inbound</td>
</tr>
<tr>
<td>Kitting area</td>
</tr>
<tr>
<td>Other floor space</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

Table 4.1: Total floor space breakdown
<table>
<thead>
<tr>
<th>Storage (Full racks)</th>
<th>970</th>
</tr>
</thead>
<tbody>
<tr>
<td>Empty racks</td>
<td>60</td>
</tr>
<tr>
<td>Office/Team area</td>
<td>42</td>
</tr>
<tr>
<td>Crane, packing &amp; corrosion protection</td>
<td>80</td>
</tr>
<tr>
<td>Prototypes, Spare Parts, Special Sales</td>
<td>70</td>
</tr>
<tr>
<td>BPD, FIFO &amp; Safety Boards</td>
<td>5</td>
</tr>
<tr>
<td>Forklift Parking</td>
<td>50</td>
</tr>
<tr>
<td>Aisles</td>
<td>710</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1987</td>
</tr>
</tbody>
</table>

Table 4.2: Available outbound floor space (shipping area)

<table>
<thead>
<tr>
<th>Storage Area Kitting Parts</th>
<th>620</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage Area Non-Kitting Parts</td>
<td>528</td>
</tr>
<tr>
<td>Overflow – Area</td>
<td>280</td>
</tr>
<tr>
<td>Qty Check / Conformity Check – Area</td>
<td>200</td>
</tr>
<tr>
<td>Receiving Audit Area</td>
<td>45</td>
</tr>
<tr>
<td>Office / Team Area</td>
<td>42</td>
</tr>
<tr>
<td>BPD, FIFO &amp; Safety Boards</td>
<td>5</td>
</tr>
<tr>
<td>Forklift Parking</td>
<td>82</td>
</tr>
<tr>
<td>Scale (20 kg, 2 tons) for Cycle Counts / Checks</td>
<td>48</td>
</tr>
<tr>
<td>Aisles</td>
<td>835</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2685</td>
</tr>
</tbody>
</table>

Table 4.3: Available inbound floor space

<table>
<thead>
<tr>
<th>Shelves</th>
<th>470</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kit conveyor</td>
<td>80</td>
</tr>
<tr>
<td>Kit carts</td>
<td>45</td>
</tr>
<tr>
<td>Label printer</td>
<td>15</td>
</tr>
<tr>
<td>Error proofing</td>
<td>30</td>
</tr>
<tr>
<td>Aisles</td>
<td>145</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>785</td>
</tr>
</tbody>
</table>

Table 4.4: Available floor space for the Kitting area
<table>
<thead>
<tr>
<th>Material On Hold</th>
<th>200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Return</td>
<td>120</td>
</tr>
<tr>
<td>Pilot Store</td>
<td>170</td>
</tr>
<tr>
<td>Obsolete Material</td>
<td>195</td>
</tr>
<tr>
<td>Package – Waste</td>
<td>100</td>
</tr>
<tr>
<td>Dunnage</td>
<td>100</td>
</tr>
<tr>
<td>Aisles</td>
<td>235</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1120</td>
</tr>
</tbody>
</table>

Table 4.5: Other floor space

Container Yard Assumptions:
- 1 Delivery per Week
- 60 Containers per Week @ 300 k
- 180 Full Containers = 2 Weeks min.
- 90 Empty Containers
- Staple Height: Max. 3 Containers on top of each other
- Operating Distance for Reach-stacker: 18 m
- 2 Unloading Docks at Logistics Optimization Center
- Access to both rail tracks for rail unloading

4.6 Workforce

The total number of workers in the material handling team per shift is 24 people. Each shift consists of 2 teams by 12 people in receiving and shipping areas.

<table>
<thead>
<tr>
<th>Shift Leader</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Team Leader #1</td>
<td>1</td>
</tr>
<tr>
<td>6 Shipping / 1 Returning / 4 Kitting</td>
<td>11</td>
</tr>
<tr>
<td>Team Leader #2</td>
<td></td>
</tr>
<tr>
<td>5 Receiving / 1 Yard to Reach-Stacker / 5 to Point of use</td>
<td>11</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>25</td>
</tr>
</tbody>
</table>

Table 4.6: Amount of material handling team members per shift
4.7 Plant layout

Figure 4.4: GMPT-UZ plant layout: general view (a) and assembly & machining lines with number of parts which should be delivered to workstations (b).
4.8 Part Presentation Methods

There are different methods of part presentation to the assembly line:

- Direct feed
- Small lot
- Kit
- Minomi
- Bulk

As it was stated above one of the goals of Lean thinking is a removal of waste and a maximization of value-added content of workstation operator. It is important to provide only the tools and parts they need to do the job without distracting. Therefore it is preferred to deliver parts to operators as much possible in smaller amounts.

Direct feed

Direct feeding is used for connecting two systems with minimal opportunity for manual intervention. Examples can be conveyors (Figure 4.5), Automated Guided Cart (AGC), Shuttle Cart, etc.

![Figure 4.5: Conveyor](image)

Small lot

This method is the most common method of part delivery (Figure 4.6). Requirements:

- Lot size must be as small as possible based on a factor of the number 72 (1, 2, 3, 4, 6, 8, 9, 12, 18, 24, 36 and 72)
- The lot size must not exceed one hour's production based on Actual Takt Time
- Requires return lane for empty dunnage and only one pick face for operator
- Dunnage that can be manually handled

![Figure 4.6: North America Standard GSC Totes](image)
**Kit**

Kitting is a process in which individually separate but related parts are grouped, packaged, and supplied together as one unit. There are two types of kits: simple (Figure 4.7) and engineered (precision).

Figure 4.7: Standard tote with simple dividers (a) and engineered kit which is injection molded in order only correct part fits in correct orientation (b)

Kit holds multiple components for one assembly only, i.e. the same tote cannot hold the same component for more than one assembly. For example, if one tote holds two chain and sprockets, this is not a kit; at best, it is a “composite small lot”. Kit must be capable of traveling with assembly as required.

**Minomi**

“Minomi” is a unit load where no container is used (Figure 4.8). It translates as “a peanut without a shell”, i.e. a part without packing (e.g. rack, cart, tree, cassette).

“Powertrain Minomi” (e.g. Christmas Tree Minomis) Requirements:
- Must FIFO Minomis and FIFO within Minomis (including carts)
- Standardized work to load and unload Minomis
- Label part positions/lanes
- Minimal layers (layers increase sediment); layers must be divided to reduce sediment
- Quantity of parts a factor of 72
- Standards for each part type (Brad Rife)

Figure 4.8: Examples of standard (Flywheel) and composite Minomi (GF6 pump, Front Differential Ring Gear & Filter)

**Bulk**

Bulk parts have large sizes and can be heavy (Figure 4.9). Therefore it is difficult to maintain a true FIFO process.

Figure 4.9: Pallets
4.9 Part Presentation according to Decision Tree

First of all, it is necessary to determine the area for analyzing (machining, sub-assembly, kit assembly, final assembly, etc.). Then, for each component within a workstation (one component at a time), find out the source (i.e. where does the component come from?). Next, the decision tree tool is used in determining containerization and presentation.

Factors Impacting Part Presentation Decisions:
- Layout / Footprint
- Capital Cost
- Quality Concerns with Repack
- Volume / Takt Time
- Part Size, Weight, Orientation
- Error-Proofing Requirements
- Proliferation
- Automated Assembly
- Pack Density

There are two main Decision Tree Tools: Simple Excel Matrix (Figure 4.10) and VB Software. In addition, Set Part Strategy (SPS) Reference Guide is also used (Figure 4.11).

<table>
<thead>
<tr>
<th>Rank</th>
<th>Part Presentation</th>
<th>Build Plan</th>
<th>Criteria Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>Precision Kit</td>
<td>Sequenced</td>
<td>Is the size or weight of the part prohibitive for lifting? Is it impossible or cost prohibitive to get the part direct from the supplier in a precision kit? Is the quality of the part be compromised if repacked?</td>
</tr>
<tr>
<td>8</td>
<td>Minomi</td>
<td>Mix Sequenced</td>
<td>Is part proliferated? Does part presentation exceed floor space requirements within the footprint? Is it impossible or cost prohibitive to get the part direct from the supplier in minomi? Is the quality of the part be compromised if repacked? Is there a quantifiable advantage to repack into Minomi vs. bulk?</td>
</tr>
<tr>
<td>9</td>
<td>Minomi</td>
<td>Sequenced</td>
<td>Does part presentation exceed floor space requirements within the footprint? Is it impossible or cost prohibitive to get the part direct from the supplier in minomi? Is the quality of the part be compromised if repacked? Is there a quantifiable advantage to repack into Minomi vs. bulk?</td>
</tr>
<tr>
<td>10</td>
<td>Bulk</td>
<td>Sequenced</td>
<td>Does part presentation exceed floor space requirements within the footprint? Does standard pack quantity disrupt planned production by site?</td>
</tr>
</tbody>
</table>

Figure 4.10: Simple Excel Matrix
A Pull System is a type of production system used in Lean Production in which production is triggered by demand. Usually when an item, or small batch of items, is 'consumed' a kanban triggers replenishment. Kanbans 'pull' product through each stage of production. This differs from a traditional 'push' system where production is scheduled to meet anticipated demand, and then 'pushed' through production as quickly as possible. Push systems usually generate too much inventory and items that should have priority are often delayed behind items that are less urgent.

PPS reads the model option specification of a vehicle being built to determine the part requirements for that vehicle. As the vehicle moves throughout the plant a tracking image will compare data to the part specs and order material as it is consumed. PPS automatically orders those consumed parts to the line from the material storage location (DLOC) via an electronically generated list. PPS is commonly used for small lot or hand tote parts but may be used for bulk material as well in a process referred to as “mini bulk”. Using the mini bulk process levels material requests to the off-site and lessens the in-plant inventory and storage area.

The off-site location receives pick lists at determined intervals throughout a shift. The bulk material on the list is picked and shipped to the plant during scheduled delivery windows. PPS will only order bulk from the off-site to the in-house storage location. Bulk material replenishment to the ULOC (lineside) will continue to be processed via pendant pushes (Electronic Pull System).
How it works?
1. As a vehicle moves into General Assembly, the model option specification is automatically read by a bar code scanner and electronically recorded into the tracking image.
2. When the vehicle enters a region in an operator’s station, the model option specification is compared in the system to the parts routed to that station.
3. For each part number used at that station, the PPS inventory will count down the quantity of parts that have been used based on the engineering specifications.
4. Once the PPS inventory has counted down to zero the system orders a new box of parts from the material storage area (DLOC). The inventory then resets to a standard pack quantity and continues to count down.
5. At specific times throughout the day the system transmits material requests to the DLOC. A pick list and delivery list prints out and the orders are picked and placed onto the platforms.
6. The route driver delivers the parts according to the delivery list and verifies the lineside inventory levels at all using locations (ULOC) along his route. The driver will complete multiple delivery cycles per shift.

Benefits of Production Pull System:
- Provides problem solving tools – Reports can be generated from the PPS system that provides history and trends of part consumption to root-cause problems.
- Drives standardized work – If standardized work is not followed, gaps and issues become visible.
- Levels consumption requests – Material orders are system generated, not people generated, which reduces spikes or lulls in material orders. This also maximizes efficiency of the material delivery driver and picker.
- Helps error-proof vehicle build – Material will build up or run out if part data, specs, or routings are not correct. This will draw attention to the problem for resolution.
- Reduces premium transportation costs – Lineside inventory is set up and managed so that plenty of reaction time is available if a part number is in danger of running out.

4.11 Kanban

Kanban, also spelled kamban, and literally meaning "signboard" or "billboard", is a concept related to lean and just-in-time (JIT) production (Figure 4.12). Kanban is a communication method to ensure the replenishment of used material/parts based on consumption. It is similar to a work order which gives information concerning what to produce, in what quantity, where to store it, and the type of container to be used. It is used to set priorities in production, prevent overproduction, and ensure the right material at the right time is replenished.
4.12 First-In-First-Out (FIFO)

FIFO is an acronym that stands for “First-In-First-Out,” meaning the oldest parts/products should be used or shipped first. FIFO attains a sequential flow of material to ensure traceability which is a key to containing quality and reducing the timeframe for problem solving /reducing defects (Figure 4.13). FIFO used for repacking, kitting, buffers, work in-process (WIP), overflow, and staging areas.

Facility Layout should support natural and continuous FIFO through the use of “Flow Thru” storage and lanes; otherwise, a FIFO rotation schedule is necessary.

![Figure 4.13: Daily Single Lane Flow FIFO](image)

Whenever the flow of a single part is disrupted (e.g. repacking it into another container, placing it in an overflow area, using it as a buffer, using it in a subassembly area, placing it in a material storage area), there must be a way to get the part back into the main product flow. This is accomplished by having good FIFO processes in storage areas, subassembly areas, overflow areas, kitting areas, and staging areas.

As an example, the engine FIFO process is shown below:

![Figure 4.14: Engine FIFO process board. Layout of Main storage area displayed on board. Colored and numbered magnets created to show engine models. “Star” magnets to show which row should be shipped next.](image)
Advantages:

- **Flexibility** - Use of entire storage area
- The visual display of engines that should not be shipped eliminates unnecessary handling and staging of engines, having to return them to storage and replacing them with engines not affected by containment.
- FIFO board provides a quick visual way to assess the engine inventory status. The board determines where and when engines will be stored, retrieved and shipped to the customer.
- Easy to audit and correct by re-arranging the sequence of the magnets.
- Can track the oldest engine easily.
- Easy and Quick way to Forklift operator to identify different lanes visually.

### 4.13 Min/Max System Process

Min/Max Process specifies minimum and maximum inventory levels for the assembly components (parts) on the storage (Figure 4.15). Its calculation depends on the inventory model: min/max quantity is defined differently. In some model the min/max is dynamic. For example, in probability model, minimum is the safety stock, which is calculated based on the sigma or the demand volatility during replenishment time with a confidence level, say 99.97%, the maximum is the safety stock plus average demand during the lead time. If monthly average demand is 30 unit, sigma is 3, and replenish lead time is also 30 days, 99.7% coverage is 9. Therefore, minimum is 9 and maximum is 39.

![Figure 4.15: Basic information of the part along with Min/Max level](image)

### 4.14 Plan for Every Part Data File

Plan for Every Part (PFEP) is a database for every part number entering the plant that contains the part’s specifications, supplier, location of supplier, storage points, point of use, rate of usage, and other important information.

![Figure 4.16: Plan for Every Part (PFEP)](image)
4.15 Routes

Routes were arranged logically according to the number of parts which should be delivered to workstations (see Figure 4.4b).

Figure 4.17: Preliminary routes
### 4.16 Mobile equipment

Below is given different types of mobile equipment used by material handling teams.

<table>
<thead>
<tr>
<th>#</th>
<th>Pcs</th>
<th>Vehicle</th>
<th>Tonnage, ( t )</th>
<th>Usage</th>
<th>Picture</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Sit-on Tow Truck</td>
<td>6.0</td>
<td>Dolly transport to Heads line</td>
<td><img src="image1.png" alt="Picture" /></td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>Forklift truck</td>
<td>3.5</td>
<td>Move Incoming Materials to Storage</td>
<td><img src="image2.png" alt="Picture" /></td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>Forklift truck</td>
<td>3.5</td>
<td>Move Materials from Storage to Point of Use</td>
<td><img src="image3.png" alt="Picture" /></td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>Forklift truck</td>
<td>3.5</td>
<td>Move Materials to Reclaim Sites (Metal and Sand)</td>
<td><img src="image4.png" alt="Picture" /></td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>Forklift truck</td>
<td>1.6</td>
<td>Unload containers</td>
<td><img src="image5.png" alt="Picture" /></td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>Forklift truck</td>
<td>4.9</td>
<td>Rack handling</td>
<td><img src="image6.png" alt="Picture" /></td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>Forklift truck</td>
<td>4.9</td>
<td>Rack loading</td>
<td><img src="image7.png" alt="Picture" /></td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>Stand-on Tow Truck</td>
<td>3.0</td>
<td>Intern transport</td>
<td><img src="image8.png" alt="Picture" /></td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>Walkie (lifting)</td>
<td>1.6</td>
<td>Re-packing</td>
<td><img src="image9.png" alt="Picture" /></td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>Burden Carrier</td>
<td>2.0</td>
<td>Internal transport</td>
<td><img src="image10.png" alt="Picture" /></td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>Reachstacker / Diesel powered</td>
<td>45.0</td>
<td>Container yard</td>
<td><img src="image11.png" alt="Picture" /></td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>Terminal Truck &amp; Trailer</td>
<td>40,0</td>
<td>Container yard</td>
<td></td>
</tr>
<tr>
<td>----</td>
<td>----</td>
<td>--------------------------</td>
<td>------</td>
<td>---------------</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>Forklift truck</td>
<td>45,0</td>
<td>Container yard</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.7: Number of mobile equipment

Material delivery strategy (but it has direct impact on resources (structural cost) is impacted by:
– Delivery Distance
– Material replenishment frequency
– Material replenishment method
– Type of equipment
– Aisle size

Material replenishment frequency to workstations was set one time per hour which helped to make assumption about hourly usage of parts.

4.17 Delivery methods

There are various types of equipment for the conveyance of parts to workstations. Here is given some examples:

Figure 4.18: Small Lot Delivery Dollies (a, b), Elevated Roller Deck (c), Tug Delivery (d)
4.18 Storage area

Figure 4.19: Examples of storage area: Lineside storage (a), Central Materials Area (b), Scrap parts storage area (c), Engines in Shipping zone (d), Buffer zone (e), Kitting area (f)
Conclusions

The overall aim of this research was to explore the impact of design parameters on material flow efficiency in terms of space and time utilization. The specific research objectives were, within the context of lean manufacturing, to:

(i) identify the forces driving and the barriers to the successful factory material flow process.

(ii) critically evaluate the models and frameworks relevant to the defined targets.

(iii) investigate best practices (benchmarking) related to factory material flow.

(iv) formulate recommendations based on practical findings.

The key design parameters for material flow efficiency of the plant found to be an optimal storage layout, effective conveyance of parts to workstations according to production level, optimal amount of material handling staff, a waste elimination and a continuous improvement.

As a result of this research project a simple process flow was applied for the satisfaction of demand by customers, several models were experimented by carrying out benchmarking with assembly plants of GM India and GM Korea and finally, the temporary optimal model was proposed and implemented. For future work it is recommended to optimize the material flow process through the line balancing, time-sequencing and simulation.
References


