Automated or Self Guided Vehicles (AGV/SGV) are computer-controlled “driverless” mobile vehicles (normally battery operated) equipped with optical, magnetic or laser guidance systems for automated functionality, categorized as either load carrying (forked, mandrel, unit load deck, etc) or load towing (tugger, tow train). Automated Guided Vehicles are recommended for applications wherein long-distance horizontal transport of materials is required from or to multiple destination points and/or the requirements for material transport include repetitive/predictable and/or dangerous tasks. AGVs also have several advantages inherent to their design, such as the reduction of product damage from removal of human error, the ability to travel into hazardous areas without concern for operator safety, the ability to automatically track and record product movement, the reduction of labor, and the flexibility and adaptability especially prevalent in laser guided systems.

The decision as to the proper vehicle type is extremely important when designing an AGV system. The first vehicle type to be discussed is a Deck AGV, which is categorized as a unit load-carrying AGV. This vehicle type uses a variety of deck-top mechanisms that can be used to carry and transfer the unit load.

Typically, the load is carried on top of the vehicle via a customized deck mechanism. The deck serves as the load-carrying device as well as the mechanism for conveyance of the load during transfer to the pick-up and deposit (P&D) stand. P&D stands can be conveyor systems that communicate with the vehicle via “handshake” sensors during load transfer. There are also applications where the vehicle drives under or next to a static P&D stand and the deck mechanisms either lifts or shuttles the unit load onto the “non-intelligent” stationary platform. An additional advantage of a deck-top AGV is the ability to carry multiple unit loads, thereby increasing the throughput and efficiency of the system. (This advantage could also result in reducing the number of vehicles required for the system). When interfacing with the P&D stand, deck AGVs are typically parallel to the direction of the travel aisle, thereby minimizing aisle contention during load transfer.

The second vehicle type, also a unit load-carrying vehicle, is a forked AGV. Conventional forked vehicles have standard fork truck masts (hydraulic or ball-screw) and forks integrated into their design. Interface between the AGV and load is made via the pallet or container fork pocket.

Pick-up and deposit (P&D) points can be on the floor or at a height above the floor. A significant advantage of a forked AGV is its ability to interface with conventional/existing storage rack systems. Typically, these vehicles will require a more extensive sensor array than other types of AGV. Additional advantages of a forked-style AGV include its ability to store and retrieve unit loads from multi-level storage racks and its integration with standard pallet platforms (CHEP, GMA pallets). Roll-handling forked vehicles have forks that rest under the unit load (roll). Typically, the forks are tapered and adjustable for roll handling applications to minimize product damage and accommodate varying roll diameters.

A mandrel (“ram”, “rhino”) vehicle has similar functionality and design to forked vehicles and has standard lift mechanisms (hydraulic or ball-screw) integrated into its design. Interface between the AGV and roll load is made via the core of the roll. Pick-up and deposit (P&D) points can be on the floor or at a height above the floor. Typically, the mandrel will have a sensor array that can locate varying heights of insertion for varying roll diameters or if settlement of the roll has lowered the core center.

The third type of vehicle is categorized as a load-towing vehicle. The tugger, or tow-train AGV, has a design similar to standard tow tractors. Interface between the AGV and load (cart or dolly) is made via a coupling device (i.e. “pin and clevis”). Pick-up and deposit (P&D) points can be a designated parking location on the floor or a staged location adjacent to a P&D stand for automated transfer. There are numerous designs for the carts and dollies used in conjunction with the load towing (tugger) AGV and are typically custom to the application. There are also numerous
coupling designs (automatic and manual) used to facilitate the interface between the vehicle and trailing equipment. An additional advantage is the tugger’s ability to tow a long train of carts, thereby drastically decreasing the number of vehicles required to meet system throughput requirements.

There are many variations of these vehicle types and the optimal design solution is contingent on the specific application. One important consideration is the inherent flexibility with designing a system with one universal vehicle type. Once the decision about the proper vehicle has been made, a few fundamental questions need to be answered to properly design the AGV system:

**What will the AGV carry or tow (load definition)?**

There are many characteristics of the load that should be defined early in the system design effort. It is important to consider designing the vehicles with the capability of handling any increased size or weights anticipated in future production or processes. Load definition characteristics to consider are (note that all characteristics do not apply to all vehicle types): load weight, cumulative load weight for all trailing loads, load size, pallet definition, pallet overhang, fork pocket definition, center of gravity, core size, cart or dolly type and connection device.

**How many trips will the AGV have to make (system throughput)?**

System design should include a to/from matrix that indicates how many loads the AGV fleet will carry from all load origin points to all load destination points. This matrix should clearly define all current volume and the design volume anticipated. The system design should consider exceptions to “normal” throughput (damages, rejects, etc) and whether the cost implications (fleet size) are justified or if auxiliary vehicles (fork-trucks) are available to handle the exceptions. The peak volume of product movement should be understood so that there will not be a “starvation” of downstream activity due to an undersized fleet. Consideration should also be given to designing the vehicle with a load-carrying or towing mechanism that can handle multiple loads, especially if the travel distance is substantial. Additionally, the proper contingencies (blocking percentage, battery charging, etc.) should be figured into system throughput.

**Where will the AGV vehicles carry the load from/to (route/traffic planning)?**

It is important to consider all auxiliary traffic (fork trucks, personnel, etc) when planning AGV routes. The minimization of traffic congestion, vehicle “dead-lock” and blocking zone delay can prove significant with regard to delivery reliability. It may be cost-effective to widen aisles and/or doorways to allow two-way AGV traffic, thereby keeping the vehicle count to a minimum.

Certain AGV types provide an advantage over others with regard to perpendicular versus parallel interface orientation. In other words, a forked vehicle will typically deposit a load at a P&D stand while perpendicular to the aisle. This aisle contention can be increased when the interface design does not allow the vehicle outriggers under the conveyor. An AGV design that stops the entire vehicle at the face of the conveyor and extends the fork carriage will further block the aisle. This requires wider aisles, if there is a desire to have multiple vehicles pass one other while interfacing (minimize blocking percentage), or locating the P&D stands off-aisle (more facility square footage). A unit load deck AGV can maneuver to the P&D stand while remaining parallel to the aisle, thereby minimizing aisle requirements and blocking.

There should be several locations within the AGV system for parking idle vehicles (no assigned tasks). Typically, these queues are located to provide the quickest response time to the next anticipated or highest priority tasks. In other words, if a vehicle has completed a task and has no further tasks in the queue, it should proceed to a parking area closest to a priority “1” move.

Battery charging of an AGV is similar to that of conventional fork trucks. Swap systems, where depleted batteries are swapped in a battery handling area with fully charged batteries, and Opportunity Charging Systems, where vehicles park and charge at various charging locations when the opportunity arises, are both available. The preferred system for a given operation is application-specific. Typically, a vehicle will be sent to the charging area when the battery level has reached a certain percentage of depletion or during off-work shifts. In addition to the volume/velocity data mentioned above, the to/from matrix should not only indicate how many loads the system will carry, but where and how far the AGV will travel for each “mission”. This will affect the frequency with which battery charging must be performed.

**What is the proper guidance method?**

Fixed path (floor wire, magnetic tape, reflective tape) guidance is beneficial when the system path is well defined, simple and permanent. Open path (laser, inertia) guidance provides significant benefit with regard to path flexibility. If there is a possibility of future expansion and or route modifications, it makes sense to target those areas during initial site survey and
target installation. Semi-fixed (magnetic) guidance, wherein magnets are embedded in the floor at the extents of the intended vehicle path, allow a small amount of “free-range” vehicle movement between magnets, but do not allow vehicle travel outside the magnet-defined boundaries. An encoder typically tracks vehicle position, using odometry or dead-reckoning.

It is imperative that the proper conductive floor/aisle paint be used in the facility if planning to use an Automated Guided Vehicle System. Accumulation of static electricity on the vehicles from a non-conductive surface can be detrimental to vehicle performance. Static elimination straps should also be used.

**What will the AGV’s be interfacing with?**

Interface design is an integral part of the AGV System. The type of interface and all design detail should be understood prior to final vehicle design. In addition, all interface locations must be established prior to simulation so that load transfer time, blocking and vehicle routing can be established. Conveyor (or automation) interface uses a “handshake” sensor array. Upon arrival at an interface, the AGV will communicate with the interface via “handshake” sensors located on the interface and on the AGV. The interface will communicate to the AGV that it is ready for interface and the AGV will communicate that it is positioned properly for pick-up or deposit of the load. The speed of the rollers on the vehicle should be synchronized with the speed of the rollers on the interface. Static Position Interfaces (stands, floor) are typically loaded or unloaded with manual equipment. Therefore, there must be design considerations to insure controlled placement of the load. For example, if a manual fork truck retrieves a load from a rack system and deposits it on a static stand, the load must be positioned accurately via guide rails.

**Is a simulation required?**

A time based computer simulation of the entire AGV System (including coexisting systems, such as vehicle interfaces and non-AGV mobile equipment) should be developed to demonstrate the operation of the system design under anticipated operating conditions. The simulation model should be data-driven to allow the model to be run under different operating conditions (i.e. sensitivity testing).

The simulation should be completed after the layout is finalized and all pick-up and deposit stations are finalized. The vehicle traffic management (identification of blocking between vehicles) is critical to simulation results. Modeling activities should at a minimum address:

- Number of Vehicles Required
- Vehicle Utilization
- Material Transport
- Dry Haul (Dead Head)
- Battery Charging
- Idle Queue
- Vehicle Performance Characteristics
- Acceleration, Deceleration, Average Velocity

The control algorithms utilized in the simulation must reflect the algorithms that will be utilized in the System. The analysis report shall, at minimum, include explanations of:

- Traffic Control
- Routing Decisions
- Resource Management
- Communications
- Vehicle Performance Descriptions (i.e. acceleration, deceleration, velocity, etc.)
- Vehicle Downtime
- Charging Details and Recommendations
- Idle Vehicle Queue Location
- Traffic Congestion and Blocking
- Shortest Route Versus Traffic Minimization
- Facility Modification in High Traffic Areas
- Load Transfer Time
- Maneuvering Decisions
- Pivot Turns versus Radius Turns
- Simulation Duration

**Long Lead Time Components**

The most critical issue regarding schedule is the long lead time required for procurement of the vehicle masts, drives, forks and frames. It is not uncommon for these items to require six to eight months of lead-time. Therefore, it is imperative that the vehicle design be finalized as soon as possible. In summary, one (1) year or twelve (12) months should be allowed for project implementation from award of vendor contract.

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