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COMPLEXITIES OF AGV MODELING IN NEWSPAPER ROLL DELIVERY SYSTEM

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ABSTRACT

Swisslog Logistics Inc., a leader in Automated Guided Vehicle (AGV) technologies, proposed to update a major Northeastern newspaper company's AGV press delivery system. The project requirements included the development of a simulation model to confirm the proposed vehicle quantity and controls as well as evaluate the performance of the AGV system in response to press changeovers, peak production, and weekly production scenarios

The model provided Swisslog and its customer with the capabilities to evaluate dynamic vehicle scheduling, task priorities, press changeover requirements, vehicle routings and battery charging logic. This paper shall present the concepts and techniques used to model the detailed AGV components necessary to successfully meet the project's objectives.

1 INTRODUCTION

The operations surrounding the supply of paper rolls to the presses is a very dynamic and time-critical function. The ability to keep the presses continually running is essential in the newspaper industry. Minimizing press downtime is a requirement in meeting the distribution and circulation demands to maintain a competitive advantage in the industry.

In an effort to improve performance and provide the foundation for future growth, a major Northeaster newspaper company contracted with Swisslog to evaluate replacing its twenty year old AGV system with up-to-date vehicles and controls.

The new system must be able to support the current operations of six (6) presses with the ability to be expanded to support the future growth to eight presses. Key performance requirements and design criteria set by the customer included the following:

- Press changeovers must be completed within twenty minutes;
- Vehicle moves must be completed within 10 minutes of task request;
- Batteries could not be charged during changeover or peak performance scenarios.

The following paragraphs summarize the AGV system operations, the modeling approaches used, and the simulation results that demonstrate Swisslog's solution to meet its customer's needs.

2 SYSTEM OVERVIEW

During newspaper production, various paper rolls are supplied to the presses based on the current newspaper being printed. A single press may have as many as 10 reelstands where paper rolls are delivered during a print run. The following paragraphs summarize the major system components and material flows.

2.1 Roll Sizes and Container Types

Newspaper rolls enter the press area from the production area. Typically three sizes of newspaper rolls are used in the print operations as described in Table 1.

Table 1: Paper Roll Sizes

Description	Characteristics
Full Paper Roll	50 inches wide by 54 inches long
¾ Paper Roll	50 inches wide by 40.5 inches long
½ Paper Roll	50 inches wide by 27 inches long
Butt Rolls	Full, ¾, ½, partial roll remainder

The "Butt" roll described in Table 1 is generated when a press changeover occurs and the current roll on the press is removed. This "partial" roll, also known as a butt roll, is removed and stored for reuse when a press changeover occurs requiring that butt roll's paper width.

All rolls are moved via AGV from the production area to either the presses or storage areas. Two other container types that are required to be moved by the AGVs are waste and core containers. Waste containers are filled at the presses when rolls are delivered in preparation for processing. Core containers hold the tubes or cores from the empty rolls generated during the press run.

2.2 Laydown (Storage) Area

Rolls from the production area, not destined for the presses, are stored in one of thirty-two (32) laydown lanes. Only one roll type could be stored in each lane. The rolls are retrieved from each lane using Last-In-First-Out (LIFO) storage methodology. Each lane could hold 10-15 rolls depending upon the roll length. Figure 1 depicts a series of the simulated laydown lanes.

2.3 Press and Reelstands

The Press area consists of 6 presses. Each press can simultaneously run a maximum of 10 paper input locations called reelstands. The number of reelstands in use on each press depends on the current paper being printed. Each reelstand can hold a maximum of three paper rolls; the roll currently feeding the press and two staged rolls. Each reelstand is setup to run a single roll size (i.e. full, ¾, or ½ size roll).

AGVs must crab (travel sideways) into the reelstand load location to position the roll in the proper orientation for loading into the reelstand. During normal operations of newspaper production, a replacement roll is requested from storage when a roll is consumed at a reelstand. A roll would typically be consumed at a rate of 1 roll per half hour per reelstand in use.

During the changeover of a press, AGVs must remove the staged roll(s) at the reelstand prior to removing the partial roll (or Butt Roll) that was feeding the press. After removal of these 2 to 3 rolls, AGVs can deliver the new rolls needed for the next press run.

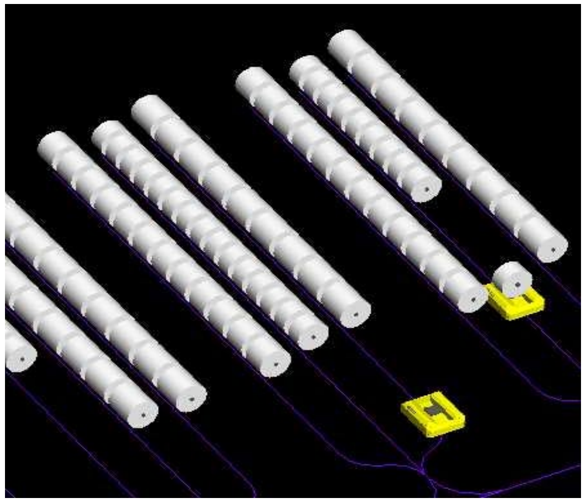

Figure 1: Simulated Laydown Lane Configuration

2.4 Charging Requirements

A critical element in the operations of the press delivery system is the monitoring of the battery levels on each vehicle. Swisslog proposed to use opportunity charging locations strategically located within the facility. Charging locations existed at each press as well as in the laydown areas. An existing charging room provided the extra locations needed for the vehicle fleet.

Vehicle charging was permitted during normal weekly operations. Vehicle charging was prohibited during peak periods and during press changeovers.

3 VEHICLE AND GUIDEPATH REQUIREMENTS

The following section presents some of the system requirements and complexities of the AGV system to be modeled. Figure 2 depicts the AutoMod™ simulation of a Swisslog's Automated Guided Vehicle carrying a ¾ size paper roll.

3.1 Vehicles

The AGV system is required to handle all of the movement of the three types of paper rolls. The vehicles move the rolls between the production (also known as prep), laydown, presses, and butt roll stands. Only one roll is handled by a vehicle at a time. The vehicles are capable of making dynamic vehicle decisions which are used to minimize the request to completion times.

The vehicles are slightly higher on one side making vehicle orientation very important. The presses/reelstands can only be serviced when the short side of the vehicle is facing the press. Some rerouting of the vehicles is required

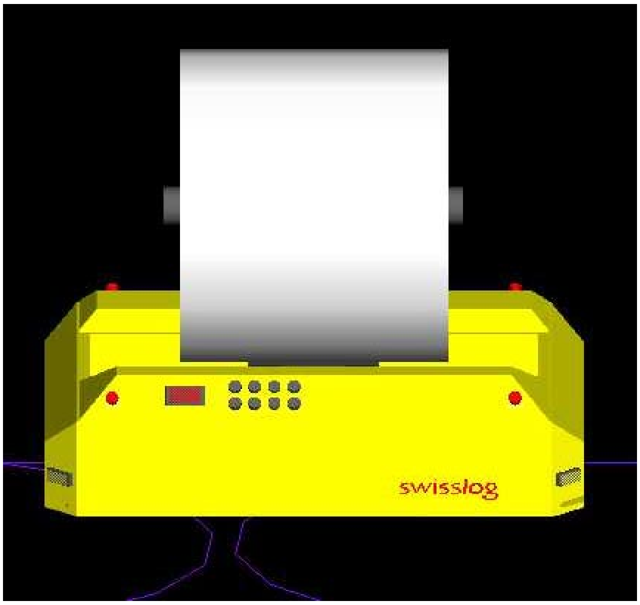

Figure 2: AutoMod Animation of Swisslog Vehicle

in order to ensure correct vehicle alignment for proper roll presentation to the reelstand.

3.2 Guidepath

Within the system, the guidepath consists of both one-directional and bi-directional track. Tight vehicle control is necessary to avoid collision or vehicle deadlocking.

Parking and charging locations are placed at several points along the vehicle's path. Bumping logic, the process of moving a parked vehicle, is used to allow vehicles to continue uninterrupted with their current task in an effort to minimize response times.

Vehicles crab on the spurs that lead to reelstands, waste stands, and butt roll stands. The vehicles are delayed at the beginning of each of these spurs for communication and vehicle alignment prior to crabbing.

3.3 Charging Requirements

The vehicles require battery recharging based on movement time. Vehicles can take advantage of opportunity charging locations or if their battery level is critical, they may be sent to the charging room. During peak periods and changeovers, the system will prevent vehicles from going to charge. The system will also force all vehicles to go charge, e.g. at the end of a shift. Table 2 summarizes the details built into the model to accurately represent battery depletion based on vehicle tasks and speeds.

Battery charging rates (amps/hour) were based on the current charge level of the battery. Figure 3 displays the rates incorporated into the model.

Battery Data	Battery Level (Ah)
Capacity	240
Emergency Charg	72

Tasks	Current (Amps)	0 - 99 ft/min	100 - 149 ft/min	150 - 200 ft/min
Loading	40			
Unloading	4			
Idle	3			
Traveling Empty		10	14	16
Traveling Loaded		13	20	24

Table 2: Battery Depletion Rates Built into the Model

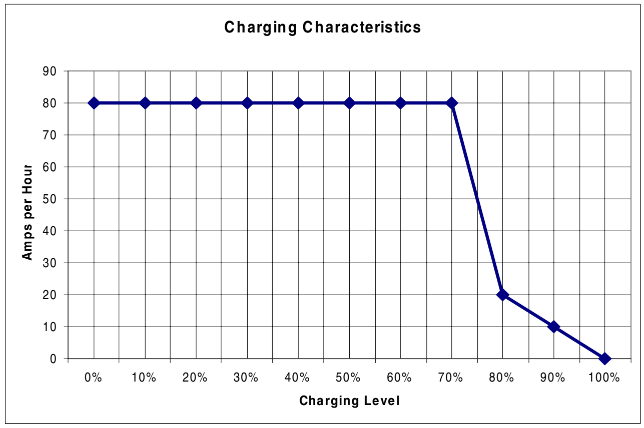

Figure 3: Battery Charging Rates

4 MODELING COMPLEXITIES

The following paragraphs summarize some of the complex modeling issues incorporated into the simulation model.

4.1 Dynamic Vehicle Assignments and Rerouting

Rolls enter the system at the production/prep area and try to go to an available press. If there are no presses that currently need that type of roll, the AGV will start to move towards a laydown lane. All vehicles in route to the laydown area are tracked on a list based on the type of roll they are carrying. If a request for roll is issued at a press for a roll that is currently being delivered towards laydown, then the closest vehicle (if multiple AGVs carrying the requested roll type) will be rerouted to the needy press.

This is true of vehicles carrying rolls to any location other than a press. Once a vehicle is traveling with a roll towards a press, it will not be rerouted to another press. Empty vehicles can also be rerouted. If an empty vehicle is traveling to a park location and a roll needs to be picked up, the vehicle will be rerouted to the pickup location.

This type of vehicle rerouting cuts down on the time it takes to fulfill a press' request. It is a system requirement to keep this time below 10 minutes. Dynamic vehicle scheduling allows the system to met this requirement.

4.2 Vehicle Orientation, Handshaking, and Alignment

Due to the asymmetrical shape of the vehicles modeled, vehicle orientation is critical. Vehicles can only enter a reelstand from one direction. Before entering the path in the press leading to a reelstand, the vehicle's orientation is checked. If it is wrong, the vehicle is rerouted to enter the press from the other side.

Once the vehicle enters the press, it must stop before entering the spur leading to the reelstand to allow a handshaking event to occur before crabbing. This must also happen before a vehicle crabs into a waste stand or a butt roll stand.

At the base of the reelstand, the vehicle must take another delay in order to establish the correct alignment for picking up or unloading a roll. An alignment delay is also taken in the laydown area, just before picking up or delivering a roll.

4.3 Battery Charging

As a vehicle travels through the system, its battery level is adjusted based on the activities it performs and how fast it travels. A timer is kept on each vehicle to determine how long it has been in its current state. When the state changes, this timer is used to deplete the battery. A detailed schedule of how a battery is depleted based on state is shown in Table 2.

There are charging locations placed around the system. There are eight locations in the charge room, one location at each press in the crossover lane, one location at each of the four prep lanes, and one location at the head of each set of three laydown lanes. Opportunity charging can be utilized by having the vehicles park at these locations. However, if a vehicle's battery hits a critical level, the vehicle will be sent to a charging location as soon as it finishes its current task.

At each charge location, the amount of battery recharge is determined by how long the vehicle is at the location as well as the level of the battery when it begins to charge. A minimum time must be taken in order to receive any charge at all. There are enough charge locations in the system for every vehicle to charge at the same time.

5 RESULTS

The following sections summarize the simulated system's results. Simulation scenarios were executed with various quantities of vehicles and multiple replications for statistical validity. In analyzing the three scenarios, the key performance and design criteria for determining a successful system design were:

1. Press changeovers must be completed within 20 minutes.
2. The AGV system must be capable of completing all transactions from the time the move is requested to delivery within 10 minutes.
3. Battery levels must be sufficiently maintained during changeover and peak production periods as to not impede system performance.

5.1 Changeover Scenario

The requirement placed on the AGV system during a changeover was to be able to changeover 2 reelstands on 6 presses (total of 12 reelstands) within twenty minutes.

During the press changeover cycle, vehicles were prohibited from charging or picking up rolls from productions. Table 3 displays the changeover durations for this scenario utilizing 18 to 24 vehicles.

Although all of the vehicle combinations performed well, Swisslog thought that twenty one vehicles with a twenty second spare vehicle would provide its customer with more than enough capability to meet the changeover and delivery demands.

Table 3: Changeover Duration and Delivery Times for Changeover Scenario

Vehicle Quantity		18	19	20	21	22	23	24
Changeover Duration	Average	19.1577	17.7125	17.7903	17.9879	17.0387	17.3285	17.0617
	Std. Dev.	1.45996	0.753182	0.677861	1.63376	0.927239	1.16962	1.39987
	Minimum	17.0457	16.725	16.7399	15.7782	15.7846	15.6818	15.1598
	Maximum	21.7209	18.8138	18.8726	20.4199	18.6308	19.069	19.2224
	Median	18.71265	17.83475	17.75005	17.842	16.94915	17.00285	16.9884
	# of Runs	10	10	10	10	10	10	10
Delivery Time in Sys.	Average	6.3192	6.122	6.1006	5.9729	5.9749	6.1391	6.1289
	Std. Dev.	0.20614	0.1699	0.15269	0.17472	0.11312	0.20822	0.22435
	Minimum	6.0703	5.9421	5.9207	5.683	5.7171	5.8243	5.8942
	Maximum	6.7737	6.5028	6.4102	6.2143	6.0891	6.4845	6.5169
	Median	6.2673	6.05685	6.06465	5.9724	5.99325	6.0938	6.0479
	# of Runs	10	10	10	10	10	10	10

5.2 Peak Production Scenario

The simulated system was required to demonstrate the performance of the Swisslog AGV system solution under a three hour peak production scenario. The peak performance period consisted of the AGV system supporting the delivery of 120 rolls per hour to the presses (6 presses running 10 reelstands per press) as well as retrieving up to 40 rolls per hour from the production area. Table 4 summarizes the total AGV transactions during a simulated peak production run utilizing 21 vehicles.

Table 5 summarizes the delivery performance of the AGV system during the Peak Period of operations.

The battery loss during the peak operations was estimated to be approximately 30 Amps per battery, equivalent to 12.5 % of the total battery capacity on a vehicle. Table 6 summarizes the battery depletion for a given 3 hour peak production run utilizing a fleet of 21 vehicles.

5.3 Weekly Production Scenario

The major concern surrounding the weekly production scenarios was to ensure that the AGVs could support the changeover and production requirements, and maintain sufficient battery levels to handle the variability associated with the weekly schedule of operations. An exact schedule was utilized in the simulation which indicated rolls to be consumed, press and reelstand configurations as well as reelstands changeovers required to support the press changes.

The AGV system was more than capable of servicing the reelstand changeovers within the required twenty minutes during the weekly schedule scenario. During the weekly schedule of operations no single changeover ever stressed the system to the level required in the Changeover mode (6 presses 2 reelstands), thus, twenty minutes was easily attained.

The battery levels during the weekly production run also eliminated any concerns regarding charging. Ample idle time existed throughout the week providing plenty of opportunity charging for the AGV fleet. Figure 4 displays the charging levels over the course of the week.

6 CONCLUSIONS

Through the use of simulation, Swisslog was able to demonstrate the robustness and flexibility of their proposed Automated Guided Vehicle System to its major Northeastern Newspaper Client. Simulation provided the means of validating the Swisslog design in response to the following key areas:

1. Press Changeovers
2. Peak Production Demands
3. Weekly Production Schedule
4. Battery Charging Capabilities

Table 4: AGV Hourly Task Breakdown for Peak Production Run with 21 AGVS

21 Vehicles	Hour		
	1	2	3
Total Moves	152	164	156
Total Reelstand Deliveries	112	120	115
Total Laydown Deliveries	40	44	41
Total Waste Deliveries	0	0	0
Total Core Deliveries	0	0	0
To Reelstand From Prep	33	33	37
To Reelstand From Laydown	79	87	78
To Reelstand From Reelstand	0	0	0
To Reelstand From Butt Stand	0	0	0
To Laydown From Prep	40	44	41
To Laydown From Press	0	0	0

Table 5: Delivery Times for Peak Production Scenario Simulation Runs

Vehicle Quantity		18	19	20	21	22	23	24
Delivery Time in Sys. (Mean)	Average	5.647	5.508	5.400	5.547	5.388	5.333	5.410
	Std. Dev.	0.111	0.091	0.112	0.190	0.063	0.061	0.383
	Minimum	5.473	5.389	5.232	5.252	5.306	5.277	4.976
	Maximum	5.798	5.637	5.613	5.910	5.487	5.483	6.209
	Median	5.671	5.487	5.400	5.550	5.381	5.329	5.300
	# of Runs	10	10	10	10	10	10	10

Table 6: AGV Battery Level (in Amps) for the Peak Performance Scenario

	Hour		
Vehicle	1	2	3
AGV 1	165.5	149.8	136.8
AGV 2	164.7	148.3	134.5
AGV 3	164.3	152.0	135.9
AGV 4	165.3	150.5	134.0
AGV 5	165.7	149.0	132.2
AGV 6	167.0	151.1	134.8
AGV 7	164.3	148.8	134.0
AGV 8	164.5	151.1	137.8
AGV 9	167.8	152.2	135.9
AGV 10	168.2	152.3	136.3
AGV 11	167.2	154.6	138.7
AGV 12	166.9	152.8	137.7
AGV 13	166.3	149.6	135.4
AGV 14	168.6	152.1	136.1
AGV 15	165.8	152.3	138.0
AGV 16	168.4	153.9	138.0
AGV 17	165.0	148.1	131.7
AGV 18	164.9	148.6	133.8
AGV 19	166.1	152.5	137.2
AGV 20	166.8	150.4	138.0
AGV 21	163.3	150.7	134.9

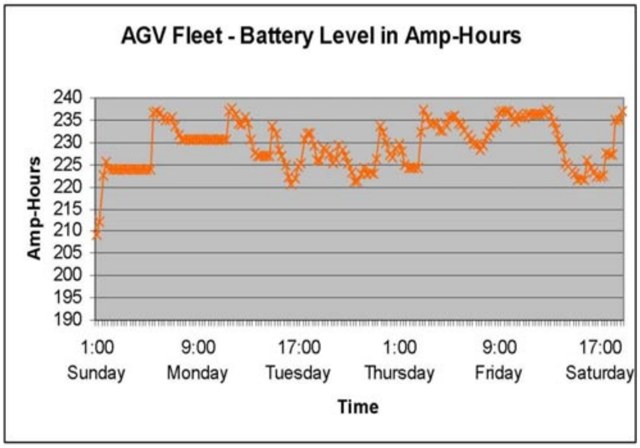

Figure 4: AGV Battery Levels during Weekly Production Run Scenario

Through the use of an AutoMod 3-D animation, vehicle performance, system operations, and dynamic control algorithms were visually communicated in the model.

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