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CASE STUDY: MODULAR PHYSICS SIMULATION APPROACH FOR AMAZON FULFILLMENT FACILITIES

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ABSTRACT

Physics simulation model have become essential tools in Amazon's fulfillment network for analyzing and optimizing material handling equipment (MHE) design. This paper presents a modular framework developed using Emulate3D to model MHE across multiple Amazon fulfillment facilities. The framework incorporates three main components: material to be handled module, material flow control module and package chute module. Through comprehensive validation against pilot results and statistical analysis, the model demonstrates high fidelity in replicating real-world operational dynamics. The framework's applications span from future automated conveyance flow control logic optimization to existing chute design retrofits. The physics model is used to identify chute jams before launch, location of sensors, optimal jam free merge logic, reducing time/cost for development. Key challenges including package softness, human operator behavior representation, and unexpected operational events are discussed. The study concludes by highlighting future directions in physics simulation to enhance simulation fidelity.

1 BACKGROUND

Amazon's fulfillment facilities incorporate various automation technologies, multiple chute applications and miles of conveyance with sophisticated flow control logic. The design complexities necessitate sophisticated simulation tools for design validation against target system throughput and potential jam locations. Different vendors have different merge logic or chute designs. Modularization simplifies modeling of these similar components. Discrete event simulation modeling approach often struggles to capture the full complexity of these systems, particularly regarding package interactions. This study presents a modular simulation framework that addresses these challenges through flexible merge flow control configuration and chute testing module. The framework enables both tactical optimization of current designs and strategic evaluation of future flow control concepts, while accounting for real-world constraints and operational variability.

2 SIMULATION APPROACH

Customized material to be handled catalog was created. Modular framework was used to test different combinations of merge control logic. This comprehensive approach enabled us to benchmark different merge control scenarios against target system throughput and potential package jams. For chute design validation, the framework incorporates a specialized testing module that focuses on package velocity, jams and capacity. Auto package jam collector custom catalog was developed using C# scripting to automatically record images and clear jammed packages during simulation run. This enables engineers to rapidly identify potential design issues and optimize chute configurations before physical implementation, reducing the need for costly design iterations.

3 CASE STUDY

3.1 MATERIAL TO BE HANDLED

The properties of the material being handled are crucial for accurate physics simulations in flow control systems. Different package types were modeled using Blender software to incorporate different package textures, geometry and center of mass offset. These package types were further optimized to reduce the number of vertices for faster computation. The packages were imported as wavefront file format into Emulate3D software to create customized catalog items. Customized package generator using C# script was created to simulate instantaneous spikes in bulk package flow. Customized package generator was also created to generate totes filled with different package types to incorporate accurate interactions between packages. Accurately modeling these properties in simulations ensures that the flow control logic and chute designs can be validated under realistic conditions, leading to more reliable and efficient system designs.

3.2 FLOW CONTROL LOGIC

Physics-based simulation proved instrumental in validating the flow control logic by accurately modeling package dynamics for Amazon fulfillment conveyance system. Customized package merge logic (i.e. opportunity merge, priority merge, timer based merge, slug merge and combinations of slug and opportunistic merge) were developed in Emulated3D using quicklogic scripting and saved as catalog items. This modular approach helped running different virtual scenarios that stakeholders could visualize without the costs and risks of physical testing. The simulation environment allowed for rapid iteration and refinement of merge logic, ultimately leading to a more robust and reliable system that could handle both steady-state operations and edge cases. The physics simulation model guided the design and controls team choose optimized flow control logic with highest system throughput and no package jams.

3.3 PACKAGE CHUTE DESIGN OPTIMIZATION

Modular framework was further used to validate different chute design concepts, particularly package jam, exit velocity, chute capacity and fullness. The model incorporated packages diverting from cross-belt sorters into chutes and carts. Auto package jam custom catalog automatically takes images of jammed packages and clears them while the simulation is running. This helps to expedite simulation runs. The chutes have fullness tracking photo-eyes to control package overflow. Spaghetti chart of package trajectories were captured for accurate analysis of system behavior. The model drove improvement in cart utilization by 6% at chute exit. This finding was validated across 12 pilot sites, demonstrating consistent 5-6% improvement in cart utilization. The research led to the establishment of network-wide guidelines for sensor placement, driving improvements in cart and truck utilization while reducing transportation costs and carbon footprint. This approach showcases the power of physics-based simulation in solving complex operational challenges and provides a framework for future optimization efforts in material handling systems.

4 CHALLENGES AND FUTURE DIRECTION

Current challenges center on the computational demands of modeling package softness and its effects on handling dynamics. Limited historical failure data and environmental factors like humidity and dust can impact system performance in ways that are difficult to predict and model effectively. These environmental and material factors create a complex web of inter-dependencies that further complicate the development of accurate simulation models. Looking forward, the physics simulation model connectivity with discrete event modeling tools could substantially reduce need for computational resources. The developed catalog modules will be used in cloud based collaborative platforms for faster model development. Controls emulation of recommended flow control logic will help to ensure First Time Launch Quality (FTLQ).