Session: Decision Support for Manufacturing and Other Options

Exploring the benefits and challenges of drone-assisted material handling in manufacturing

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14 JULY 2023

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The 23rd Conference of the International Federation of Operational Research Societies
July 10-14 · SANTIAGO, CHILE
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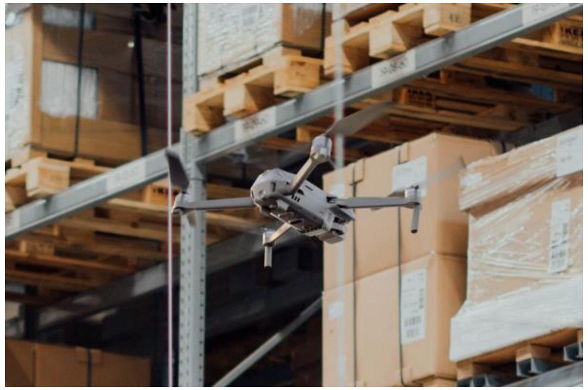
ISCI Instituto Sistemas Complejos de Ingeniería

OUTLINE

- Background
- Research Plan
- Mathematical and Simulation Models
- Equipment and Grasping Mechanism
- Preliminary Results
- Future Work

BACKGROUND

- Drone technology has seen much recent improvement.
- Most drone research is focused on outdoor logistics or photography / monitoring / surveillance.
- The most developed indoor applications are surveillance and inventory counting.



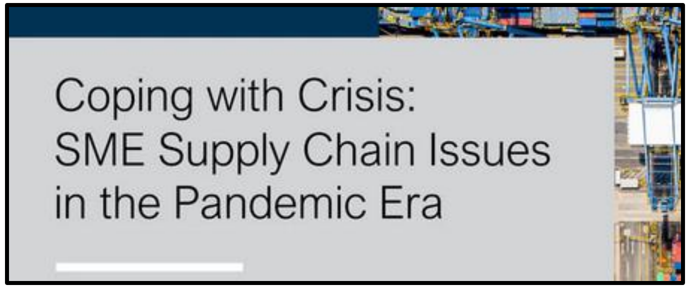
BACKGROUND

- Recent events have shown that our logistics chain is fragile and that current technology is not enough to keep up with increasing demand.
- Manufacturing is a key component of most logistics chains.
- Material handling can be a significant bottleneck, especially for small to medium-sized enterprises.
- **Can the use of Uncrewed Aerial Vehicles (UAVs) provide a viable tool to support material handling activities in manufacturing processes?**

Source: Global Capitalist 2021

Source: McKinsey 2021

Source: CES 2021



WHY UAVs?

- In production environments, space is at a premium.
- Most automated material handling systems are large and/or require specialized layouts.
- Human-based systems require aisles and have additional safety requirements, some affecting throughput (weight, walking speed).
- Drones can fly using the fastest route possible and can do so at high speeds.
- Drones can utilize 3D space efficiently and without requiring significant investment. For new or existing facilities, drones only need the empty space above to fly through. This eliminates costly floorspace investments.
- Indoor positioning technology has seen strong development. (Computer vision, ultra-wideband, visual odometry, LIDAR.)
- Automation and drone flexibility align with Industry 5.0 and smart manufacturing principles.

WHAT IS MISSING?

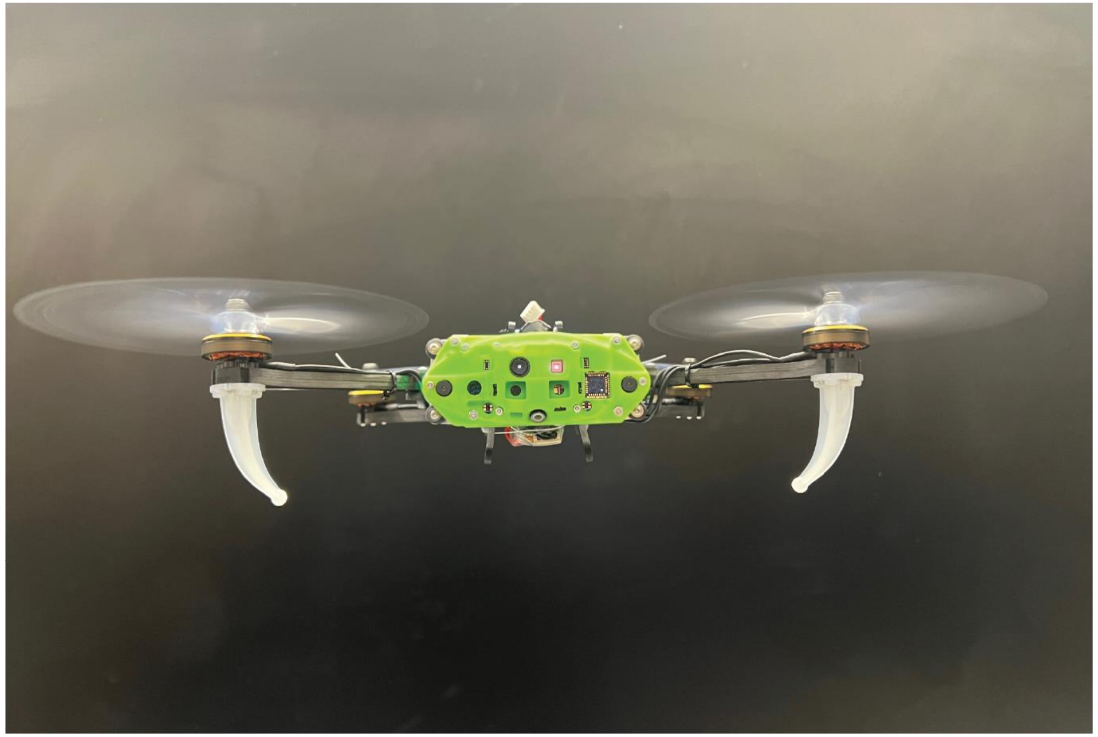
Models and algorithms optimized for 3D air-based movement.

This includes routing and scheduling models.

Real-time heuristics for route planning and scheduling.

Grasping and carrying mechanisms.

Integration with production systems.



ICAMS

The Interdisciplinary Center for Advanced Manufacturing Systems (ICAMS) at Auburn University is an important resource for small and medium manufacturers throughout the southeastern United States. Established in 2018, ICAMS offers the equipment, space and expertise to train and educate students and industry personnel in advanced manufacturing technologies. ICAMS' efforts focus on reducing the barriers inhibiting the introduction of advanced manufacturing systems (e.g., the implementation of Industry 4.0 technologies) in small and medium manufacturing operations.

RESEARCH PLAN

Phase I
Virtual
Experimentation

Mathematical Models and Heuristics

Virtual Trials on Simulation Environment

Phase II
Physical
Experimentation

Drone Outfitting

Physical Trials at Tiger Motors Laboratory

MATHEMATICAL MODEL

$x_{ijk}: \begin{cases} 1 \ if\ drone\ k\ uses\ arc\ i,j \\ 0\ otherwise \end{cases}$

w_{ik}: start of service at node i when serviced by drone k

$$\min \sum_{k \in K} c_{ij} x_{ijk} \quad (1)$$

$$\sum_{k \in K} \sum_{i \in N} x_{ijk} = 1 \ \forall\, i \in N \quad (2)$$

$$\sum_{j \in N} x_{0jk} = 1 \ \forall\, k \in K \quad (3)$$

$$\sum_{i \in N} x_{ijk} - \sum_{i \in N} x_{jik} = 0 \ \forall\, k \in K, j \in N \quad (4)$$

$$\sum_{j} x_{j,n+1,k} = 1 \ \forall\, k \in K \quad (5)$$

$$w_{ik} + s_i + t_{ij} - w_{jk} \le (1 - x_{ijk}) M_{ij} \ \forall\, k \in K, (i,j) \in A \quad (6)$$

$$a_i \sum_{j \in N} x_{ijk} \le w_{ik} \le b_i \sum_{j \in N} x_{ijk} \quad \forall k \in K, i \in N \quad (7)$$

$$\sum_{i \in N} d_i \sum_{j \in N} x_{ijk} \le C \ \forall k \in K \quad (8)$$

$$\sum_{i \in N} w_{ik} x_{0ik} \ge w_{n+1,k-1} \forall k \in K \quad (9)$$

$$x_{ijk} \in \{0,1\} \ \forall\, k \in K, (i,j) \in A \quad (10)$$

$$w_{ik} \ge 0 \forall\, k \in K, i \in N \quad (11)$$

DISTANCE MATRIX

Takes a definition of the room’s dimensions and cuboid-shaped obstacles as input.

Generates a discretized representation.

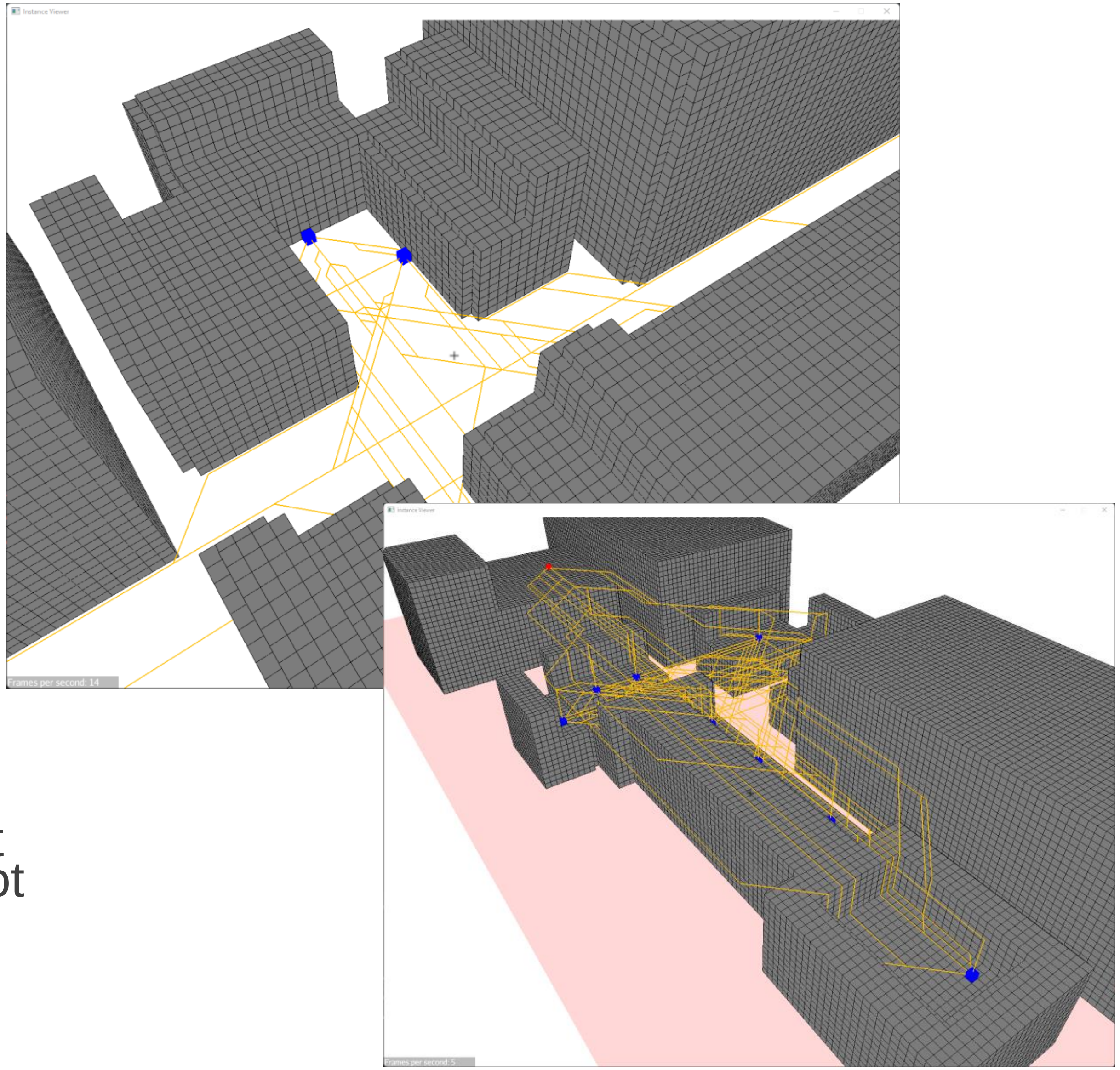
Models the drone as a particle.

Considers a safety distance, achieved by “growing” walls and obstacles by the specified amount.

Allows for separate vertical and horizontal speeds.

After the network is generated, the shortest paths between delivery points and the depot are obtained. Intermediate nodes are exported separately to generate path visualizations.

Unused nodes are discarded.



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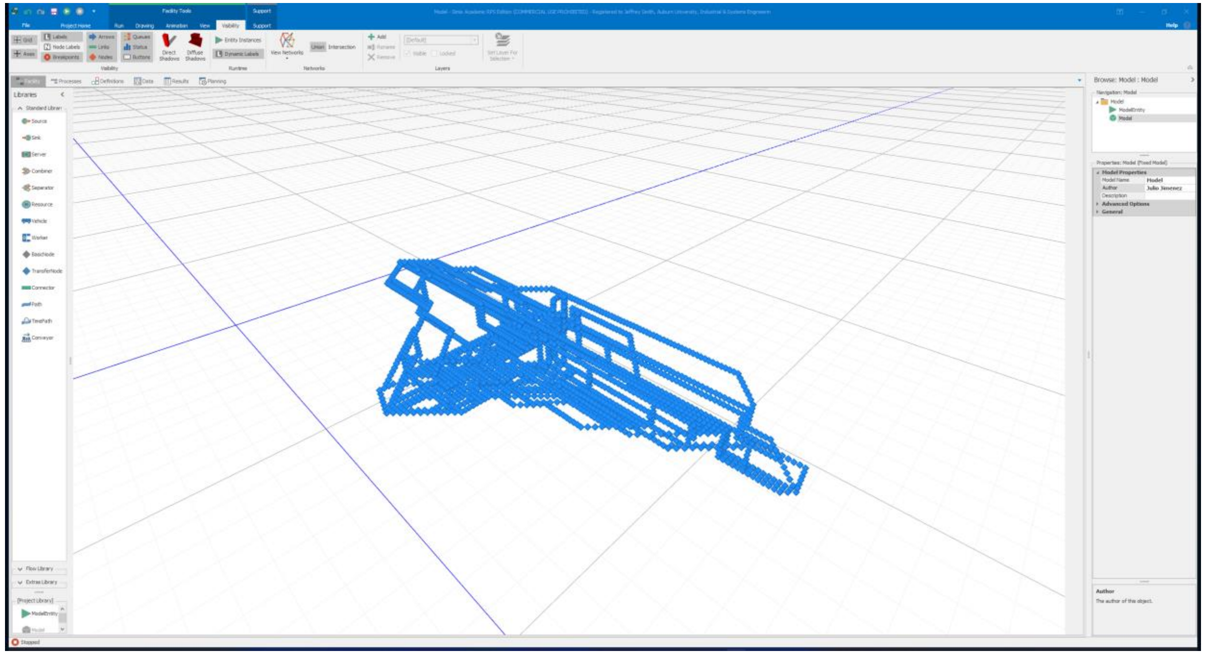
SIMULATION MODEL

Developed using Simio.

Can generate orders dynamically or from an order list.

Uses the network generated by the distance matrix generation process.



EQUIPMENT

GPS-less environments (indoor) require the use of specialized drones.

The Lab imposes strict limitations on the size of the UAV.

We purchased a small indoor drone with SLAM (simultaneous localization and mapping) capabilities.

The drone is a Seeker by ModalAI, a company based in San Francisco.

We have also acquired an external indoor positioning system made by Pozyx, a Belgium company.

EQUIPMENT

TIGER MOTORS LAB

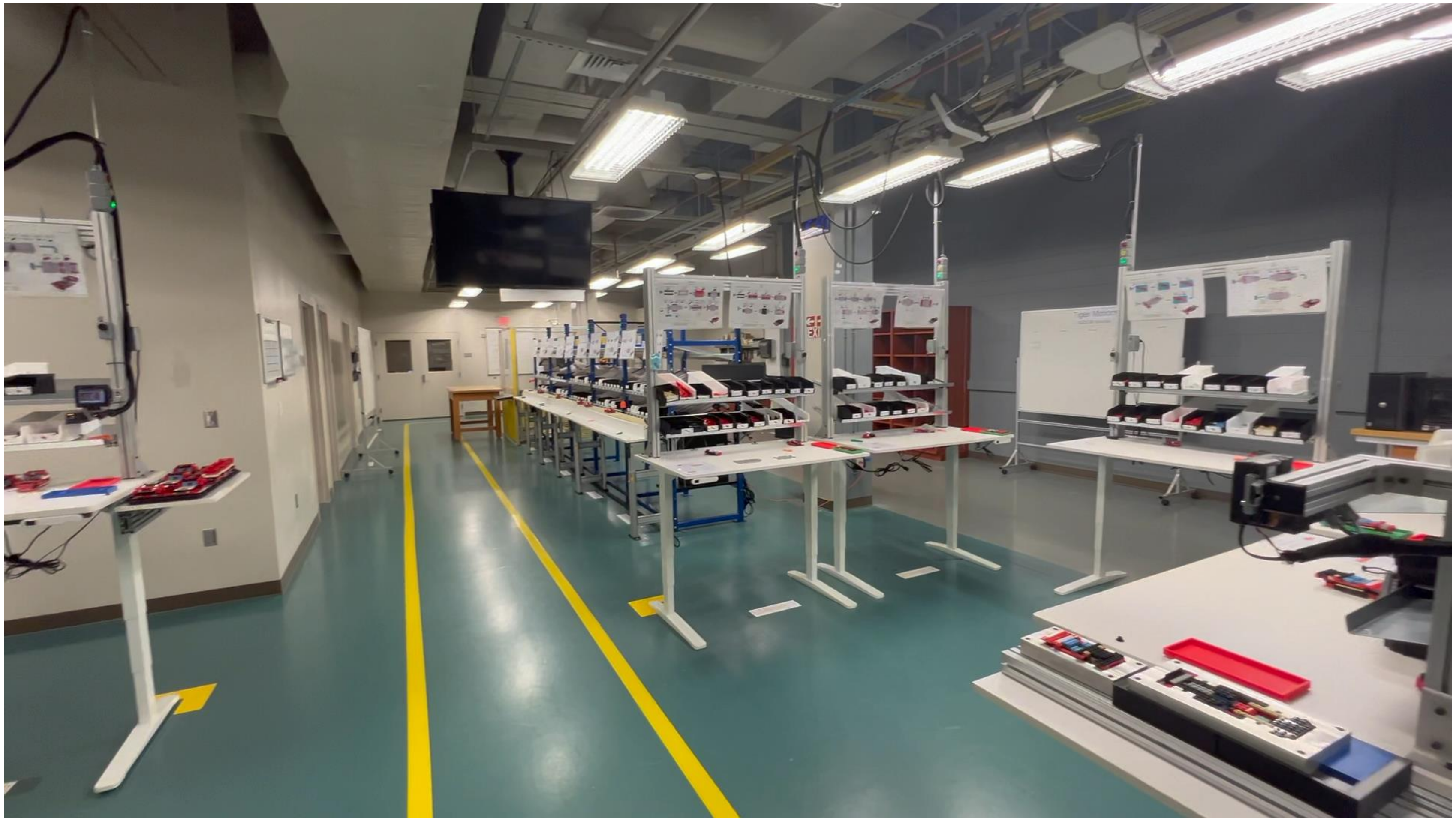
Our next task is to perform a proof-of-concept limited field trial at the Tiger Motors Lab, commonly referred to as the Lego Lab.

As a scaled-down version of a manufacturing floor, it allows us to perform realistic trials in a safer and more controlled environment.

To generate the routes and flight schedules, we plan an initial set of trials in a virtual environment, based on the Lego Lab.

We will use this to generate routes for both drones and humans.

TIGER MOTORS LAB



GRASPING AND CARRYING MECHANISM

For our initial physical experiments, some human or robotic assistance for the payload/order preparation will likely be needed.

We are using 3D printing to create our prototypes, as well as Arduino boards, for the pickup and drop-off mechanism.

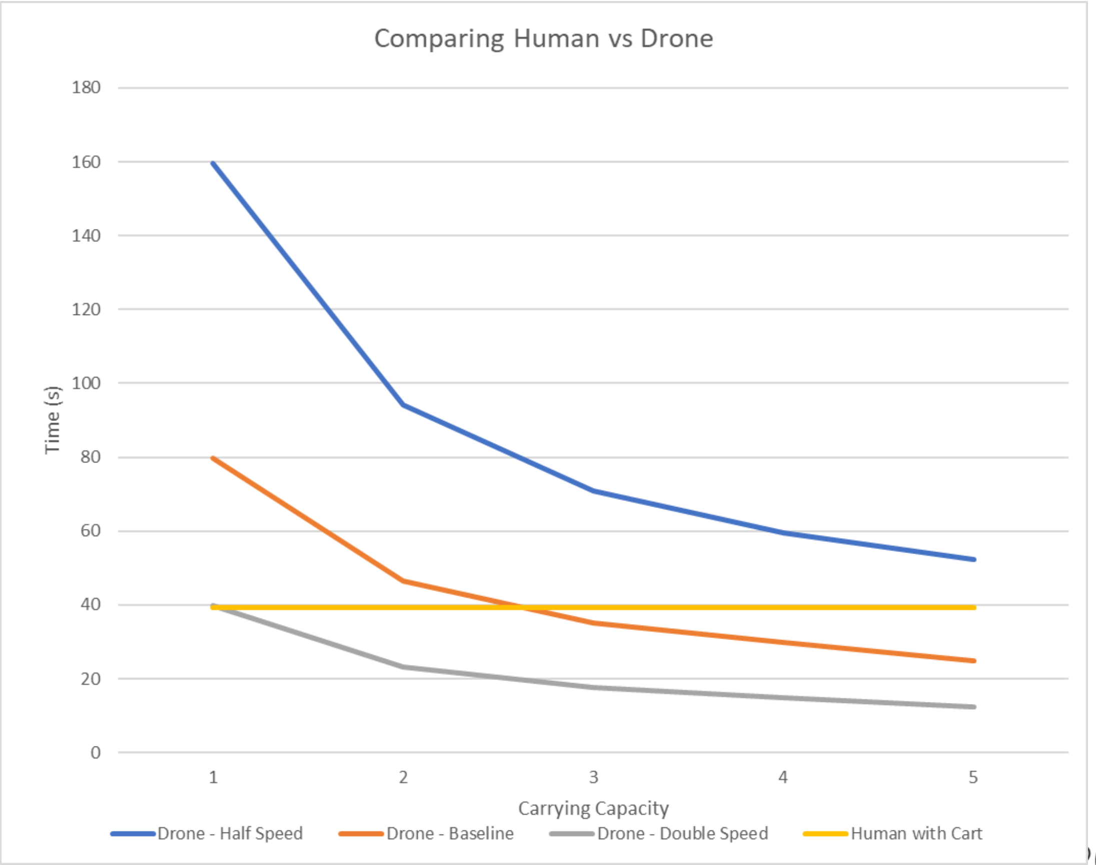
This will be integrated with the drone's software so it can be autonomously controlled.

PRELIMINARY RESULTS

We have been able to conclude that there exists potential in using a drone-based material handling system.

Even when drone capacity is quite limited, drones are able to scale very easily because of their ability to use the 3D space and avoid congestion.

Both the baseline and the fastest model quickly surpass the ground-based system. The slowest drone, while not better, still performs well at less than half the effective capacity when compared to the human.



FUTURE WORK

Our proposal for year 2 has been submitted and accepted by ICAMS.

Year 2 will focus on bigger and more complicated instances.

We have purchased another indoor drone from the same company that has improved cargo capacity.

As we look beyond year 2, we are already considering novel ways to incorporate modern control interfaces to aid the human-drone interaction in production environments.

THANK YOU

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ACKNOWLEDGEMENT

This work is supported by the Interdisciplinary Center of Advanced Manufacturing Systems (ICAMS) with funding from the Industrial Base Analysis & Sustainment Program of the Industrial Base Policy Office of the Office of the Secretary of Defense.

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