Modeling Excavation Forces for Chain Driven Mechanisms with Buckets and Picks. M. C. Guadagno[1], F. D. Gaertner[2], and P. J. van Susante[3]. [1,2,3]Dept. of Mechanical Engineering-Engineering Mechanics, Michigan Technological University 1400 Townsend Drive, Houghton, MI 49931 (contact: pjvansus@mtu.edu).

Introduction: A loose layer of regolith overburden is believed to exist within PSRs which was formed by repeated asteroid impacts with the lunar surface and desiccated by the gradual off-gassing of volatiles to space [1]. Beneath the top layers, water ice is theorized to exist in cemented aggregates formed by the same impact events. The subsurface deposits of hardened icy lunar regolith potentially have compressive strengths like that of concretes used on Earth [2].

Chain driven mechanisms have proven to be an effective solution to excavating both overburden [3] and hardened material [4]. While trenchers have seen success in competitions and testing in relevant lunar environmental analogues [5][6], optimizing performance has largely been an empirical process using test data with force modeling focused on individual tools rather than an entire system.

A computational excavation force model for chain driven systems is presented in the following abstract. Simultaneous force contributions from multiple bucket and pick style end effectors are accounted for in the model. These models and tests aim to ultimately support mission planners when evaluating the viability of chain-driven excavation systems for lunar rovers.

Methods: In the most basic configuration, a trencher consists of a motor attached to a sprocket that drives a chain connected to an idler, forming a geometric stadium shape. The chain may have various attached tools that perform a spectrum of functions between cutting (picks) and transportation (buckets). While capable of incorporating many tool geometries, layouts used by the PRIMROSE rover in the BTIL competition (Figure 1) [5] and a trencher developed by the PSTDL for excavation loose regolith in vacuum conditions [6] were selected to verify model accuracy with real-world data.

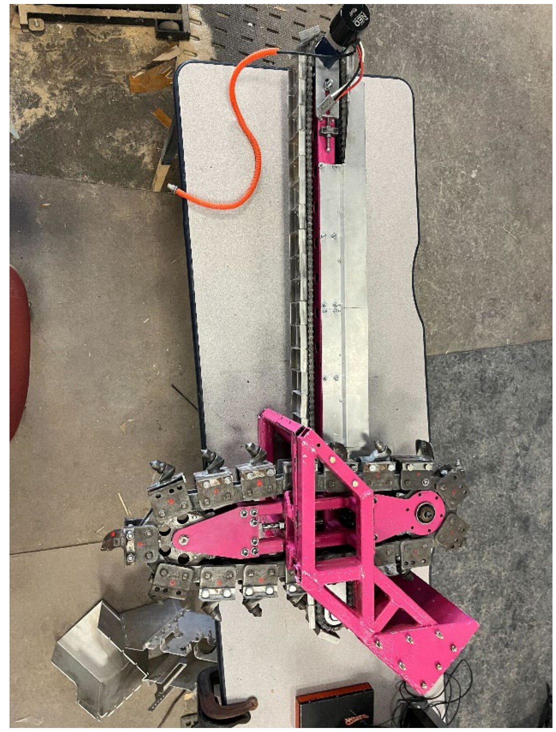
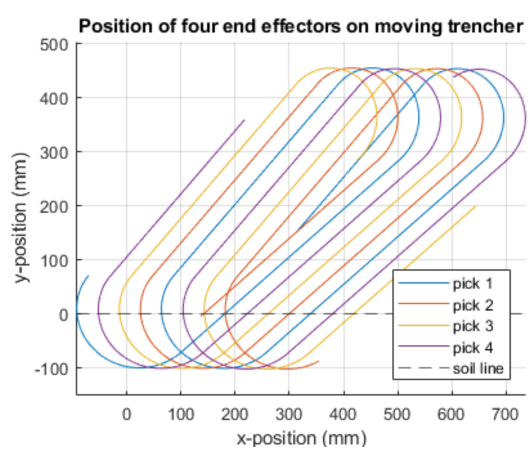


Figure 1: The PRIMROSE rover excavation mechanism. Picks were used to break up hardened CLSM while blades were used to transport material to an internal hopper.

Once the trencher geometry is established a position model for every end effector is generated. The position model accounts for the dynamics imparted onto the end effectors by both the motion of the chain and the translation and rotation of the entire excavation system. Position is solved iteratively in a set of parametric equations for each section of the tool path (Figure 2).



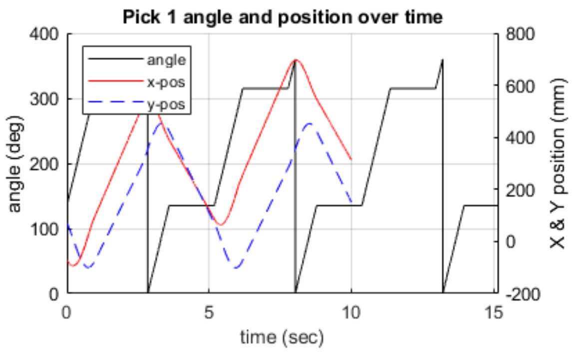


Figure 2: Output position plot of an example 4-pick trencher model (top) with corresponding changing position and angle variables versus time (below).

Forces on point attack picks were initially modeled using the Goktan and Gunes model [7] while the Balovnev model [8] was used for buckets. Both methods use the position model for inputs to their respective equations.

Simulations are run with the goal of understanding how various parameters affect cut depth, a value critical to both models due to an exponential relationship with output force. In addition to standard excavation parameters, cut depth on trenchers varies with the chain speed and the movement of the attached rover.

Results & Discussion: Model development is still ongoing, but results are expected to show that excavation forces from picks in cemented icy regolith simulant will be orders of magnitude greater than those experienced by buckets for loose regolith overburden.

While there are many factors which may affect the effective cutting depth of trenchers, there are just as many ways to control it. So long as the tip of the pick remains the first impact point, a rover can adjust the chain speed and forward velocity to change effective cut depth. Such changes in continuous excavation systems are relatively easy to make compared to discrete counterparts.

Conclusion: In this abstract, a novel chain trencher excavation model which determines multiple pick and blade forces is shown. Initial results are promising and await validation from results produced by the force test stand at the PSTDL.

Additional work includes further modularizing the software so that other users may apply this model to help size trenchers for their excavation needs.

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