Multi-objective Optimization Using Genetic Algorithms to Design the Optimal Excavator

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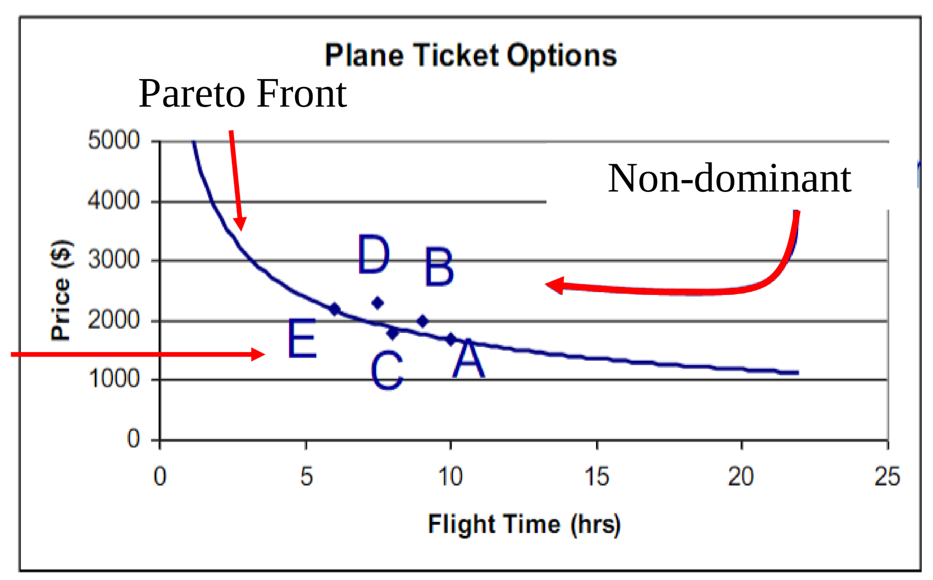
Introduction

Multi-objective formulations enable optimization of realistic, complex engineering problems. Often, objectives under consideration in these problems conflict with each other. This prevents simultaneous optimization of each objective and can yield unacceptable results. Multi-objective optimization provides a way to generate a set of solutions that each satisfy the target objectives. Genetic algorithms can be used to find the optimal input parameters to maximize or minimize the target objectives. The problem of focus is to design the optimal excavation rover by minimizing the mass of the rover, maximizing the excavator's load rate, maximizing the torque-based slip factor of safety (FOS), and maximizing the net forward thrust the rover can generate. The tunable input parameters and the objective net forward thrust are based on the Bekker and Baylonev equations for draft force generation and excavation force required, respectively.

Methodology

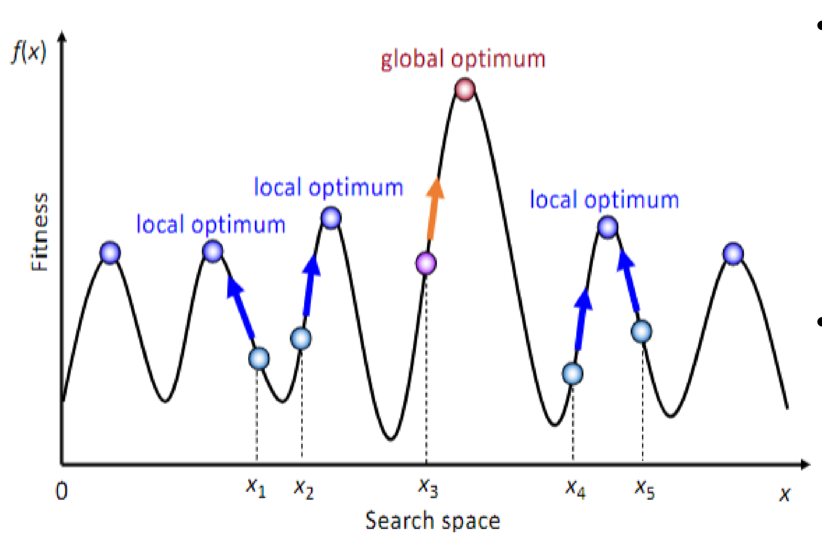
Multi-objective Optimization (MOO)

Find solutions that minimize a set of non-commensurable, indifferent objective functions.



Genetic Algorithms

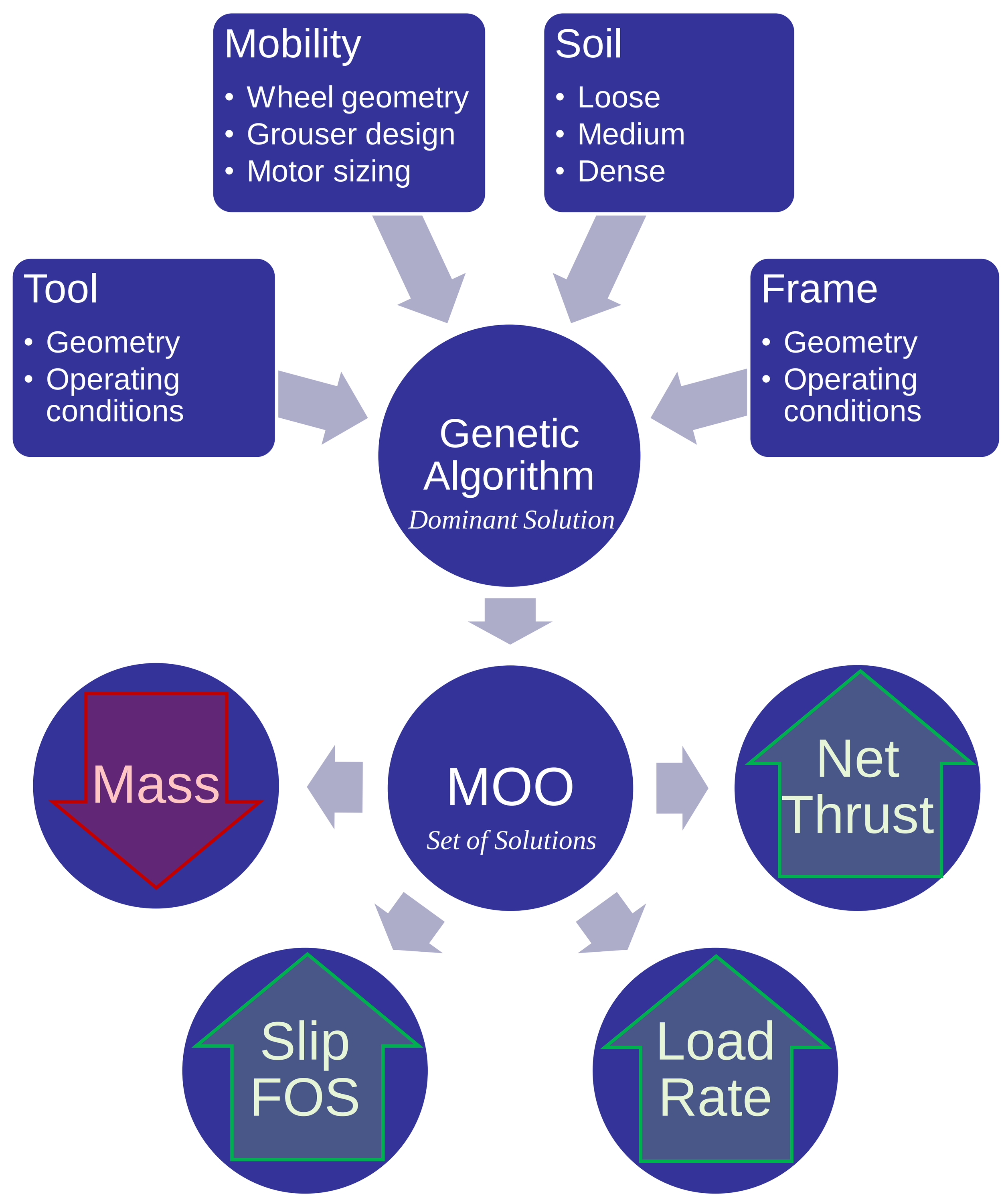
Identify a dominant solution set in terms of a fitness function via evolutionary processes.



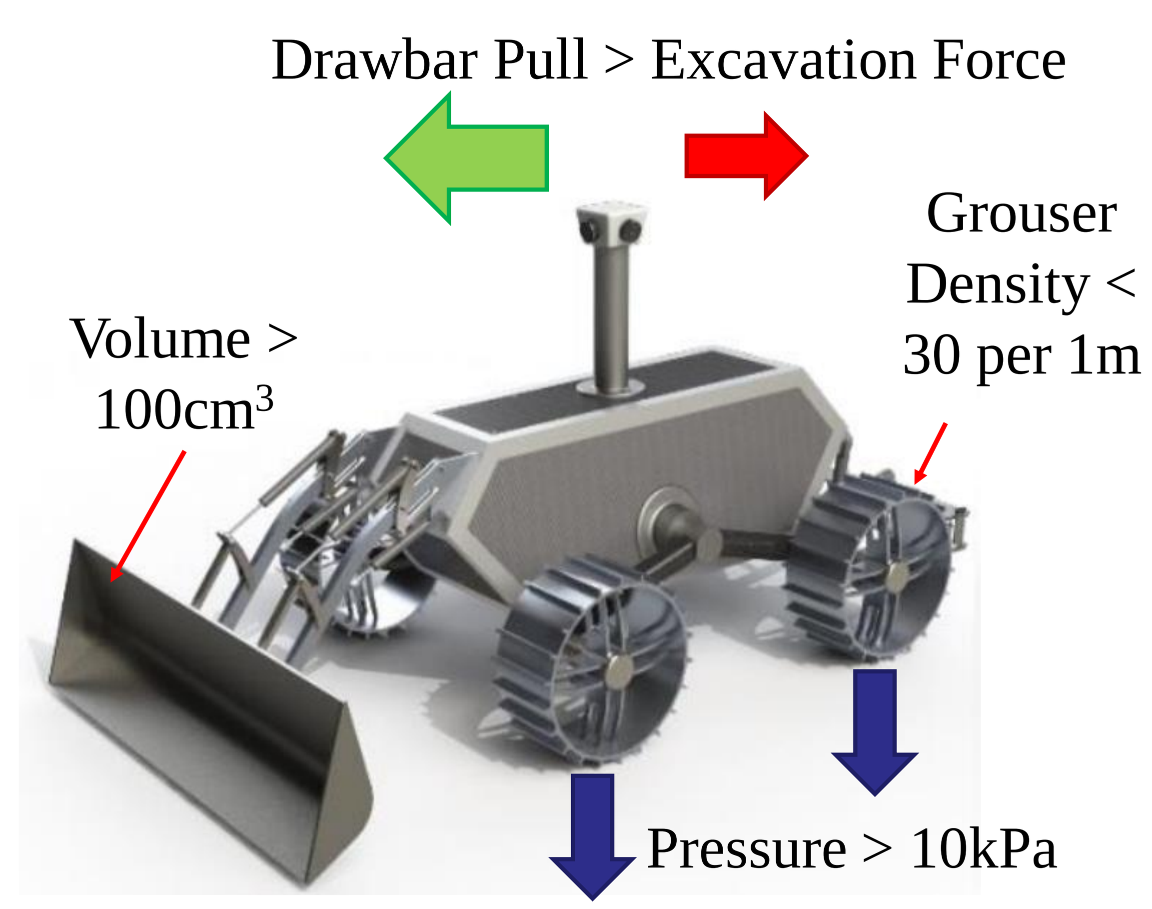
- Finds global optimum solution in search space. Gradient descent and many other methods can only find local optimum
- Enables a population-to-population approach versus the conventional method of point-to-point

Problem Formulation

Model

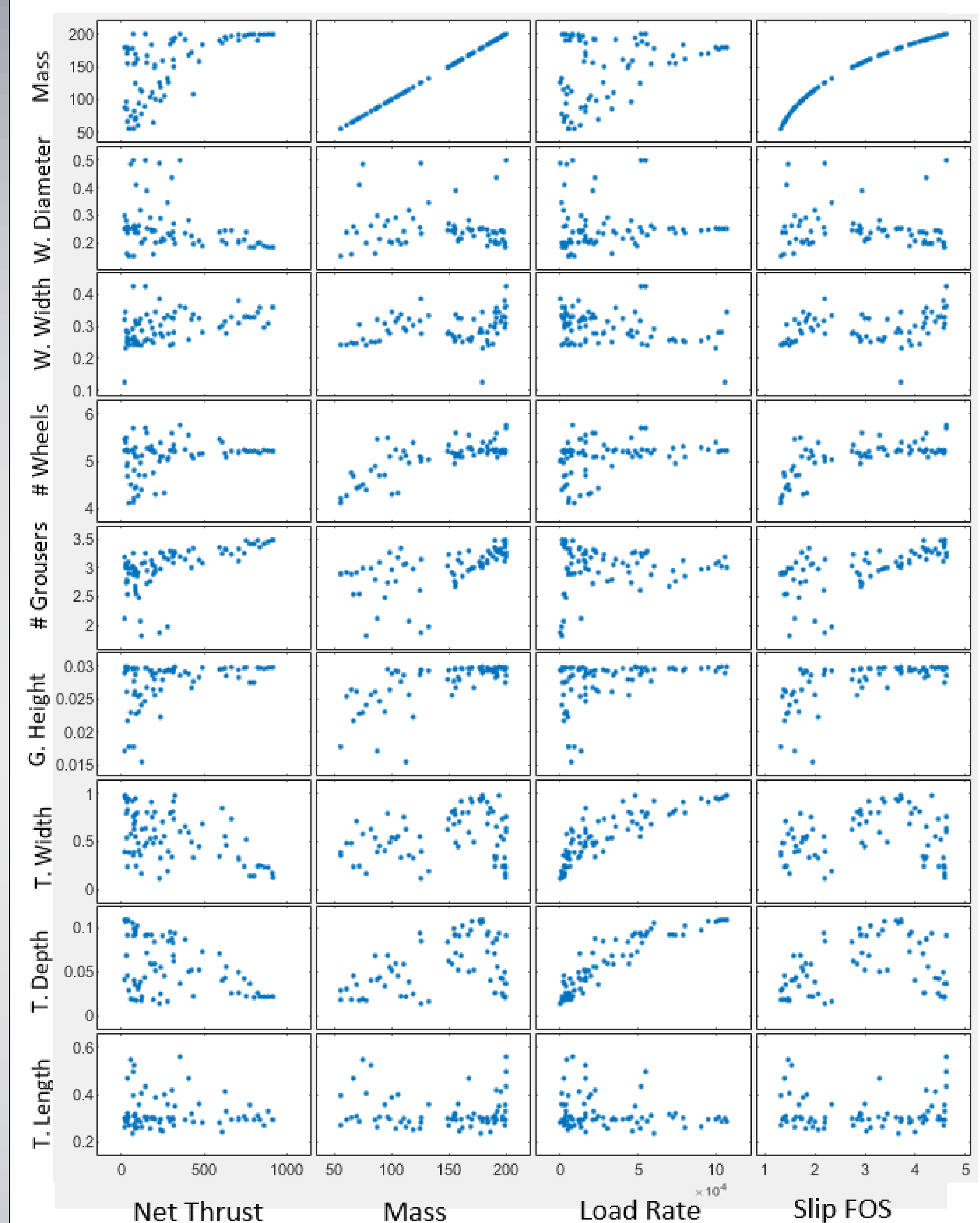


Constraints



Results

Input – Output Relationships

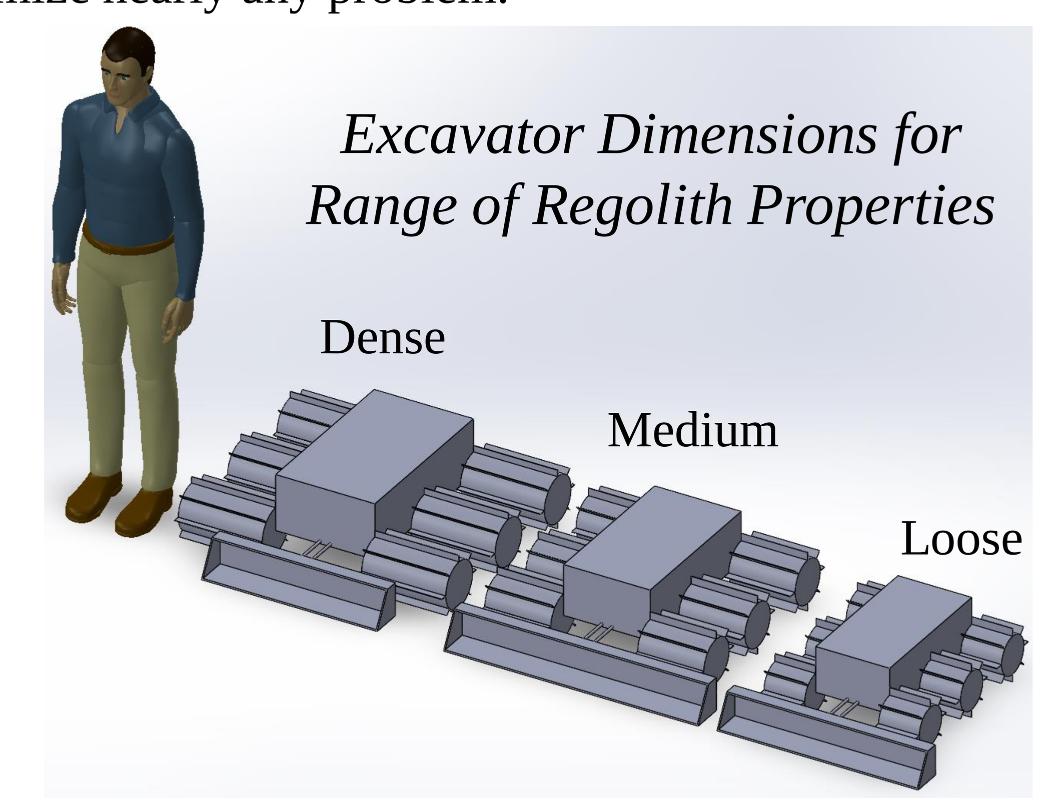


Relative Importance (RI)

Sample Solution Set for Loose Regolith Design				
Emphasis	Mass	Rate	Equal	**Ideal**
Mass (kg)	38	171	118	**45**
Wheel Diameter (cm)	16	19	19	**15**
Wheel Width (cm)	15	34	6	**16**
# wheels	6	6	6	**6**
# Grousers in Contact w Ground	2.2	3.1	3.5	**2.8**
Tool Width (cm)	61	100	98	**79**
Load Rate (mT/hr)	26	127	103	**45**
Slip Torque FOS	1.3	3.4	2.0	**1.3**

Conclusions

This method for design gives the ability to optimize against several conflicting objectives simultaneously. Minimizing objectives, such as mass, while ensuring all mission or operational objectives are considered yields a low-cost, yet effective design. The optimal solutions indicate that wheel width and grouser density scale with regolith density and mass of the excavator while grouser height, tool speed, and number of wheels are uniformly maximized. The tool geometry variables have inflection points as the regolith density increases, indicating a ceiling on possible load rates. The results appear to be heavily subjected to the constraints, consequently further iterations would include a range of values. This method is highly adaptable and can be made to optimize nearly any problem.



RI: 60%, 20%, 10%, 10% for Mass, Rate, Thrust, Slip Outputs			
Regolith	Loose	Medium	Dense
Mass (kg)	45	82	109
Net Thrust (N)	20	21	23
Load Rate (mT/hr)	45	49	55
Slip Torque FOS	1.3	1.5	1.9
Grouser Penetration Pressure (kPa)	10	10	10

Bibliography

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