Field Robotics
Driving Off-Road Equipment Productivity and Convenience

Dr. Stewart Moorehead

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John Deere Was Founded On Innovation

Integrity

Quality

Commitment

Innovation

Our Innovations have increased productivity and convenience for our customers

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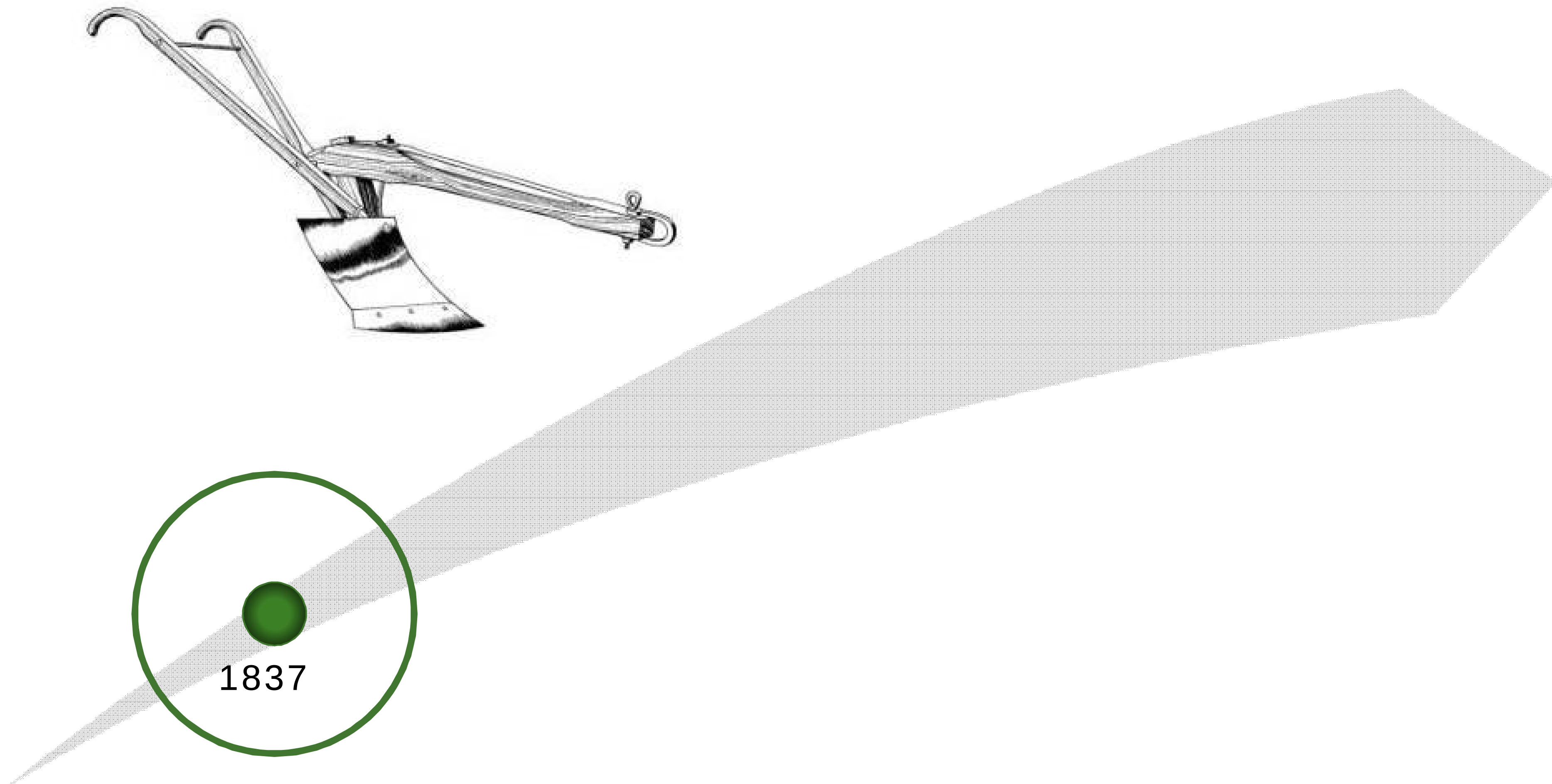
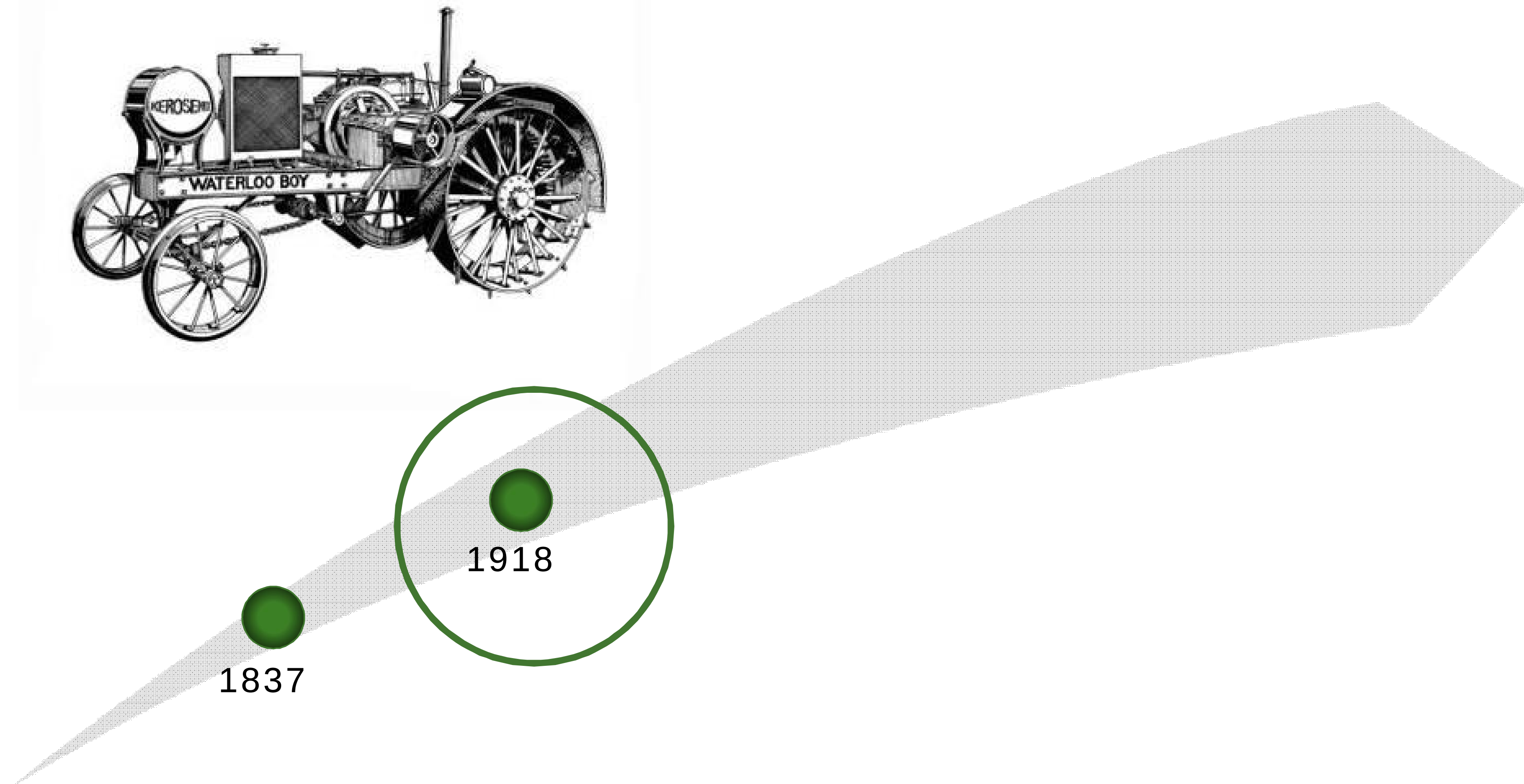
173 YEARS OF INNOVATION

John Deere Founded



173 YEARS OF INNOVATION

Motorized Equipment Era



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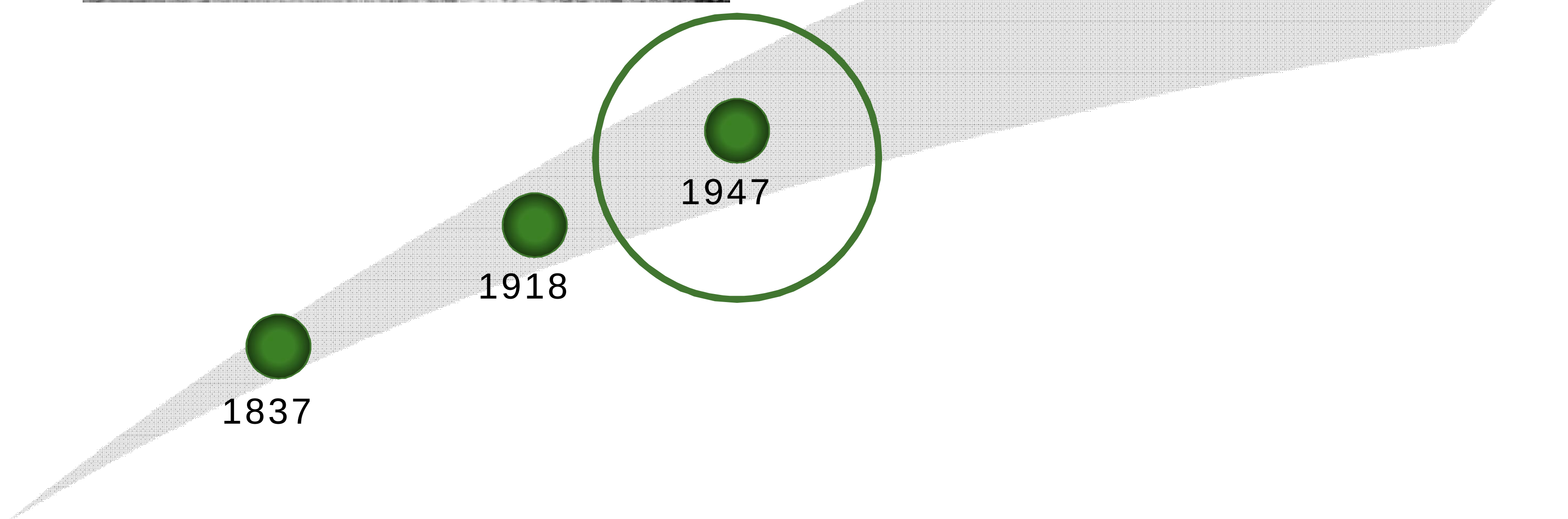
173 YEARS OF INNOVATION

Self-propelled Machines



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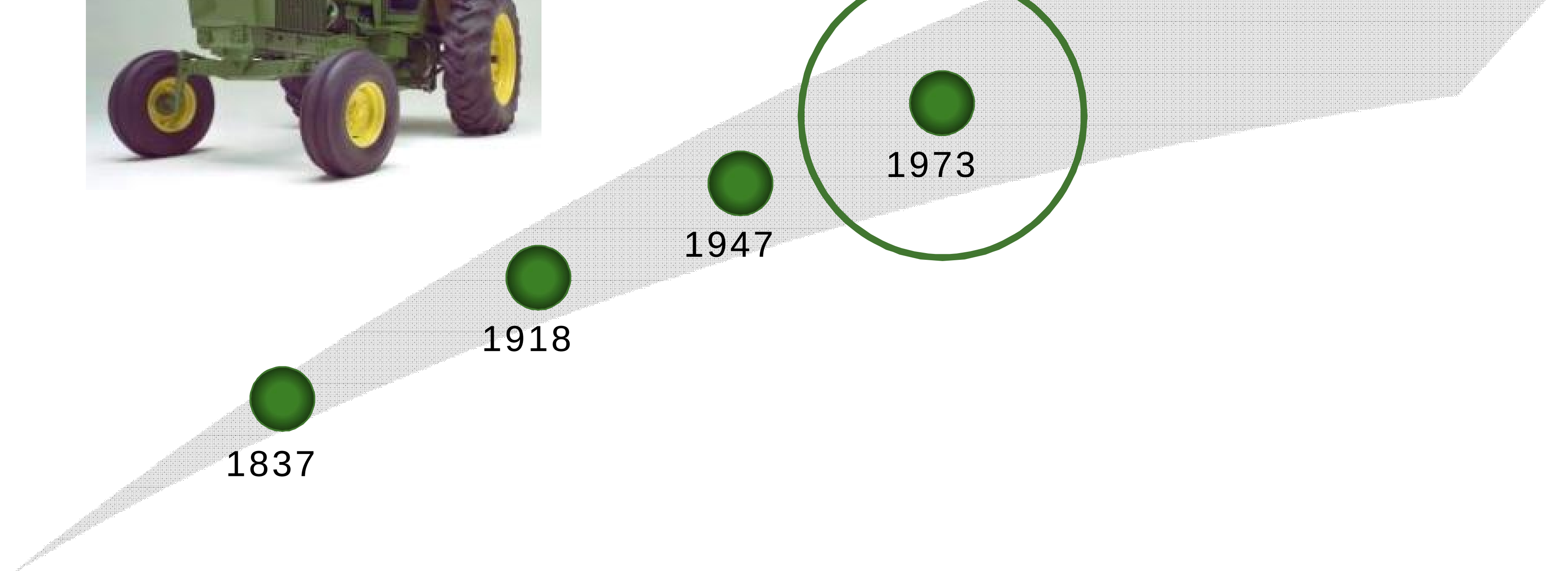
173 YEARS OF INNOVATION

Operator Environment



173 YEARS OF INNOVATION

Intelligent Mobile Equipment

1837
1918
1947
1973
1999

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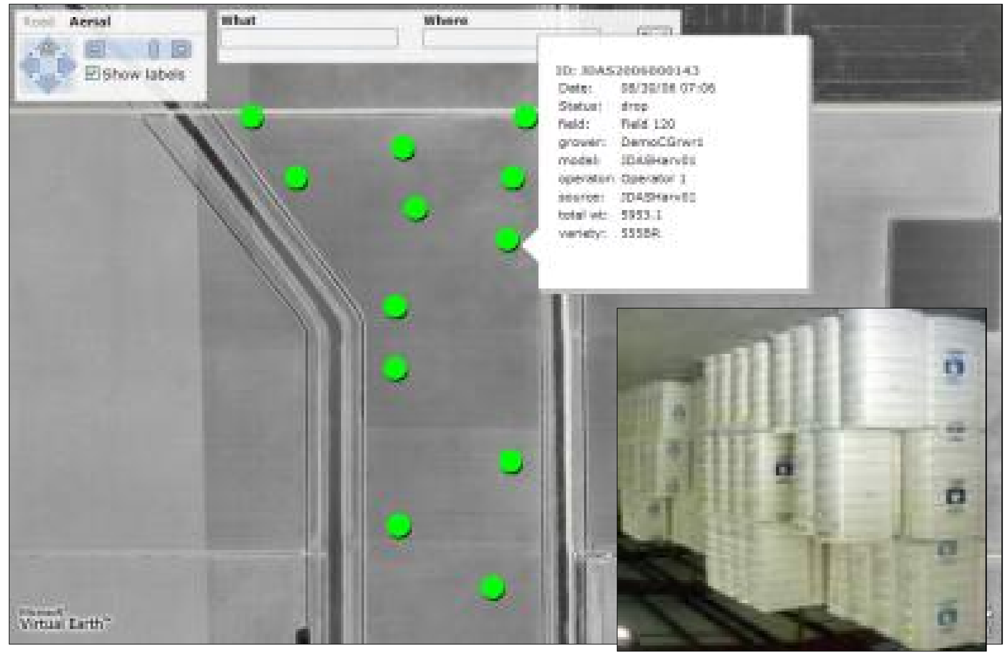
Worksite Solutions

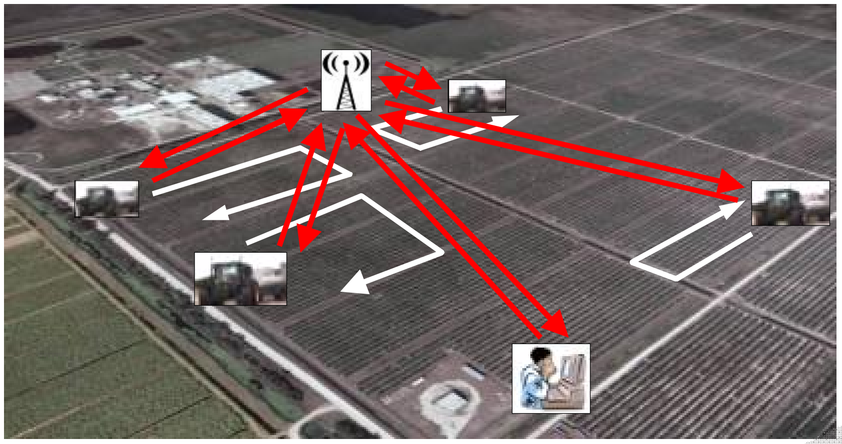


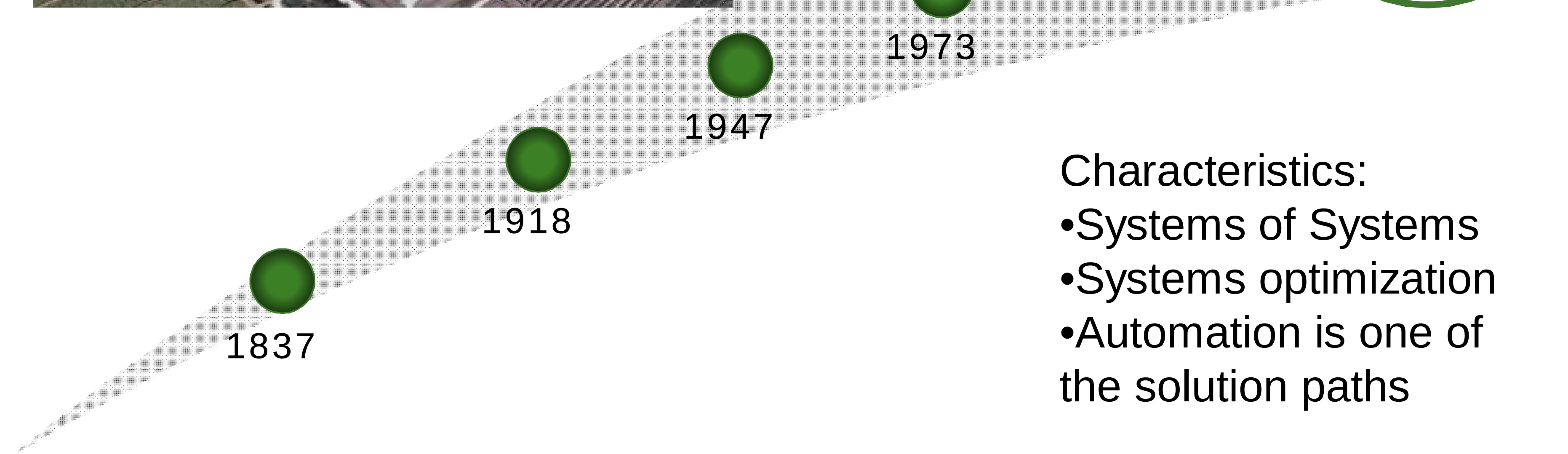
Moving from Breakthrough Machines to Breakthrough Solutions:

- Real-time optimization of worksite systems
- Information management and decision support

Autonomous Worksite Solutions

Autonomous Worksite Solutions





Characteristics:
- Systems of Systems
- Systems optimization
- Automation is one of the solution paths

Innovation Opportunity Spaces

- Continued evolution of machine automation:
  - Smart Machine Systems
  - Integration of the functions (e.g., tractors and implements working as a system)
  - Convergence of technologies on the Worksite
- Building the base environment for autonomous worksite solutions:
  - Highly integrated machine systems
  - Integrated communications across the landscape

Smart Machines

Customers want solutions that:

- Reduce Labor costs
- Increase machine and labor productivity
- Reduce operator stress

Breakthrough growth in machine productivity through automation:

- Automation of machine functions
- Coordination of machine-to-machine operations
- Increased levels of machine autonomy

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Integrated Functions and Smart Implements

- More than just smart tractors, there is a need for an integrated smart system
- ISOBUS Class 3 is a standard for tractor-implement communications
- Implements controlling tractors
  - Automated baler
  - Smart spraying

Convergence of Technologies to create Automated Worksites

The building blocks for autonomous worksite solutions are being laid through the natural evolution of agricultural production systems

Autonomous Worksite Systems

...

Integrated Intelligent Machine Systems

Hybrid Electric Vehicle Systems

Information, Telematics, and Decision Support

Intelligent Mobile Equipment

Hydraulics, Electronics and Software Architecture

Enabling Technologies

- Perception
- Mission Planning
- Machine to Machine Communications
- User Interfaces

Perception and Safeguarding

Role:

- Provides human-like awareness
- Protects the machine system footprint

Challenges:

- Sensor capabilities
- Sensor Integration
- Sensor Cost
- Commercial availability

Perception Video

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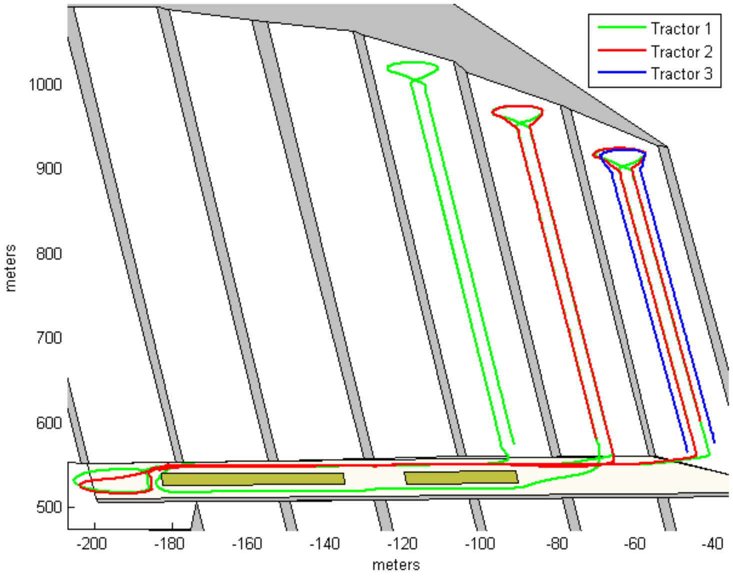
Path Planning

- Coverage planning
  - Implement coverage
- Formation Driving
  - Station keeping
  - Mixed man and machine controlled vehicles
- Multi-vehicle Path Planning
  - How best to cover fields with multiple machines
- Limited resource planning
  - Accounting for fuel, spray tanks, grain storage in plan
- Worksite Planning
  - Extend planning to entire task



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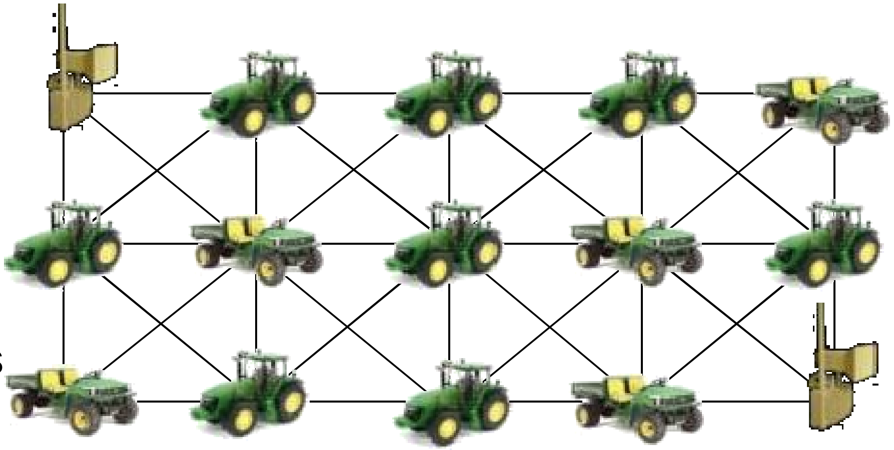
Machine to Machine Communications

- Fixed, closed systems between vehicles
  - Currently used for formation driving.
  - Exchange position information.
  - Unable to dynamically add vehicles.
- Examining other information sharing
  - A-B Lines for AutoTrac
  - Status such as fuel level
- Ultimately would like a more ubiquitous communications system
  - Mesh networks
  - Internet connectivity
    - Software updates
    - Commodity prices
    - Field-Processor coordination
  - Dynamically add and remove vehicles from mesh



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User Interfaces

- Need for non-technical users to control complex machine.
- Displaying large amounts of data without overpowering user
- Using gaming technology
  - R Gator : at most 2 button presses on X Box 360 controller
- Make use of eye trackers
  - Where is user looking?

Business Model

- How and what to sell with smart machines is just as important as the technical issues.
- Research needed to take out the complexity and assure autonomous availability
- Buying fully autonomous robots is not a likely scenario
  - Managed systems by well-certified operators
  - Sell a service

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Business Model Elements

Opportunity ID and Requirements
- Customer Acquisition
- Reqs & Specs

Solution Development
- Design
- Manufacturing
- Quality Control

Solution Delivery and Support
- Distribution
- Sales
- Service

Traditional Equipment Manufacturers

Autonomous Opportunity ID | Custom Systems | Worksite Service and Support

Field Robotics Architectures

Examples of Field Robotics at John Deere

- Operator Assisted Bucket fill
- Combine-Grain Cart Coordination
- Automated Peat Moss Harvesting
- Autonomous Orchards

Wheel Loader Bucket Fill – Operator Assist

- Automate the bucket fill operation
  - Increase productivity
  - Reduce load variability

- Operator drives up to pile then engages bucket fill automation

- Allows a novice operator to perform like an expert driver

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Combine-Grain Car Coordination

Overview

- Extension of AutoTrac

Key Technologies

- Relative positioning
- Speed and steering control

Customer Needs

- Bottleneck machine/operator is often the grain cart
- Single Grain cart cannot keep up with two combines with 12 row heads
- Give grain cart operator information where to go next
- Tight formation driving is high stress/skill

Automated Peat Moss Harvesting

Project Overview

- Fielded team of 3 autonomous tractors
- Operator supervised prototype tractors via tablet PC
- Field testing completed in New Brunswick (2007)

Meeting Customer Needs

- Increased Productivity
  - Addresses labor availability issues
  - Reduces labor and training costs
- Increased Quality
  - Uniform coverage harvests only dry peat

Key Technologies

- Mission director
- Teams of vehicles

Video

Autonomous Orchards

- Many tractor tasks in orchards are repetitive and frequent.
- It is possible to remove the operator and let the tractor drive by itself.
- How would that affect orchard productivity?
- What tasks could it do?

Perception and Safeguarding

- Perception is key to automating tractors.
- Vehicle needs to detect people, vehicles but not detect small tree branches and long grass.
- Combine multiple sensors
  - SICK Laser
  - Color cameras
  - MA/COM radar
  - Thermal camera
- Perception system computes a safe speed to gradually slow to a stop for obstacles.

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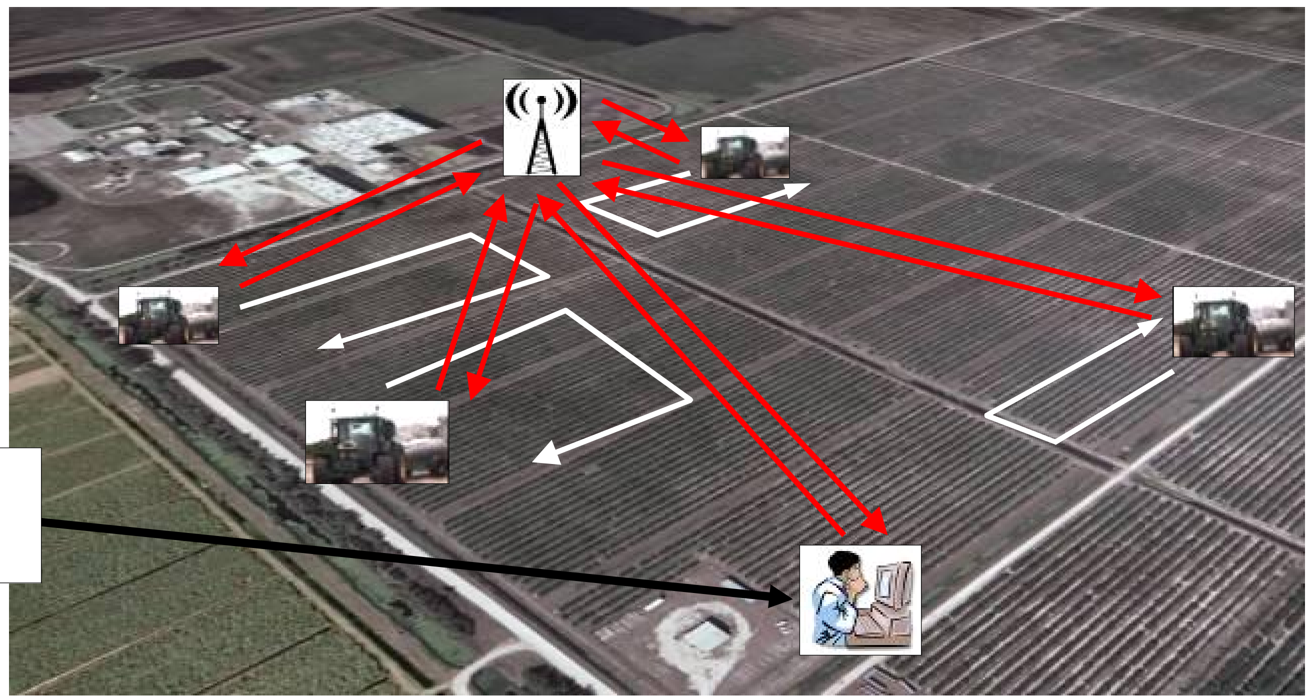
Orchard Movie

Force Multiplication Approach

- Full autonomy of the worksite not possible in near term.
- Leverage productivity of humans with supervisory control
- A single operator supervises multiple automated machines
- Machines will operate autonomously for the majority of time (>90%) and will page remote operator for help as needed over the wireless radio



Challenges for Adoption of Field Robotics

- Competing Technologies
- General Constraints and Available Resources
- Regulatory Factors

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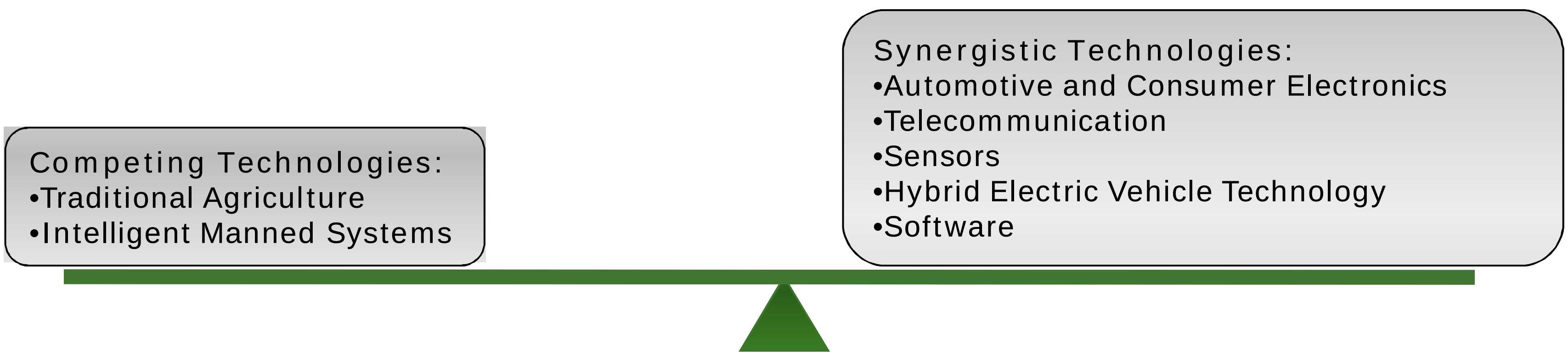
Competing Technologies

Competing Technologies may limit the adoption of field robots:

- Significant productivity and convenience continues to be extracted through partial automation
- Emerging economies continue to fuel traditional approaches and slow the technology evolution
- Scale issues slow the industry's ability to develop common solutions.



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General Constraints Outweigh Required Resources

Required Resources:

•Supporting infrastructure

•Higher skill level requirements

•Significant challenges in the support model for the business channel

•R&D for agricultural automation has been left to industry; significant robotics work has been for the military

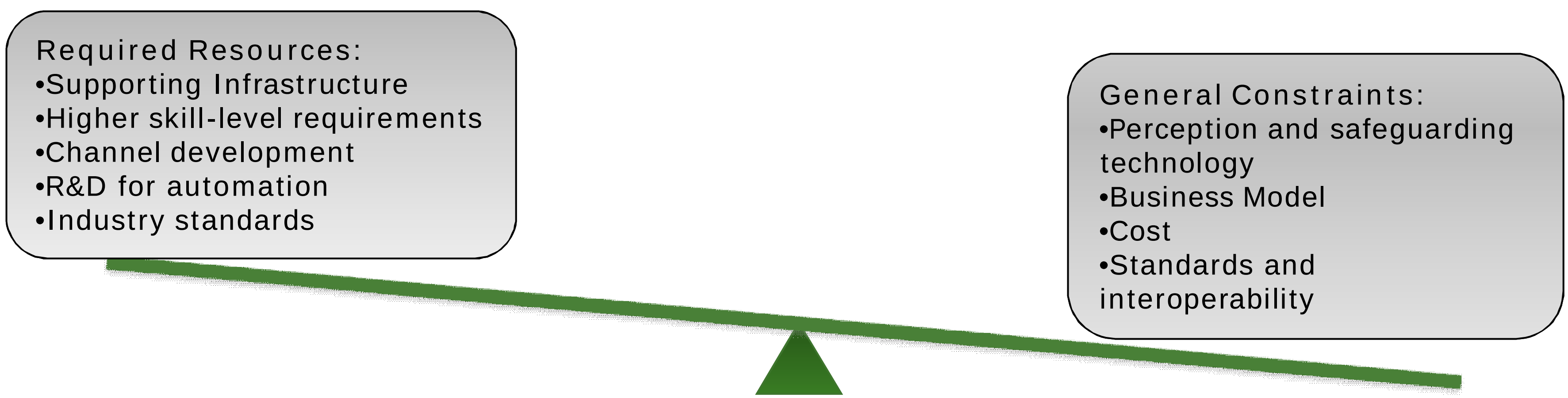
General Constraints:

•Perception Technologies will are the critical rate-limiter

•Need a clear understanding on "what is being sold" in autonomous worksite solutions

•Cost needs to be looked at from a systems perspective and not in terms of discrete products

•Solutions need to work across manufacturers platforms



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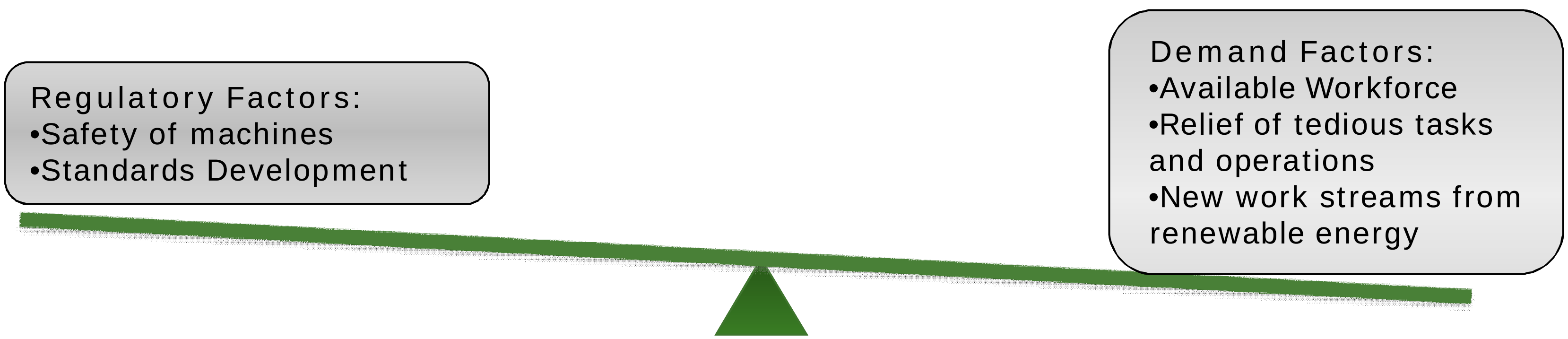
Demand Factors May Outweigh Regulatory Factors

Regulatory Factors:

- Despite awareness, there are significant challenges in safety and standards with respect to autonomous systems
- Existing laws which could prevent robotics
- Liability laws

Demand Factors:

- Population growth and global food demand will continue to drive towards increased productivity and efficiency
- Productivity of specialty crop systems are not going to be addressed using the traditional approaches of agricultural mechanization and automation
- Renewable energy is adding to the work streams



Final Thoughts

- Field robotics has the potential to increase productivity and convenience
- The greatest technical barrier is perception
- Technology is not enough
- To maximize productivity we must think of the worksite

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R Gator

- Deployments
  - Security patrol at SPAWAR
  - Airborne Assault Expeditionary Force
  - RS-JPO
- Customer Needs
  - Keeps soldiers out of harm's way
  - Transports supplies autonomously
- Key technologies
  - User interface, mobility, perception